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An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska

Volume 3 – Appendices E-J

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U.S. Environmental Protection Agency

Region 10

Seattle, WA

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Bristol Bay Wild Salmon Ecosystem

Baseline Levels of Economic Activity and Values

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UAA Institute of Social
and Economic Research
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BIOECONOMICS

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Executive Summary

The objective of this report is to characterize the baseline levels of economic activity and related ecosystem services values for the Bristol Bay wild salmon ecosystem. The overarching purpose of this report is to provide baseline economic information to the Environmental Protection Agency in order to inform review of mining proposals in the Nushugak and Kvichak drainages. Both regional economic significance and social net economic accounting frameworks are described in this report. This study reviews and summarizes existing economic research on the key sectors in this area and reports findings based on original survey data on expenditures and net benefits. This report combines efforts on the part of Bioeconomics, Inc. and the University of Alaska Institute of Social and Economic Research. John Duffield and Chris Neher compiled the report and authored the executive summary, Sections 1, 2, and 5. Gunnar Knapp wrote Section 3 (commercial fisheries), and Tobias Schwörer, Ginny Fey and Scott Goldsmith wrote Section 4.

The major components of the total value of the Bristol Bay area watersheds include subsistence use, commercial fishing, sport fishing and other recreation, and the preservation values (or indirect values) held by users and the U.S. resident population. The overall objectives of this study is to estimate the share of the total regional economy (expenditures, income, and jobs) that is dependent on these essentially pristine wild salmon ecosystems and to provide a preliminary but relatively comprehensive estimate of the total economic value (from an applied welfare economics perspective) that relies on a healthy ecosystem.

It is important to note that while the geographic scope of this economic characterization report is targeted to the Bristol Bay wild salmon ecosystem, the scope of the proposed mining activity is somewhat narrower, including the Nushugak and Kvichak drainages. Values tied to, and specific to, the proposed mining activity (and discharges) in the Nushugak and Kvichak Drainages would be a subset of those reported here, and have not been identified in this general characterization analysis. This report uses existing information and data to target this economic characterization report to ecosystem services and associated economic activity and values, specific to the Bristol Bay Region. However, data on different economic sectors vary in quality, and available data on some economic activities (such as non-consumptive tourism) make it more difficult to identify activities and associated economic values narrowly targeted to the Bristol Bay area. The overall intent of this report is to provide a general picture of the full range of economic values associated with ecosystem services supplied by the entire Bristol Bay region.

Following this executive summary, the report is organized into five main sections. Section 1 provides a brief introduction to the report. Section 2 addresses economic visitation and expenditures related to sport fishing, subsistence harvests, hunting, and non-consumptive recreation. Section 3 focuses on commercial fishing. Section 4 combines the regional economic activity associated with recreation and commercial fishing into an analysis of regional economic significance of these activities. Finally, Section 5 focuses on the net economic values associated with recreation and commercial fisheries in the Bristol Bay ecosystem.

For purposes of a baseline year, the most recent generally available data year is used (2009). Where available, (primarily in the commercial fisheries discussion) data on 2010 is also shown. Summary values are presented for 2009 data and in 2009 dollars.

The rivers that flow into the Bristol Bay comprise some of the last great wild salmon ecosystems in North America (Figure 1). The Kvichak River system supports the world's largest run of sockeye salmon. While these are primarily sockeye systems, all five species of Pacific salmon are abundant, and the rich salmon-based ecology also supports many other species, including Alaska brown bears and healthy populations of rainbow trout. The Naknek, Nushugak, Kvichak, Igushik, Egegik, Ugashik, and Togiak watersheds are all relatively pristine with very few roads or extractive resource development. Additionally, these watersheds include several very large and pristine lakes, including Lake Iliamna and Lake Becherof. Lake Iliamna is one of only two lakes in the world that supports a resident population of freshwater seals (the other is Lake Baikal in Russia). Additionally, there are nationally-important public lands in the headwaters, including Lake Clark National Park and Preserve, Katmai National Park and Preserve, Togiak National Wildlife Refuge, and Wood-Tikchick State Park (the largest state park in the U.S.).

The existing mainstays of the economy in this region are all wilderness-compatible and sustainable in the long run: subsistence use, commercial fishing, and wilderness sport fishing, hunting, and wildlife viewing and other non-consumptive recreation. Commercial fishing is largely in the salt water outside of the rivers themselves and is closely managed for sustainability. The subsistence, sport fish and other recreation sectors are primarily personal use and catch and release fishing, respectively. The limited harvest from these activities is relatively low impact when compared to the commercial fishery harvest.

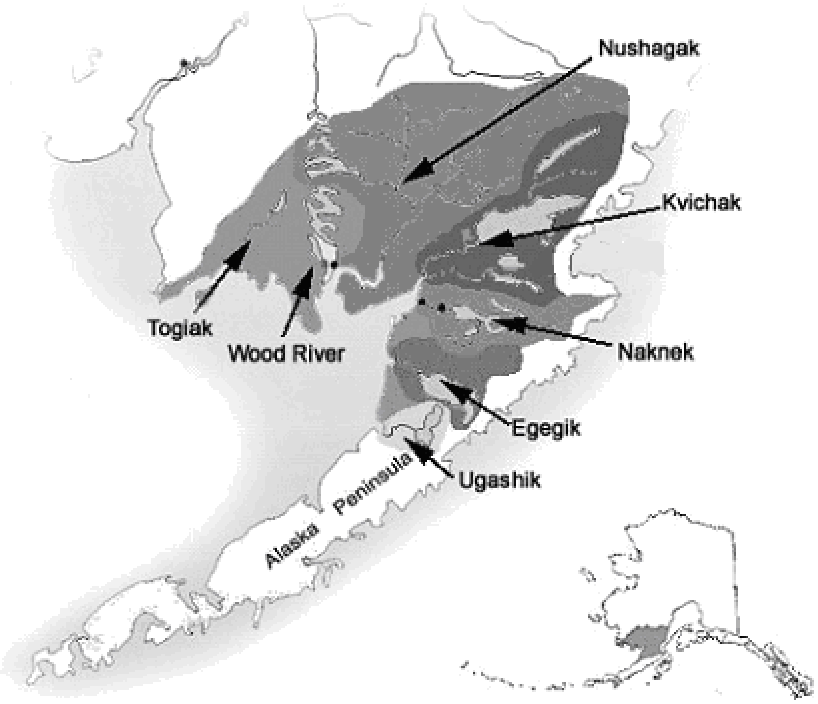

Figure 1. Map of Bristol Bay Study Area

This report focuses on an overview of values based on existing data and previous studies, and estimation of both the regional economic significance (focusing on jobs and income) of these ecosystems using an existing regional economic model. Total value in a social benefit-cost framework is also considered. This report provides a preliminary but relatively comprehensive estimate of the range of fishery-related values in this region (Figure 1).

This summary provides a brief characterization of each of the major sectors, followed by the primary economic findings.

Subsistence and Village Economies

The Bristol Bay economy is a mixed cash-subsistence economy. The primary features of these socio-economic systems include use of a relatively large number of wild resources (on the order of 70 to 80 specific resources in this area), a community-wide seasonal round of activities based on the availability of wild resources, a domestic mode of production (households and close kin), frequent and large scale non-commercial distribution and exchange of wild resources, traditional systems of land use and occupancy based on customary use by kin groups and communities, and a mixed economy relying on cash and subsistence activities (Wolfe and Ellanna, 1983; Wolfe et al. 1984). The heart of the cash-subsistence economy in Bristol Bay is the resident population of 7,475 individuals located in 25 communities (Table 1) spread across this primarily un-roaded area (Figure 2). Archeological evidence indicates that Bristol Bay has been continuously inhabited by humans at least since the end of the last major glacial period about 10,000 years ago. Three primary indigenous cultures are represented here: Aleuts, Yupik Eskimos, and the Dena'ina Athapaskan Indians. The share of the population that is Alaska Native is relatively high at 70 percent, compared to Alaska as a whole, with 16 percent.

Table 1. Bristol Bay Area Communities, Populations, and Subsistence Harvest

Bristol Bay Area Community /year of AKF&G survey	Population (2010 census)	Per Capita Harvest (AKF&G Surveys)	Total Annual Harvest (lbs)	% Native Population (2000 census)
Aleknagik 2008	219	296	64,824	81.9%
Clark's Point 2008	62	1210	75,020	90.7%
Dillingham 1984	2,329	242	563,618	52.6%
Egegik 1984	109	384	41,856	57.8%
Ekwok 1987	115	797	91,655	91.5%
Igiugig 2005	50	542	27,100	71.7%
Iliamna 2004	109	469	51,121	50.0%
King Salmon 2008	374	313	117,062	29.0%
Kokhanok 2005	170	680	115,600	86.8%
Koliganek 2005	209	899	187,891	87.4%
Levelock 2005	69	527	36,363	89.3%
Manokotak 2008	442	298	131,716	94.7%
Naknek 2008	544	264	143,616	45.3%
New Stuyahok 2005	510	389	198,390	92.8%
Newhalen 2004	190	692	131,480	85.0%
Nondalton 2004	164	358	58,712	89.1%
Pedro Bay 2004	42	306	12,852	40.0%
Pilot Point 1987	68	384	26,112	86.0%
Port Alsworth 2004	159	133	21,147	4.8%
Port Heiden 1987	102	408	41,616	65.6%
South Naknek 2008	79	268	21,172	83.9%
Ugashik 1987	12	814	9,768	72.7%
Togiak City 2000	817	246	200,982	86.3%
Twin Hills 2000	74	499	36,926	84.1%
Un-surveyed communities	457		--	
Total	**7,475**	**343**	**2,563,313**	

Sources: US Census Bureau (2010 census statistics), and ADF&G Division of Subsistence Community Profile Data Base; Personal Comm. David Holen, ADF&G Oct 25, 2011.

Wild renewable resources are important to the people of this region and many residents rely on wild fish, game, and plants for food and other products for subsistence use. Total harvest for these 25 communities is on the order of 2.6 million pounds based largely on surveys undertaken from the late 1980s through 2008, as summarized in the Alaska Division of Subsistence community profile data base. A new round of surveys is now underway to update this data. Estimates for the 2004-2008 study years (Fall et al. 2006; 2008; 2009) are included in the data presented in Table 1. Additionally, as yet unpublished data from 2009 for Alegnagik, Clarks Point and Manokotak are included in the table (Per. Com. David Holen, ADF&G, Oct. 25, 2011). Per capita harvests average about 343 pounds. Primary resources harvested include salmon, other freshwater fish, caribou, and moose. Based on recent surveys, subsistence use continues to be very important for communities of this region and participation in subsistence activity, including harvesting, processing, giving and receiving is quite high. Compared to other regions of Alaska, the Bristol Bay area has many features characteristic of an unique subsistence economy, including the great time depth of its cultural traditions, its high reliance on fish and game, the domination of the region's market economy by the commercial salmon fishery, and the extensive land areas used by the region's population for fishing, hunting, trapping and gathering. (Wright, Morris, and Schroeder, 1985; Fall, Krieg, and Holen, 2009).

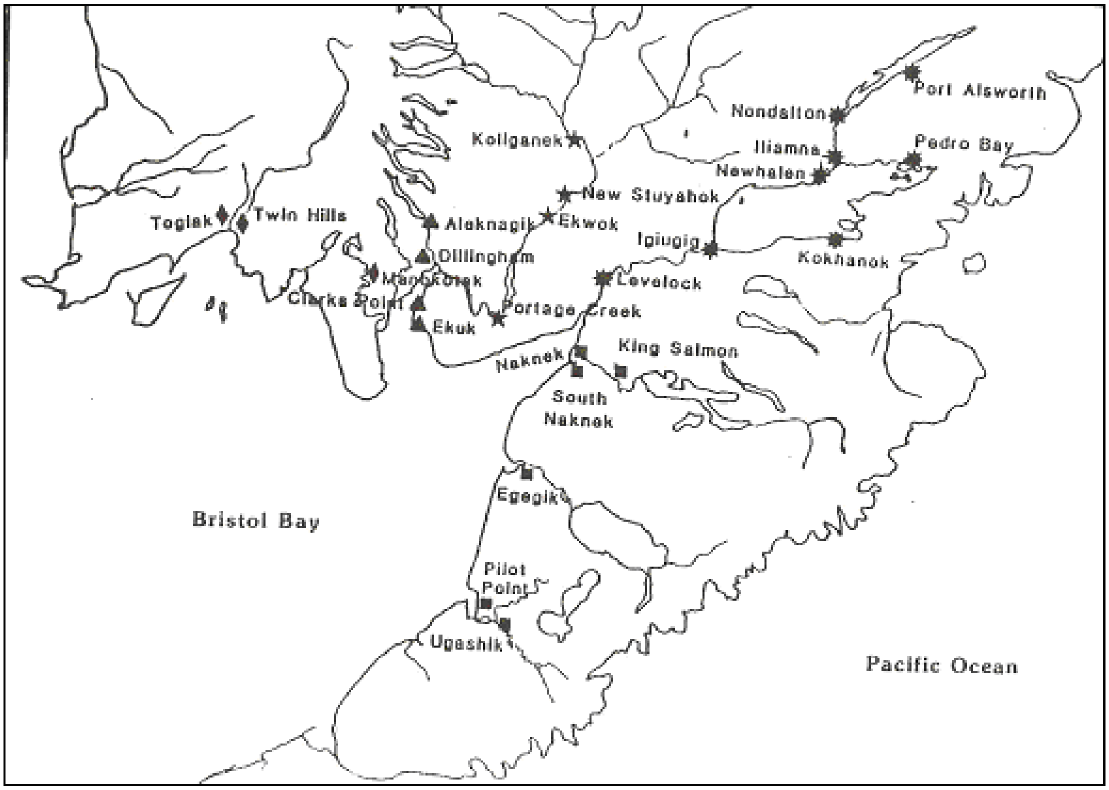

Figure 2. Bristol Bay Area Location and Major Communities

The primary private source of cash employment for participants in Bristol Bay's mixed cash-subsistence economy is the commercial salmon fishery. The compressed timing of this fishery's harvesting activity makes it a good fit with subsistence in the overall Bristol Bay cash-subsistence economy. Participation in the Bristol Bay salmon fishery is limited to holders of limited entry permits and their crew. There are approximately 1,860 drift gillnet permits for fishing from boats and approximately 1,000 set net permits for fishing from the shore. The driftnet fishery accounts for about 80% of the harvest. Most of the harvest is processed by about ten large processing companies in both land-based and floating processing operations which employ mostly non-resident seasonal workers.

Many commercial fishing permit holders and crew members, as well as some employees in the processing sector, are residents of Bristol Bay's dominantly-native Alaskan villages. An ADF&G summary of subsistence activity in Bristol Bay (Wright, Morris, and Schroeder 1985) noted that as of the mid-1980's traditional patterns of hunting, fishing, and gathering activities had for the most part been retained, along with accommodations to participate in the commercial fishery and other cash-generating activities. In the abstract to this 1985 paper, the authors characterize the commercial salmon fishery as "a preferred source of cash income because of its many similarities to traditional hunting and fishing, and because it is a short, intense venture that causes little disruption in the traditional round of seasonal activities while offering the potential for earning sufficient income for an entire year." Commercial fishing is a form of self-employment requiring many of the same skills, and allowing nearly the same freedom of choice as traditional subsistence hunting and fishing (Wright, Morris, Schroeder 1985; p. 89).

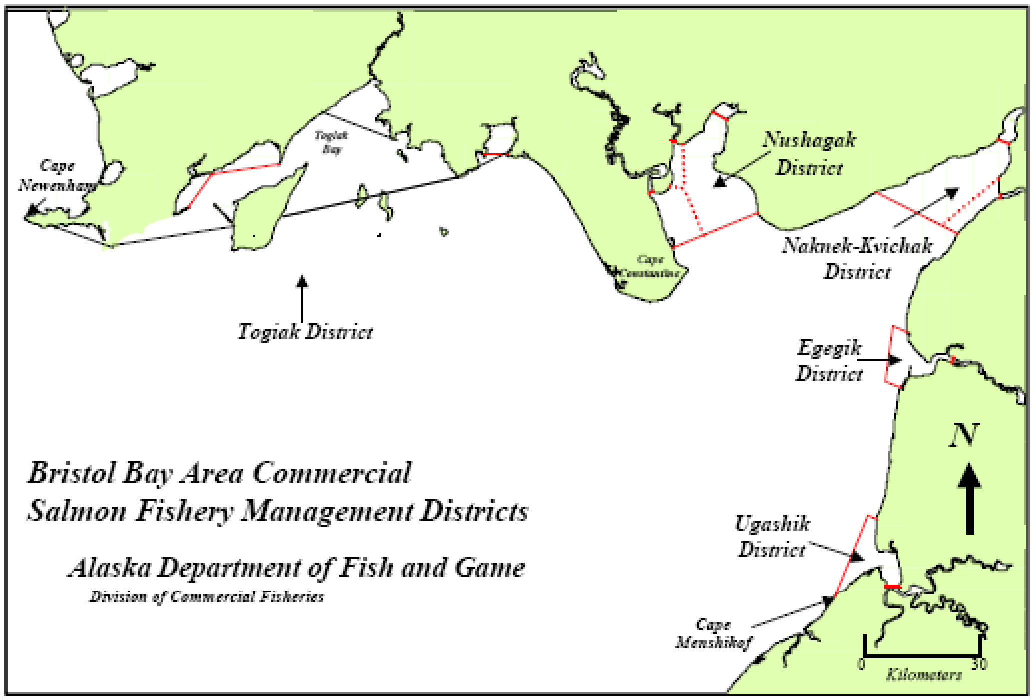

Figure 3. Bristol Bay Area Commercial Salmon Fishery Management Districts

Commercial Fisheries

The Bristol Bay commercial salmon fishery harvests salmon which spawn in and return to numerous rivers over a broad area. The Bristol Bay commercial fishery management area encompasses all coastal and inland waters east of a line from Cape Menshikof to Cape Newhenham (Figure 3). This area includes eight major river systems: Naknek, Kvichak, Egegik, Ugashik, Wood, Nushagak, Igushik and Togiak. Collectively these rivers support the largest commercial sockeye salmon fishery in the world (ADF&G, 2005). This is an interesting and unique fishery, both because of its scale and significance to the local economy, but also because it is one of the very few major commercial fisheries in the world that has been managed on a sustainable basis. The substantial diversity in this system, both across species and within species (population diversity or the "portfolio effect"), leads to relatively stable populations. Schindler (2010) estimated that variability in annual Bristol Bay salmon runs is 2.2 times lower than if the system consisted of a single population, and that a single homogeneous population of salmon would lead to 10 times more frequent fisheries closures. These findings indicate the importance of maintaining population diversity in order to protect the ecosystem and the economy that depends on it.

The five species of pacific salmon found in Bristol Bay are the focus of the major commercial fisheries. Sockeye salmon account for about 94% of the volume of Bristol Bay salmon harvests and an even greater share of the value. The fishery is organized into five major districts (Figure 3) including Togiak, Nushagak, Naknek-Kvichak, Egegik, and Ugashik. Catches in each district vary widely from year to year and over longer time periods of time, reflecting wide variation in returns to river systems within each district. Currently there is particular interest in the significance of fisheries resources of river systems in the Nushagak and Kvichak districts, because of potential future resource development in these watersheds. Over the period 1986-2010, the Naknek-Kvichak catches ranged from as low as 5% to as high as 52% of total Bristol Bay catches; Nushagak district catches ranged from as low as 9% to as high as 45% of total Bristol Bay catches. For most of the past decade, the combined Nushagak and Naknek-Kvichak districts have accounted for about 60% of the total Bristol Bay commercial sockeye harvest.[1]

Management is focused on discrete stocks with harvests directed at terminal areas at the mouths of the major river systems (ADF&G, 2005). The stocks are managed to achieve an escapement goal based on maximum sustained yield. The returning salmon are closely monitored and counted and the openings are adjusted on a daily basis to achieve desired escapement. Having the fisheries near the mouths of the rivers controls the harvest on each stock, which is a good strategy for protection of the discrete stocks and their genetic resources. The trade-off is that the fishery is more congested and less orderly, and the harvest is necessarily more of a short pulse fishery, with most activity in June and early July. This has implications for the economic value of the fish harvest, both through effects on the timing of supply, but also on the quality of the fish. Most fish are canned or frozen, rather than sold fresh. Total catches vary widely from year to year. Between 1980 and 2010, Bristol Bay sockeye salmon harvests ranged from as low as 10 million fish to as high as 44 million fish. Harvests can vary widely from year to year and annual pre-season forecasts are subject to a wide margin of error.

Strong Japanese demand for frozen sockeye salmon drove a sharp rise in Bristol Bay salmon prices during the 1980s. Competition from rapidly increasing farmed salmon production drove a protracted and dramatic decline in prices between 1988 and 2001, which led to an economic crisis in the industry. However, growing world salmon demand, a slowing of farmed salmon production growth, diversification of Bristol Bay salmon products and markets, and improvements in quality have driven a strong recovery in prices over the past decade. The real ex-vessel value paid to fishermen fell from $359 million in 1988 to $39 million in 2002, and rose

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[1] Bristol Bay salmon harvest statistics can be found at http://www.adfg.alaska.gov/index.cfm?adfg=commercialbyareabristolbay.salmon

to $181 million in 2010 (values in 2010 dollars).[2] The real first wholesale value of Bristol Bay salmon production fell from $616 million in 1988 to $124 million in 2002, and then rose to $390 million in 2010. In 2009, the ex-vessel value of Bristol Bay salmon harvest was approximately $300 million. Many other factors, such as changes in wild salmon harvests, exchange rates, diseases in Chilean farmed salmon, and global economic conditions have also affected prices. In general, changes in ex-vessel prices paid to fishermen have reflected changes in first wholesale prices paid to processors.

There are many potential economic measures of the Bristol Bay salmon industry (Table 2). Which measure is most useful depends upon the question being asked. For example, if we want to know how the Bristol Bay salmon fishery compares in scale with other fisheries, we should look at total harvests or ex-vessel or wholesale value. If we want to know how it affects the United States balance of payments, we should look at estimated net exports attributable to the fishery. If we want to know how much employment the industry provides for residents of the local Bristol Bay region, Alaska or the United States, we should look at estimated employment in fishing and processing for residents of these regions. If we want to know the net economic value attributable to the fishery, we should look at estimated profits of Bristol Bay fishermen and processors. These different measures (Table 2) vary widely in units, in scale, and in the measure of how economically "important" the fishery is. For example, for the period 2000-2010, Bristol Bay harvests were 62% of all Alaska sockeye salmon harvests and 45% of total world production for the species.

Table 2. Selected Economic Measures of the Bristol Bay Commercial Salmon Industry, 2000-2010.

Measure	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg.	Range
Sockeye Salmon Havests													
Millions of fish	21	14	11	15	26	25	28	30	28	31	29	23	11 - 31
Millions of pounds	125	96	65	93	152	155	165	173	160	183	170	140	65 - 183
Bristol Bay harvest volume as a share of:													
Alaska sockeye salmon	61%	56%	48%	50%	59%	58%	69%	62%	71%	71%	74%	62%	48% - 74%
World sockeye salmon	45%	40%	28%	38%	47%	47%	49%	47%	52%	55%		45%	28% - 55%
Alaska wild salmon (all species)	18%	12%	10%	13%	19%	16%	22%	18%	23%	25%		18%	10% - 25%
World wild salmon (all species)	7%	5%	4%	5%	8%	7%	8%	7%	9%	7%		7%	4% - 9%
World wild & farmed salmon (all species)	3%	2%	1%	2%	3%	3%	3%	3%	3%	3%		2%	1% - 3%
Gross Value ($ mllions)													
Ex-vessel value	80	40	32	48	76	95	109	116	117	144	181	94	32 - 181
First wholesale value	175	115	100	114	176	220	237	249	262	293	390	212	100 - 390
Total value of US exports of Bristol Bay salmon products	150	137	97	111	172	193	173	183	206	230	254	173	97 - 254

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[2] The ex-vessel value is the total post-season adjusted price paid to fishermen for the first purchase of commercial harvest.

Recreation

Next to commercial fishing and processing, recreation is the most important private economic sector in the Bristol Bay region. This recreational use includes sport fishing, sport hunting, and other tourism/wildlife viewing recreational trips to the Bristol Bay Region. The 2005 Bristol Bay Angler Survey (Duffield et al. 2007) confirmed that the fresh water rivers, streams, and lakes of the region are a recreational resource equal or superior in quality to other world renowned sport fisheries.

In survey responses Bristol Bay anglers consistently emphasize the importance of Bristol Bay's un-crowded, remote, wild setting in their decisions to fish the area. Additionally, a significant proportion of these anglers specifically traveled to the region to fish the world-class rainbow trout fisheries. These findings indicate that Bristol Bay sport fishing is a relatively unique market segment, paralleling the findings of Romberg (1999) and Duffield, Merritt and Neher (2002) that angler motivation, characteristics, and values vary significantly across Alaska sport fisheries.

Recreational fishing use of the Bristol Bay region is roughly divided between 58% trips to the area by Alaska residents and 42% trips by non-residents. These non-residents (approximately 12,500 trips in 2009 (personal communication, ADF&G, 2011)) account for the large majority of total recreational fishing spending in the region. It is estimated that in 2009 approximately $50 million was spent in Alaska by nonresidents specifically for the purpose of fishing in the Bristol Bay region. In total, it is estimated that $60 million was spent in Alaska in 2009 on Bristol Bay fishing trips.

While sport fishing within the Bristol Bay region comprises a large and well-recognized share of recreational use and associated visitor expenditures, thousands of trips to the region each year are also made for the primary purpose of sport hunting and wildlife viewing. Lake Clark and Katmai National Parks are nationally significant protected lands and are important visitor destinations attracting around 65,000 recreational visitors in 2010 (NPS public visitation statistics). Additionally, rivers within Katmai NP provide the best locations in North America to view wild brown bears.

Summary of Economic Significance

Table 3 through 7 detail the summary results of the analysis of economic values. Table 3 shows estimated direct expenditures in Alaska related to harvest or use of Bristol Bay area renewable resources. Total estimated direct expenditures (that drive the basic sector of the economy) were estimated to be $479 million in 2009. The largest component is commercial fishing harvesting and processing. These estimates were obtained from the Alaska Department of Revenue and the Commercial Fishing Entry Commission. The next most significant component is wildlife viewing/tourism at $104 million in 2009. Sport fishing is estimated to constitute another $60 million in spending. This estimate is derived from the 2005 Bristol Bay Angler survey data as well as AK F&G use estimates. Sport hunting is less important economically.

The direct economic spending and sales shown in part A of the table supports an estimated 14,200 direct full and part-time jobs in the Bristol Bay region during peak season.

Table 3. Summary of Regional Economic Expenditures Based on Wild Salmon Ecosystem Services (Million 2009 $)

Ecosystem Service	**Estimated direct expenditures / sales per year**
(A) Direct Expenditures and Sales	
Commercial fish wholesale value[3]	300.2
Sport fisheries	60.5
Sport hunting	8.2
Wildlife viewing / tourism	104.4
Subsistence harvest expenditures	6.3
Total direct annual economic impact	**479.6**
(B) Estimated Direct Full & Part-Time Jobs at Peak Season	
Commercial fish Sector	11,572
Sport fisheries	854
Sport hunting	132
Wildlife viewing / tourism	1,669
Subsistence harvest expenditures	Not Captured by the Market
Total direct annual economic impact	**14,227**

Table 4 provides additional detail on recreation expenditures, including number of trips and spending by residence of the participants. A large share of total recreation expenditures is by nonresident anglers ($49.8 million) and nonresident non-consumptive (tourism/wildlife viewing) visitors ($92.9 million). This reflects the high quality of this fishery and other recreational opportunities in the region, in that the area is able to attract participants from a considerable distance in the lower 48 states as well as foreign countries. Subsistence harvest expenditures are based on limited data and are likely to be conservative. (Goldsmith, 1998)

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[3] Estimates of some year-specific commercial fishery total harvest and total sales vary slightly within this report. This is due to differences in how these data are aggregated and reported by the Alaska Fish and Game, and the point in time these statistics were accessed during the preparation of this report.

Table 4. Total Estimated Recreational Direct Spending in Alaska Attributable to Bristol Bay Wild Salmon Ecosystems, 2009

	Local residents	Non-local residents	Non-residents	Total
Visitors				
Non-consumptive	-	4,506	36,458	**40,964**
Sport fishing	13,076	3,827	12,464	**29,367**
Sport hunting	-	1,319	1,323	**2,642**
Total	**13,076**	**9,652**	**50,245**	**72,973**
Spending per visitor				
Non-consumptive	-	$2,548	$2,548	
Sport fishing	$373	$1,582	$3,995	
Sport hunting	-	$1,068	$5,170	
Spending ($million)				
Non-consumptive	-	$11.5	$92.9	**$104.4**
Sport fishing	$4.9	$6.0	$49.8	**$60.7**
Sport hunting	-	$1.4	$6.8	**$8.2**
Total	**$4.9**	**$18.9**	**$149.5**	**$173.3**

Table 5 summarizes the full time equivalent employment (annual average) for the cash component of the economy associated with the major economic sectors of the Bristol Bay economy, those dependent on wild salmon ecosystems—recreation, commercial fishing, and subsistence, as well as other major employment sectors. The economy of the Bristol Bay Region depends on three main activities or sectors—publicly funded services through government and non-profits, commercial activity associated with the use of natural resources (mainly commercial fishing and recreation), and subsistence. Subsistence is a non-market activity in the sense that there is no exchange of money associated with the subsistence harvest. However, local participants invest a significant portion of their income to participate in subsistence and the harvest has considerable economic value and their expenditures have significant economic effects.

Public services and commercial activities bring money into the economy (basic sectors) and provide the basis for a modest support sector. The support sector (non-basic sector) consists of local businesses that sell goods and services to the basic sectors including the commercial fishing industry, the recreation industry, the government and non-profit sectors. The support sector also sells goods and services to participants in subsistence activities.

The relative importance within the regional economy of government as contrasted with commercial fishing and recreation can be measured by the annual average employment in each sector. In 2009, more than two thousand jobs were directly associated with government spending from federal, state, and local sources. Commercial fishing and recreation accounted for approximately three thousand or 57 percent of total basic sector jobs. Since much of the recreation is using public lands and resources, a share of the government sector; for example administration of the federal and state parks and wildlife refuges, is directly related to providing jobs and opportunities in the recreation sector. Accordingly, the estimate of recreation-dependent jobs is conservative.

The support sector depends on money coming into the regional economy from outside mainly through government, commercial fishing, and recreation. The relative dependence of the support sector on the three main sectors is difficult to measure. One reason for this is that government employment is stable throughout the year, while employment in commercial fisheries and recreation vary seasonally. Due to the seasonal stability of government jobs, the payroll spending of people employed in government is likely to contribute more to the stability of support sector jobs in the region than their share of basic sector jobs indicates.

Table 5. Cash Economy Full-time Equivalent Employment Count by Place of Work in the Bristol Bay Region, 2009

	Annual Average	Summer	Winter	Swing
Total jobs count	**6,648**	16,386	3,792	12,594
Basic	**5,490**	14,877	2,430	12,447
Fish harvesting	**1,409**	6,909	-	6,909
Fish processing	**1,374**	4,480	354	4,126
Recreation	**432**	1,297	-	1,297
Government & Health	**2,039**	1,712	2,056	(344)
Mineral Exploration	**197**	450	70	380
Non-basic	**1,406**	1,509	1,362	147
Construction	**61**	92	55	37
	634	717	593	124
Trade/Transportation/Leisure				
Finance	**155**	142	162	(20)
Other wage & salary	**239**	241	235	6
Non-basic self employed	**317**	317	317	-
Resident jobs count	**4,675**	10,351	3,225	7,126

Note, estimates based on ISER Input-Output modeling described in section below. Fish harvesting and processing include other fisheries besides salmon, thus employment numbers cannot be compared with other tables shown in this report. Summer and winter employment shown, are point estimates that either show the maximum or minimum job count. Swing refers to the difference between maximum and minimum.

Subsistence users are not the only hunter-gatherers in this economy. Essentially the entire private economy is “following the game” (or in this case fish), with many commercial fishermen, processors, sport anglers, sport hunters, and wildlife viewers coming from elsewhere in Alaska or outside the state to be part of this unique economy at the time that fish and game are available. The estimated earnings associated with the salmon ecosystem-dependent jobs are shown in Table 6. The total of $283 million was divided among $78 million for residents of the Bristol Bay region, $104 million to residents of the rest of Alaska, and $100 million to residents of other states.

Table 6. Cash Economy Estimated Economic Significance of Bristol Bay Ecosystems

	Total		Residents		Non-
		Non-local	Local	Total	Residents
Direct jobs					
Peak	**14,227**	4,365	2,273	6,639	7,587
Commercial fish	***11,572***	*3,251*	*1,089*	*4,341*	*7,231*
Recreation	***2,655***	*1,114*	*1,184*	*2,298*	*356*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Annual average	**2,811**	914	585	1,499	1,313
Commercial fish	***1,897***	*530*	*177*	*707*	*1,190*
Recreation	*914*	*384*	*408*	*792*	*123*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Multiplier Jobs	**3,455**	2,008	1,447	3,455	-
Total jobs (annual average)	**6,266**	2,922	2,032	4,954	1,313
Direct wages ($000)	**$166,632**	$40,149	$31,048	$66,199	$100,435
Commercial fish	***$134,539***	*$22,698*	*$17,608*	*$40,307*	*$94,233*
Recreation	***$32,093***	*$12,451*	*$13,440*	*$25,892*	*$6,202*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Multiplier wages	**$115,976**	$69,250	$46,724	$115,976	-
Total wages	**$282,608**	$104,399	$77,772	$182,175	$100,435

Note, estimates based on ISER Input-Output modeling described in section below.

Table 6 provides an accounting of jobs and wages for the cash economy component of the Bristol Bay mixed cash-subsistence economy. Kreig et al. (2007) describe the participation in the subsistence side of the economy through sharing, bartering, and cash exchange for subsistence harvests. An estimate of the number of jobs or livelihoods supported by the subsistence sector (besides those associated with expenditures for tools, equipment, and supplies in Table 3) can be approximated through either a top-down or bottom-up estimation approach.

Population levels in Bristol Bay were 7,475 in 2010 (Table 1). Based on 2010 census counts, the number of Bristol Bay residents aged 16 and over was 5,448. The cash economy and equivalent full-time employment of Alaskans in the Bristol Bay region is estimated at 4,675 (Table 5). The estimated cash economy employment for local Bristol Bay residents only is 2,032 (Table 6). By not choosing to move elsewhere, Bristol Bay residents reveal their preference for the livelihood presented by the mixed cash-subsistence economy. This is supported by the findings in Borass (2011). For example, several local interviewees were quoted as saying "But I wouldn't trade this place for anything. This is home; this is where I find clean water to drink." And "We love this place. Moving is not an option to me." (Boraas (2011) p. 3.)

Data in Holen et al. (2011) indicate that for Bristol Bay communities participation in subsistence activities is very high. In the towns of King Salmon, Naknek and South Naknek 90% or more of residents reported participation in subsistence harvest activities (p. 20). One estimate of participation (employment) in the subsistence livelihood (full-time equivalent jobs) would be to attribute the residual of the adult (16 and over) population less the cash economy jobs (Table 5)—or around 3,400 jobs to this sector. Therefore, the non-cash economy jobs associated with the subsistence sector may be roughly 3,400.

Another approach would be to examine the effort levels (days in subsistence activities) based on subsistence fishing permit data. Fall et al. (2009) indicates that the harvest levels per day are actually constrained not by potential daily harvest, but by the processing capacity of the family unit (or extended family).

The total number of full-time equivalent jobs directly dependent on the wild salmon ecosystem is the sum of the cash economy jobs (6,266) plus the subsistence sector livelihoods (roughly estimated at (3,400 jobs), or about 9,600 jobs.

Net Economic Values

The preceding discussion has focused on a regional economic accounting framework and job and wage-related measures of economic significance. This section introduces the net economic value measures for evaluation of the renewable Bristol Bay resources. The framework for this accounting perspective is the standard federal guidelines for estimating net economic benefits in a system of national accounts (Principles and Standards, U.S. Water Resources Council 1985). EPA (2010) is a more recent and complementary set of guidelines.

The Alaskan subsistence harvest is not traditionally valued in the marketplace. Because the subsistence resources are not sold, no price exists to reveal the value placed on these resources within the subsistence economy. The prices in external markets, such as Anchorage, are not really relevant measures of subsistence harvest value. The supply/demand conditions are unique to the villages, many of which are quite isolated. Native preferences for food are strongly held and often differ from preferences in mainstream society. Additionally, because these are highly vertically integrated economies, substantial value-added may occur before final consumption (such as drying, or smoking fish and meats). In their research on estimating the economic value of subsistence harvests, Brown and Burch (1992) suggest that these subsistence harvests have two components of value, a product value, and what they call an "activity value." The product value is essentially the market value of replacing the raw subsistence harvest. The activity value would primarily include the cultural value of participating in a subsistence livelihood. The activity value component is also associated with the value of engaging in subsistence harvest and food processing activities. This activity value would include maintaining cultural traditions associated with a subsistence livelihood. Duffield (1997) estimated a hedonic model of subsistence harvest of 90 Alaskan communities. This model was updated to incorporate current subsistence harvest data, and education and income data, and estimated a total NEV per pound of usable subsistence harvest of between $60.24 and $86.06.

Based on an estimated 2.6 million pounds of subsistence harvest per year in the Bristol Bay region, and valued at an estimated range of $60.24 to $86.06 per pound, this harvest results in an estimated net economic value annually of subsistence harvest of between $154.4 and $220.6 million.

The net economic value of commercial fisheries is estimated based on data on salmon fishery permit sales prices for Bristol Bay. The Commercial Fish Entry Commission reports average permit transfer prices annually (and monthly) for the Bristol Bay salmon fishery.[4] Over the period from 1991-2011 the average sales price for Bristol Bay drift net permits has been $149,000 (in 2011 dollars). The average price for set net permits over the same period has been $42,200. The 95% confidence interval on the mean drift net price for this period is from $105,500 to $192,700. For the set net permit transfers, the 95% C.I. on the mean sales price was between $28,700 and $55,700.[5] For both types of permits combined, it is estimated that the total market value of the permits ranges from approximately $225 million to $414 million.

In order to be comparable to other annual net economic values in this analysis (such as sport fishing or sport hunting) the net present value of commercial fishing permits, as represented by the market value, must be converted into an annual value reflecting expected annual permit net income The permit total value can be annualized using an appropriate amortization (or discount) rate. The decision to sell a commercial fishing permit at a given price is an individual (or private) decision. In deciding on an acceptable sales price, a permit holder considers past profits from operating the permit, risk associated with future operation of the permit (both physical and financial), and many other factors. All these considerations weigh on how heavily a permit seller discounts (reduces) potential future profits from fishing the permit in order to arrive at a lump-sum value for the permit. Huppert et al. (1996) specifically looked at Alaska commercial salmon permit operations and sales and estimated the individual discount rate on drift net permit sales in the Bristol Bay and surrounding fisheries. This discount rate was estimated from both profitability and permit sales price data. Huppert et al. estimated the implied discount rate

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[4] A long time series of monthly and annual permit transfer prices is continuously updated at, http://www.cfec.state.ak.us/pmtvalue/mnusalm.htm

[5] Over the period 1991-2011, a total of 3,246 Bristol Bay drift net salmon permits and 1,867 set net salmon permits were reported sold by the Commercial Fish Entry Commission.

appropriate for annualizing permit sales prices in this setting at 13.52%. This estimate was consistent with previous estimates for the fishery.[6] Use of the 13.52% discount rate from Huppert results in an estimated average annual permit net income associated with Bristol Bay commercial salmon fishing of between $30.4 million and $55.9 million.

Net income for the processing sector is more difficult to estimate. Relative to the fishing sector, with ex-vessel value of $181 million in 2010, the processing sector provides an approximately equal value added of $209 million in 2010 (first wholesale value of $390 million in 2010 less the cost of buying fish at the ex-vessel cost of $181 million. (Figure 4) However, information on profits or net income for this sector are difficult to obtain. As with permit prices, processor profits are highly variable year-to-year. The average value added associated with salmon processing for the Bristol Bay fishery is generally equal to or more than the ex-vessel value. Salmon processors in the Bristol Bay fishery have an “oligopsony” market structure, in that a small number of buyers of raw fish exist in the market. Additionally, these buyers are largely “price makers” in that they set the price paid per pound to fishermen each season. Given the unique relationship between fisherman that the small number of processors in the Bristol Bay, it is estimated that processors derive profits (net economic value) equal to that earned by fishermen. Therefore, for the purposes of this report it is estimated that the NEV for salmon producers is equal to that for the fishing fleet. Estimation of harvest and processing sector net income using a second independent set of net income estimates and assumptions supports the result that a range of annual NEV commercial fisheries estimates from $60.8 to $111.8 million provides a conservative estimate for this sector.

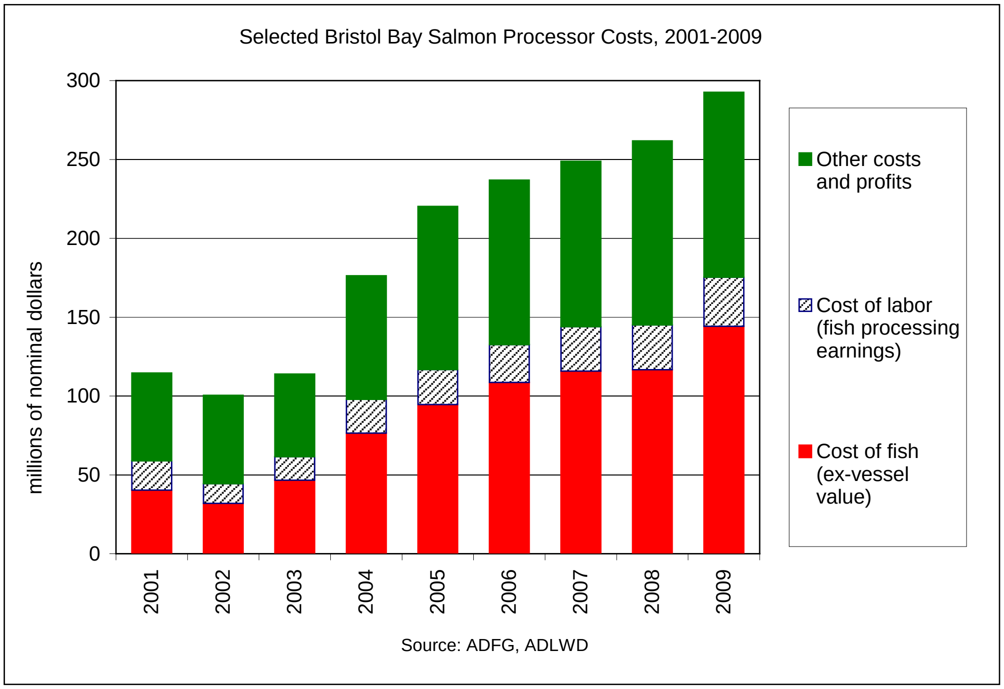

Figure 4. Selected Bristol Bay Salmon Processor Costs: 2001-2009

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[6] Huppert, Ellis and Nobel (1996) estimated the real discount rate associated with sales of Alaska drift gill-net commercial permits of 13.52%. Karpoff (1984) estimated the discount rate from sales of Alaska limited entry permits at 13.95%.

The sportfish net economic values are angler recreational benefits (consumer surplus) in Duffield et al. (2007). These estimates are consistent with values from the extensive economic literature on the value of sportfishing trips (for example Duffield, Merritt and Neher 2002). Sport hunting values are based on studies conducted in Alaska McCollum and Miller (1994). Direct use values for all uses total from $237 million to $354 million per year. In addition to recreationist's net benefits, net income (producer's surplus) is recognized by the recreation and tourism industry. This is a component that remains to be estimated.

Based on the National Research Council panel on guidelines for valuation of ecosystem services (NRC 2005), it is important to include intrinsic or passive use values (aka "non-use" values) in any net economic accounting of benefits (Figure 5).

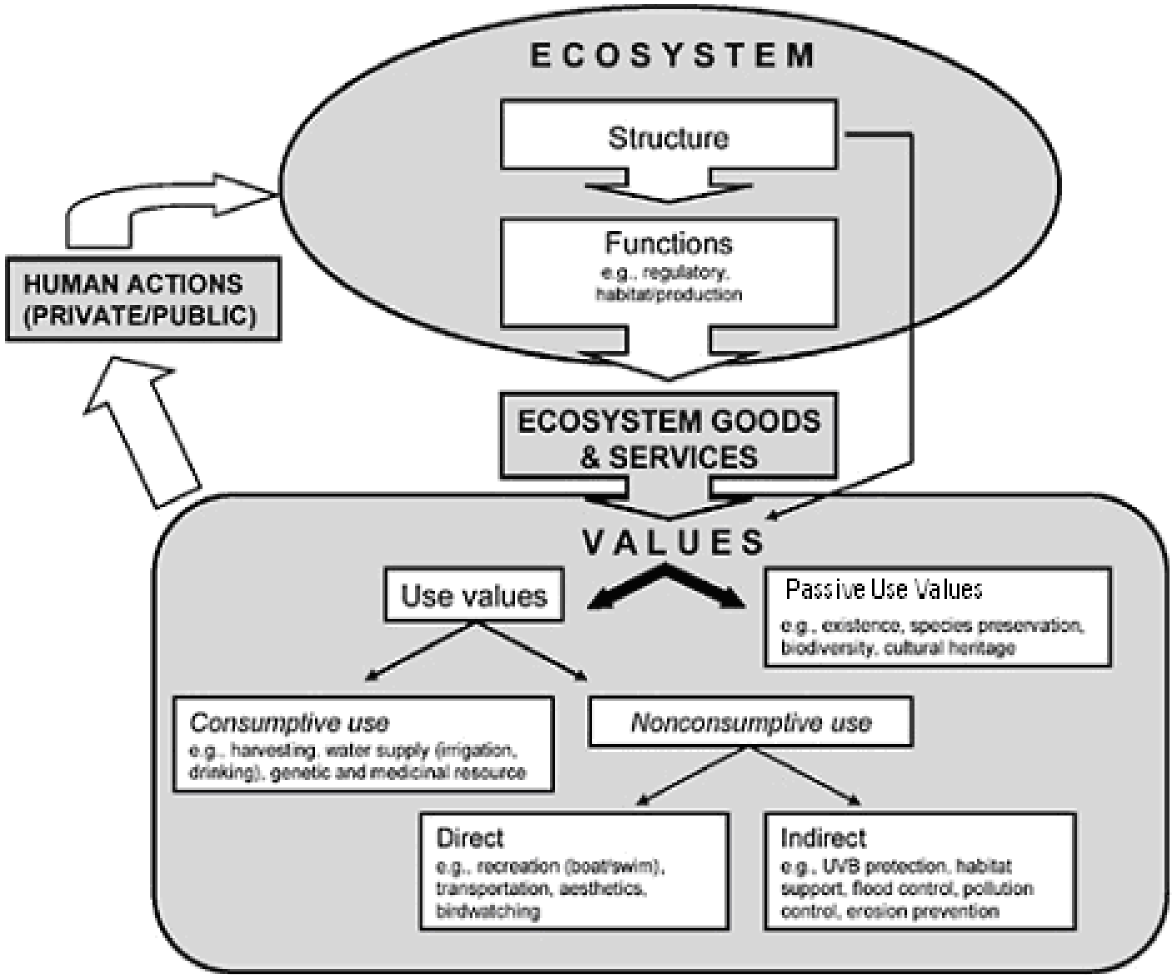

Figure 5. Flows of Ecosystem Services (adapted from (National Research Council 2005))

A major unknown is the total value related to existence and bequest motivations for passive use values. Goldsmith et al. (1998) estimated the existence and bequest value for the federal wildlife refuges in Bristol Bay at $2.3 to $4.6 billion per year (1997 dollars). There is considerable uncertainty in these estimates, as indicated by the large range of values. Goldsmith's estimates for the federal wildlife refuges are based on the economics literature concerning what resident household populations in various areas (Alberta, Colorado) (Adamowicz et al. 1991; Walsh et al. 1984; Walsh et al. 1985) are willing to pay to protect substantial tracts of wilderness. Similar literature related to rare and endangered fisheries, including salmon, could also be applied here. It is possible that from a national perspective the Bristol Bay wild salmon ecosystems and the associated economic and cultural uses are sufficiently unique and important to be valued as highly as wilderness in other regions of the U.S.. Goldsmith et al.'s (1998) estimates assume that a significant share of U.S. households (91 million such households) would be willing to pay on the order of $25 to $50 per year to protect the natural environment of the Bristol Bay federal wildlife refuges. The number of these households used in Goldsmith's analysis is based on a willingness to pay study (the specific methodology used was contingent valuation) conducted by the State of Alaska Trustees in the Exxon Valdez oil spill case (Carson et al. 1992). These methods are somewhat controversial among economists, but when certain guidelines are followed, such studies are recommended for use in natural resource damage regulations (for example, see Ward and Duffield 1992). The findings of the Exxon Valdez study were the basis for the $1 billion settlement between the State and Exxon in this case. Willingness-to-pay analyses have also been upheld in court (Ohio v. United States Department of Interior, 880 F.2d 432-474 (D.C. Cir.1989)) and specifically endorsed by a NOAA-appointed blue ribbon panel (led by several Nobel laureates in economics) (Arrow et al. 1993).

While the primary source of passive use values for Bristol Bay are likely to be with national households (lower 48), it is important to note that the Alaska natives living in Bristol Bay also likely have significant passive use values for the wild salmon ecosystem. For example, Boraas (2011) quotes Bristol Bay natives in saying "We want to give to our children the fish, and we want to keep the water clean for them…It was a gift to us from our ancestors, which will then be given to our children.) (Boraas p. 33).

Goldsmith's estimates for just the federal refuges may be indicative of the range of passive use values for the unprotected portions of the study area. However, there are several caveats to this interpretation. First, Goldsmith et al. estimates are not based on any actual surveys to calculate the contingent value specific to the resource at issue in Bristol Bay. Rather, they are based on inferences from other studies, a method referred to as benefits transfer. Second, these other studies date from the 1980's and early 1990's and the implications of new literature and methods have not been examined. Additionally, the assumptions used to make the benefits transfer for the wildlife refuges may not be appropriate for the larger Bristol Bay study area which includes not only the wildlife refuge, but also two large national parks. This topic is an area for future research.

Table 7. Summary of Bristol Bay Wild Salmon Ecosystem Services, Net Economic Value per Year (Million 2009 $)

Ecosystem Service	Low estimate	High estimate
Commercial salmon fishery		
Fishing Fleet	$30.4	$55.9
Fish Processing	$30.4	$55.9
Sport fishing	$12.2	$12.2
Sport hunting	$1.4	$1.4
Wildlife viewing / tourism	$8.1	$8.1
Subsistence harvest and activity	$154.4	$220.6
Total Direct Use Value	**$236.90**	**$354.10**

Table 7 provides a summary of annual net economic values. Since these are values for renewable resource services that in principle should be available in perpetuity, it is of interest to also consider their present value (e.g. total discounted value of their use into the foreseeable future). The controlling guidance document for discounting in cost benefit analysis, OMB Circular A-4 (2003), generally requires use of discount rates of 3% and 7%, but allows for lower, positive consumption discount rates, perhaps in the 1 percent to 3 percent range, if there are important intergenerational values. Weitzman (2001), conducted an extensive survey of members of the American Economic Association, and suggests a declining rate schedule, which may be on the order of 4 percent (real) in the near term and declining to near zero in the long term. He suggests a constant rate of 1.75% as an equivalent to his rate schedule. Weitzman's work is cited both in the EPA guidance (EPA 2000) and in OMB guidance (*Circular A-4* (2003)). Table 8 shows the estimated net present value in perpetuity of direct use values within the Bristol Bay Ecosystem. The table shows a range of alternative discount rates from the standard "intragenerational" rates of 7% and 3% to the more appropriate "intergenerational" rates for the Bristol Bay case of 1.75% and 1.0%. The entire range of NPV estimates in the table is from $3.4 to $35.4 billion. The range of estimated direct use NPV of the resource using the more appropriate intergenerational discount rates is from $13.5 to $35.4 billion. These estimates are likely quite conservative as they do not include estimates of passive use values, but are limited to direct economic uses of the wild salmon ecosystem services.

Table 8. Estimated Net Present Value of Bristol Bay Ecosystem Net Economic Use Values and Alternative Assumed Perpetual Discount Rates

Estimate		Net Present Value (million 2009 $)			
	Annual Value	7% Discount	3% Discount	1.75% Discount	1% Discount
Low Estimate	$236.9	$3,384	$7,897	$13,537	$23,690
High Estimate	$354.1	$5,059	$11,803	$20,234	$35,410

1.0 Introduction and Setting

This report provides information on the importance of wild fisheries and the natural environment in the Bristol Bay region to the economies of the Bristol Bay region, the State of Alaska and the U.S. as a whole.

1.1 Study Objectives and Report Organization

The primary purpose of this report is to estimate baseline levels of economic activity and values associated with the current Bristol Bay Region wild salmon resource. This comprehensive report includes and synthesizes individual reports on separate components of economic activity and values linked to the Bristol Bay Ecosystem. Economic activity linked to Bristol Bay includes sportfishing, subsistence harvest, sport hunting, and commercial fishing. Additionally, an analysis of the structure of the Bristol Bay economy and the significance of these ecosystem-related economic activities to the economy is presented.

This report on the baseline levels of economic activities (as of 2009) within the Bristol Bay Ecosystem is organized as follows:

Section 1: Introduction and Setting
Section 2: Baseline Recreation and Subsistence Economics
Section 3: Baseline Commercial Fisheries Activity
Section 4: Economic Significance Analysis (Schworer et al.)
Section 5: Baseline Net Economic Values

The major components of the total value of the Bristol Bay area wild salmon ecosystems include subsistence use, commercial fishing and processing, sportfishing, and the preservation values (or indirect values) held by users and the U.S. resident population. The overall objectives of this work are to estimate the share of the total regional economy (expenditures, income and jobs) that is dependent on these essentially pristine wild salmon ecosystems, and to provide a preliminary but relatively comprehensive estimate of the total economic value associated with the ecosystem.

It is important to note that while the geographic scope of this economic characterization report is targeted to the Bristol Bay wild salmon ecosystem, the scope of the proposed mining activity is somewhat narrower, including the Nushugak and Kvichak drainages. Values tied to, and specific to, the proposed mining activity (and discharges) in the Nushugk and Kvichak Drainages would be a subset of those reported here, and have not been identified in this general characterization analysis.

This report used existing information and data to target this economic characterization report to ecosystem services and associated economic activity and values, specific to the Bristol Bay Region. However, data on different economic sectors vary in quality, and available data on some economic activities (such as non-consumptive tourism) make it more difficult to identify activities and associated economic values narrowly targeted to the Bristol Bay area. The overall intent of this report is to provide a general picture of the full range of economic values associated with ecosystem services supplied by the entire Bristol Bay region.

1.2 Definition of Study Area

The Bristol Bay region is located in southwestern Alaska. The region, which includes Bristol Bay Borough, the Dillingham Census Area, and a large portion of Lake and Peninsula Borough, contains a relatively small number of communities, the largest of which are shown in Figure 6. The area is very sparsely populated and the large majority of its population is comprised of Alaskan Natives (Table 9). Although median household income varies among census areas within the region, outside of the relatively small Bristol Bay Borough, income is somewhat lower than for the state of Alaska as a whole. As noted, Alaskan Natives make up over two-thirds of the total population within the region as compared to approximately 15% for the entire state (Table 9)

Table 9. Demographic and Socioeconomic Characteristics of the Bristol Bay Region

Area	Population 2010	Percent Alaska Native	Percent 18 or over	Number of households	Median household income 2009
Bristol Bay Borough	997	48.2%	77.4%	423	$ 64,418
Dillingham Census Area	4,847	80.4%	67.1%	1,563	$ 46,580
Lake & Peninsula Borough	1,631	74.6%	69.8%	553	$ 42,234
Total Bristol Bay Region	7,745	73.8%	66.7%	2,539	$ 48,010
State of Alaska	710,231	14.8%	73.6%	234,779	$ 66,712

Source: US Census Quickfacts. Quickfacts.census.gov

Table 10. Bristol Bay Area Communities and Populations

Bristol Bay Area Community	Population (2010 census)
Aleknagik	219
Clark's Point	62
Dillingham	2,329
Egegik	109
Ekwok	115
Igiugig	50
Iliamna	109
King Salmon	374
Kokhanok	170
Koliganek	209
Levelock	69
Manokotak	442
Naknek	544
New Stuyahok	510
Newhalen	190
Nondalton	164
Pedro Bay	42
Pilot Point	68
Port Alsworth	159
Port Heiden	102
South Naknek	79
Ugashik	12
Togiak City	817
Portage Creek	2
Twin Hills	74

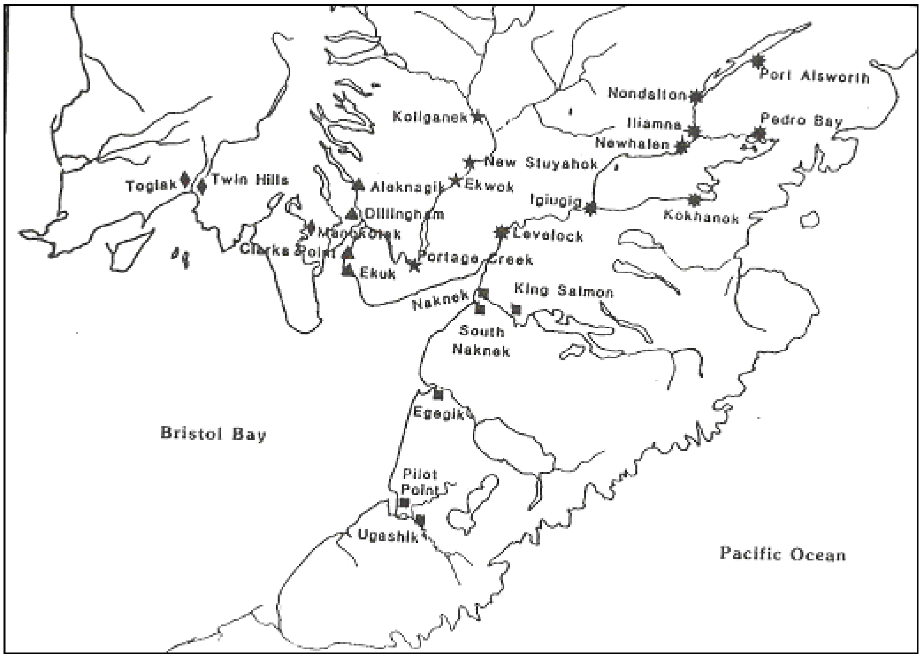

Figure 6. Bristol Bay Area Location and Major Communities

This study focuses on the economic contributions of the Bristol Bay ecosystem. The rivers that flow into the Bristol Bay comprise some of the last great wild salmon ecosystems in North America (Figure 7). All five species of Pacific salmon are abundant, and the rich salmon-based ecology also supports many other fish species, including healthy populations of rainbow trout. The Naknek, Nushagak-Mulchatna, and Kvichak-Lake Iliamna watersheds are relatively pristine with very little roading or extractive resource development. The existing mainstays of the economy in this region are all wilderness-compatible and sustainable in the long run: subsistence use, commercial fishing, and wilderness sportfishing. Commercial fishing largely takes place in the salt water outside of the rivers themselves and is closely managed for sustainability. The subsistence and sportfish sectors are relatively low impact; primarily personal use and catch and release fishing, respectively. Additionally, there are important public lands in the headwaters, including Lake Clark National Park and Preserve, Katmai National Park and Preserve, and Togiak National Wildlife Refuge.

The Bristol Bay area includes the political designations of Bristol Bay Borough, the Dillingham census area, and most of Lake and Peninsula Borough. The largest town in the area is Dillingham. In 2010 the Dillingham census area had an estimated population of 4,847 (US Census, Quick Facts).

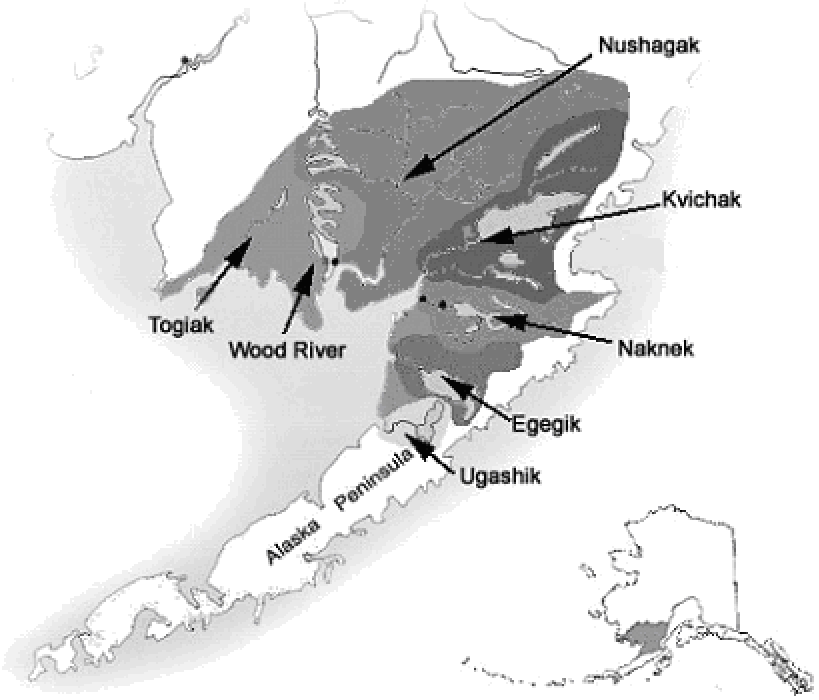

Figure 7. Map of Bristol Bay Study Area

1.3 Focus of Study-Economic Uses

As noted, this report focuses on estimating baseline levels of ecosystem services provided by the Bristol Bay Region. These services are broad and substantial and include, but are not limited to commercial, aesthetic, recreational, cultural, natural history, wildlife and bird life, and ecosystem services.

A primary dichotomy of economic value is the division of values into those that are, or can be traded within existing economic markets, and those for which no developed market exists. Examples of ecosystem services specific to the Bristol Bay region that are traded in markets are commercial fish harvests and guided fishing trips. While a number of services provided by Bristol Bay natural resources can be classified as market services (with associated market-derived values), there are many services provided by this area that are classified as non-market services. These non-market resource services include noncommercial fishing, wildlife watching, subsistence harvests, protection of cultural sites, and aesthetic services.

A second dichotomy of resource services and associated values is that of direct use and passive use services and values. The most obvious type, direct use services, relates to direct onsite uses. The second type of resource services are so-called passive use services. These services have values that derive from a given resource and are not dependent on direct on-site use. Several types of passive use values were first described by Weisbrod (1964) and Krutilla (1967), and include existence and bequest values. Existence values can derive from merely knowing that a given natural environment or population exists in a viable condition. For example, if there were a proposal to significantly alter the Bristol Bay natural ecosystem, many individuals could experience a real loss, even though they may have no expectation of ever personally visiting the area. Bequest values are associated with the value derived from preserving a given natural environment or population for future generations. While use values may or may not have associated developed markets for them, passive use services are exclusively non-market services.

When passive use and use values are estimated together, the estimate is referred to as total valuation. This concept was first introduced by Randall and Stoll (1983) and has been further developed by Hoehn and Randall (1989).

The National Research Council in their 2005 publication “Valuing Ecosystem Services: Toward Better Environmental Decision Making” provided an outline of ecosystem services. Table 11 provides an application of the NRC outline to Bristol Bay resources, and details examples of the ecosystem services, both use and passive use, that are produced by natural resources such as those found in the Bristol Bay region.

Table 11: Types of Ecosystem Services

Use Values		**Nonuse Values**
Direct	**Indirect**	**Existence and Bequest Values**
Commercial and recreational fishing	Nutrient retention and cycling	Cultural heritage
Aquaculture	Flood control	Resources for future generations
Transportation	Storm protection	Existence of charismatic species
Wild resources	Habitat function	Existence of wild places
Potable water	Shoreline and river bank stabilization	
Recreation		
Genetic material		
Scientific and educational opportunities		

A comprehensive economic evaluation of these Bristol Bay wild salmon ecosystems needs to include two distinct accounting frameworks. One is regional economics or economic significance, focused on identifying cash expenditures that drive income and job levels in the regional economy. The other is a net economic value framework that includes all potential costs and benefits from a broader social perspective. The latter necessarily includes non-market and indirect benefits, such as the benefits anglers derive from their recreational activity, over and above their actual expenditure. Both perspectives are important for policy discussions and generally both accounting frameworks are utilized in evaluating public decisions.

2.0 Bristol Bay Recreation and Subsistence Economics

Section 2 of this report addresses the regional economic activity associated with the recreation and subsistence sectors. Primary recreational activities examined include sportfishing, sport hunting, and tourism/wildlife viewing.

2.1 Bristol Bay Sportfishing Economics

Sportfishing is a consistently economically significant economic activity in the Bristol Bay Region. Information sources for this section are the Duffield et al. (2007) report on Bristol Bay Salmon Ecosystem economics (referred to hereafter as the 2005 Bristol Bay Study), and Alaska Department of Fish and Game estimates of the total populations of anglers fishing the Bristol Bay Area waters. (pers. Comm. G. Jennings, August 2011)

The sport angler and trip characteristics, expenditures, and values are presented using several sub-sample breakouts. Comparisons of sub-samples are presented to highlight similarities as well as differences between sample groups. Primary sub-samples examined include non-resident anglers, non-local Alaska resident anglers, and Bristol Bay resident anglers.

The 2005 Bristol Bay study examined angler responses to a wide range of questions on their opinions, preferences, and experiences relating to fishing in the Bristol Bay area. The following sportfishing results focus on key characteristics of Bristol Bay sportfishing. Estimates of angler spending and net economic values have been adjusted from the original 2005 dollars to 2009 dollars using the Consumer Price Index-Urban (CPI-U).

2.1.1 Bristol Bay Area Trip Characteristics and Angler Attitudes

The 2005 Bristol Bay Study reported several differences between how nonresident anglers and Alaska anglers access Bristol Bay fisheries and the types of accommodations they use when there. For non-resident anglers the most common trip included staying at a remote lodge and flying or boating with a guide (35.2%). Resident anglers accessed the Bristol Bay area with their own plane or boat (49.9%), driving to area by motor vehicle (11.3%), and “other” type of trips (24%). Those who reported driving to access Bristol Bay fisheries were primarily residents and nonresidents staying in the King Salmon and Dillingham area, where a few local roads exist and provide some access to nearby fisheries.

Table 12. Bristol Bay Angler Distribution across Trip Types, by Residency

Trip Type	***Non-residents (%)***	***Alaska Residents (%)***
Stayed at a remote lodge and flew or boated with a guide to fishing	35.2	-
Stayed at a tent or cabin camp and fished waters accessible from camp	23.7	7.8
Hired other lodging in an area community and either fished on own or contracted for travel on a daily basis	6.4	4.2
Floated a section of river with a guided party	3.9	2.8
Hired a drop-off service and fished and camped on our own	4.3	2.2
Accessed the area with my own airplane or boat	8.3	49.9
Drove to the area by motor vehicle	4.3	11.3
Other	14.0	24.0
Sample Size	246	55

Note: sample size for resident sample is not large enough to divide into local and non-local sub-samples

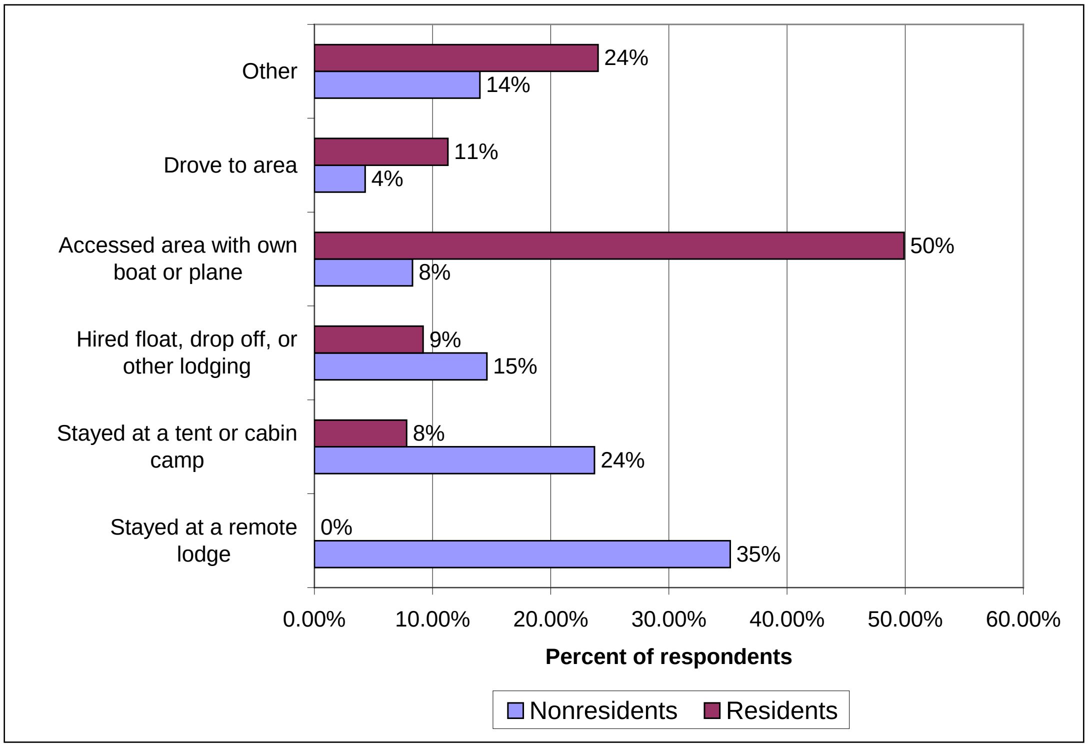

Figure 8. Comparison of Resident and Nonresident Bristol Bay Angler Trip Types

Respondents to the 2005 Bristol Bay survey were asked what was the primary purpose of their trip to the Bristol Bay area. A majority of nonresidents (73%) reported fishing as their major purpose; 30% of resident anglers reported fishing as the main purpose of their most recent Bristol Bay trip. Table 13 also shows that a much larger proportion of non-residents (45%) than residents (11.4%) were on their first trip to their primary fishing destination.

Table 13: Bristol Bay Angler Trip Characteristics.

Statistic	*Nonresidents (sample size)*	*Alaska Residents*
Major purpose of trip was for fishing	72.7% (246)	29.5% (54)
Trip was first trip to primary destination	45.2% (245)	11.4% (48)

Survey respondents in the 2005 study were asked what fish species they targeted on their most recent trip to Bristol Bay. Table 14 reports these results. Overall, king salmon and rainbow trout were the most frequently targeted species for both residents and non-residents.

Table 14: Bristol Bay Angler Survey, Targeted Species.

	Bristol Bay Anglers	
Primary species targeted on trip / statistic	**Nonresidents**	**Alaska Residents**
Rainbow Trout	30.6%	31.3%
King Salmon	35.2%	29.8%
Silver Salmon	16.3%	16.5%
Sockeye Salmon	9.1%	0%
Other Species	8.8%	22.4%
Sample size	235	48

Respondents to the 2005 Bristol Bay angler survey were presented with a series of statements regarding fishing conditions on their Bristol Bay area trip. They were asked to indicate their level of agreement or disagreement with each statement. Table 15 shows the percent of residents and non-residents who either “agreed” or “strongly agreed” with each statement. Across all of the statements presented in the survey, majorities of both resident and non-resident respondents agreed with the positive statements about their fishing experience. The highest levels of agreement for both nonresidents and Alaska resident anglers were with the statements “there was a reasonable opportunity to catch fish”, “there was minimal conflict with other anglers”, and “fishing was in a wilderness setting.”

Table 15: Bristol Bay Angler Rating of Selected Attributes of Fishing Trip

Statement	*% of respondents who either "agree" or "strongly agree"*	
	Nonresidents	**Alaska Residents**
Fishing conditions were un-crowded	87.2%	75.4%
There was a reasonable opportunity to catch fish	96.5%	93.0%
There was minimal conflict with other anglers	93.3%	90.7%
Fishing was in a wilderness setting	92.4%	95.0%
There was opportunity to catch trophy-sized fish	81.4%	70.0%
There was opportunity to catch and release large # of fish	87.3%	76.6%
Sample Size	235	47

2.1.2 Bristol Bay Angler Expenditures

Respondents to the 2005 Bristol Bay angler survey were asked a series of questions relating to the amount of money they spent on their fishing trips. Average spending per trip was estimated for three types of anglers: local Bristol Bay Area residents, Alaska residents from outside the Bristol Bay region, and nonresidents. Adjusted to 2009 price levels, nonresidents reported spending the most for their sportfishing trips to Bristol Bay ($3,995). Alaska resident anglers, those from outside Bristol Bay spent an average of $1,582 per trip and those living within the Bristol Bay region reported spending an average of $373 per sportfishing trip.

Table 16 breaks out average expenditures by impact region and type of fishing trip for the nonresident angler sample. Where money is spent on a trip determines local economic impacts. For instance, a given amount of money spent within the very small Bristol Bay economy has a much greater relative impact than the same amount of money spent in a larger economy, such as Anchorage. Table 16 shows that the largest per-trip spending is made by nonresident anglers who stay at a remote lodge with daily guiding services ($6,950/trip). This compares to the lowest spending levels per trip of about $1,400 for driving to the fishing site, accessing the area with own plane or boat, and hiring a drop-off service and fishing or camping on own.

The first two rows of Table 16 show that a large portion of Alaska trip costs for remote lodge or tent or cabin camp trips is associated with the cost of a sport-fishing package or tour. This sport-fishing package spending is assumed to be spent in the Bristol Bay region.

Table 16. Nonresident Trips to Bristol Bay Waters, Mean Expenditure Per Trip Estimates By Trip Type

Trip type	*Total Reported Trip Spending*	*Bristol Bay spending*[a]	*Package sport-fishing trip spending*
Stayed at a remote lodge and flew or boated with a guide to fishing sites most days	$6,950	$1,900	$6,089
Stayed at a tent or cabin camp and fished waters accessible from this base camp	$4,158	$1,357	$3,517
Hired other lodging in an area community and either fished on own or contracted for travel on a daily basis	$2,643	$1,818	$2,576
Floated a section of river with a guided party	$2,187		
Hired a drop-off service and fished and camped on our own	$1,515	$1,145	
Accessed the area with my own airplane or boat	$1,437	$1,291	
Drove to the area by motor vehicle	$1,453	$1,062	
Other	$2,233	$1,047	$2,422

[a] all spending in Bristol Bay except package sportfishing trip expenditures (package trip expenditures are also assumed spent in the Bristol Bay Region)

Note: cells with less than 5 observations are left blank. Category values are the average values for those respondents reporting an expense in that category. Bristol Bay spending and Package sport-fishing tour spending will not necessarily sum to Total spending due to varying sample sizes.

Table 17 details the distribution of Bristol Bay trip spending across expenditure categories. For non-residents visitors, the largest three spending categories within the Bristol Bay area were for commercial and air taxi service and for lodging or camping fees (totaling about 66% of all spending in Bristol Bay). For non-local Alaska residents the three largest categories of spending were “gas and other Alaska travel costs,” camping fees, and commercial air travel (totaling about 58% of all Bristol Bay spending by non-local Alaska residents).

Table 17: Distribution of Trip Expenditures across Spending Categories, by Residency and Area

	Nonresidents		***non-local AK residents***
Expenditure category	**In Bristol Bay**	**In rest of AK**	**In Bristol Bay**
Commercial air travel	31.1%	51.9%	18.1%
Air taxi service	20.5%	1.3%	11.1%
Transportation by boat	0.0%	0.0%	0.0%
Boat or vehicle rental	5.3%	4.8%	7.5%
Gas or other travel costs in AK	4.1%	1.4%	16.3%
Lodging or camping fees	13.9%	11.9%	23.6%
food or beverages	9.2%	19.3%	16.7%
Guide fees	6.2%	0.6%	0.0%
Fishing supplies	4.1%	5.2%	6.7%
Other non-fish package tours	0.1%	0.7%	0.0%
Other	5.4%	2.9%	0.0%

2.1.3 Aggregate Direct Sport fishing Expenditures in Bristol Bay

In order to derive estimated aggregate angler expenditures related to sportfishing in the Bristol Bay region, two primary pieces of information were needed: 1) the number of angler trips per year to the region by Alaska residents and nonresidents, and 2) the average spending per trip by resident and nonresident anglers. A trip is defined here as a roundtrip visit from home, and return. Estimates of the number of anglers who fished in the Bristol Bay region in 2009 were derived by ADF&G staff (Table 18). The average number of trips per angler, estimated from responses to the 2005 Bristol Bay angler survey, is also shown in Table 18. In total approximately 29,000 sport fishing trips were taken in 2009 to Bristol Bay freshwater fisheries. These trips are roughly split between 12,000 nonresident trips, 13,000 Bristol Bay resident trips, and 4,000 trips by Alaskans living outside of the Bristol Bay area.

Table 18. Estimated 2009 Bristol Bay area angler trips, by Angler Residency

Statistic	*Nonresidents*	*Out-of-area AK residents*	*BB Residents*
Annual Anglers fishing Bristol Bay waters	9,572	2,561	1,133
Average trips per angler for 2005	1.30	1.49	11.54
Estimated total trips	12,464	3,827	13,076

Table 19 presents the aggregation of total angler expenditures within the Bristol Bay region. This table shows average and aggregate estimated expenditures for three angler groups: 1) nonresident anglers, 2) local-area resident anglers (those who live in the Bristol Bay area), and 3) non-local resident anglers (those Alaska residents living outside of the Bristol Bay region). This table also shows average and total annual spending by nonresident anglers for package sportfishing trips in the Bristol Bay region.

Overall, the large majority of angler spending in the region is attributable to nonresident anglers. Additionally, the majority of nonresident spending is due to the purchase of sportfishing packages such as accommodation and angling at one of the areas remote fishing lodges. Estimates of variability were derived for average expenditure levels, and total visitation estimates. It is estimated that annually Bristol Bay anglers spend approximately $58 million within the Bristol Bay economy. Given the variability in the components of this estimate, the 95% confidence interval for Bristol Bay area spending by anglers from outside the area ranges from $0 to $130 million annually. The vast majority of this spending (approximately $47 million annually) is spent by nonresident anglers.

Table 19. Estimated Aggregate Spending Associated with Sportfishing in the Bristol Bay Region (2009 dollars)

	Nonresidents		*out-of-area AK residents*	*BB Residents*	**Total**
	All Non Residents	Remote Lodge Increment			
Mean expenditures in Bristol Bay region	$ 1,471	$4,698	$ 1,582	$ 373	
Estimated trips	12,464	6,187	3,827	13,076	29,367
Total Bristol Bay direct expenditures	$ 18,333,187	$ 29,068,303	$ 6,053,700	$ 4,874,848	$ 58,330,039

Table 20 presents total estimated direct angler expenditures by residency, and location of spending. Again, among all direct spending related to Bristol Bay angling, the large majority is associated with nonresidents traveling to Alaska. Additionally, the large majority of this spending is reported to have occurred within the Bristol Bay economy. This table categorizes spending by origin and destination. This classification is then used in the regional economic significance analysis presented in Section 4.

Table 20. Bristol Bay Sportfishing: Aggregate in and out of Region and State Spending (2009)

Population	In Bristol Bay Spending		In Alaska Spending	
	Total spending in Bristol Bay	Total spending from outside Bristol Bay	Total in-state spending	Spending from outside Alaska
NONRESIDENT Base trip spending	$ 18,333,187	$ 18,333,187	$ 20,727,318	$ 20,727,318
NONRESIDENT Sportfish package spending	$ 29,068,303	$ 29,068,303	$ 29,068,303	$ 29,068,303
NONRESIDENT TOTAL	$ 47,401,490	$ 47,401,490	$ 49,795,621	$ 49,795,621
RESIDENTS				
OUT-OF-BB RESIDENT base trip spending	$ 6,053,700	$ 6,053,700	$ 6,053,700	$ -
BB RESIDENT base trip spending	$ 4,874,848	$ -	$ 4,874,848	$ -
ALASKA RESIDENT TOTAL	$ 10,928,549	$ 6,053,700	$ 10,928,549	$ -
TOTAL	**$ 58,330,039**	**$ 53,455,190**	**$ 60,724,170**	**$ 49,795,621**

2.2 Bristol Bay Subsistence Harvest Economics

The subsistence harvest within the Bristol Bay region generates regional economic impacts when Alaskan households spend money on subsistence-related supplies. Goldsmith (1998) estimated that Alaskan Native households that use Bristol Bay wildlife refuges for subsistence harvesting spend an average of $2,300 per year on subsistence-related equipment to aid in their harvesting activities. Additionally, Goldsmith estimated that Non-Native households spend $600 annually for this purpose. Correcting for inflation from 1998 to 2009 implies annual spending for subsistence harvest of about $3,054 for Native households and $796 for Non-Native households.[7]

Figure 9 shows the general distribution of subsistence harvest by Bristol Bay residents. Overall, salmon make up the largest share of all harvest (on a basis of usable pounds), and accounts for over one-half of all harvest. Another nearly one third of harvest come from land mammals (31%), and non-salmon fish comprise another 10% of harvest.

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[7] A 1998-99 survey of the village of Atyqasuk (North Slope Borough) found that 33% of households spent between $4,000 and $10,000 on subsistence activities and 9% spent more than $10,000 per year (US DOI, BLM and MMS 2005). The simple parametric mean for this inland community that harvested no whales was $3,740 per year per household (1999 dollars). The use of the adjusted Goldsmith estimates therefore likely provides a conservative estimate of subsistence expenditures.

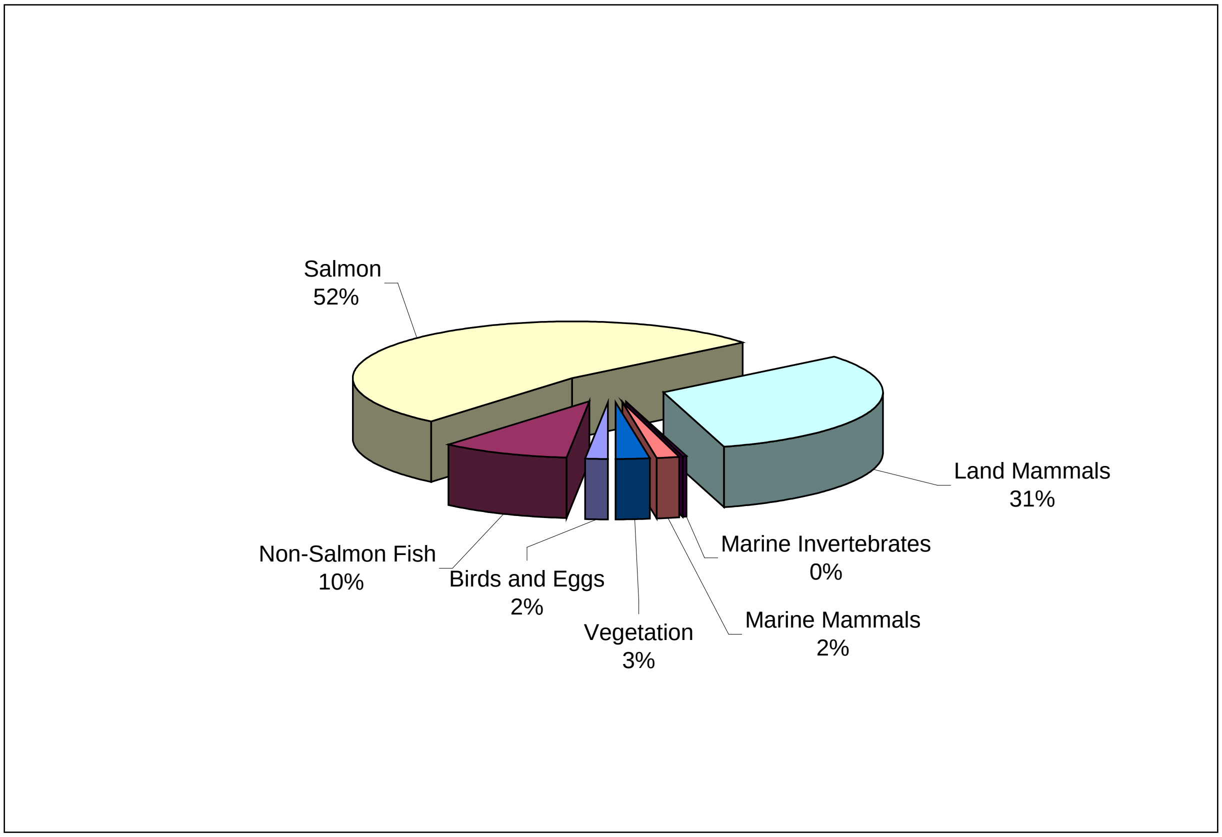


Figure 9. Distribution of Bristol Bay Subsistence Harvest

Table 21 shows average per capita and total estimated community subsistence harvest for the Bristol Bay communities. In total, individuals in these Bristol Bay communities harvest about 2.6 million pounds of subsistence harvest per year for an average of 343 pounds per person annually. Table 22 and Table 23 detail Bristol Bay area subsistence harvest by salmon species and location.

Table 21. ADF&G Division of Subsistence Average Per Capita Subsistence Harvest for Bristol Bay Communities

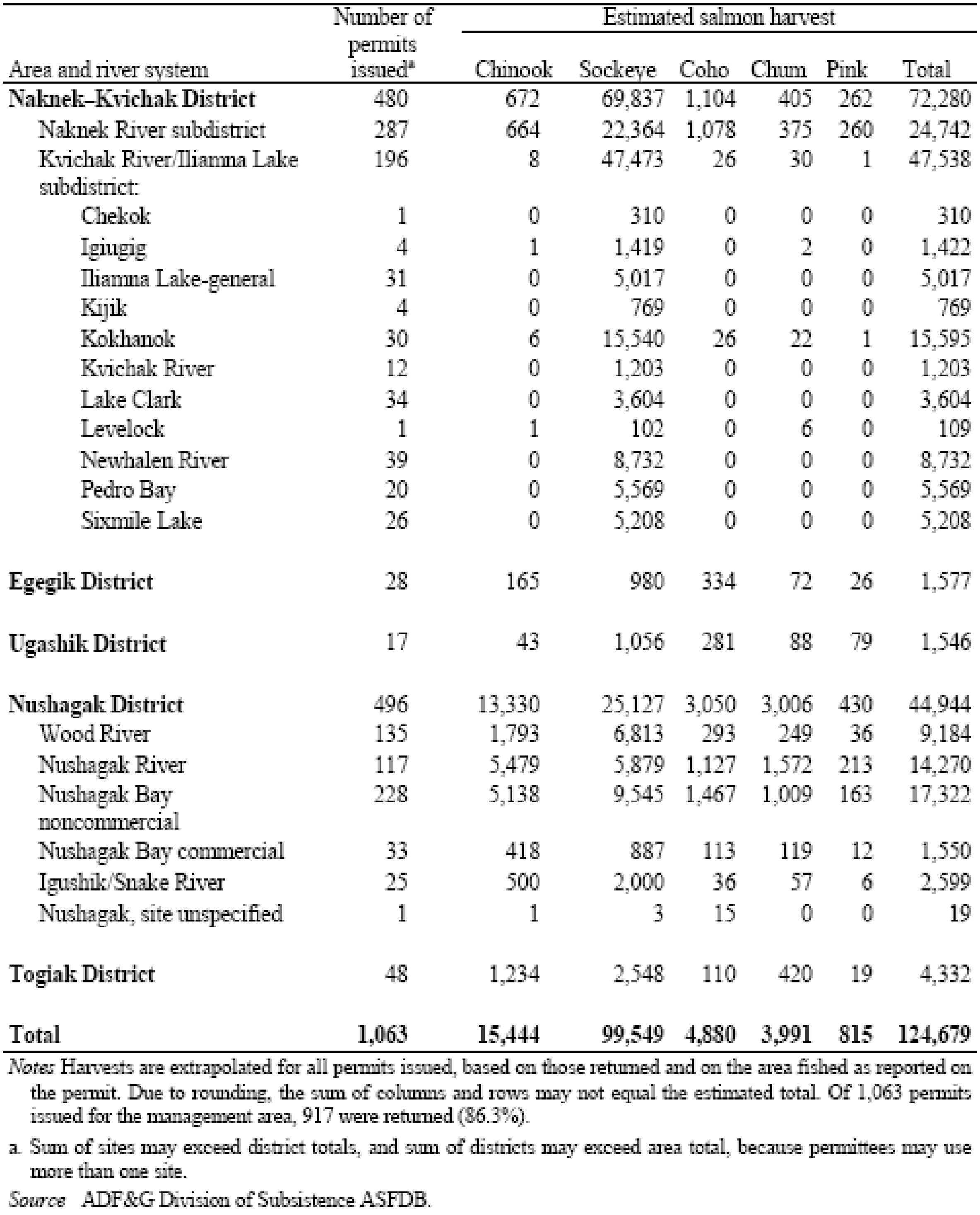
Bristol Bay Area Community /year of AKF&G harvest data survey	Population (2010 census)	Per Capita Harvest (raw pounds of harvest)(AKF&G Subsistence Surveys)	Total Annual Harvest
Aleknagik 2008	219	296	64,824
Clark's Point 2008	62	1210	75,020
Dillingham 1984	2,329	242	563,618
Egegik 1984	109	384	41,856

Ekwok 1987	115	797	91,655
Igiugig 2005	50	542	27,100
Iliamna 2004	109	469	51,121
King Salmon 2008	374	313	117,062
Kokhanok 2005	170	680	115,600
Koliganek 2005	209	899	187,891
Levelock 2005	69	527	36,363
Manokotak 2008	442	298	131,716
Naknek 2008	544	264	143,616
New Stuyahok 2005	510	389	198,390
Newhalen 2004	190	692	131,480
Nondalton 2004	164	358	58,712
Pedro Bay 2004	42	306	12,852
Pilot Point 1987	68	384	26,112
Port Alsworth 2004	159	133	21,147
Port Heiden 1987	102	408	41,616
South Naknek 2008	79	268	21,172
Ugashik 1987	12	814	9,768
Togiak City 2000	817	246	200,982
Twin Hills 2000	74	499	36,926
Total surveyed communities	7,018		
Un-surveyed communities	457		--
Total including un-surveyed areas	**7,475**	**343**	**2,563,313**

Table 22. Historical Subsistence Salmon Harvest for Bristol Bay, Alaska: 1975-2007 (ADF&G Division of Subsistence ASFDB)

		Number of Fish Harvested						
Year	Permits	Chinook	Sockeye	Coho	Chum	Pink	Total	Harvest per permit
1975	686	8,600	175,400	8,500	7,500	1,300	192,700	280.9
1976	716	8,400	120,900	3,500	9,100	4,400	137,900	192.6
1977	738	7,000	127,900	6,600	9,100	300	143,900	195
1978	773	8,100	127,600	4,400	16,200	12,700	160,900	208.2
1979	829	10,300	116,500	7,300	7,700	500	132,000	159.2
1980	1,243	14,100	168,600	7,300	13,100	10,000	199,000	160.1
1981	1,112	13,000	132,100	12,200	11,500	2,600	158,400	142.4
1982	806	13,700	110,800	11,500	12,400	8,600	143,300	177.8
1983	829	13,268	143,639	7,477	11,646	1,073	177,104	213.6
1984	882	11,537	168,803	16,035	13,009	8,228	217,612	246.7
1985	1,015	9,737	142,755	8,122	5,776	825	167,215	164.7
1986	930	14,893	129,487	11,005	11,268	7,458	174,112	187.2
1987	996	14,424	135,782	8,854	8,161	673	167,894	168.6
1988	938	11,848	125,556	7,333	9,575	7,341	161,652	172.3
1989	955	9,678	125,243	12,069	7,283	801	155,074	162.4
1990	1,042	13,462	128,343	8,389	9,224	4,455	163,874	157.3
1991	1,194	15,245	137,837	14,024	6,574	572	174,251	145.9
1992	1,203	16,425	133,605	10,722	10,661	5,325	176,739	146.9
1993	1,206	20,527	134,050	8,915	6,539	1,051	171,082	141.9
1994	1,193	18,873	120,782	9,279	6,144	2,708	157,787	132.3
1995	1,119	15,921	107,717	7,423	4,566	691	136,319	121.8
1996	1,110	18,072	107,737	7,519	5,813	2,434	141,575	127.5
1997	1,166	19,074	118,250	6,196	2,962	674	147,156	126.2
1998	1,234	15,621	113,289	8,126	3,869	2,424	143,330	116.2
1999	1,219	13,009	122,281	6,143	3,653	420	145,506	119.4
2000	1,219	11,547	92,050	7,991	4,637	2,599	118,824	97.5
2001	1,226	14,412	92,041	8,406	4,158	839	119,856	97.8
2002	1,093	12,936	81,088	6,565	6,658	2,341	109,587	100.3
2003	1,182	21,231	95,690	7,816	5,868	1,062	131,667	111.4
2004	1,100	18,012	93,819	6,667	5,141	3,225	126,865	115.3
2005	1,076	15,212	98,511	7,889	6,102	1,098	128,812	119.7
2006	1,050	12,617	95,201	5,697	5,321	2,726	121,564	115.8
2007	1,063	15,444	99,549	4,880	3,991	815	124,679	117.3
Average	**1,035**	**13,825**	**121,906**	**8,329**	**7,733**	**3,099**	**152,371**	**153**

Table 23. Bristol Bay Subsistence Salmon Harvests by District and Location Fished, 2007. (Fall et al. 2009)



Area and river system	Number of permits issued[a]	Estimated salmon harvest Chinook	Sockeye	Coho	Chum	Pink	Total
Naknek–Kvichak District	480	672	69,837	1,104	405	262	72,280
Naknek River subdistrict	287	664	22,364	1,078	375	260	24,742
Kvichak River/Iliamna Lake subdistrict:	196	8	47,473	26	30	1	47,538
Chekok	1	0	310	0	0	0	310
Igiugig	4	1	1,419	0	2	0	1,422
Iliamna Lake-general	31	0	5,017	0	0	0	5,017
Kijik	4	0	769	0	0	0	769
Kokhanok	30	6	15,540	26	22	1	15,595
Kvichak River	12	0	1,203	0	0	0	1,203
Lake Clark	34	0	3,604	0	0	0	3,604
Levelock	1	1	102	0	6	0	109
Newhalen River	39	0	8,732	0	0	0	8,732
Pedro Bay	20	0	5,569	0	0	0	5,569
Sixmile Lake	26	0	5,208	0	0	0	5,208
Egegik District	28	165	980	334	72	26	1,577
Ugashik District	17	43	1,056	281	88	79	1,546
Nushagak District	496	13,330	25,127	3,050	3,006	430	44,944
Wood River	135	1,793	6,813	293	249	36	9,184
Nushagak River	117	5,479	5,879	1,127	1,572	213	14,270
Nushagak Bay noncommercial	228	5,138	9,545	1,467	1,009	163	17,322
Nushagak Bay commercial	33	418	887	113	119	12	1,550
Igushik/Snake River	25	500	2,000	36	57	6	2,599
Nushagak, site unspecified	1	1	3	15	0	0	19
Togiak District	48	1,234	2,548	110	420	19	4,332
Total	**1,063**	**15,444**	**99,549**	**4,880**	**3,991**	**815**	**124,679**

Notes Harvests are extrapolated for all permits issued, based on those returned and on the area fished as reported on the permit. Due to rounding, the sum of columns and rows may not equal the estimated total. Of 1,063 permits issued for the management area, 917 were returned (86.3%).

a. Sum of sites may exceed district totals, and sum of districts may exceed area total, because permittees may use more than one site.

Source ADF&G Division of Subsistence ASFDB.

In 2010 the US Census reported an estimated 1,873 Native and 666 non-native households in the Bristol Bay Region (Bristol Bay Borough, Lake and Peninsula Borough, and Dillingham). Based on the Goldsmith (1998) estimate of direct expenditures related to subsistence harvest, this implies an annual direct subsistence-related expenditure of approximately $6.3 million in the Bristol Bay region.

Table 24. Estimated Total Annual Bristol Bay Area Subsistence-Related Expenditures (2009 $)

Area	*Population 2010*	*Percent Alaska native*	*Number of households*	*Number of Native Households*	*Number of non-native Households*
Bristol Bay Borough	997	48.2%	423	204	219
Dillingham Census Area	4847	74.6%	553	413	140
Lake & Peninsula Borough	1631	80.4%	1563	1257	306
Total Bristol Bay Region	7,475	73.8%	2539	1873	666
Annual Spending/ household				$ 3,054	$ 796
Total Estimated Subsistence Spending				$ 5,720,054	$ 530,350
Total					$ 6,250,404

2.3 Bristol Bay Sport Hunting and Non-consumptive Economics

2.3.1 Sport Hunting

In addition to sport fishing, sport hunting also plays a significant (but smaller) role in the local economy of the Bristol Bay region. While not a large share of the economy, sport hunting in the Bristol Bay area offers high quality hunting opportunities for highly valued species. Bristol Bay sport hunting provides hunting opportunities for caribou, moose, and brown bear, among other species. Table 25 shows reported hunter numbers for the most recently reported representative years for several species hunted in the region. The big game hunting numbers are reported for the two Game Management Units (GMUs) that comprise the Bristol Bay Region. GMUs are spatial areas delineated by AKF&G to more closely correspond to wildlife habitat and population ranges than do other geographical or political boundaries.

Table 25. ADF&G Reported Big Game Hunting in Bristol Bay and Alaska Peninsula Game Management Units

Most recent Big Game Hunting Estimates from ADF&G Wildlife Management Reports
(Number of hunters)

	Alaska Peninsula (GMU 9)		**Bristol Bay (GMU 17)**	
	Non-local Residents	**Nonresidents**	**Non-local Residents**	**Nonresidents**
Moose	91	157	200	195
Caribou	0	0	311	230
Brown bear	600	624	117	117
	691	781	628	542

The caribou estimate for GMU 17 is for the Mulchatna herd and extends beyond GMU 17 borders
Shaded cells include both non-local residents and local residents
Sources: AKDF&G Species-specific Wildlife Management Reports

Table 26 outlines the estimation of total annual expenditures for big game hunting within the Bristol Bay region. These estimates are based on an assumption of one trip per hunter per year for a species, and utilize estimates of hunter expenditures per trip developed by Miller and McCollum (1994) adjusted to 2009 price levels.

Table 26. Estimated annual big game hunting expenditures for Bristol Bay region

Statistic	***Non-local Residents***	***Nonresidents***
Estimated trips	1,319	1,323
Expenditure per trip	$ 1,068	$ 5,170
Total estimated direct expenditure	$ 1,408,351	$ 6,839,301
Total	**$ 8,247,652.52**	

In total, it is estimated that Bristol Bay area big game hunters living outside of the area spend about $8.2 million per year in direct hunting-related expenditures. The expenditure estimate above may include some caribou hunting of the Mulchatna herd outside of the closely defined Bristol Bay region game management units, resulting in an overestimate of spending for hunting this species.

2.3.2 Non-consumptive Wildlife Viewing / Tourism Economics

Many of the sport fishing and sport hunting visitors to the Bristol Bay region also engage in other activities such as kayaking, canoeing, wildlife viewing or bird watching. These activities are typically referred to as non-consumptive because unlike hunting or fishing, no resource is "consumed," rather the goal is to leave the resource (flora and fauna) unchanged.

The Bristol Bay region has a number of nationally-recognized special management areas for wildlife. These include Katmai and Lake Clark National Parks, the Togiak and Becherof National Wildlife Refuges, and Wood-Tikchick State Park. The most accessible and popular destination for visitors interested in non-consumptive recreation activities is Katmai National Park, and in particular Brooks Camp on Naknek Lake which is world famous as a site for bear viewing. The camp accommodates both day and overnight visitors who are there to view the bears, as well as sport fishermen.

Information on the number of non-consumptive use visitors, their itineraries and activities while in the region, and their expenditures is somewhat limited. Unlike sport fishing and sport hunting, no license is required for these other activities so there is no consistent and comprehensive record documenting these trips.

The visitation estimates that form the basis for the analysis of non-consumptive use in Southwest Alaska are primarily based on McDowell Group's (2006) Alaska Visitor Statistics Program (AVSP) estimate . The AVSP is a comprehensive State of Alaska research program initiated in 1982 and follows a strict and proven methodology. The methodology utilizes an exit survey to intercept visitors. As a result of the concentration of visitors in urban parts of the state, the survey method tends to oversample urban visitors and undersample rural visitors. Based on a separate stratified rural sample conducted during the 2001 AVSP, it is known that the survey methodology tends to underestimate visitation to remote rural parts of the state such as Southwest Alaska. Thus, the overall visitation used for this analysis can be considered conservative. In addition to McDowell Group (2006), Fay and Christensen (2011)'s 2007 estimate of visitation to Katmai was utilized.

For this analysis non-consumptive users are defined as those who reported wildlife viewing, camping, kayaking, hiking, or photography as their primary purpose of their visit. We adjust the most recent 2006 summer and winter visitor estimate for Southwest Alaska excluding Kodiak by applying the 2006-2009 percent difference in air travelers for Alaska overall (McDowell Group, 2007a & 2007b). The trend in air travelers to Alaska serves as the best indicator for changes to visitation in Southwest Alaska for two reasons. First, visitors to rural Alaska are mainly independent travelers, and second they primarily arrive by air in comparison to the statewide largest share of visitors who arrive by cruise ship. The Southwest Alaska region closely matches the Bristol Bay study region with the exception of Kodiak and the Aleutian Islands. Our analysis excludes Kodiak but includes an insignificant portion of visitors to the Aleutian Islands.

Since the Alaska Visitor Statistics Program counts out-of-state visitors only, we calculate visitor volume originating within the state based on Littlejohn and Hollenhorst (2007) and Colt and Dugan (2005) resident share of between ten and eleven percent. We treat visitation to Katmai NPP separate from other areas of the Bristol Bay region. Visitor volume and expenditure for Katmai NPP are from Fay and Christensen (2010) and for the remaining Bristol Bay area are from McDowell Group (2007a). We net out sport fishing and hunting visitation in Katmai NPP using Littlejohn and Hollenhorst (2007) and for the rest of the region by applying the McDowell

Group (2007a and 2007b) estimate. We assume equal expenditures for residents and non-residents because the non-resident per person expenditure estimate in both cases does not include the cost of travel to and from Alaska. For most non-residents all in-state travel expenditures are included, based on the assumption that the primary reason for the travel to Alaska is the visit the Bristol Bay region. For all of these estimates, we paid special attention to the potential for double counting and addressed those issues.

Based on the most recent studies of non-resident visitors to the state and two studies that estimated visitation and economic impacts related to Katmai National Park and Preserve, we estimate that on an annual basis including summer and winter visitation, approximately 2,300 residents and 18,900 non-residents visited Katmai NPP. Other areas in the Bristol Bay region received approximately 2,300 resident visitors and 19,000 non-resident visitors. Note, these estimates exclude visitation where sport fishing or sport hunting was in part or the primary activity of choice. After adjusting the per capita expenditures to 2009 dollars we estimate per person expenditures to amount to $2,245 annually for Katmai NPP and $2,873 per person annually for visiting other destinations in the Bristol Bay region.

To be consistent with the expenditure data for sport fishing and hunting, we assume that the visit to the Bristol Bay region was the primary reason for their visit to Alaska. Based on these assumptions, 2009 total expenditure for this group is estimated to be $104.2 million.

It should be noted that an earlier estimate of Bristol Bay non-consumptive (wildlife watching) visitor expenditures (Duffield et al. 2007) reported a much lower spending level by this group ($17.1 million). As noted in that report, the estimate was based on extremely limited and dated information from one location within the region (Brooks Camp). The estimate was derived and presented as an approximation, as was also noted in the report, “This is an approximate estimate based on limited and outdated information, and is an area for further research.”(Duffield et al. 2007, p. 91).

The estimates derived in this later, current report utilizes both visitation and expenditure estimates that were not available when the earlier report was drafted.

3.0 Bristol Bay Commercial Fisheries

3.1 Introduction

This section provides an economic overview of Alaska's Bristol Bay commercial salmon industry. The report begins with a brief overview of the industry. Subsequent sections discuss harvests, products and markets, prices, harvest and wholesale value, fishermen, processors, employment, taxes, the regional distribution of permit holders, fishery earnings and processing employment, and the role of the industry in the Bristol Bay regional economy. The final section discusses selected economic measures of the Bristol Bay salmon industry.

A challenge in characterizing the Bristol Bay fishery is that there is wide variation from year to year in catches, prices, earnings, employment and other measures of the fishery. No single recent year or period is necessarily "representative" of the fishery or what it will look like in the future. To illustrate the range of historical variation in the fishery, wherever possible this report provides data or graphs for at least the years since 2000, and in many cases for longer periods.

This report focuses on the economic significance of the entire Bristol Bay commercial salmon fishery. The fishery harvests salmon returning to several major river systems, including the Nushagak and Kvichak. Currently, because of potential future resource development in these watersheds, there is particular interest in the fisheries resources and economic significance of these two river system. As discussed in greater below, historically the relative contribution of these river systems to total Bristol Bay commercial salmon harvests has varied widely from year to year and over longer-term periods. There is no simple way to characterize what share of the Bristol Bay commercial fishery is attributable to the Nushagak and Kvichak river systems, or what this share will be in the future.

Some of the prices and values presented in this report are presented as *nominal* prices and values (not adjusted for inflation), and others are presented as *real* prices and values (adjusted for inflation). In general, we used nominal prices where our primary purpose was to show actual prices and values over time (and as they appeared to people over time), and we used real prices where our primary purpose was to compare prices and values over time. Prices and values are expressed in nominal dollars except where the report specifically notes that they are real dollars. All real prices are expressed in 2010 dollars, as calculated using the Anchorage Consumer Price Index. This is far from an ideal measure, but it is the only long-term measure of inflation available for any Alaska location.[8]

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[8] In theory, it may appear more technically accurate to express all prices in real dollars. In practice, there are several reasons why nominal prices are preferable for much of the data presented in this report. First, it is far from obvious what the measure of inflation should be: while the Anchorage CPI is the best available measure, it is not necessarily a good characterization of the inflation actually experienced by Bristol Bay fishermen or processors. Secondly, when price or value data are converted to "real" values it is harder to compare them to other data unless those data have been converted to real values for the same year. Data converted to real dollars quickly use their utility as a reference source. Third, people familiar

The report presents a wide variety of data for the Bristol Bay salmon industry in graphs and tables as well as in the text of the report. Detailed information on the data sources for all graphs , tables and text are provided in the data appendix at the end of the report. The report is based on data available as of October 2011.

We've included pictures in the report to help readers who haven't had the opportunity to visit Bristol Bay to have a sense of what the industry looks like. Except where otherwise noted, pictures in the report were taken by Gunnar Knapp.

3.2 Overview of the Bristol Bay Salmon Industry

The Bristol Bay salmon fishery is one of the world's largest and most valuable wild salmon fisheries. Between 2006 and 2010, the Bristol Bay salmon industry averaged:

- Annual harvests of 31 million salmon (including 29 million sockeye salmon)
- 51% of world sockeye salmon harvests
- Annual "ex-vessel" value (the value earned by fishermen) of $129 million
- Annual first wholesale value after processing of $268 million.
- 26% of the "ex-vessel" value to fishermen of the entire Alaska salmon harvest.
- Seasonal employment of more than 6800 fishermen and 3700 processing workers.

Bristol Bay is located in southwestern Alaska. Each year tens of millions of sockeye salmon return to the major river systems which flow into Bristol Bay, of which the most significant (in numbers of returning salmon) are the Nushagak, Kvichak, Naknek and Egegik Rivers. Sockeye salmon spend a year or more in freshwater lakes before migrating to saltwater. The large lakes of the Bristol Bay region provide habitat for sockeye salmon during this life stage.

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with the Bristol Bay fishing industry remember what fish and permit prices actually were in any given year: it is harder for them to recognize and believe prices or values converted to real dollars.

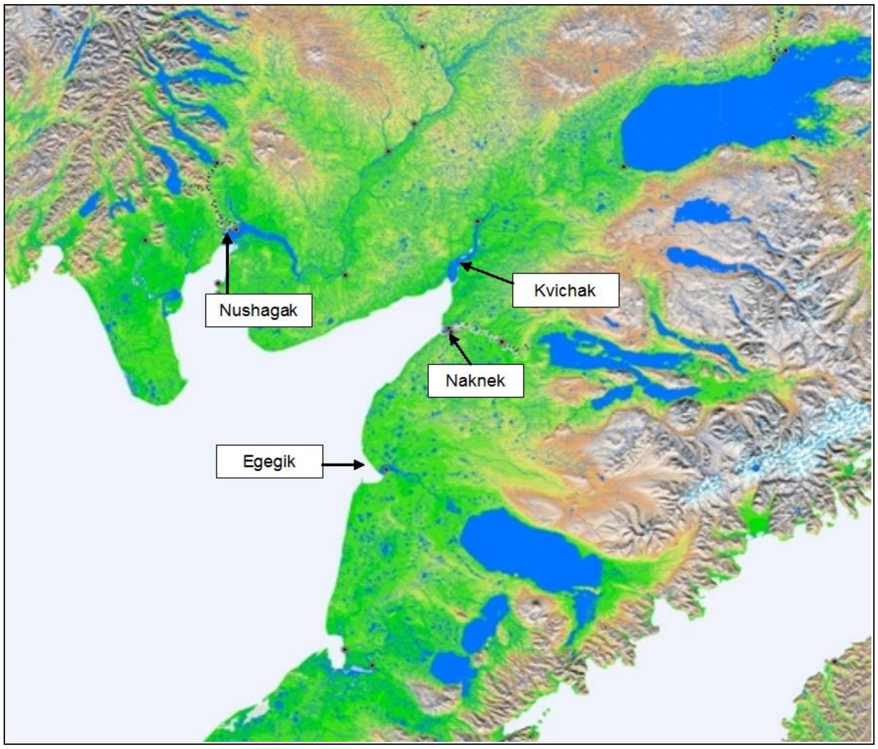


Figure 10. Major Bristol Bay River Systems

Map source: www.purebristolbay.com/images/layout/BBNC_Base_Map-800.jpg

Almost all Bristol Bay commercial fish harvests occur during a brief four-week season from mid-June to mid-July. At the peak of the season, millions of salmon may be harvested in a single day.

The Naknek River near King Salmon

Two kinds of fishing gear are used in the Bristol Bay fishery: drift gillnets (operated from fishing boats) and set gillnets (operated from shore). Drift gillnets account for most of the total catch. Technically, the drift gillnet fishery and the set gillnet fishery are managed as separate fisheries.

Both the drift gillnet fishery and the set gillnet fishery are managed under a “limited entry” management system which was implemented for all of Alaska’s twenty-seven salmon fisheries in the mid-1970s. The basic purpose of the limited entry system is to limit the number of boats fishing in each fishery, which makes it easier for managers to control the total fishing effort and makes the fishery more profitable for participants than it would be if entry (participation) were unrestricted and more boats could fish. Every drift gillnet fishing boat or set net operation must have a permit holder on board or present—so the number of boats or set net operations cannot exceed the number of permit holders. There are approximately 1860 drift gillnet permits and approximately 1000 set net permits. Section 3.7 below (Bristol Bay Salmon Fishermen) provides more details about the limited entry system and Bristol Bay management regulations.

Drift Gillnet Boats Fishing in the Naknek River

The Bristol Bay salmon harvest is processed by about 10 large processing companies and 20 smaller companies employing about 3700 processing workers at the peak of the season in both land-based and floating processing operations. Most of the land-based processors operate only during the short summer salmon season. Most of the workers are flown in from outside the region and live in bunkhouse facilities at the processing plants.

The Ekuk Processing Plant in the Nushagak District near Dillingham, photographed at low tide. Extreme tides complicate logistics for land processing facilities in Bristol Bay. At many plants, fish can be delivered only when the tide is in.

Most Bristol Bay salmon is processed into either frozen headed and gutted salmon or canned salmon. Formerly almost all Bristol Bay frozen salmon was exported to Japan. In recent years exports to Japan have declined sharply while shipments to the U.S. domestic market have increased and exports have increased to Europe and to China (for reprocessing into fillets sold in Europe, Japan and the United States). Most canned salmon is exported, primarily to the United Kingdom, Canada, and other markets.

Fish on a Bristol Bay fishing boat

Photograph by Gabe Dunham

Bristol Bay salmon catches vary widely from year to year and over longer periods of time. Catches set all-time records in the early 1990s, fell sharply after 1995, and then rose again after 2002. The 2011 catch was about 25% lower than the average for the previous five years.

Wholesale prices for Bristol Bay salmon products and “ex-vessel” prices paid to fishermen increased during the 1980s, peaked in 1988, and then declined dramatically during the 1990s. The main cause of the decline in prices was competition in world markets from dramatically increasing world production of farmed salmon, although many other factors also contributed. Since 2001, wholesale and ex-vessel prices have been increasing, as the growth of farmed salmon production has slowed and new markets for Bristol Bay sockeye salmon have been developed.

The decline in catches and prices during the 1990s led to a drastic decline in value in the Bristol Bay salmon fishery. The ex-vessel value paid to fishermen fell from a peak of $214 million in 1990 to just $32 million in 2002. The loss in value led to a severe economic crisis in the Bristol Bay salmon industry. Many land-based salmon processing operations closed and many floating processors left Bristol Bay. Many fishing permit holders stopped fishing, and permit prices fell drastically.

As catches and prices have improved since 2002, the Bristol Bay salmon industry has experienced a significant economic recovery. The ex-vessel value paid to fishermen increased to $149 million in 2010. Participation in the fishery has increased and permit prices have strengthened. Among both fishermen and processors there is a renewed sense of optimism about the economic future of the Bristol Bay salmon industry, taking advantage of growing world demand for wild salmon. This optimism is tempered by recognition of the variability of harvests and value associated with fluctuations in salmon returns and markets.

A tender, floating processor, and freighter anchored in the Nushagak district

Photograph by Gabe Dunham

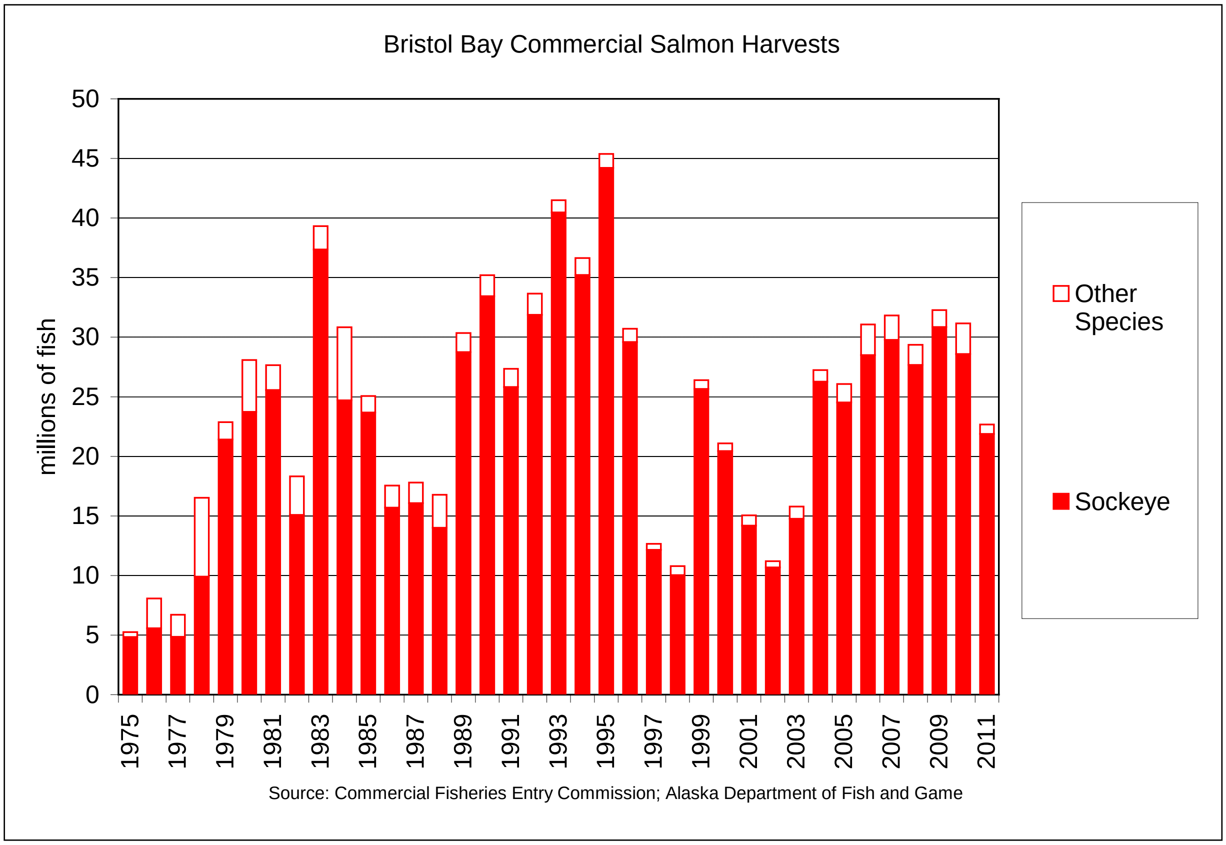
A Bristol Bay processing worker holding a sockeye salmon

Photograph by Gabe Dunham

3.3 Bristol Bay Salmon Harvests

Although all five species of Pacific salmon are caught in Bristol Bay, commercial salmon harvests are overwhelmingly sockeye salmon. Between 2001 and 2010, sockeye accounted for 94% of total Bristol Bay salmon catches. Except where otherwise noted, references in this report to harvests, production, prices, etc. are specifically for Bristol Bay *sockeye* salmon.

Between 1975 and 2010, annual Bristol Bay commercial sockeye salmon harvests ranged from 5 million to 44 million fish, with an annual average of 22.5 million fish. Harvests increased from depressed levels of less than 6 million fish in the mid-1970s to more than 15 million fish for most of the 1980s and more than 25 million fish annually for the years 1989-1996. Sockeye salmon harvests peaked at 44 million fish in 1995. Harvests then fell off sharply to lows of 10 million fish in 1998 and 2002 before rebounding to 29 million fish in 2007 and 31 million fish in 2009—the highest sockeye harvest since 1995. The 2011 harvest of 22 million fish was significantly lower than the previous five years and the lowest since 2003.



Source: Commercial Fisheries Entry Commission; Alaska Department of Fish and Game

Figure 11. Bristol Bay Commercial Salmon Harvests.

The average weight of a Bristol Bay sockeye salmon is typically about 6 pounds. Between 1975 and 2010 average weights varied from as low as 5.3 pounds to as high as 6.7 pounds. . There was no significant trend in average fish weight over this period. Fish weight tended to be slightly lower in years when more fish were harvested.[9]

Bristol Bay sockeye salmon harvests may be expressed either in fish, pounds, or metric tons. Over the period 1975-2010, sockeye salmon harvests averaged:

22.7 million sockeye
= 133 million pounds (@ average weight of 5.9 pounds per fish)
= 60,200 metric tons (@ 2204.6 pounds per metric ton)

For commercial fishery management purposes, Bristol Bay is divided into five different fishing districts: Naknek-Kvichak, Egegik, Nushagak, Ugashik, and Togiak, which correspond to different major Bristol Bay river systems.

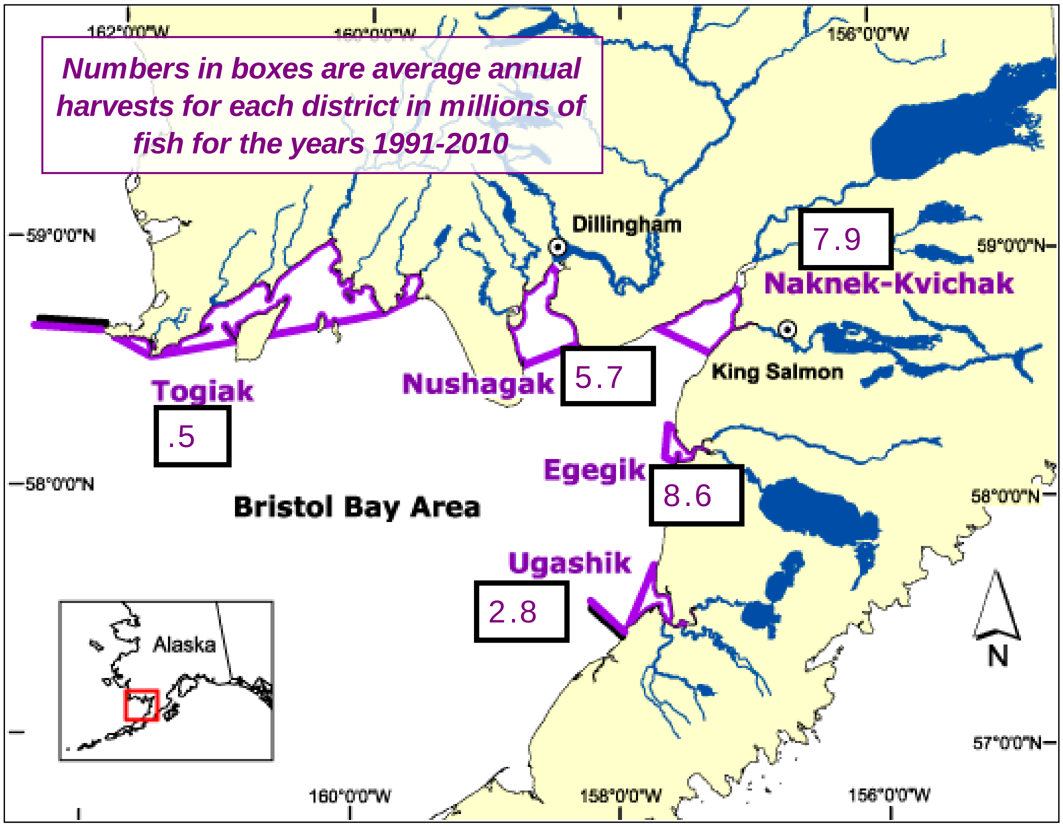


Figure 12. Bristol Bay Fishing Districts. ***Source: ADFG map posted at:***

www.adfg.alaska.gov/index.cfm?adfg=CommercialByFisherySalmon.salmonmaps_districts_bristolbay

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[9] The correlation between fish weight and the number of fish harvested was -.433, which is statistically significant at the 1% level in a one-tailed t-test (N = 36).

Annual harvests within each district vary widely from year to year, as does the relative share of each district in the total catch. Most of the record Bristol Bay catches of the mid-1990s were caught in the Naknek-Kvichak and Egegik districts. Similarly, most of the decline in catches after the mid-1990s resulted from a decline in catches in these two districts—particularly the Naknek-Kvichak. Most of the recovery in catches since 2002 has also occurred in these two districts, as well as in the Nushagak district, where catches have been very strong.

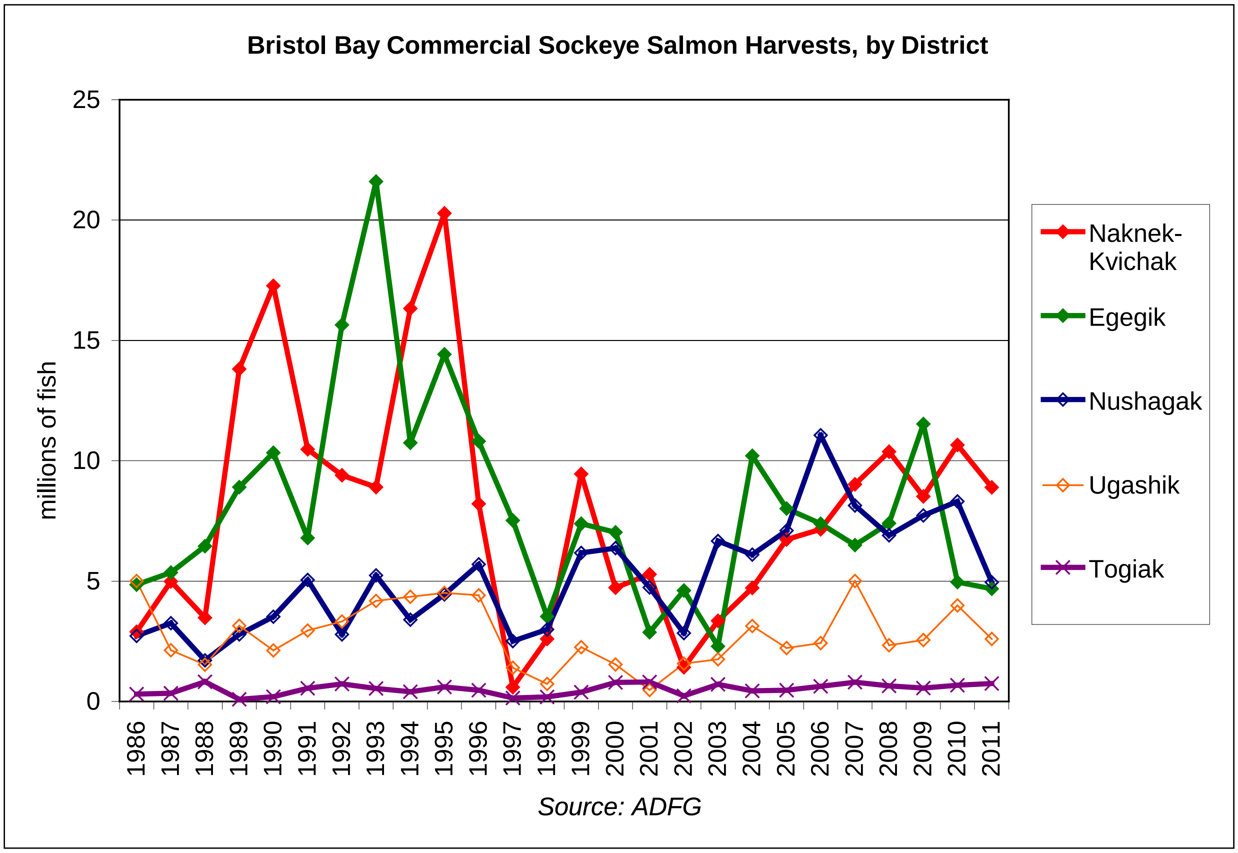


Figure 13. Bristol Bay Commercial Sockeye Salmon Harvests, by District.

Currently, there is particular interest in the fisheries resources and economic significance of the Nushagak and Kvichak watersheds because of potential future resource development in these watersheds, Given the wide variation in catches by district from year to year and over longer time periods of time, there no obvious way to characterize the relative share of the Bristol Bay commercial salmon fishery attributable to these river systems or to the rivers, streams and lakes that make up each river system.

In general, over most of the past decade, the Nushagak and Naknek-Kvichak districts have accounted for about 60% of the total Bristol Bay commercial sockeye harvest (Figure 14).

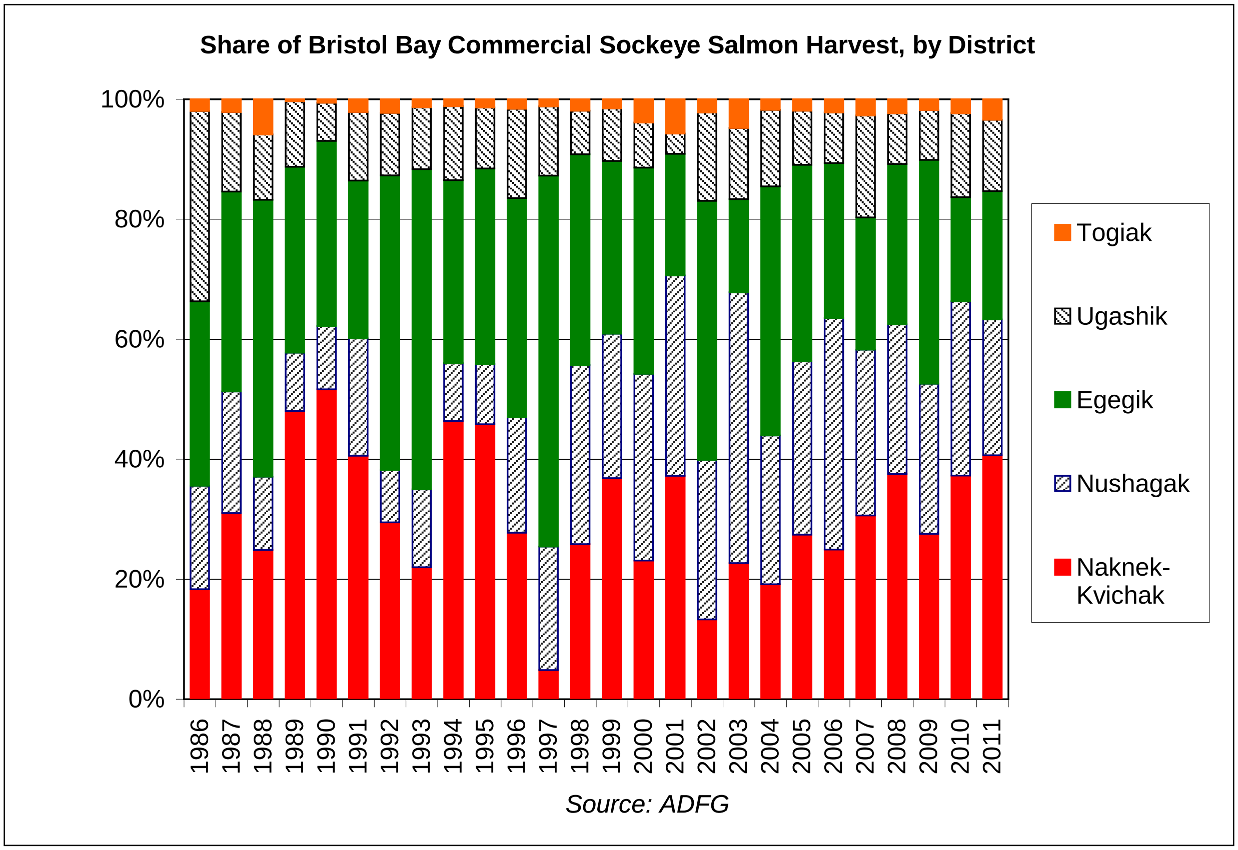
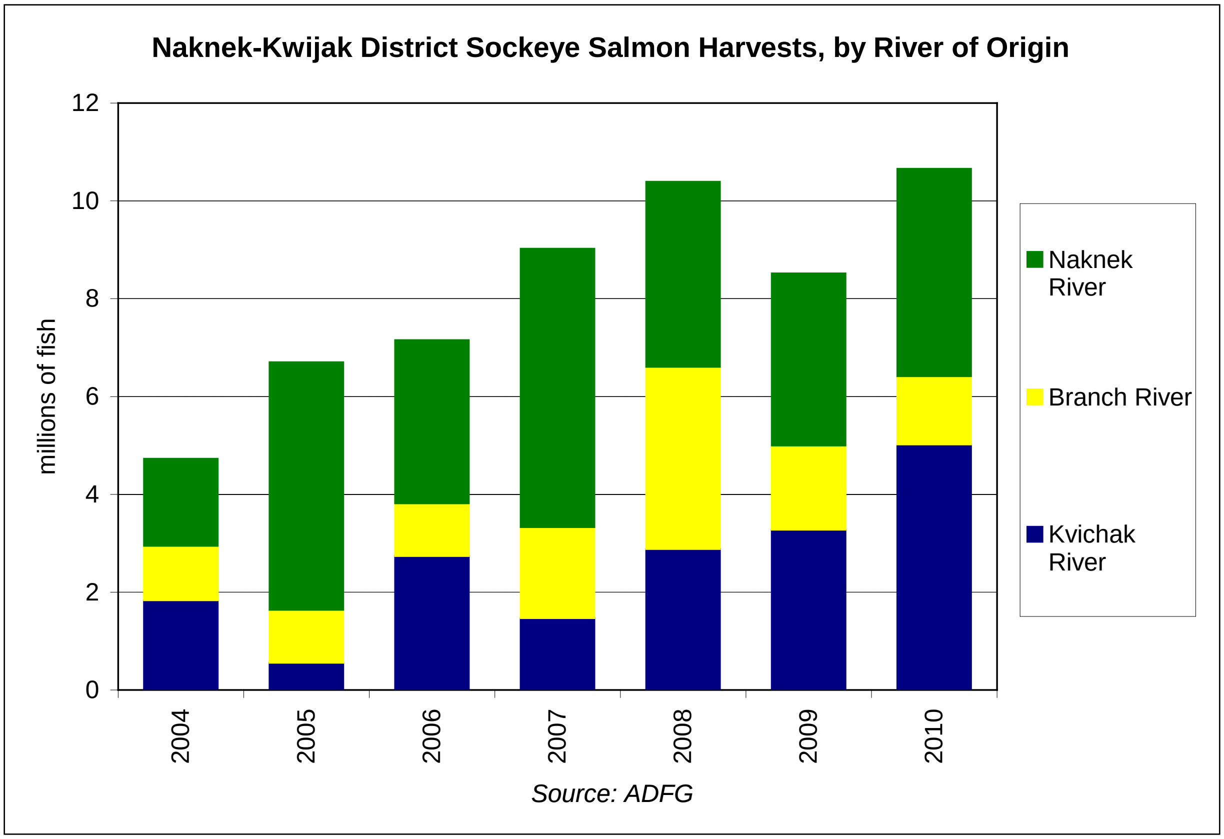


Figure 14. Share of Bristol Bay Commercial Sockeye Salmon Harvest, by District.

Note however that both districts include other major rivers beside the Nushagak and Kvijak rivers. For example, the Kvichak River generally accounts for less than half of Naknek-Kvichak district harvests (Figure 15).



Source: ADFG

Figure 15. Naknek-Kvichak District Sockeye Salmon Harvests, by River of Origin.

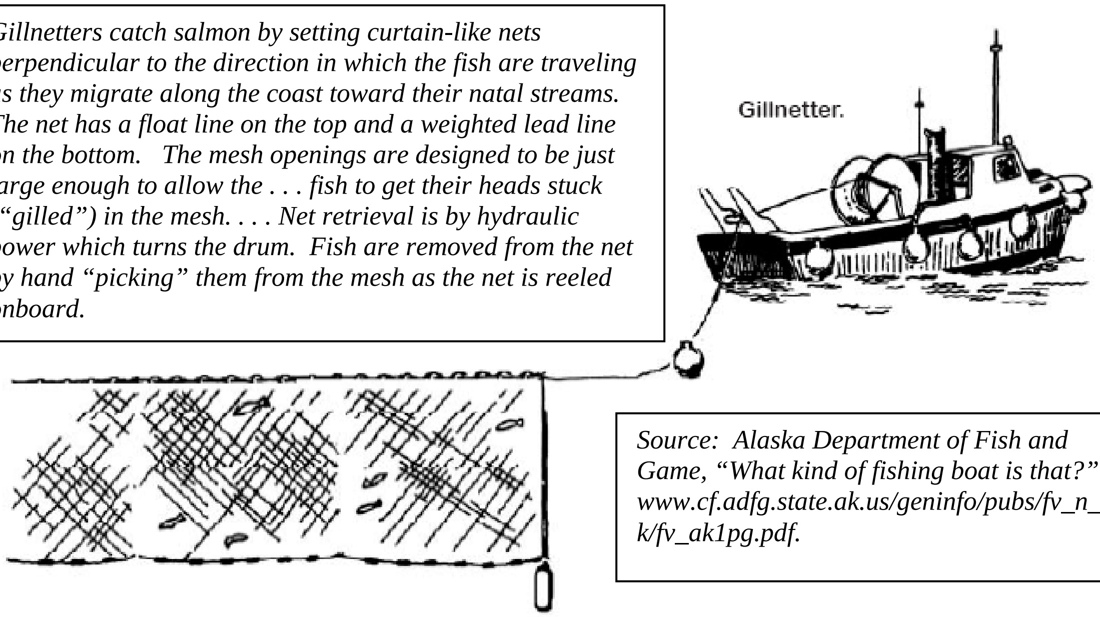
As discussed more below, economic measures of the Bristol Bay commercial fishery are not necessarily proportional to fish harvests. If total fish harvests were to change by a given percentage, the value of the fishery, employment, and other measures would not change by the same percentage amount.

Bristol Bay Gear Types

All Bristol Bay salmon are harvested using gillnets. Gillnets hang in the water perpendicular to the direction in which returning salmon are swimming. The fish get their heads stuck in the nets and are "picked" from the net as it is pulled from the water.

There are two types of gillnet fishing operations in Bristol Bay: drift gillnets and set gillnets. Drift gillnets hang in the water behind the fishing boat. After a period of time, the nets are pulled back into the boat for picking.

Gillnetters catch salmon by setting curtain-like nets perpendicular to the direction in which the fish are traveling as they migrate along the coast toward their natal streams. The net has a float line on the top and a weighted lead line on the bottom. The mesh openings are designed to be just large enough to allow the . . . fish to get their heads stuck ("gilled") in the mesh. . . . Net retrieval is by hydraulic power which turns the drum. Fish are removed from the net by hand "picking" them from the mesh as the net is reeled onboard.



Source: Alaska Department of Fish and Game, "What kind of fishing boat is that?" www.cf.adfg.state.ak.us/geninfo/pubs/fv_n_ak/fv_ak1pg.pdf.

Picking salmon from the net on a Bristol Bay drift gillnet boat

Bristol Bay fishing boats stored in a Naknek boat yard for the winter

Most Bristol Bay drift gillnet fishing boats are used only during the short, intense summer salmon season (although some are used to fish for herring in the spring) and are stored in boat yards for the rest of the year. The fact that fishing boats and processing plants are idle for much of the year adds to costs in the fishery.

Crowded fishing near the boundary of a Bristol Bay fishing district

Photograph by Bart Eaton

Drift gillnet fishermen have the advantage of being able to move to where the fishing is best—and the disadvantage that other fishermen are likely to want to fish in the same places. Bristol Bay drift gillnet fishing boats are often crowded along the "lines" which are the boundaries of legal fishing districts, established by GPS coordinates. Often fishing is best when fishermen are able to place their nets along the line, catching fish as they swim into the district.

Bristol Bay drift gillnet fishing boats are limited to 32 feet in length. Over time, wider and taller boats have been built as fishermen try to get more working space and hold capacity.

Drift gillnet boats waiting for an opening in the Nushagak district

Photograph by Gabe Dunham

In set gillnet fishing, one end of the net is attached to the shore, while the other is attached to an anchor in the water. Fishermen pick the fish from a skiff or from the beach at low tide.

A set-net fishing operation on the Nushagak River

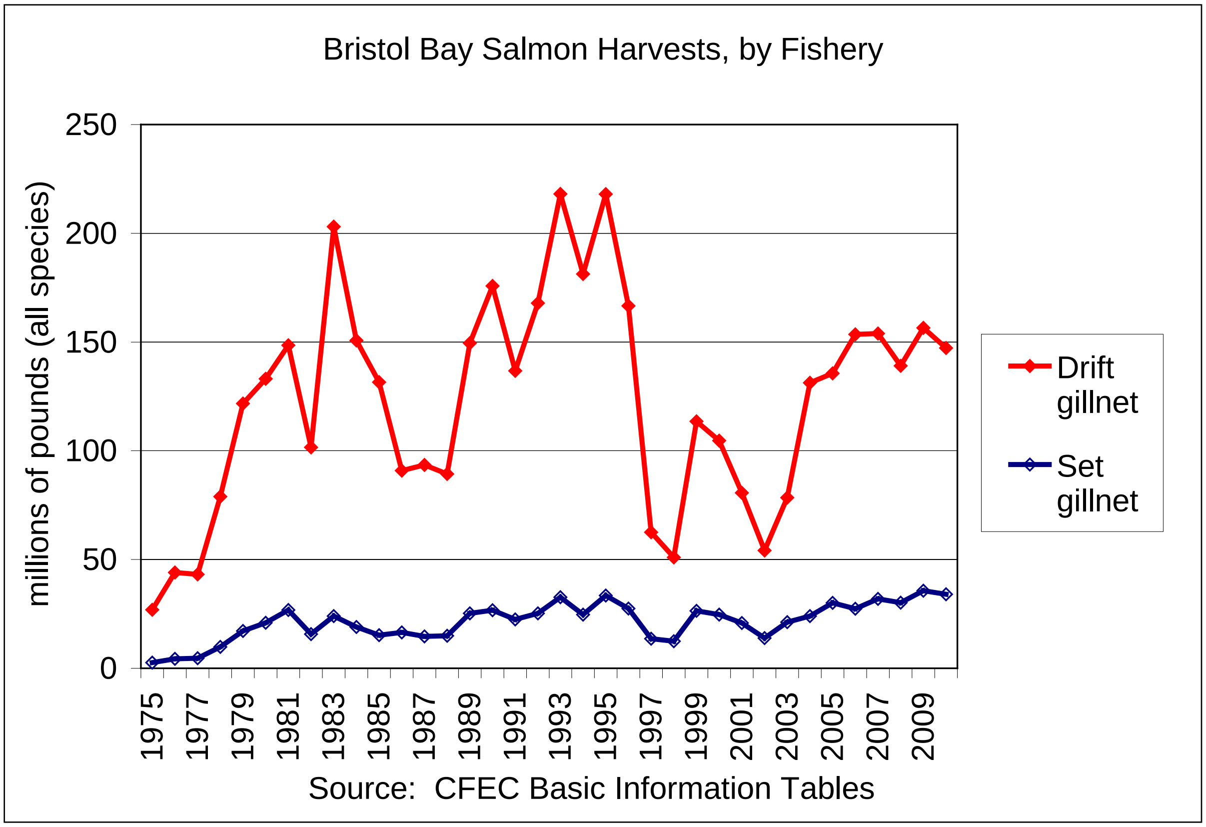
There are more drift gillnet permits fished than set gillnet permits, and average catches are higher for drift gillnet permits than for set gillnet permits. As a result, drift gillnet permits account for about four-fifths of the Bristol Bay sockeye salmon catch.

Table 27. Comparison of Bristol Bay Drift Gillnet and Set Gillnet Fisheries (2006-10 Average)

Comparison of Bristol Bay Drift Gillnet and Set Gillnet Fisheries (2006-10 Averages)

	Drift Gillnet	Set Gillnet	Total	Ratio, Drift Gillnet to Set Gillnet	Drift Gillnet %	Set Gillnet %
Total Permits Fished	1,470	847	2,317	1.7	63%	37%
Average Pounds	102,109	37,575	139,684	2.7		
Total Pounds	150,053	31,813	181,866	4.7	83%	17%

Source: Commercial Fisheries Entry Commission, Basic Information Tables.



Source: CFEC Basic Information Tables

Figure 16. Bristol Bay Salmon Harvests, by Fishery

Relative Scale of Bristol Bay Sockeye Salmon Harvests

There are several ways to measure the relative scale of Bristol Bay sockeye salmon harvests in comparison with other sources of supply, which are illustrated by the three graphs below:

<u>Sockeye salmon fisheries.</u> Bristol Bay is by far the largest sockeye salmon fishery in the world. Between 1980 and 2009 Bristol Bay averaged 59% of total Alaska sockeye salmon supply and 44% of total world sockeye salmon supply.

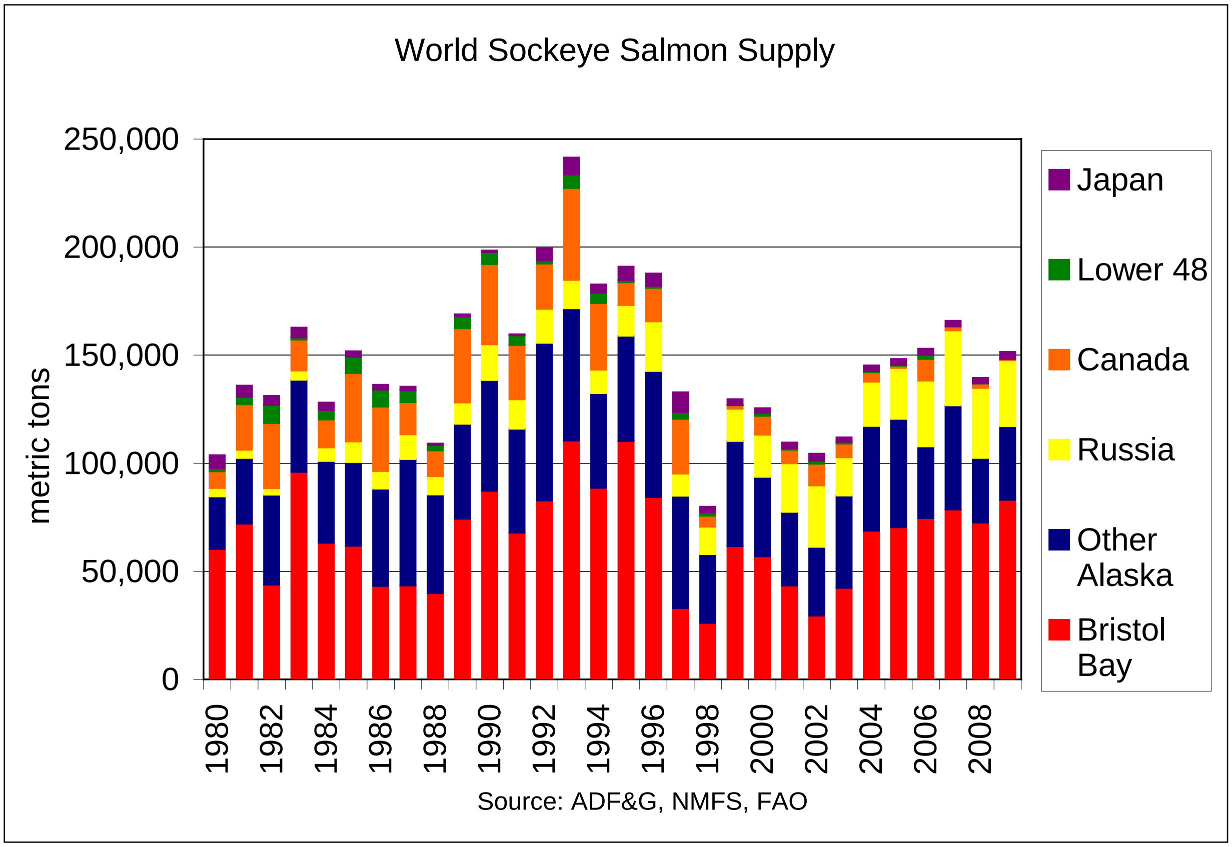
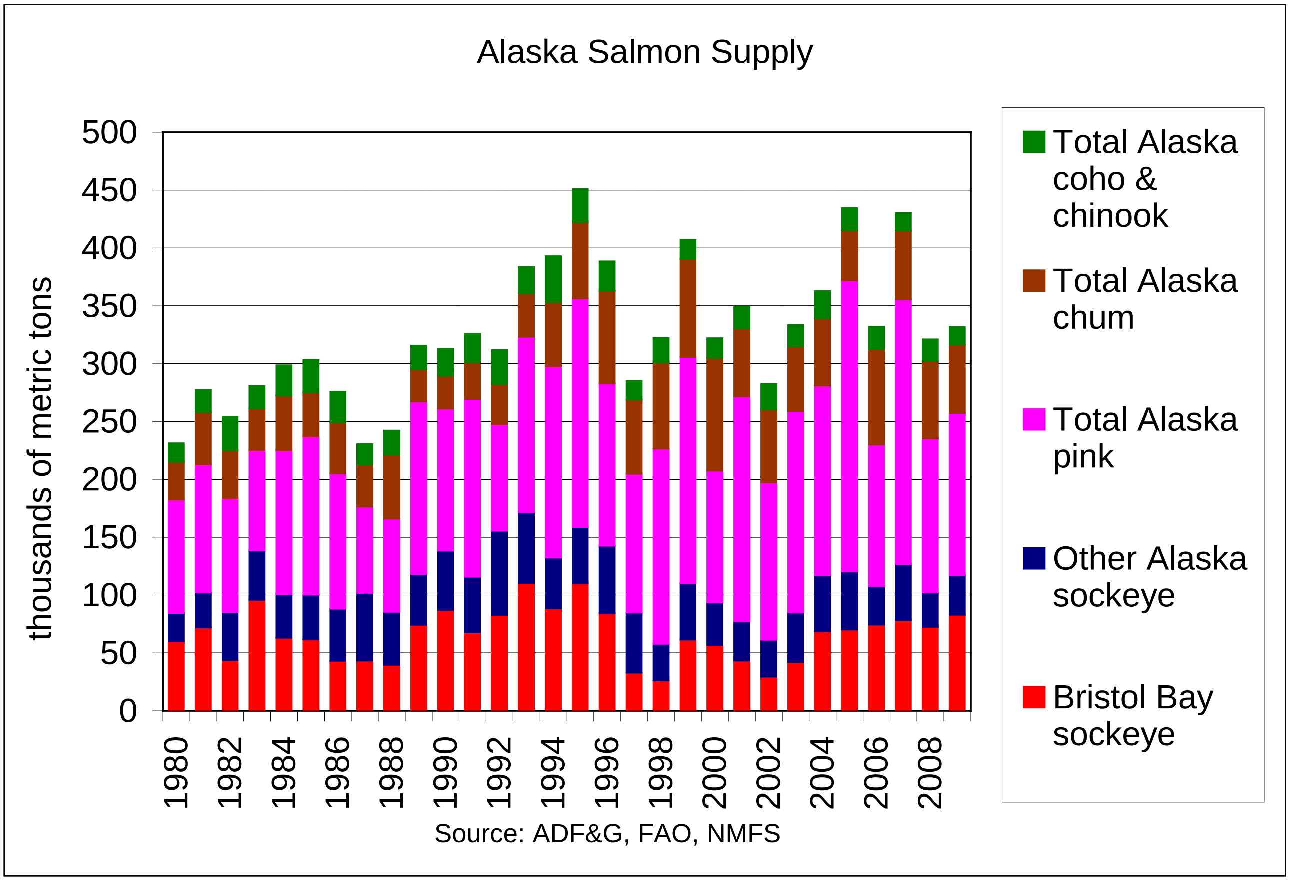


Figure 17. World Sockeye Supply

<u>Alaska salmon fisheries.</u> In most years, Bristol Bay sockeye is the single largest fishery in Alaska. Between 1980 and 2009, Bristol Bay sockeye salmon averaged 20% of Alaska salmon supply for all species combined.



Source: ADF&G, FAO, NMFS

Figure 18. Alaska Salmon Supply

World salmon supply. World farmed salmon and trout production has grown extremely rapidly since the early 1980s. As farmed salmon and trout production increased, Bristol Bay's share of total world salmon supply fell from 11% in 1980 to just 3% in 2009.

Mending gillnets at the historic Peter Pan processing plant in Dillingham

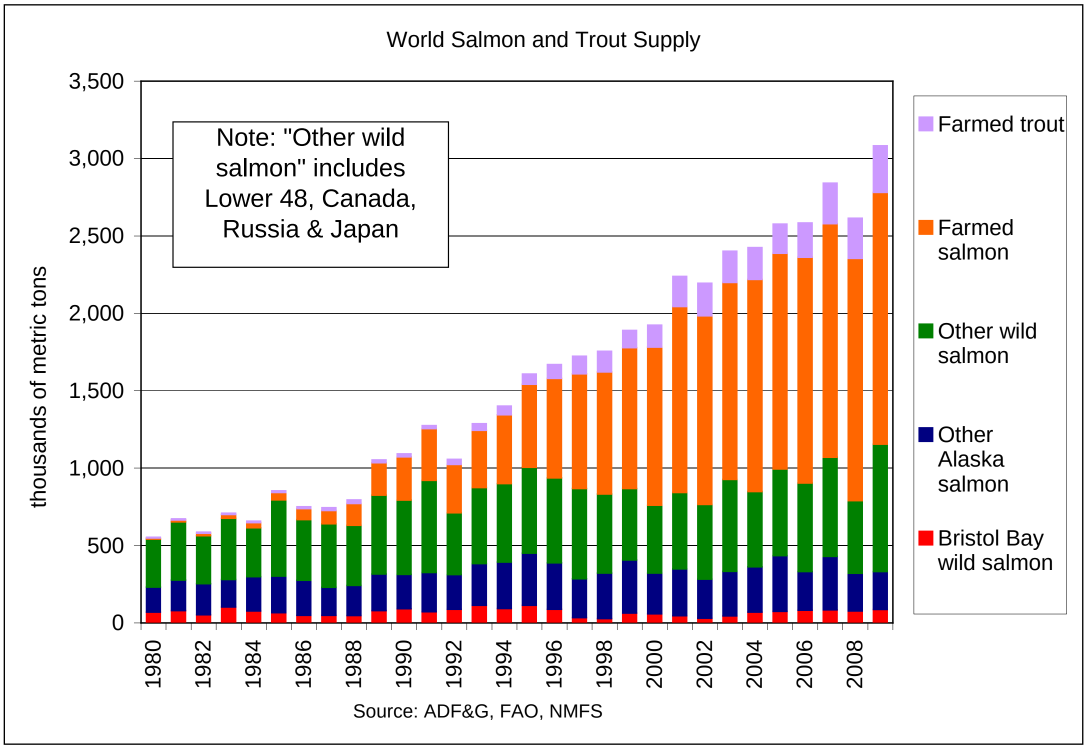
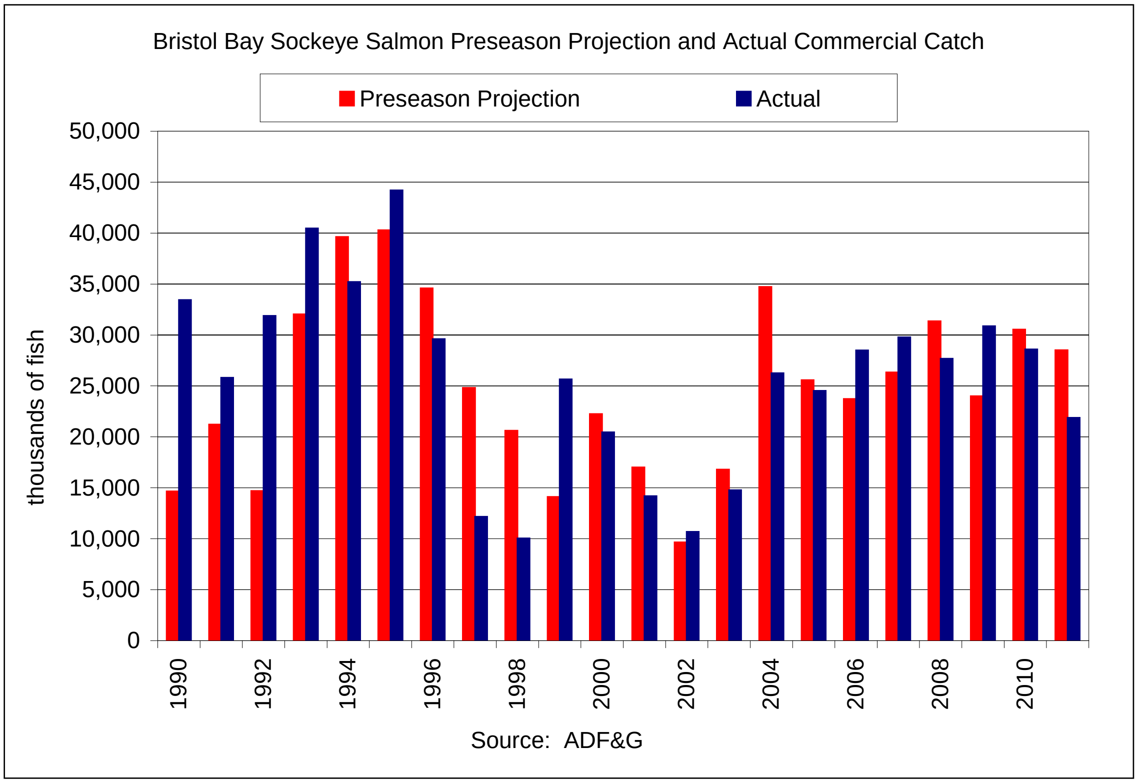


Figure 19. World Salmon and Trout Supply

Future Bristol Bay Salmon Harvests

It is very difficult to predict how Bristol Bay salmon harvests may change in the future. Every year the Alaska Department of Fish and Game, as well as the University of Washington Fisheries Research Institute (FRI) make pre-season projections of how many salmon will return to Bristol Bay and what the harvest will be. The projections are based on estimates for previous years of escapements, the number of juvenile salmon entering saltwater, and the numbers of adult salmon of different age classes which returned.

The pre-season projections provide at best a rough guide to what actual harvests will be. Between 1990 and 2011, actual catches ranged from 51% below the Alaska Department of Fish and Game’s projections to 128% over the projections, with an average annual projection error of 31%.



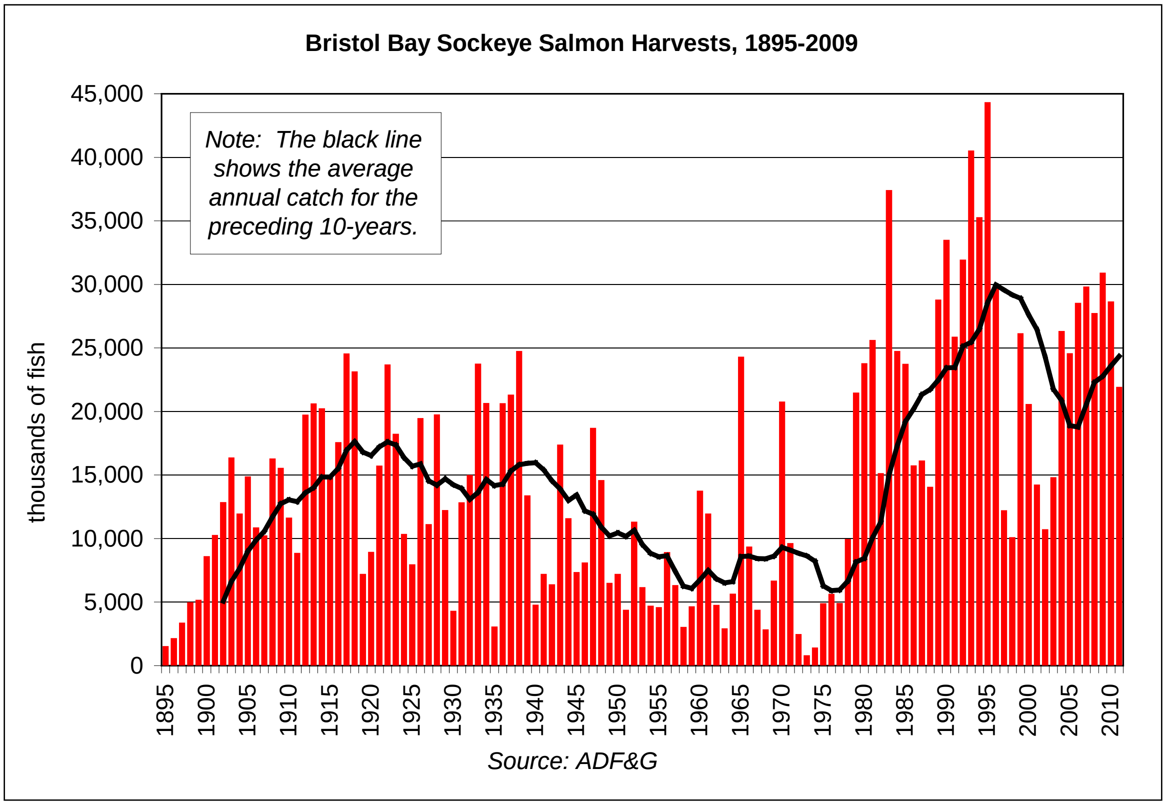
Source: ADF&G

Figure 20. Bristol Bay Sockeye Preseason Projection and Actual Commercial Catch

There are no formal projections of how Bristol Bay salmon harvests may change over the longer term future. As shown by the graph on the following page, historically harvests have varied widely from decade to decade. Analysis of lake-bed sediments has also shown significant historical variation in salmon returns in previous centuries prior to commercial harvesting.

Long-term changes in salmon returns have been shown to be associated with periodic changes in ocean conditions such as water temperature and currents, known as “regime shifts.” The much lower average harvests from the 1950s through the 1970s are thought to have resulted in part from a different ocean regime (although other factors, such as interceptions of Bristol Bay salmon by foreign fishing fleets, likely also played a role).

The potential for significant future changes in ocean conditions associated with not only regime shifts but also global climate change could significantly affect future Bristol Bay salmon returns and harvests—but it is very difficult to predict what changes might occur or when they might occur.



Note: The black line shows the average annual catch for the preceding 10-years.

Source: ADF&G

Figure 21. Bristol Bay Salmon Harvests, 1985-2009

Until the 1950s, only sailboats were allowed to harvest salmon in Bristol Bay

Source: "Sailing for Salmon" exhibition of historic Bristol Bay photographs at Anchorage Museum, summer 2011 (http://www.anchoragemuseum.org)

3.4 Bristol Bay Salmon Products and Markets

The major products produced from Bristol Bay sockeye salmon are canned salmon, frozen headed and gutted (H&G) salmon, frozen salmon fillets, fresh H&G salmon, and salmon roe. Frozen H&G salmon and canned salmon account for most of the product volume.

Bristol Bay canned salmon

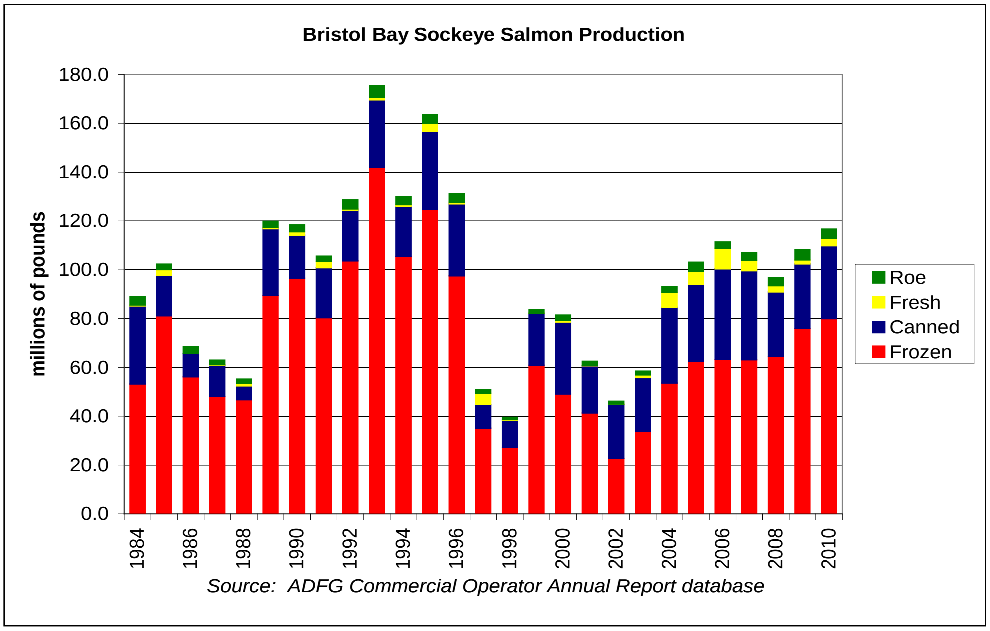
Headed and gutted salmon on trays for freezing

Bristol Bay sockeye salmon fillet

Processing Bristol Bay sockeye salmon roe

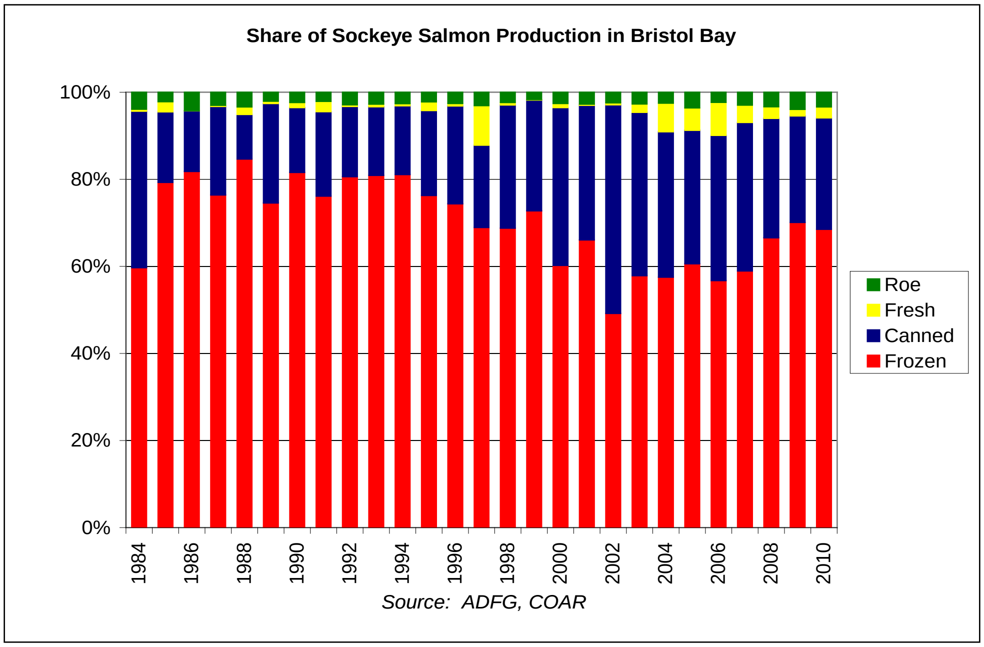
For most of the more than one-hundred year history of the Bristol Bay salmon fishery, production was overwhelmingly canned salmon. Processing plants were called “canneries” and processing companies were called “canners.”

However, in the 1970s frozen salmon production increased rapidly, as technologies for freezing salmon and shipping frozen salmon developed, and as Japanese demand for frozen Bristol Bay salmon expanded with the end of Japanese salmon fishing in international waters and within the U.S. 200-mile limit. By the mid-1980s, more than 80% of Bristol Bay salmon production was frozen, almost entirely for export to Japan. The shares of different product forms in Bristol Bay production over time reflect changes in changes in relative prices and total harvests. From the mid-1990s to the mid-2000s, as frozen sockeye salmon prices fell due to increased competition in the Japanese market from farmed salmon, and as harvest volumes fell, the frozen share of production declined and the canned share increased. Since the mid-2000s, as frozen sockeye and harvest volumes have increased, the frozen share of production has risen (Figure 22 and Figure 23).



Source: ADFG Commercial Operator Annual Report database

Figure 22. Bristol Bay Sockeye Salmon Production



Source: ADFG, COAR

Figure 23. Share of Sockeye Salmon Production in Bristol Bay

Table 28 provides more detail about product forms for canned and frozen Bristol Bay salmon in recent years. In 2010, about one-third of canned salmon production was "talls" (14.75 ounce cans) and about two-thirds "halves" (7.5 ounce cans). Between 2006 and 2010, the share of frozen fillets in total frozen production increased from about 6% to about 18%.

Table 28. Sales of Selected Sockeye Salmon Products.

Sales of Selected Sockeye Salmon Products
by Major Bristol Bay Salmon Processors (pounds)

Type	Form	2006	2008	2010
Canned	Canned Halves	23,349,893	23,672,655	23,486,265
	Canned Talls	*	*	10,592,344
Frozen	Frozen Fillet	3,939,220	7,930,710	13,788,359
	Frozen H&G	61,270,959	53,590,871	63,720,557
Fresh	Fresh H&G	2,958,201	1,904,051	*
Roe	Roe	2,902,082	3,186,876	3,657,859

* Not reported due to confidentiality restrictions

Note: Includes only sales reported by processors with more than 1 million pounds of sales of salmon products in the previous year.

Source: Alaska Department of Revenue, Annual Salmon Price Reports

In any given year, the total volume of Bristol Bay salmon products is less than the annual harvest volume, because part of the weight (25%-35%) is lost in processing as the fish heads and guts are removed, and also because some fish are shipped to plants outside the Bristol Bay region for processing. Between 1984 and 2010, the reported volume of processed salmon products sold by Bristol Bay salmon processors, or production, averaged 67% of the volume of harvests, and ranged from as low as 59% to as high as 75%. The annual variation in the ratio of production weight to harvest weight results from several factors including changes in average fish size, changes in the mix of products produced, and changes in the share of the catch shipped outside the region for processing.

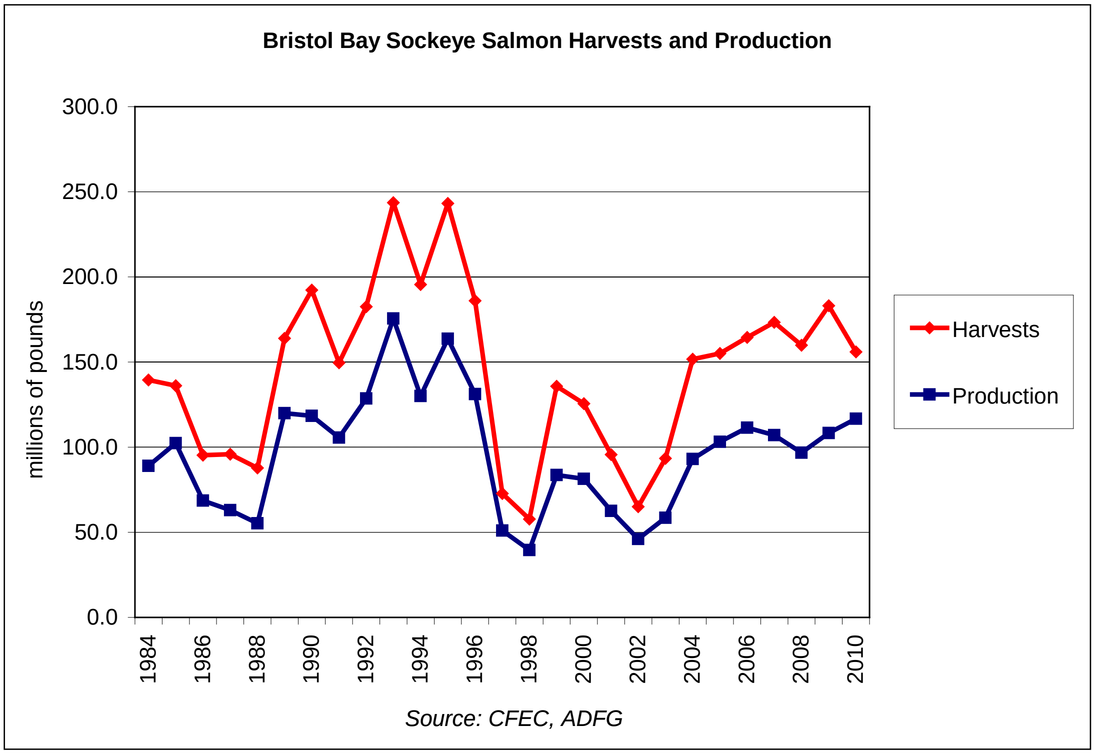
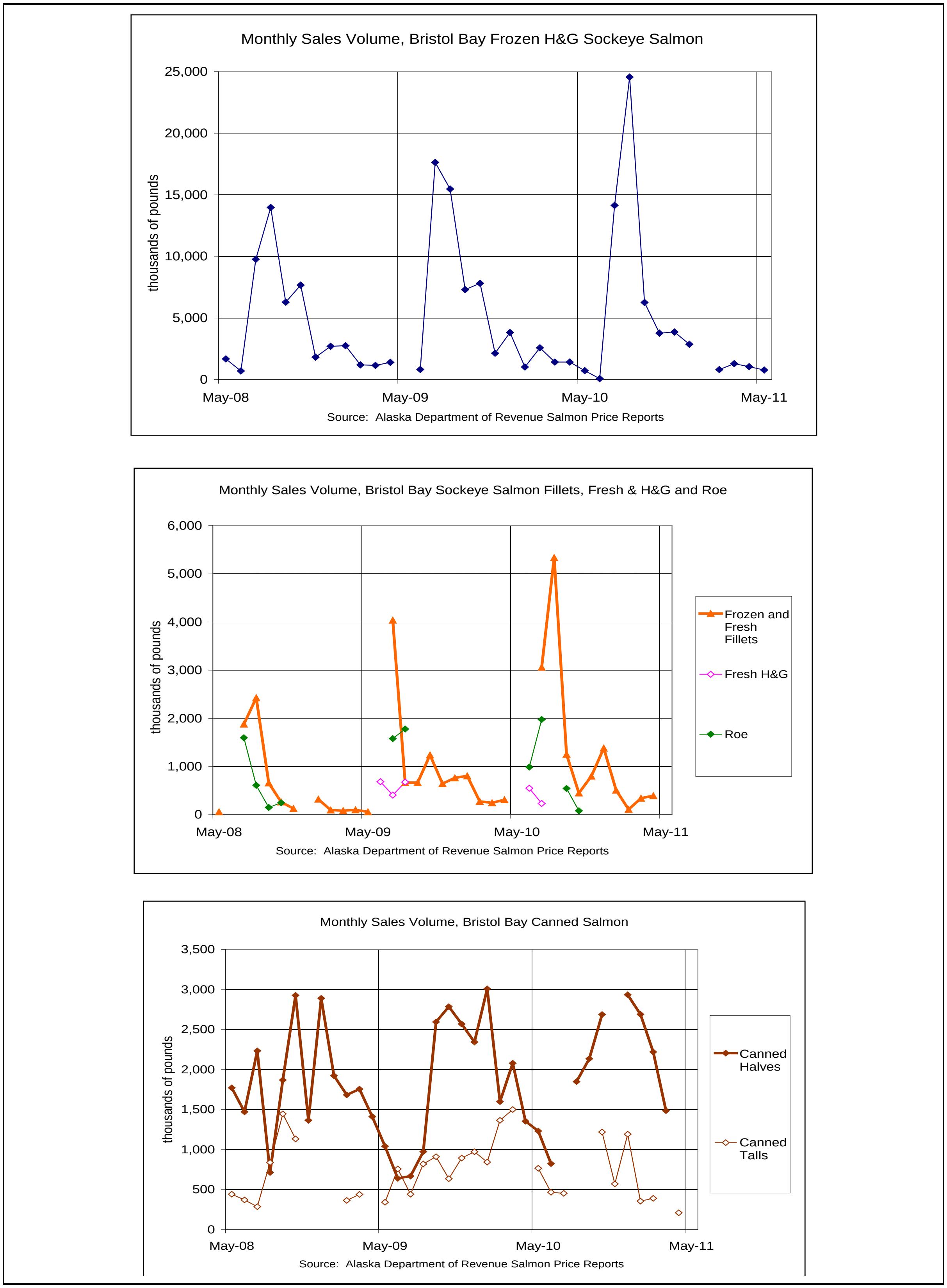


Figure 24. Bristol Bay Sockeye Salmon Harvests and Production


Monthly Sales Volume, Bristol Bay Frozen H&G Sockeye Salmon

Source: Alaska Department of Revenue Salmon Price Reports

Monthly Sales Volume, Bristol Bay Sockeye Salmon Fillets, Fresh & H&G and Roe

Source: Alaska Department of Revenue Salmon Price Reports

Monthly Sales Volume, Bristol Bay Canned Salmon

Source: Alaska Department of Revenue Salmon Price Reports

Figure 25. Monthly Sales Volume of Bristol Bay Salmon Products

The timing of processors' sales of Bristol Bay salmon reflects the highly seasonal character of the industry. Sales of products for which storage costs are relatively high—including frozen H&G salmon, frozen and fresh fillets, fresh H&G and roe—are concentrated in the summer in the months during and immediately after the season. Sales of canned salmon are distributed more evenly over the year. For some products, no data are available for sales for some months (to preserve confidentiality, sales are only reported if at least three processors report sales).

Bristol Bay Salmon Markets

Data are not available on the end-markets to which *Bristol Bay* sockeye salmon products are shipped. However, because Bristol Bay represents such a large share of Alaska and United States sockeye salmon production, we can make reasonable inferences about end markets for Bristol Bay sockeye salmon by comparing U.S. export data with Alaska statewide production data.

Prior to about 1998, almost all U.S. frozen sockeye salmon production (including Bristol Bay production) was exported, and almost all exports were to Japan. Beginning in about 1999, this pattern changed in two important ways. First, exports declined relative to production—indicating that significant volumes of Alaska frozen sockeye were beginning to be sold in the U.S. market rather than exported. Secondly, significant volumes of frozen sockeye began to be exported to countries other than Japan—particularly EU countries and China—substantially reducing the Japanese share of U.S. sockeye salmon exports (Figure 26).

These two trends together resulted in a dramatic decline in the volume of Alaska sockeye salmon shipped to Japan—from more than 100,000 metric tons in 1993 to 20,000 lbs or less since 2006—and a corresponding dramatic decline in the dependence of Alaska (and Bristol Bay) sockeye on the Japanese frozen salmon market.

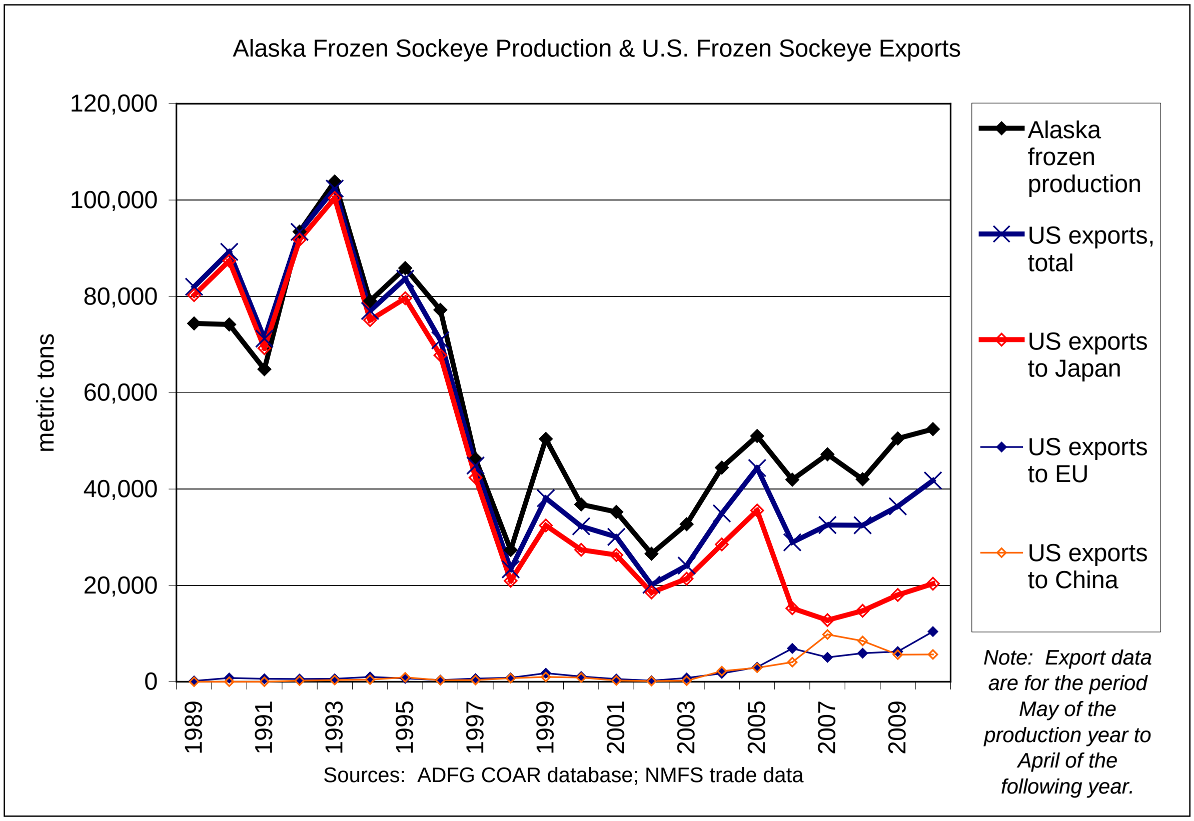


Figure 26. Alaska Frozen Sockeye Production and U.S. Frozen Sockeye Exports.

The volume of Alaska frozen sockeye salmon sold to U.S. domestic markets may be estimated as total production minus exports. This in turn allows estimation of the end-market shares of the United States and export markets. End-market shares have changed dramatically from the early 1990s, when almost all production was estimated to Japan. Between 2006 and 2010, 27-39% of production was exported to Japan, 20-31% was sold in the United States, 10-21% was exported to China, 11-16% was exported to the European Union, and 7-13% was exported to other countries.

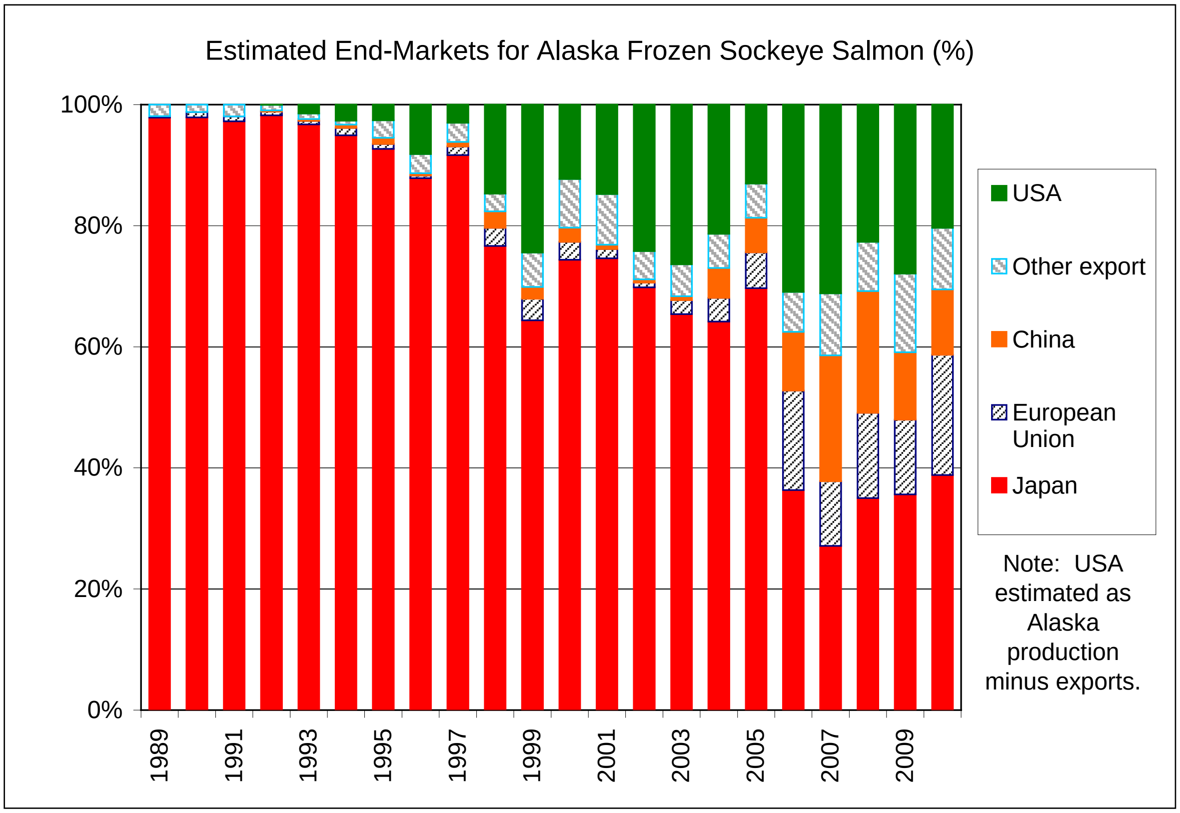
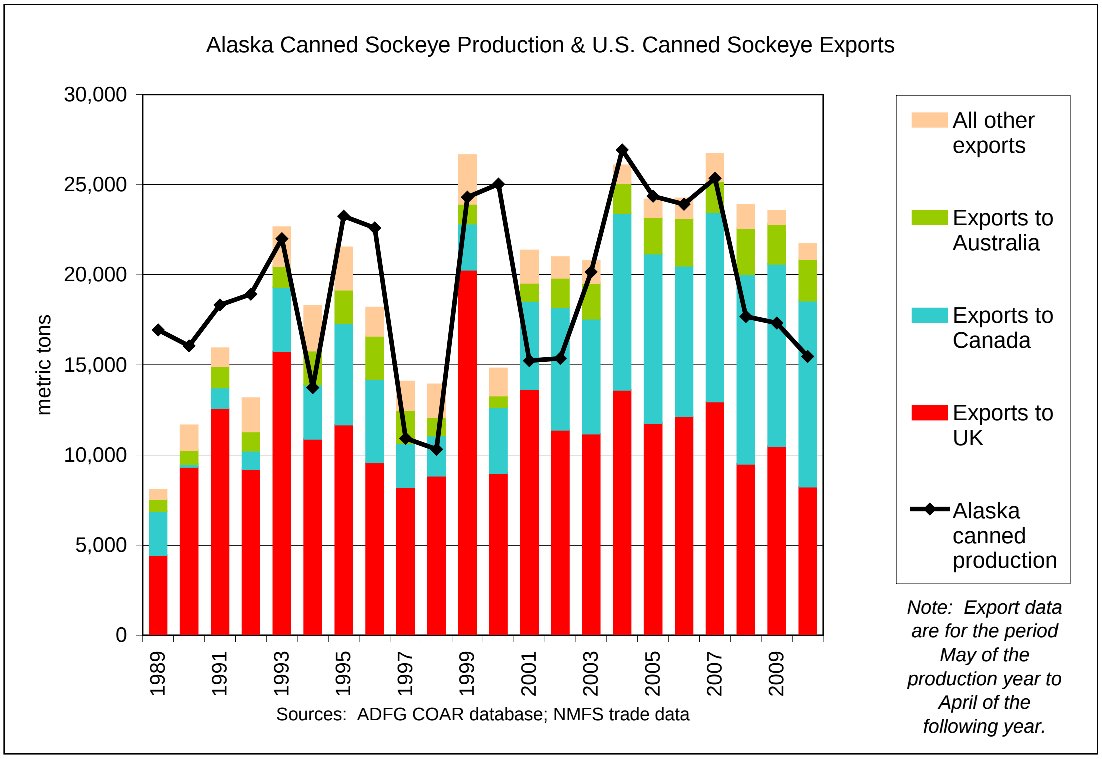


Figure 27. Estimated End-Markets for Alaska Frozen Sockeye Salmon

Note that most of the frozen sockeye exported to China are not consumed in China. Rather, they are thawed and reprocessed—using much cheaper Chinese labor—into fillet and other value-added products which are then re-exported to end-markets in Europe, the United States and Japan. Thus the final end-market shares for Europe, the United States and Japan are larger than are shown in the graph (but data are not available to indicate how *much* larger.)

Boxes of frozen Bristol Bay sockeye in the cold storage of a Chinese reprocessing plant, 2007

Most Alaska canned sockeye—including Bristol Bay canned sockeye—is exported. Total reported U.S. exports are approximately equal to total Alaska production (Figure 28).[10] Historically the United Kingdom was by far the most important market for canned sockeye. In recent years, exports of canned sockeye to Canada have grown dramatically—from which significant volumes are likely re-exported to the UK and other markets.



Sources: ADFG COAR database; NMFS trade data

Note: Export data are for the period May of the production year to April of the following year.

Figure 28. Alaska Canned Sockeye Production and U.S. Canned Sockeye Exports

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[10] In some years reported US exports of canned sockeye salmon exceed reported Alaska production. The reasons for this are not entirely clear. One likely contributing factor is that in years of large sockeye production, significant volumes may be kept in inventory and sold during a later year.

Relatively small volumes of fresh salmon are produced in Bristol Bay. It is difficult for Bristol Bay to compete with other areas of Alaska in supplying fresh markets because of the greater distance and cost required to transport fish to the United States market.

Salmon roe accounts for a relatively small share of total Bristol Bay product volume—typically less than 3%--but accounts for a higher share of product value because it commands a higher price per pound than other product forms. Most Bristol Bay sockeye salmon roe is exported as *sujiko* (roe in whole skeins) to Japan.

3.5 Bristol Bay Salmon Prices

Between the late 1980s and 2001, Bristol Bay fishermen and processors experienced a dramatic decline in prices paid for Bristol Bay salmon. The "ex-vessel price" paid to fishermen fell from a peak of $2.10/lb in 1988 to $.42/lb in 2001. After 2001 the ex-vessel price recovered gradually to $.66/lb in 2006 and $.80/lb in 2009 and then rose sharply to $1.07/lb in 2010. Final data for Bristol Bay ex-vessel prices in 2011 were not available when this report was prepared but were expected to be similar to 2010.

In nominal terms 2010 ex-vessel prices were similar to prices for much of the 1990s. In "real" prices adjusted for inflation they remained lower than any year except 1993.

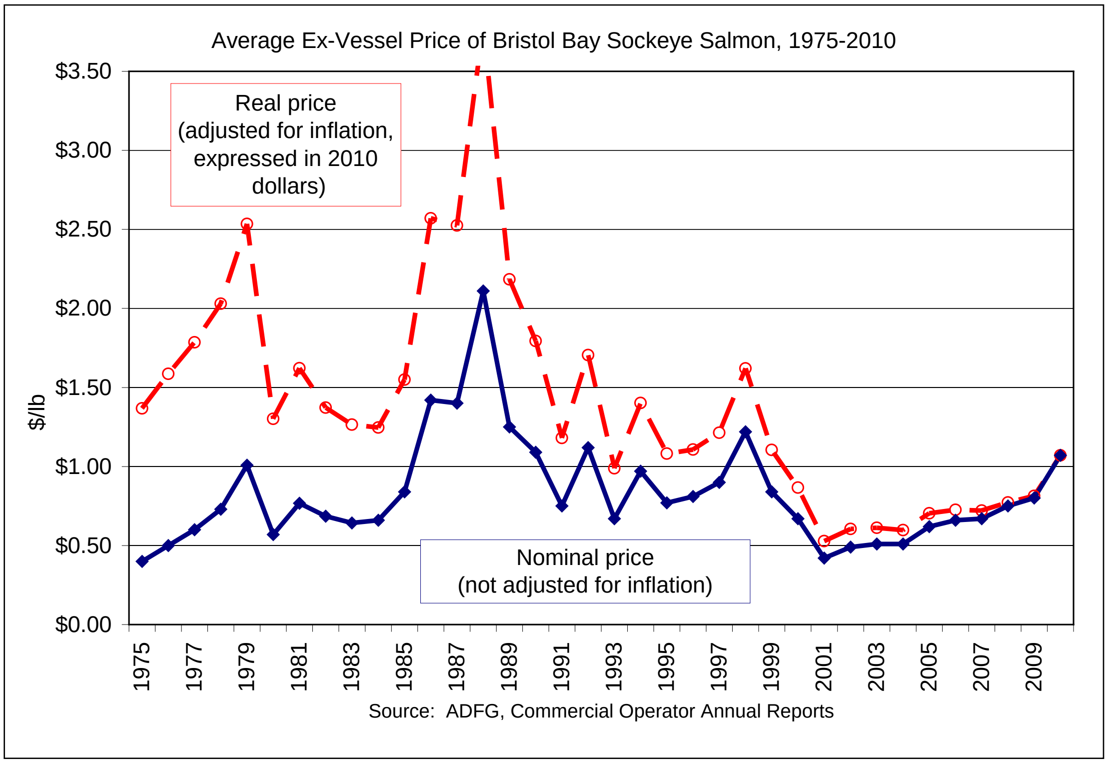
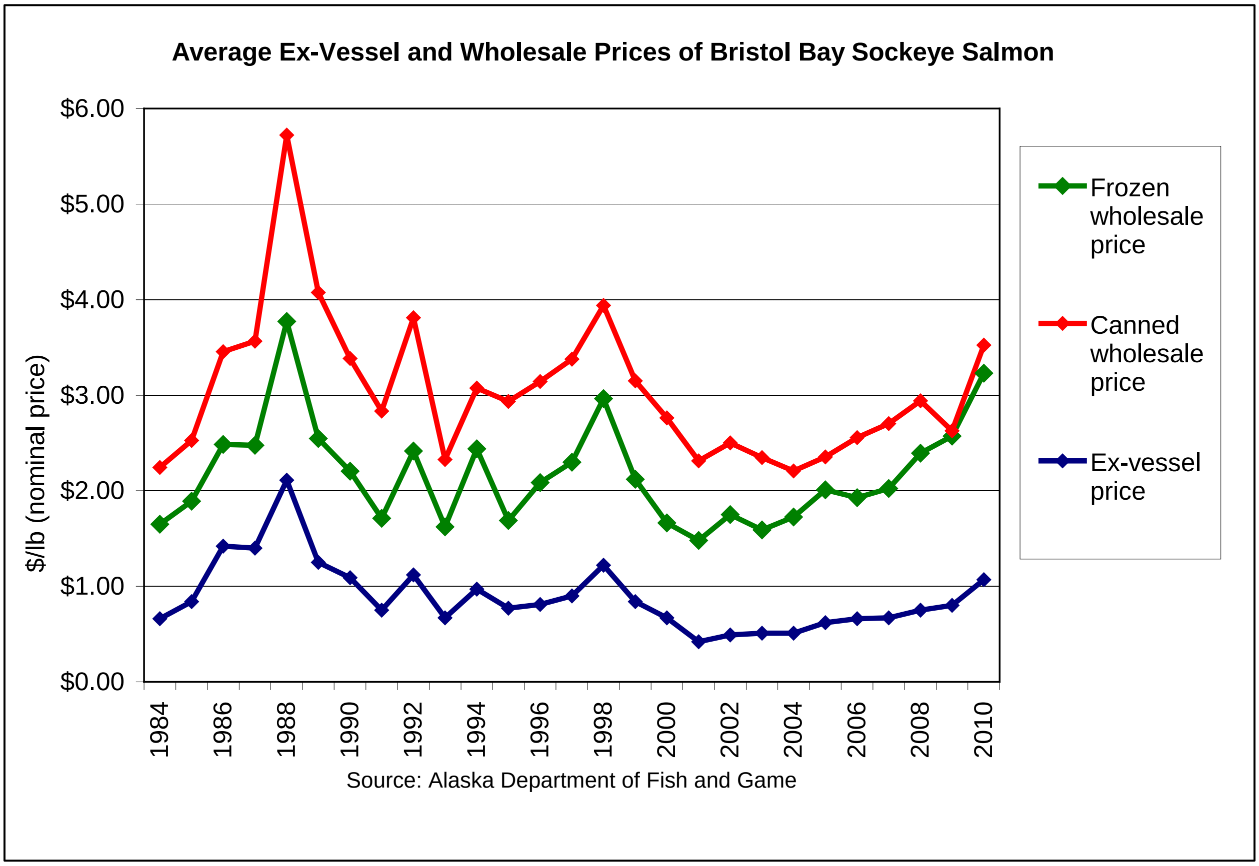


Figure 29. Average Ex-Vessel Price of Bristol Bay Sockeye Salmon, 1975-2010

Cannery at Clark's Point, Nushagak District

Photograph by Gabe Dunham

The decline in ex-vessel prices during the 1990s reflects a decline in first wholesale prices paid to processors for both canned and frozen salmon. Similarly, the increase in ex-vessel prices after 2001 reflects in first wholesale prices for both canned and frozen salmon—particularly for frozen salmon (Figure 30).



Average Ex-Vessel and Wholesale Prices of Bristol Bay Sockeye Salmon

Source: Alaska Department of Fish and Game

Figure 30. Average Wholesale and Ex-Vessel Prices of Bristol Bay Sockeye Salmon

A loaded Bristol Bay gillnetter

Photograph by Gabe Dunham

Monthly wholesale price data, available for years since 2001, provide more detail about wholesale price trends. Wholesale prices may fluctuate widely over the course of a year due to changes in supply and other market factors.

Wholesale prices for frozen headed and gutted (H&G) salmon increased from about $1.75/lb in 2001 to about $3.00/lb in early 2011. Wholesale prices for canned salmon halves increased from an average of about $2.50/lb in 2001 to about $3.50/lb in early 2011. Wholesale prices for canned salmon talls fell from an average of about $2.30/lb in 2001 to about $2.10/lb in 2005 before increasing to $3.30/lb in early 2011.

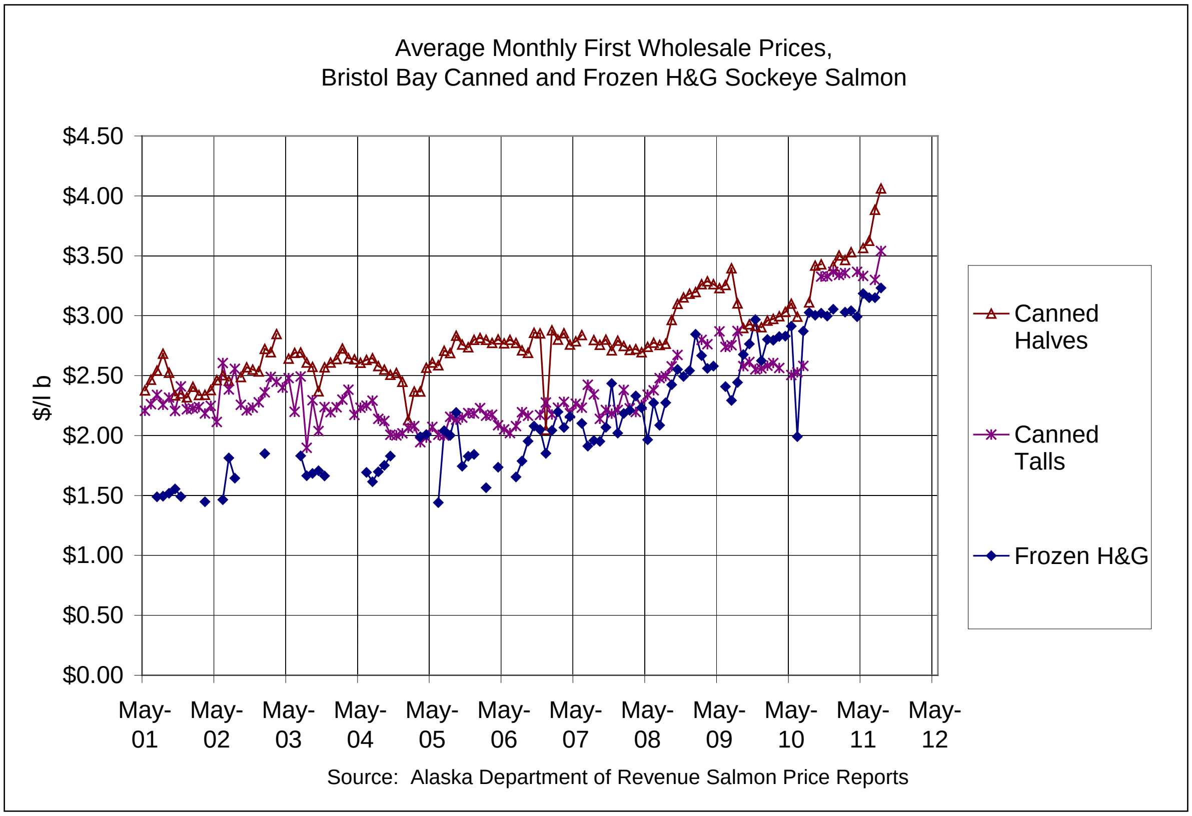
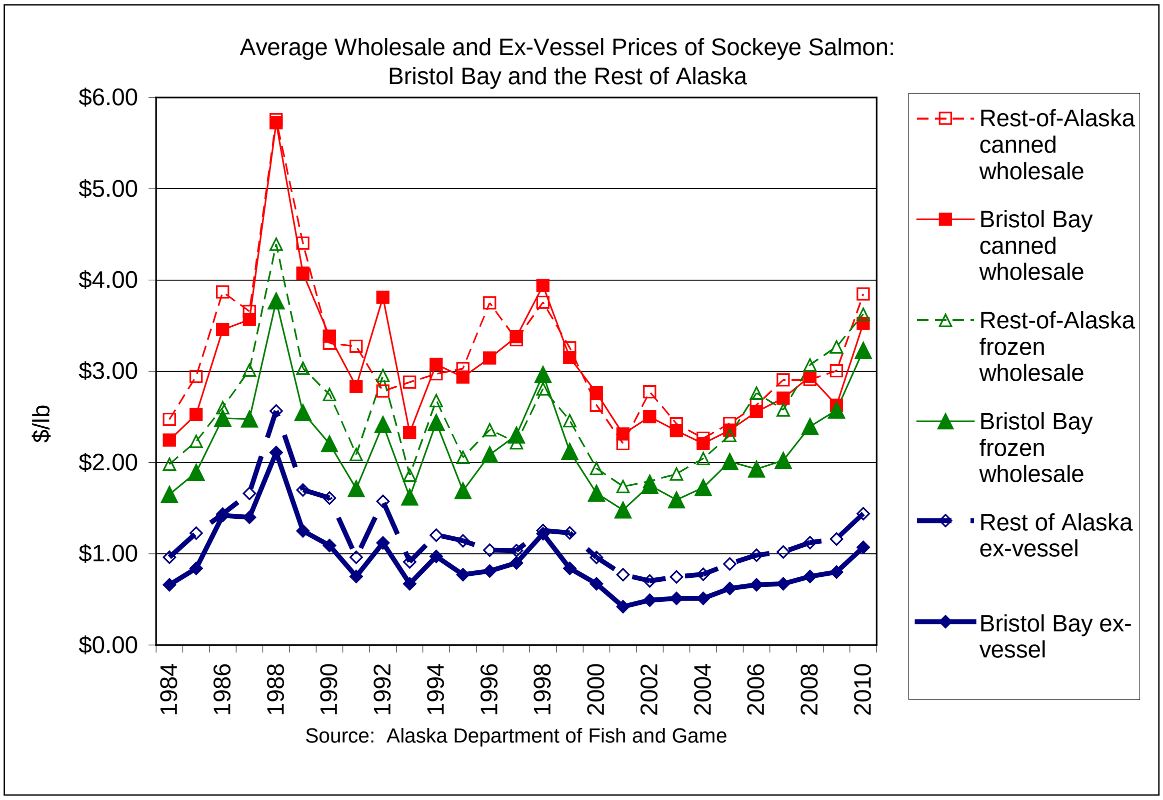


Figure 31. Average Monthly First Wholesale Prices.

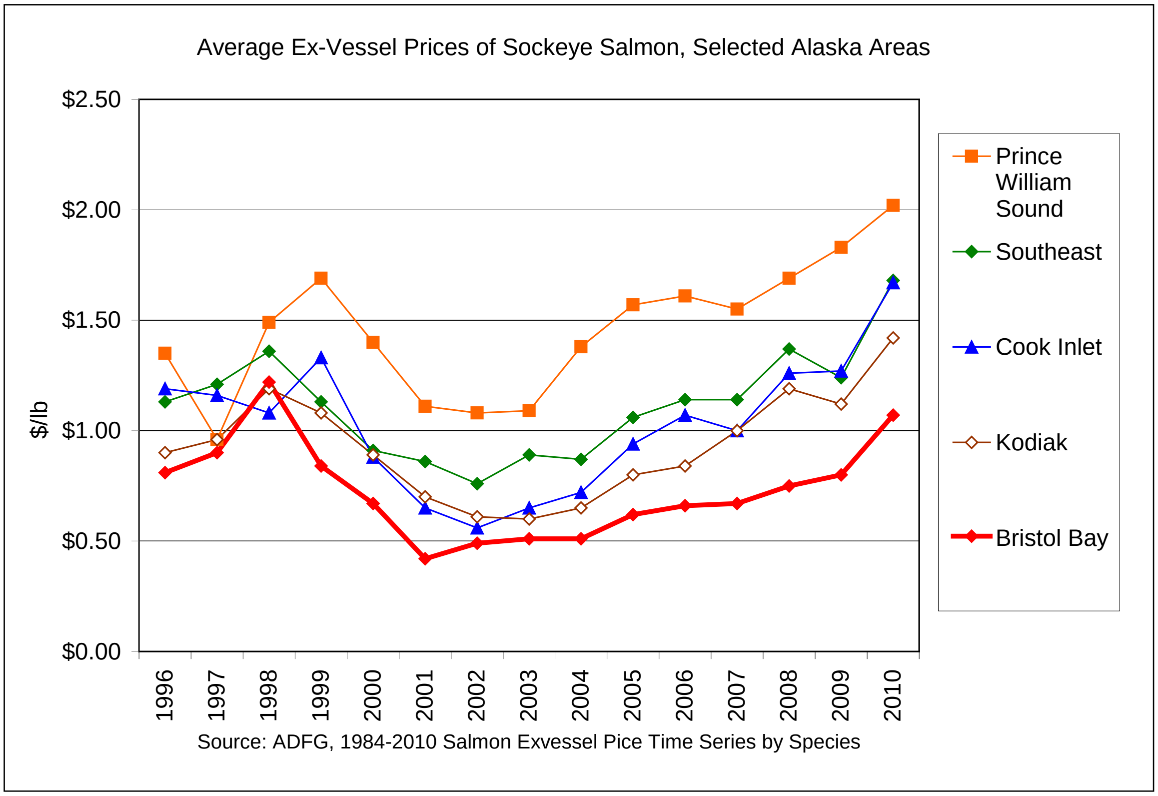
In general, wholesale prices paid to processors for canned Bristol Bay sockeye salmon are similar to wholesale prices for canned sockeye salmon from other regions of Alaska. In contrast, wholesale prices paid to processors for frozen Bristol Bay sockeye salmon are typically lower than wholesale prices for frozen sockeye salmon from other regions of Alaska (Figure 32). This may reflect differences in product mix and/or differences in the perceived quality of Bristol Bay frozen sockeye compared with frozen sockeye from other parts of Alaska.

In turn, Bristol Bay ex-vessel price for sockeye salmon are typically lower than ex-vessel prices for sockeye salmon in southcentral and southeast Alaska (Figure 33). This may reflect the fact that processors receive lower wholesale prices for frozen sockeye, as well as the fact that processors face higher operating costs in Bristol Bay than in less remote regions of southcentral and southeast Alaska, as well as generally higher costs for transporting products to market.



Source: Alaska Department of Fish and Game

Figure 32. Average Wholesale and Ex-Vessel Prices, Bristol Bay and Rest of Alaska



Source: ADFG, 1984-2010 Salmon Exvessel Pice Time Series by Species

Figure 33. Average Ex-Vessel Prices of Sockeye Salmon, Selected Alaska Areas.

Factors Affecting Bristol Bay Salmon Prices

Changes in Bristol Bay salmon prices over the past three decades reflect dramatic changes in world salmon markets over this period. The most important change was a dramatic increase in world salmon supply resulting from rapid growth in farmed salmon production, mostly in Norway, Chile, the United Kingdom and Canada.

In particular, during the 1990s, Japan—where the market for "red-fleshed salmon has previously been dominated by Alaska sockeye—began to import large volumes of farmed coho salmon from Chile and farmed trout from Chile and Norway. This, together with lower Bristol Bay salmon harvests, led to a dramatic decline in the share of Bristol Bay sockeye salmon in its most important market.

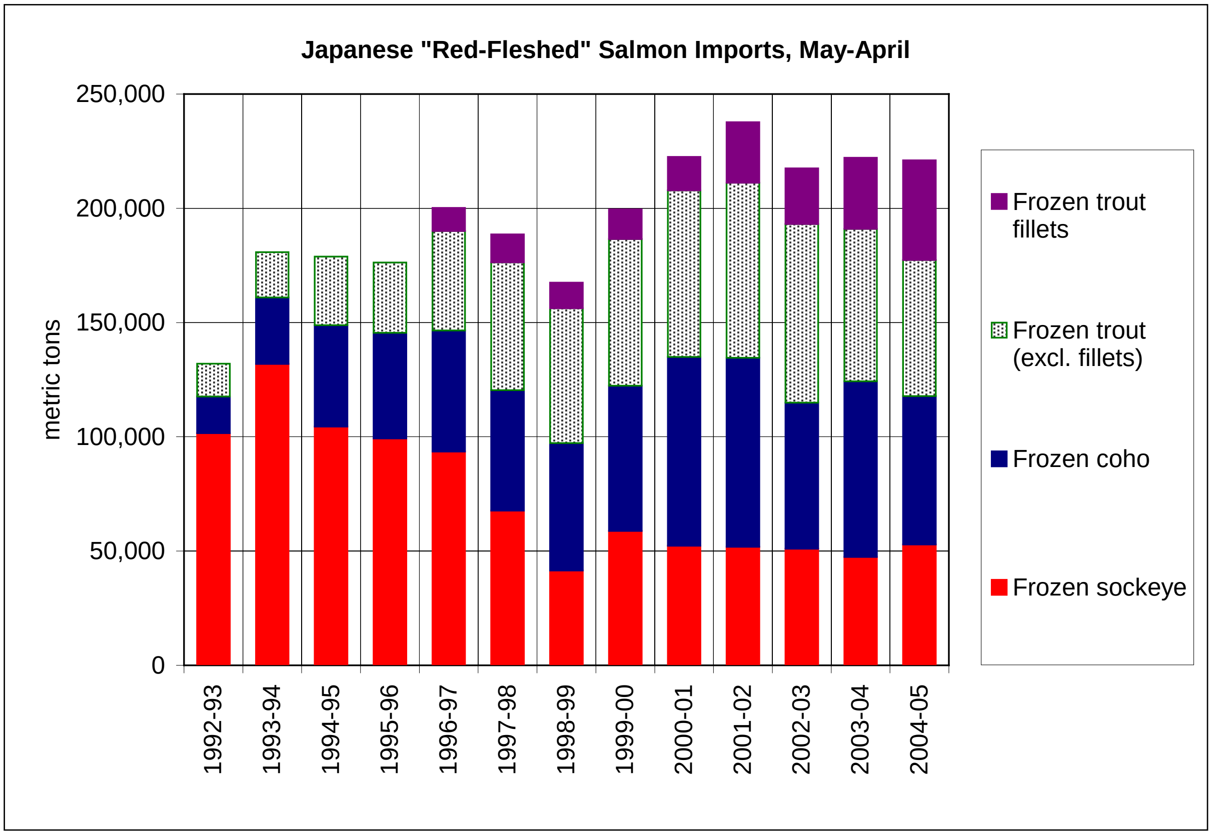


Figure 34. Japanese Red-Fleshed Salmon Imports, May-April

The effects of growing supply were compounded by an economic recession in Japan, changes in the Japanese fish distribution system which increased the market power of retailers, and long-term changes in Japanese food consumption patterns. The combined result was a sharp decline in Japanese wholesale prices paid for Bristol Bay sockeye salmon as well as farmed salmon (Figure 35). This in turn was reflected in a sharp decline in prices paid to Alaska processors and fishermen (Figure 36).

Bristol Bay headed and gutted sockeye salmon

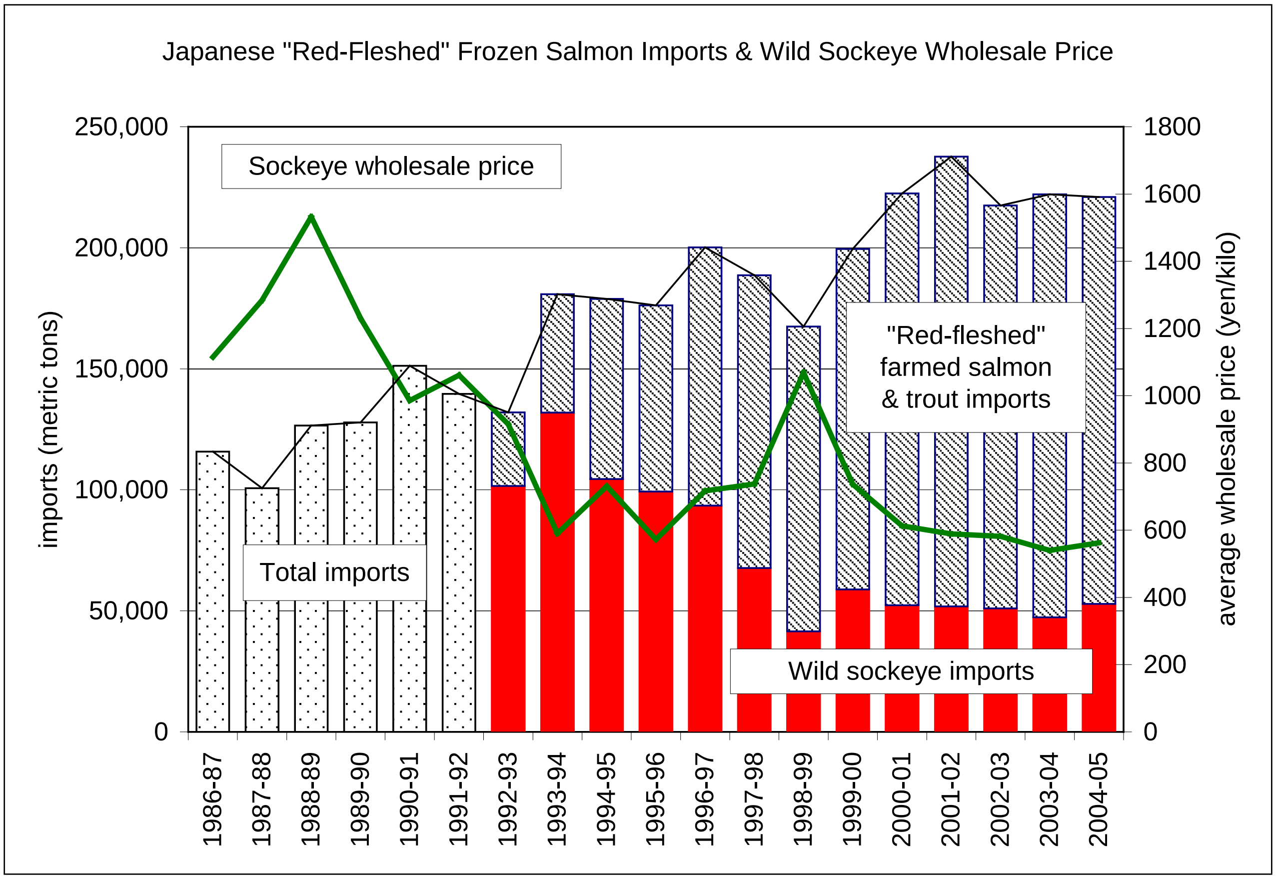


Figure 35. Japanese Red-Fleshed Frozen Salmon Imports & Wild Sockeye Wholesale Price

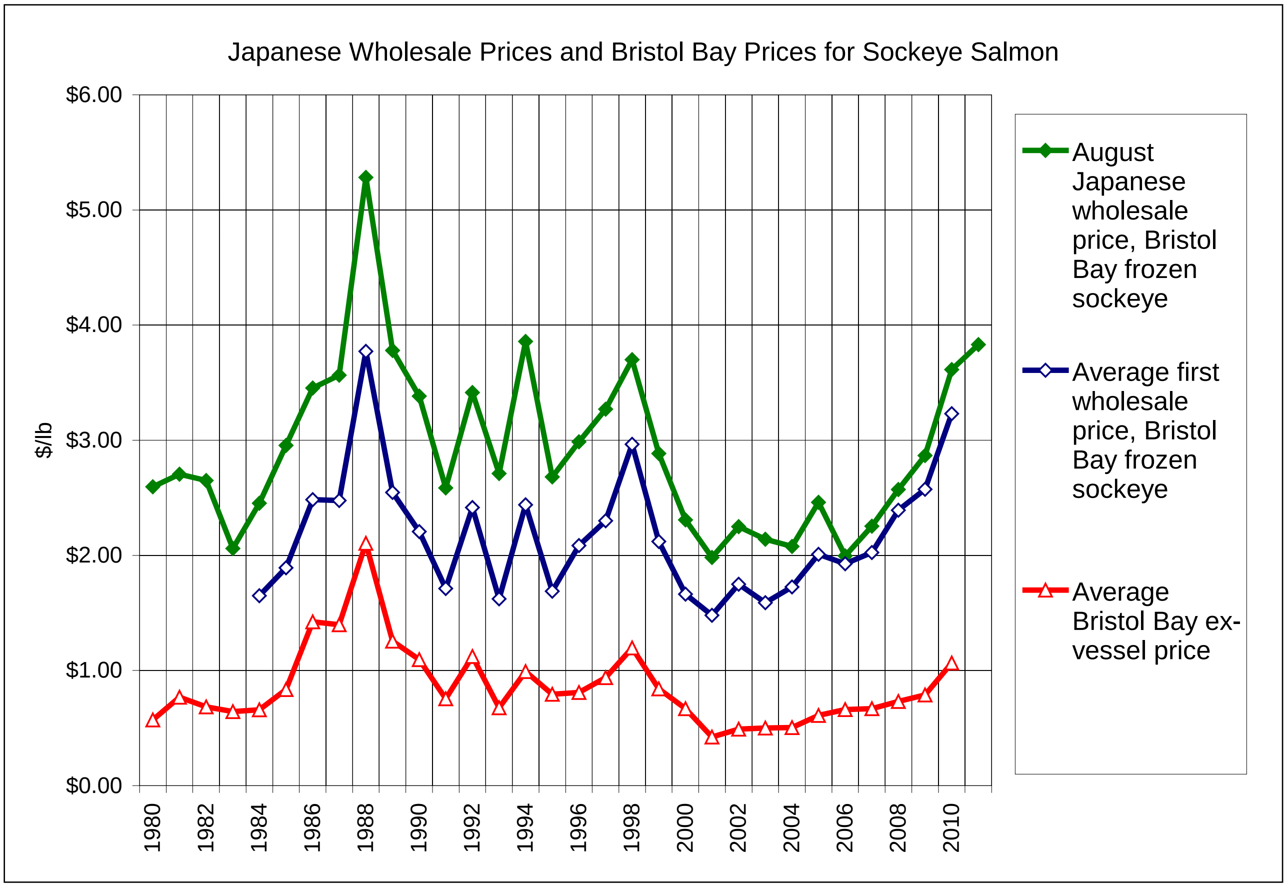
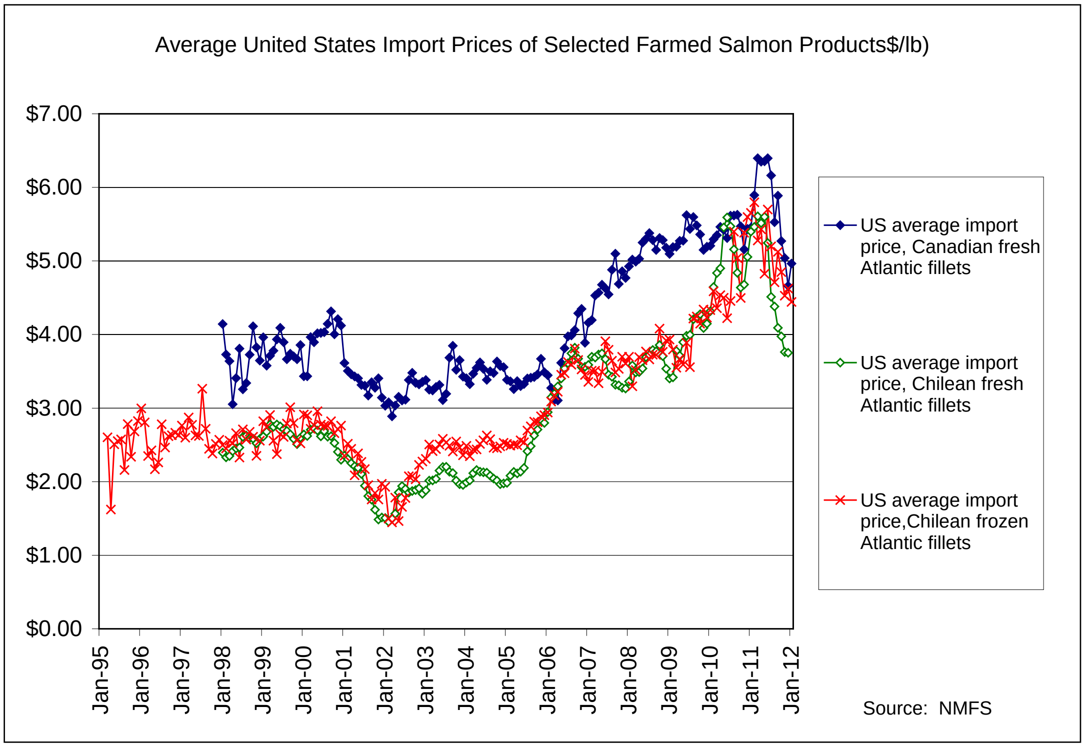


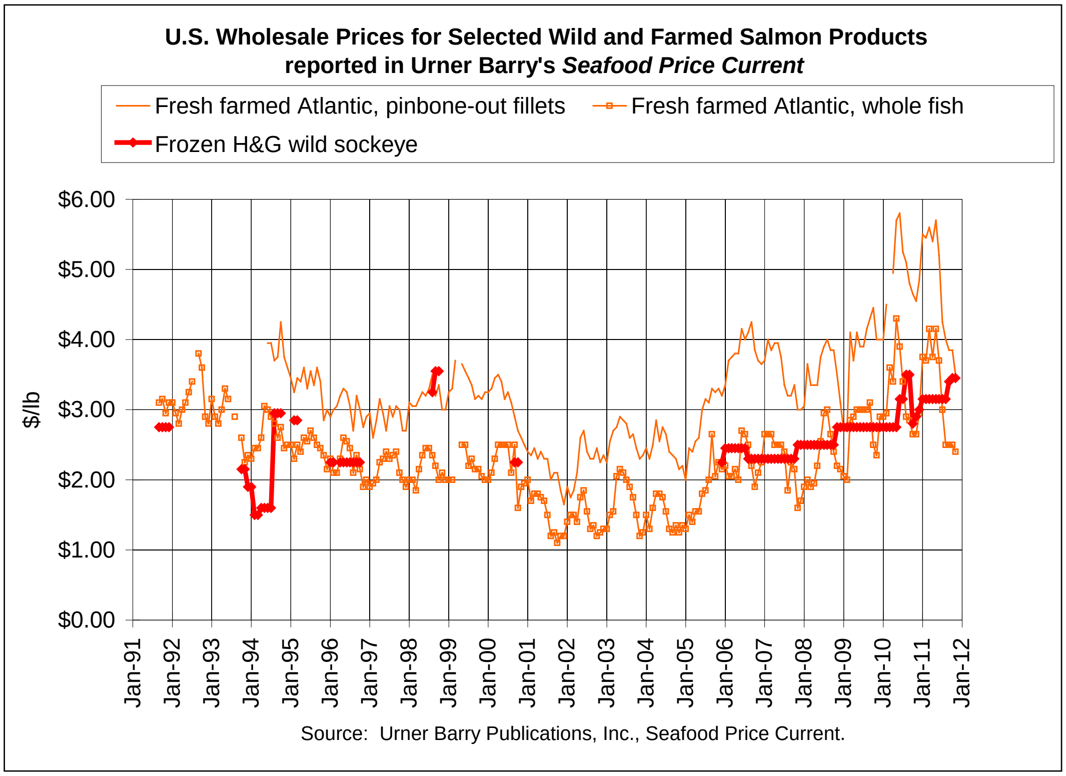
Figure 36. Japanese Wholesale Prices and Bristol Bay Prices for Sockeye Salmon

Just as multiple factors contributed to the fall in Bristol Bay salmon prices during the 1990s, multiple factors contributed to the recovery in prices after 2001. Probably the most important factors was a strong recovery in world market prices for farmed salmon, driven by rapidly rising world demand and a slowing of the growth in world salmon production (Figure III-9), exacerbated by major disease problems in the Chilean salmon industry which greatly reduced Chilean production. Prices of farmed Atlantic salmon in particular rose dramatically from 2002 through 2010 (Figure 37 and Figure 38).



Source: NMFS

Figure 37. Average United States Import Prices of Selected Farmed Salmon Products



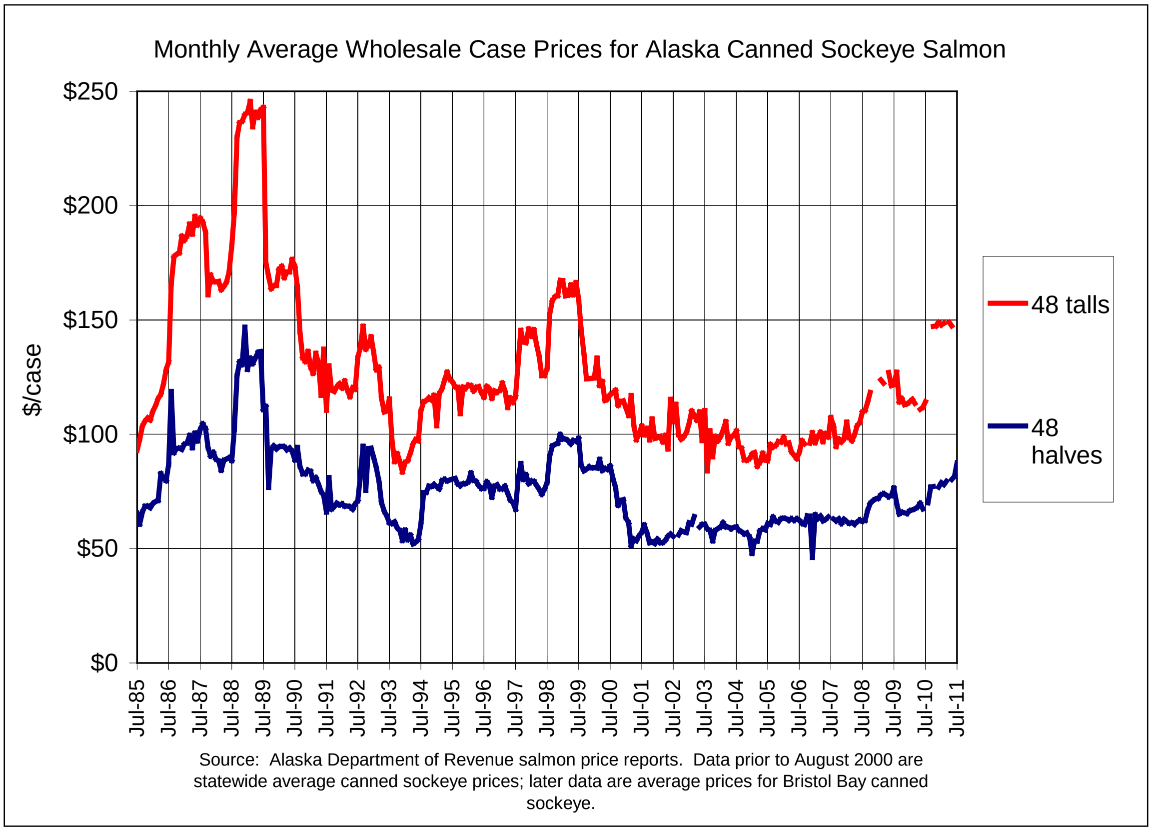
Source: Urner Barry Publications, Inc., Seafood Price Current.

Figure 38. U.S. Wholesale Prices for Selected Wild and Farmed Salmon Products

Other factors which contributed to the increase in prices for Bristol Bay sockeye salmon after 2001 include the strengthening of exchange rates between the yen and the dollar and between the euro and the dollar, diversification of markets for frozen sockeye, and the development of new product forms, particularly fillets.

Unlike frozen salmon markets, canned salmon markets have not been directly affected by competition from farmed salmon—because relatively little farmed salmon is canned. However, canned salmon markets are influenced by frozen market conditions—and thus indirectly by farmed salmon. When frozen prices are high, processors tend to freeze relatively more salmon and can relatively less, which reduces the supply of canned salmon, causing canned salmon prices to rise. When frozen prices are low, processors tend to freeze relatively less salmon and can relatively more, which increases the supply of canned salmon, causing canned salmon prices to fall. Put differently, the ability of processors to shift between freezing and canning salmon causes frozen and canned salmon prices to tend to move together.

This can be seen in the decline in the downward trend in canned salmon prices in the early 1990s, and the upward trend since the early 2000s (Figure 37). However, many other factors affect canned salmon prices, including in particular wild salmon harvests, exchange rates between the dollar and the UK pound, and changing demand patterns for canned salmon.


Monthly Average Wholesale Case Prices for Alaska Canned Sockeye Salmon

Source: Alaska Department of Revenue salmon price reports. Data prior to August 2000 are statewide average canned sockeye prices; later data are average prices for Bristol Bay canned sockeye.

Figure 39. Monthly Average Wholesale Case Prices for Alaska Canned Sockeye Salmon.

Future Bristol Bay Salmon Prices

Since the beginning of 2011 prices of farmed Atlantic salmon have fallen sharply, in response to oversupply of world markets as Chilean production has recovered (Figure 37 and Figure 38, above). Of great importance for the Bristol Bay salmon industry will be the extent to which prices of Bristol sockeye salmon remain high, or alternatively follow the recent downward trend in farmed salmon prices. At the time this report was written, it was too soon to tell how deep or long the decline in farmed salmon prices may be, or how much it may affect sockeye salmon markets.

More generally, the future outlook for Bristol Bay salmon prices is promising but uncertain. There are several reasons for optimism, including growing demand for wild sockeye salmon in the United States and Europe, the development of new higher-valued product forms (particularly fillets), and improvements in the quality of Bristol Bay salmon (discussed below). However, the Bristol Bay salmon industry will face challenges in taking advantage of these new market opportunities. These include continued competition from farmed salmon and other new farmed species, the logistical difficulties of market development given the wide variation in annual Bristol Bay catches, high costs of transportation and labor, and highly concentrated seasonal production which adds to costs and makes it difficult to slow down production and improve quality. These factors make it relatively easier for other regions of Alaska than for Bristol Bay to take advantage of growing market opportunities for wild sockeye salmon.

Bristol Bay Salmon Quality

In an increasingly competitive world seafood industry, quality is of increasing importance. An important challenge for the Bristol Bay salmon industry has been a reputation for quality problems. Many people in the industry believe these problems have historically kept wholesale and ex-vessel prices lower than they would have been with better quality—although it is difficult to quantify how important the effect of quality on prices has been.

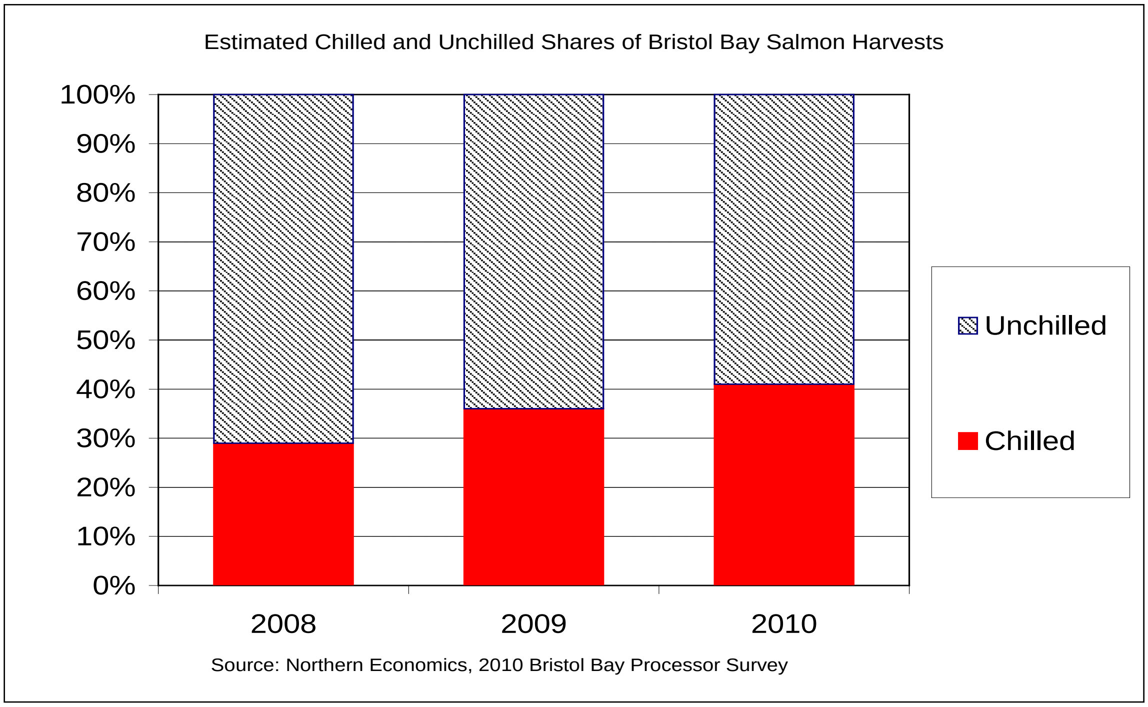
Quality problems in the Bristol Bay fishery derive in part from handling practices such as those depicted in these pictures posted on the internet. During the short, hectic and fast-paced Bristol Bay season, fishermen have historically been focused on catching large volumes of fish fast than on handling fish carefully. (In the highly quality-conscious salmon farming industry, it would be unthinkable to step on fish.)

Source: http://bbda.org/Stern_Load06.jpg

Source: www.adn.com/static/includes/highliner/cowboys.jpg

Quality problems in the Bristol Bay fishery have been compounded by the absence of ice or chilling capacity on many fishing boats; the logistics of tendering salmon long distances from fishing grounds to processors, which makes it more difficult to separate fish which have been handled carefully from those which have not (and to pay quality-conscious fisherman a corresponding price premium); and the difficulty of processing salmon soon after they are caught, especially during peak fishing periods.

Improving quality has been a primary focus of the Bristol Bay Regional Seafood Development Association (BBRSDA), [11] a fishermen's marketing association for the drift gillnet fishery financed by permit holders by means of a 1% assessment on the ex-vessel value of landings (harvests). BBRDSA has undertaken a number of projects focused on encouraging chilling (through icing and/or refrigerated sea water) as well as improved handling practices. Annual processor surveys funded by BBRDSA suggest that the share of fish which are delivered chilling is increasing (Figure V-12).[12]



Source: Northern Economics, 2010 Bristol Bay Processor Survey

Figure 40. Estimated Chilled and Un-chilled Shares of Bristol Bay Salmon Harvests

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[11] BBRSDA was established in 2005. Fishermen voted for the 1% assessment in 2006. Information about BBRSDA may be found at www.bbrsda.com.

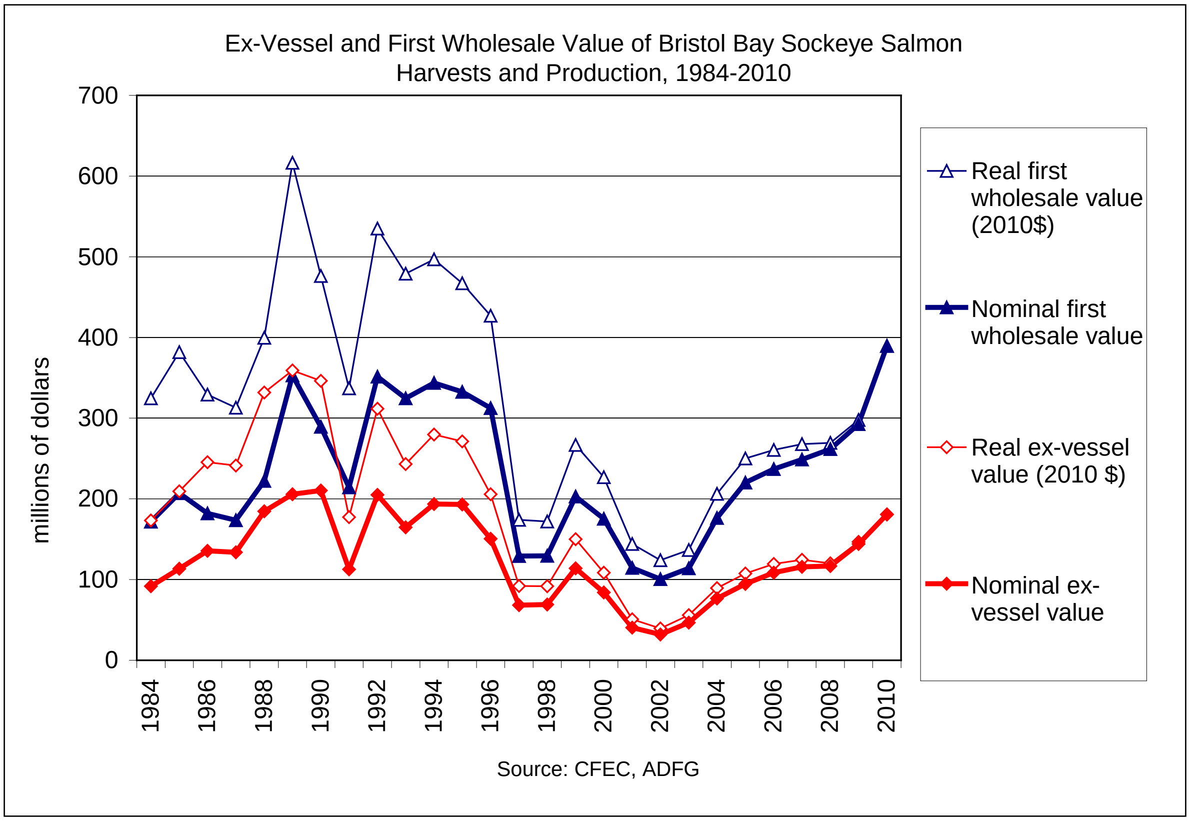
[12] Northern Economics, 2010 Bristol Bay Processor Survey. Prepared for Bristol Bay Regional Seafood Development Association, February 2011. http://www.bbrsda.com/layouts/bbrsda/files/documents/bbrsda_reports/BB-RSDA%202010%20Survey%20Final%20Report.pdf

Bristol Bay fishing boats waiting to unload to a tender

Photograph by Gabe Dunham

3.6 Bristol Bay Salmon Ex-Vessel and Wholesale Value

The decline in catches and prices during the 1990s led to a drastic decline in value in the Bristol Bay salmon fishery. The nominal ex-vessel value paid to fishermen fell from a peak of $214 million in 1989 to just $32 million in 2002—a decline of 86%. The inflation-adjusted "real" value (expressed in 2010 dollars) fell by an even greater 89% from a 1989 value of $359 million to $39 million in 2002.


Ex-Vessel and First Wholesale Value of Bristol Bay Sockeye Salmon Harvests and Production, 1984-2010

Source: CFEC, ADFG

Figure 41. Ex-Vessel and First Wholesale Value: 1984-2010

As catches and prices have improved after 2002, the Bristol Bay salmon industry experienced a significant economic recovery. Ex-vessel value increased to $181 million in 2010. However, this was well below the inflation-adjusted “real” value of the highest-value years of the late 1980s and early 1990s.

The first wholesale value of Bristol Bay salmon production exhibited similar trends over time as ex-vessel value. The nominal first wholesale value fell from a peak of $351 million in 1992 to $100 million in 2002. As catches and prices improved, nominal wholesale value rose to a record $390 million in 2010. Adjusted for inflation, however, the 2010 first wholesale value remained well below the 1989 peak real wholesale value of $616 million.

The decline in value of the Bristol Bay fishery during the 1990s and the rise in value after 2002 was experienced by both processors and fishermen. Like the ex-vessel value to fishermen, the value retained by processors after deducting payments to fishermen (sometimes called the processors’ margin) fell dramatically during the 1990s and rose dramatically after 2002 (Figure 42).

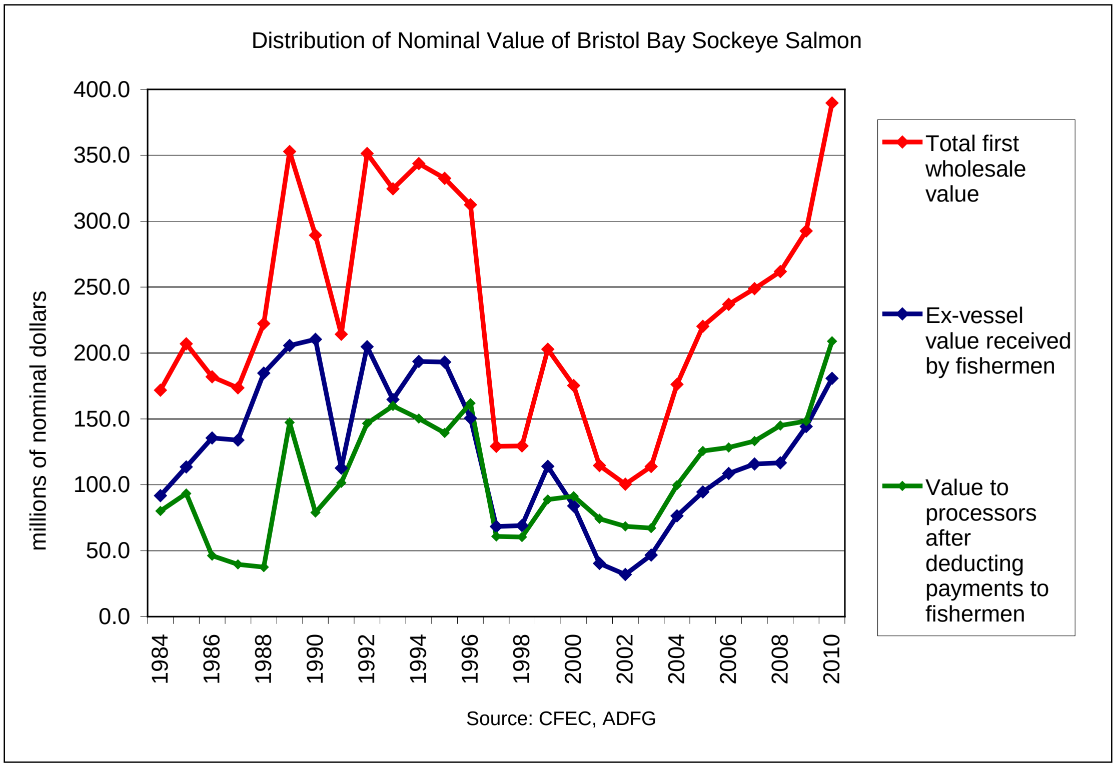
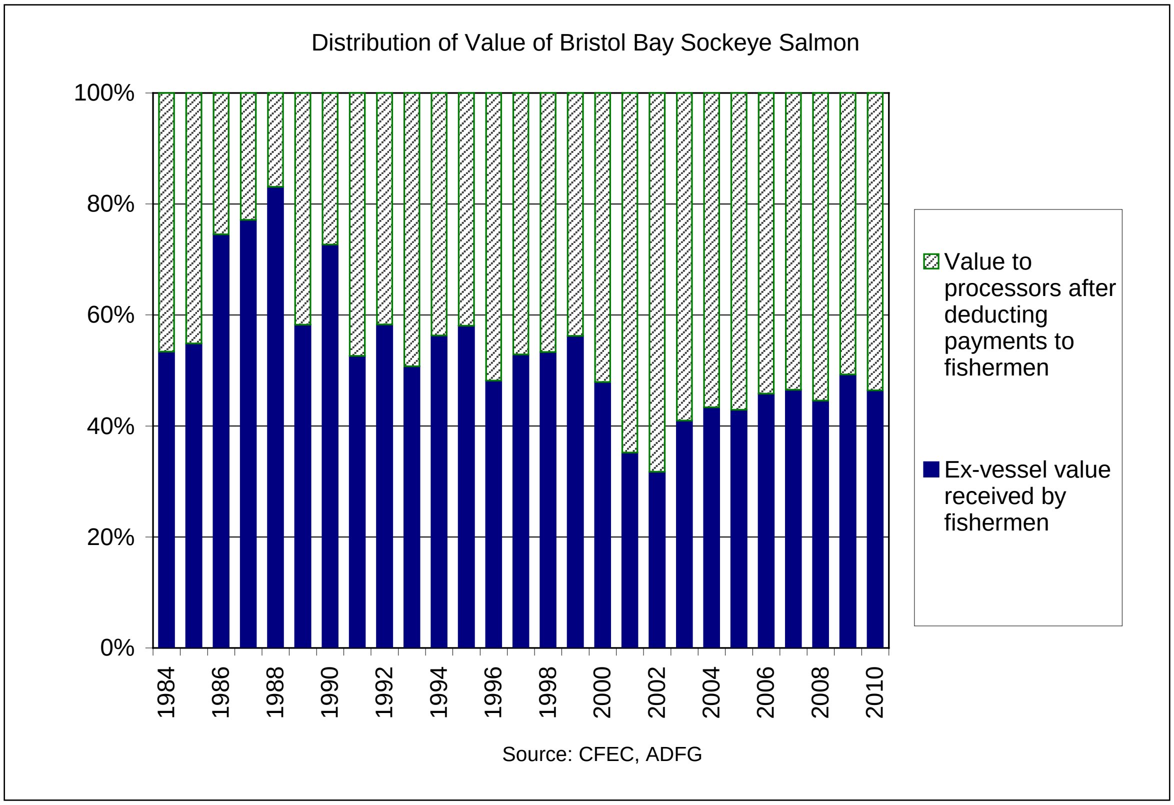


Figure 42. Distribution of Nominal Value of Bristol Bay Sockeye Salmon

The share of first wholesale value received by fishermen fell from 83% in 1988 to 32% in 2002 and then rose to 46% in 2010 (Figure 43).



Source: CFEC, ADFG

Figure 43. Distribution of Value of Bristol Bay Sockeye Salmon

The relative share of wholesale value received by fishermen and processors has been a subject of contention between fishermen and processors.[13] During the 1990s, fishermen argued that they had experienced a disproportionate and unfair share of the decline in wholesale value. Note, however, that there is no economic reason to expect fishermen or processors' shares of gross wholesale value to remain constant over time. Regardless of wholesale value, processors must cover the costs of processing—which account for a relatively larger share of wholesale value as wholesale value declines.

The loss in value during the 1990s led to a severe economic crisis in the Bristol Bay salmon industry. As discussed above, as the value of the fishery declined, the prices of limited entry permits plummeted and many fishermen stopped fishing their permits. Similarly, many land-based salmon processing operations closed and many floating processors left Bristol Bay.

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[13] The decline in the fishermen's share of ex-vessel value was a key issue in an unsuccessful class-action lawsuit filed in 1995, in which Bristol Bay permit holders alleged that major processors and Japanese importers of Bristol Bay salmon had conspired to fix prices paid to fishermen (Alakayak v. All Alaskan Seafoods, Inc). The author served as an expert witness on behalf of the defendant processors and importers.

3.7 Bristol Bay Salmon Fishermen

As discussed earlier, both the Bristol Bay drift gillnet fishery and the Bristol Bay set gillnet fishery are managed under a “limited entry” management system which was implemented for all of Alaska’s twenty-seven salmon fisheries in the mid-1970s. The basic purpose and effect of the limited entry system is to limit the number of boats fishing in each fishery, which makes it easier for managers to control the total fishing effort and makes the fishery more profitable for participants than it would be if entry (participation) were unrestricted and more boats could fish.

There are approximately 1860 drift gillnet permits and approximately 1000 set net permits. Every drift gillnet fishing boat or set net operation must have a permit holder on board or present while fishing—so the number of boats or set net operations cannot exceed the number of permit holders.

A permit represents a right (legally a revocable privilege) to *participate* in a fishery. Unlike individual fishing quota (IFQ) or catch-share systems which have been implemented in some United States fisheries, a permit does not restrict a permit-holder to catching a specific number of fish. Fishermen may catch as many fish as they can—as long as they follow the numerous regulations which restrict when, where and how they may fish.

When limited entry management was implemented in 1975, permits were allocated for free to individuals who had historically participated in the fishery. Permit holders may hold permits in perpetuity, although they must renew their permits each year for a nominal administrative fee. Persons without permits can acquire them only by gift, inheritance, or by buying them from existing permit holders.

Permit holders must register to fish in one of the five Bristol Bay fishing districts. They may transfer to fish in another district, but must wait 48 hours before fishing in the new district.

A “permit stacking” regulation implemented in 2004 for the drift gillnet fishery allows two permit holders who opt to fish together on a single vessel to use 200 fathoms of drift gillnet gear (an additional 50 fathoms more than the usual limit of 150 fathoms). The objective of the regulation was to allow two permit holders to team up to reduce their combined harvesting costs to create a more profitable operation.

In addition to permit holders, there are an average of about two crew members for each drift gillnet fishing boat and about two crew members for each set gillnet site. Crew members are usually paid a percentage share of gross earnings after deducting costs of food and fuel. A typical drift gillnet crew share is about 10%.

The Commercial Fisheries Entry Commission (CFEC) maintains detailed public data about salmon permit holders, including their names, addresses, and vessel information. It also publishes annual data on the total number of permits fished, total pounds landed, total gross earnings, and average prices paid for permits sold.[14]

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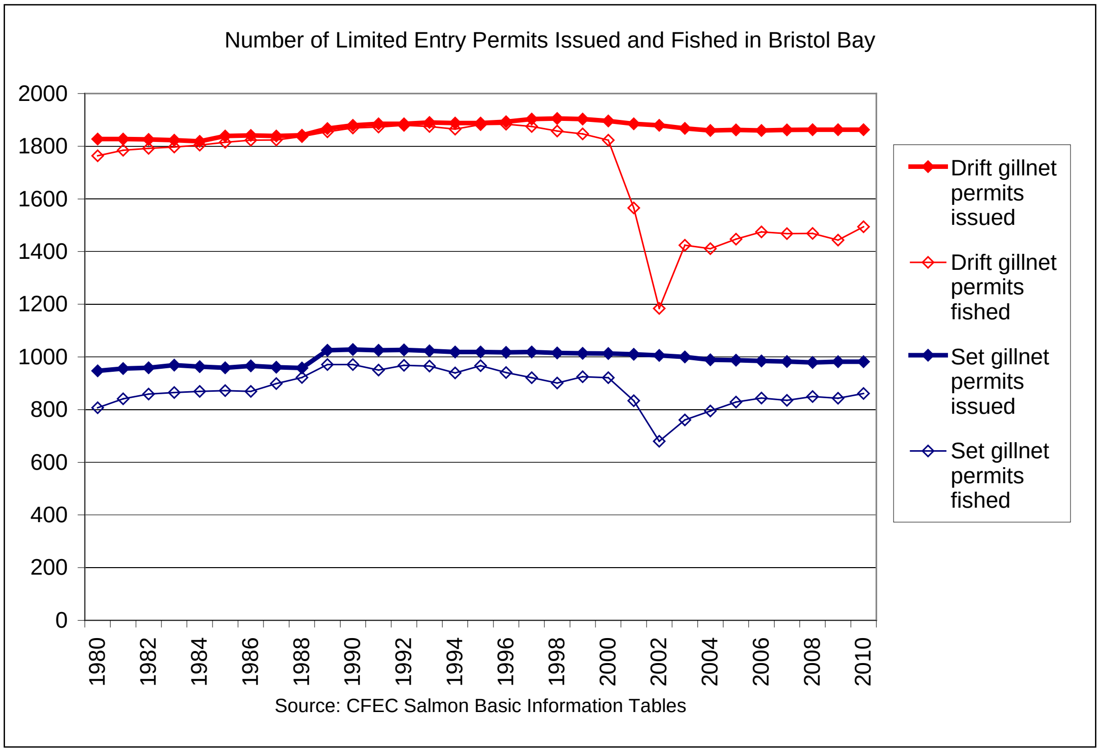
[14] The data may be found at the Commercial Fisheries Entry Commission website: http://www.cfec.state.ak.us/.

In contrast, almost no data are available about Bristol Bay crew members. Although crew are required to purchase an annual Alaska fishing crew license for a nominal fee, no data are available about whether they participate in fishing, which fisheries they fish in, or how much they earn. For this reason, most of the data presented in this section are about Bristol Bay permit holders. But keep in mind that about two-thirds of the people working in Bristol Bay fish harvesting are crew members.

Fishery Participation

Until the late 1990s, most Bristol Bay permits were fished (Figure 44). However, beginning in the late 1990s, a growing number of permit holders stopped participating in the Bristol Bay fishery, because they couldn't make enough money to cover their costs. In 2002—the lowest year for Bristol Bay ex-vessel value since the start of the limited entry program in 1975—only 63% of drift gillnet permits and 66% of set gillnet permits were fished.

Since 2002, as the value of the fishery increased, fishery participation also increased, although many permits remained unfished. In 2010, 80% of drift gillnet permits and 86% of set gillnet permits were fished.



Source: CFEC Salmon Basic Information Tables

Figure 44. Number of Limited Entry Permits Issued and Fished in Bristol Bay

Understanding the extent of participation in the Bristol Bay drift gillnet fishery since 2004 is complicated by the permit-stacking option for the drift gillnet fishery, under which two permit holders may opt to fish together (with an additional 50 fathoms of gear) from a single boat.

A CFEC analysis of the 2009 fishery, based on district registration data (both permit-holders in a two-permit operation are required to register for fishing in that district) concluded that “for the fishery as a whole, two-permit operations occurred on an estimated 20.9% (278) of the 1,331 vessels registered during the season and one-permit only operations occurred on 79.1% (1,053) of the vessels. Of the 1,610 distinct permit holders who registered during the season, 34.7% (558) were involved in a two-permit operation during the season, while 65.3% (1,052) were involved in a one-permit operation only.”[15]

Table 29 and Table 30 (on the following page) provides selected indicators of participation in the Bristol Bay drift gillnet fishery in 2009, based on various measures reported by CFEC. A total of 1863 permits were issued to 1838 permit holders. Of these, 1610 registered to fish during the season in one or more of the Bristol Bay fishing districts. Of these an estimated 1052 fished alone and 558 fished with another permit holder. Of those who fished with another permit holder, an estimated 401 reported landings on their permits while 157 reported no landings on their permits (all of the operation’s landings were reported on the other permit holder’s permit).

Thus the CFEC data for the “number of permits fished,” shown in Figure 44 above (1453 in 2009), overstates the number of boats which fished (1331 in 2009), but understates the number of permit holders who participated in the fishery (1610 in 2009).

Table 29. Selected Indicators of Participation in 2009 Drift Gillnet Fishery

Selected Indicators of Participation in the 2009 Bristol Bay Drift Gillnet Salmon Fishery

Row	Indicator	Source	Number
1	Total permits issued	a, b	1,863
2	Number of permit holders	b	1,838
3	Number of distinct permit holders who registered during the season	c	1,610
4	Estimated number involved in a one-permit operation only during the season	c	1,052
5	Estimated number involved in a two-permit operation during the season	c	558
6	Number of fishermen who fished (reported landings on their permits)	b	1,453
7	Total permits fished (with reported landings)	a, b	1,444
8	Number of vessels registered during the season	c	1,331
9	Estimated number on which only one-permit operations occurred	c	1,053
10	Estimated number on which two-permit operations occurred	c	278

(a) CFEC, Salmon Basic Informaton Tables, Bristol Bay Drift Gillnet Salmon Fishery, http://www.cfec.state.ak.us/bit/X_S03T.HTM.

(b) CFEC, "Permit & Fishing Activity by Year, State, Census Area or City," data for "Grand Total: All Fishermen Combined", http://www.cfec.state.ak.us/gpbycen/2009/00_ALL.htm.

(c) Schelle, K., N. Free-Sloan, and C. Farrington, “Bristol Bay Salmon Drift Gillnet Two-Permit Operations: Preliminary Estimates from 2009 District Registration Data (CFEC Report No. 09-6N, 2009). http://www.cfec.state.ak.us/RESEARCH/09-6N/bbr_final_v4_121409.pdf.

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[15] Schelle, K., N. Free-Sloan, and C. Farrington, “Bristol Bay Salmon Drift Gillnet Two-Permit Operations: Preliminary Estimates from 2009 District Registration Data (CFEC Report No. 09-6N, 2009). http://www.cfec.state.ak.us/RESEARCH/09-6N/bbr_final_v4_121409.pdf.

Table 30. Estimated Number of 2009 Drift Gillnet Permit Holders who Fished Alone, With another Permit Holder, or Did Not Fish

Estimated Numbers of 2009 Drift Gillnet Permit Holders Who Fished Alone, Fished with Another Permit Holder, or Did Not Fish

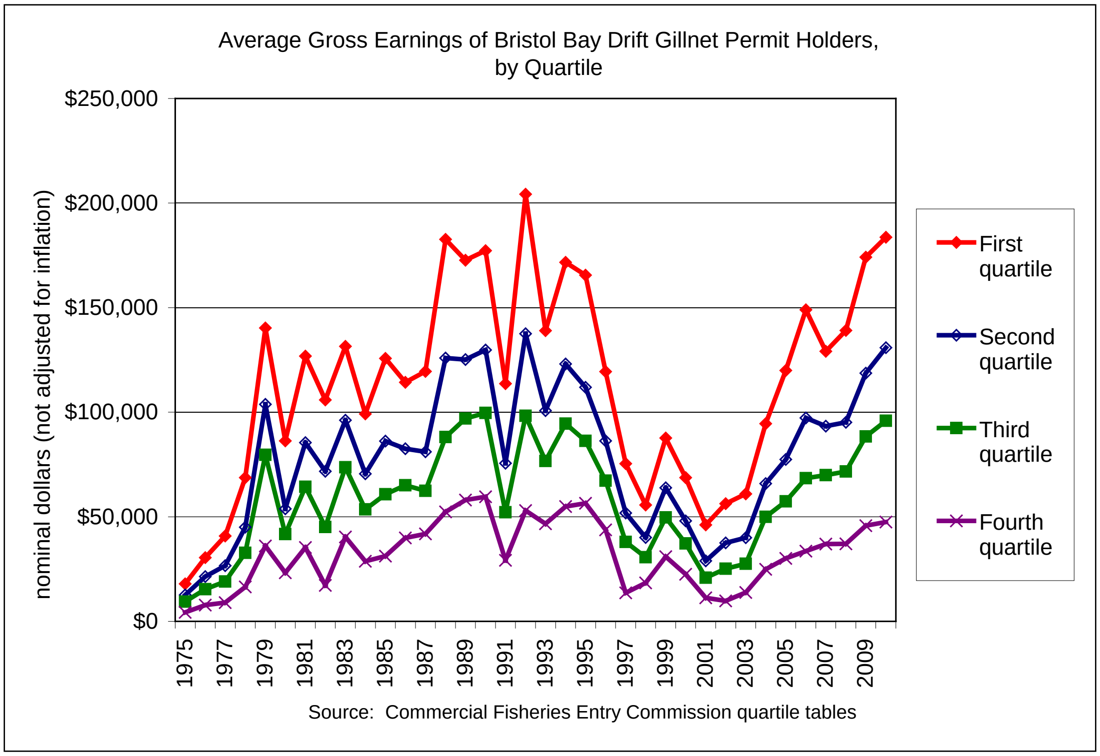
Number of permit holders who:	Estimates	How calculated*
Fished alone	**1,052**	4
Fished with another permit holder	**558**	5
Fished with another permit holder and reported landings	401	5 - (3 - 6)
As the only permit holder who reported landings	*122*	6 - 8
With both reporting landings	*279*	5 - (3 -6) - (6-8)
Fished with another permit holder but did not report landings	157	3 - 6
Held permit but did not fish it	**228**	2 - 3
TOTAL NUMBER OF PERMIT HOLDERS	**1,838**	2

*Numbers refer to rows in the previous table.

Distribution of Earnings

In both the drift gillnet and set gillnet fisheries, each year there is wide variation among permit holders in average earnings, reflecting differences in vessel size, fishing style, fishing experience and skill, how aggressively and for how long they fish, what fishing districts they choose to fish in, and good or bad luck. These differences are reflected in average earnings among four “quartile” groups of permit holders, each of which accounts for one quarter of total Bristol Bay earnings.

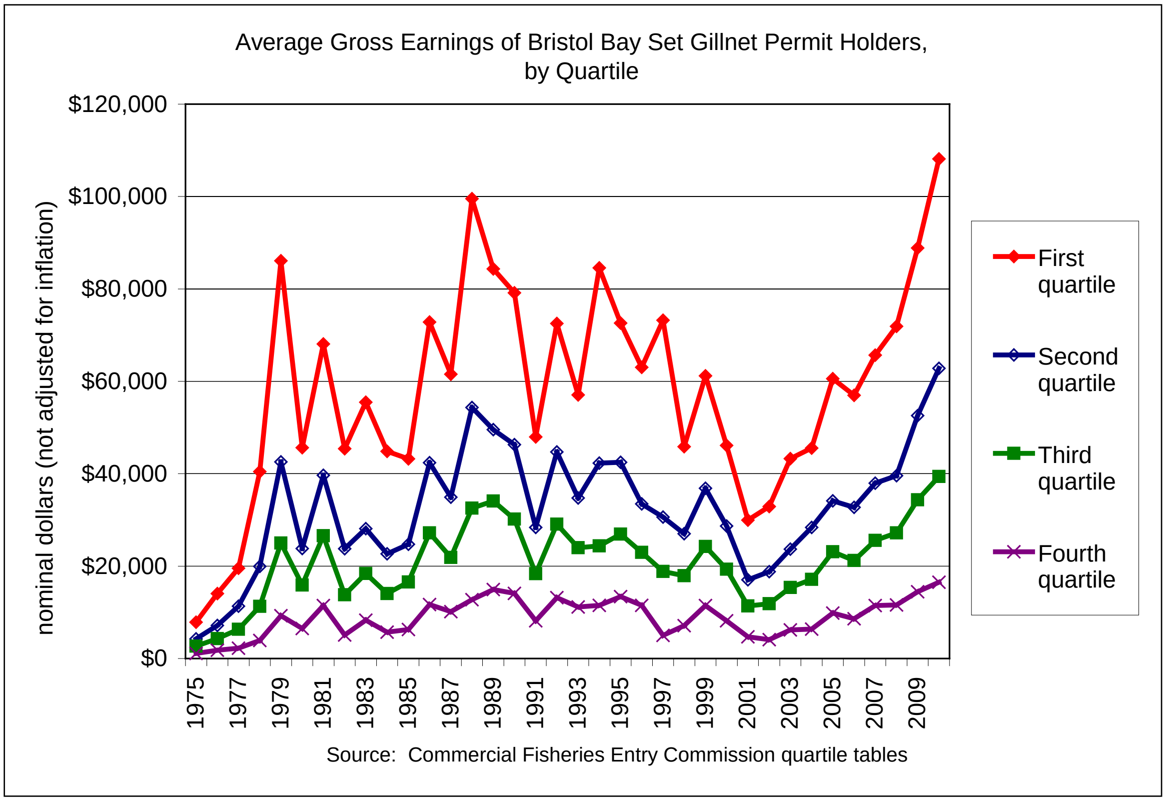
In the drift gillnet fishery, typically, the first quartile has about one-third to one-fourth as many fishermen as the fourth quartile, earning on average of about three to four times as much (Figure 45).



Source: Commercial Fisheries Entry Commission quartile tables

Figure 45. Average Gross Earnings of Bristol Bay Drift Gillnet Permit Holders

Average earnings in the set gillnet fishery are much lower than in the drift gillnet fishery. The highest earning "first quartile" set gillnet permit holders earn about half as much as the "first quartile" drift gillnet permit holders (Figure 46). There is a wider range of variation in earnings of set net permit holders, reflecting in part wide differences in the number of fish swimming past set net sites in different Bristol Bay locations.

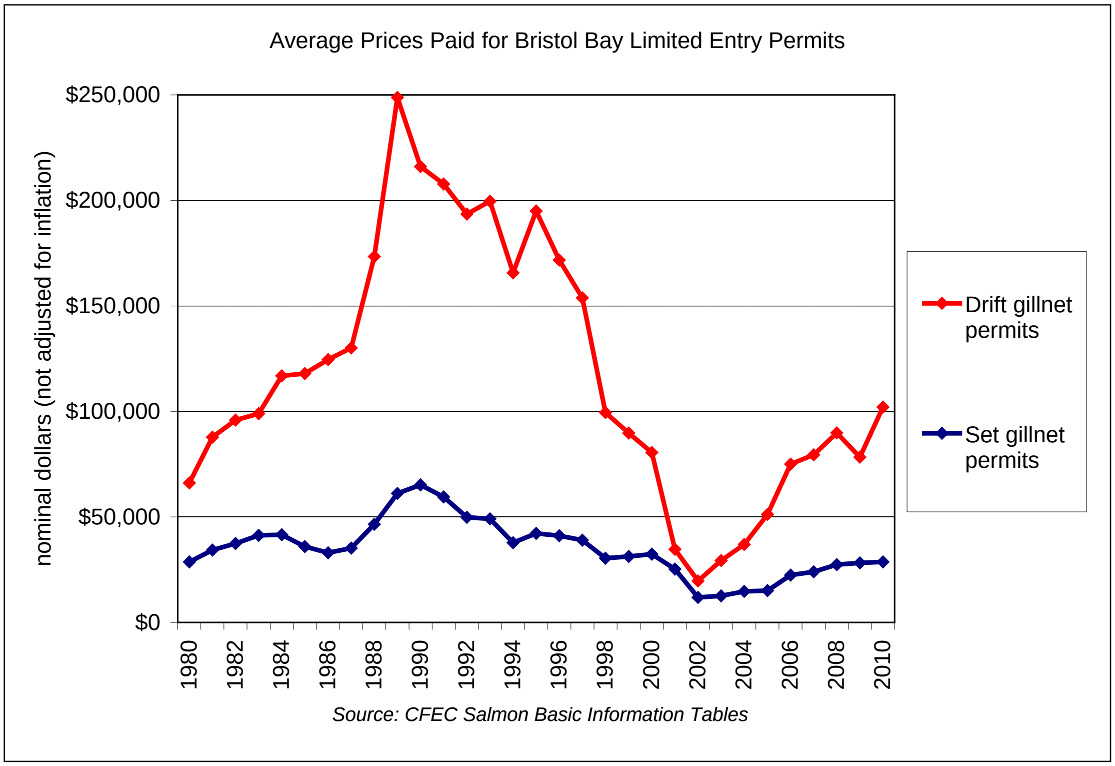

Average Gross Earnings of Bristol Bay Set Gillnet Permit Holders, by Quartile

Source: Commercial Fisheries Entry Commission quartile tables

Figure 46. Average Gross Earnings of Bristol Bay Set Gillnet Permit Holders

Permit Prices

The prices paid for Bristol Bay permits have fluctuated dramatically over time. Expressed in nominal dollars, average prices paid for drift gillnet permits rose from $66,000 in 1980 to $249,000 in 1989, fell to $20,000 in 2002, and rose again to $102,000 in 2010. Average prices paid for set gillnet permits rose from $29,000 in 1980 to $65,000 in 1989, fell to $12,000 in 2002, and rose again to $29,000 in 2010.



Source: CFEC Salmon Basic Information Tables

Figure 47. Average Prices Paid for Bristol Bay Limited Entry Permits

Bristol Bay limited entry permit prices are clearly strongly related to total earnings in the fishery. In both fisheries, trends over time in permit prices closely track trends over time in total earnings (Figure 48 & Figure 49). Economic theory suggests that permit prices would be driven by fishermen's expectations of future profits from the fishery. The close relationship between total earnings and permit prices suggests that expectations of future profits are driven by trends in average profits in recent years.

Costs of Fishing

Not all Bristol Bay permit holder earnings are profits, of course. Permit holders face significant costs of fishing, some of which are relatively fixed regardless of the volume or value of their catch—which makes fishing profits relatively more volatile than earnings.

No data are collected on a regular basis on the costs faced by Bristol Bay permit holders. From time to time, studies have estimated costs of fishing based on surveys of Bristol Bay permit holders. However, it is difficult to characterize fishing costs, for several reasons. First, costs may vary widely between fishing operations, because of differences in factors such as vessel size, number of crew, how and where permit holders fish, and where permit holders and crew live. Second, costs may vary significantly from year to year due to changes in prices of fuel, insurance and other inputs to fishing. Third, fixed costs such as vessel storage and insurance may vary widely from year to year when expressed on a per-pound basis due to changes in harvest volumes.

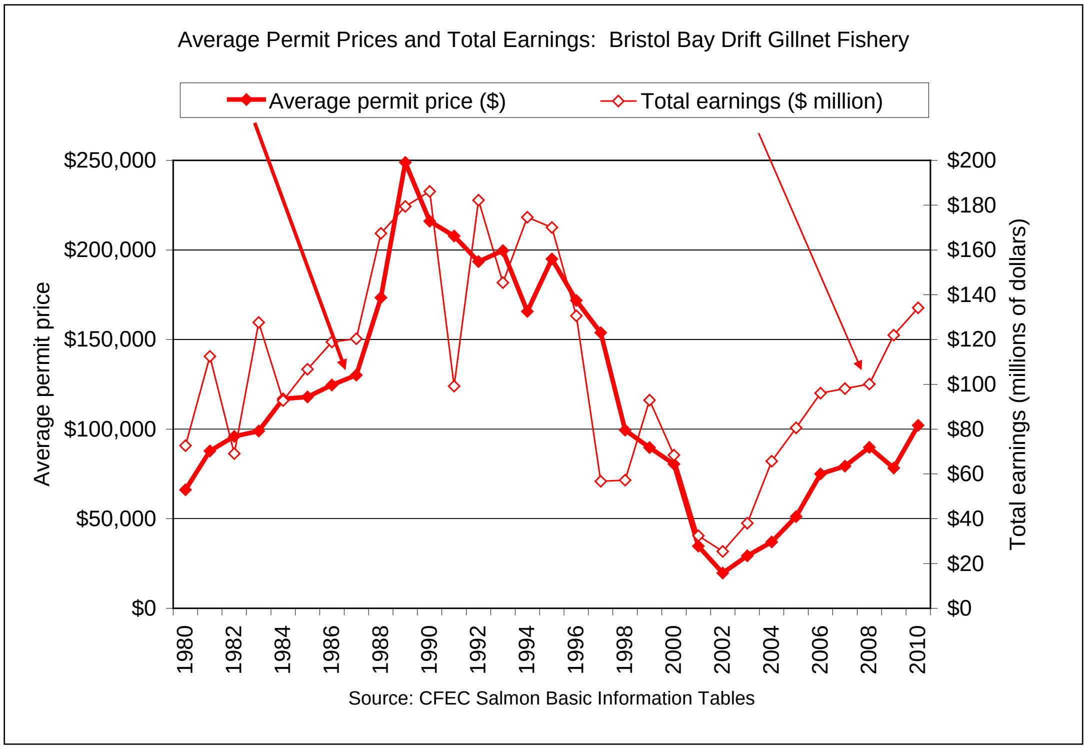


Figure 48. Average Permit Prices and Total Earnings: Bristol Bay Drift Gillnet Fishery

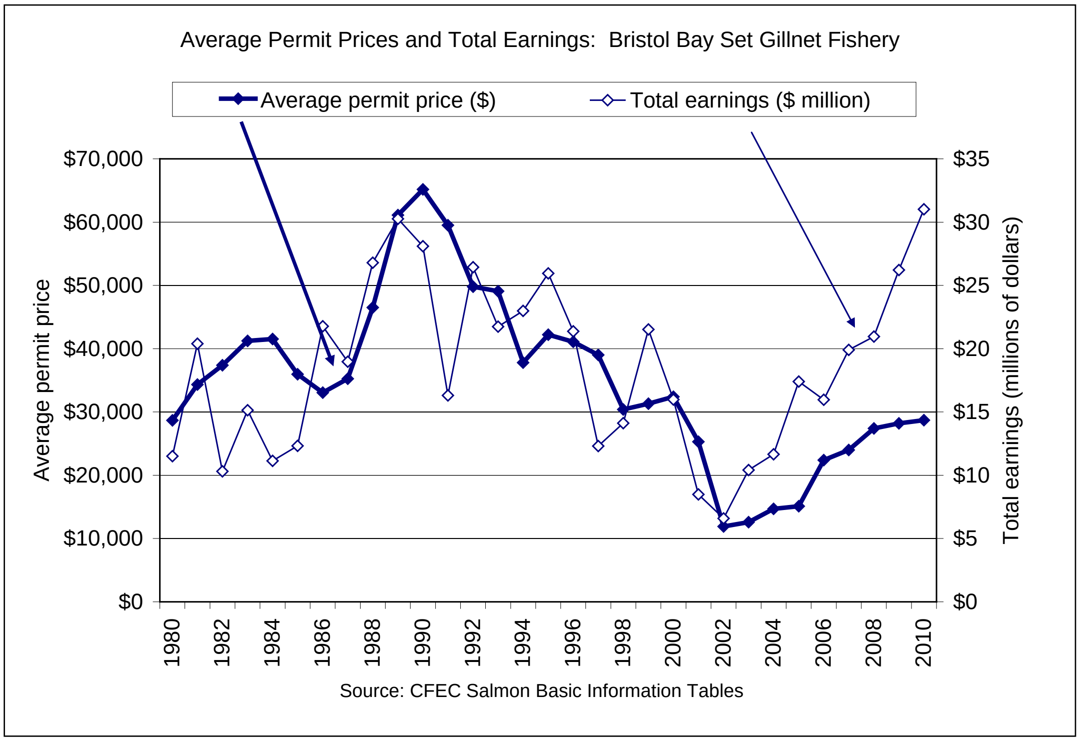


Figure 49. Average Prices and Earnings: Bristol Bay Set Gillnet Fishery

Figure 50 summarizes the estimated 2008 fishery-wide distributions of operating costs and incomes to Bristol Bay permit holders and crew reported by the Anchorage-based economic consulting firm Northern Economics in a recent detailed study of the importance of Bristol Bay salmon fisheries to the Bristol Bay region and its residents, conducted for the Bristol Bay Economic Development Corporation. The estimates were based on updates of estimates of previous analyses by CFEC and Northern Economics to account for changes in fuel prices and other costs. A review of the details of how the estimates were prepared and their limitations is beyond the scope of this report. We include them here as a general indicator of the kinds of costs which are important in the fishery and their approximate magnitudes relative to 2008 earnings. Note that operating costs in both fisheries include fuel and oil, net maintenance, gear, boat and net storage, transportation, food, insurance, taxes, fees and services. Permit holders also face costs of crew share payments (about 10% of gross earnings per crew member, after deducting costs of fuel and food), as well as loan payments for permits and boats.

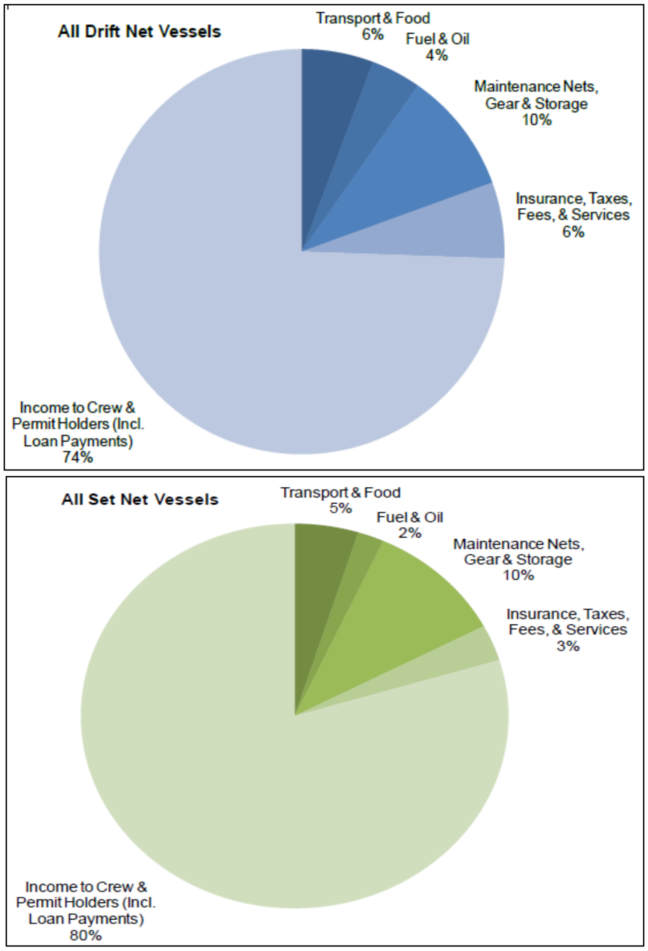


Figure 50. Northern Economics' Estimates of the Breakdown of Operating Costs and Incomes to Crew and Permit Holders, Bristol Bay Salmon Fisheries, 2008

Source: Northern Economics, *The Importance of the Bristol Bay Salmon Fisheries to the Region and its Residents* (report prepared for the Bristol Bay Economic Development Corporation, October 2009). Estimates based in part on earlier analyses by Northern Economics and CFEC.

3.8 Bristol Bay Salmon Processors

Fish processing is an integral part of the Bristol Bay commercial salmon industry, employing approximately half as many people as fish harvesting and more than doubling the value of the fish.

Bristol Bay salmon are processed in both land-based processing facilities and on floating processors. Salmon are canned only in large land-based facilities, which also have salmon freezing capacity. Floating processors produce only frozen salmon. As discussed, the Bristol Bay salmon processing industry typically employs about 3000 to 4000 workers annually at the height of the salmon processing season—depending upon the size of the harvest. Of these, fewer than 5% are residents of the Bristol Bay region. Another 10% to 15% are residents of other parts of Alaska, and about 75% to 80% are residents of other states or countries. Most are relatively unskilled short-term workers: only about 20% work in Bristol Bay for more than five years. Almost all live in bunkhouses provided by the processing companies.

Yardarm Knot Cannery, Naknek

Source: http://www.yardarm.net/red%20salmon%20cannery/cannery%20home4_files/image301.jpg

Icicle Seafoods' Floating Processor Bering Star in the Nushagak River
(the ship on the left is a cargo vessel loading frozen salmon for shipment to Japan)

In 2010, six companies operated salmon canning facilities in Bristol Bay. These included some of the largest seafood processing companies operating in Alaska, such as Trident Seafoods, Ocean Beauty Seafoods, Icicle Seafoods and Peter Pan Seafoods. Most of these companies have both land-based and floating processing operations in many parts of Alaska, which process not only salmon but other major Alaska species as well, such as pollock, crab and halibut. All large processors have home offices in or near Seattle.

In 2010, all of the processors with canning facilities, and five other larger processors purchased salmon in multiple Bristol Bay districts. There were twenty-five other buyers and smaller processors who bought salmon in just one district.

Most of the land-based processing facilities in the Bristol Bay region are located in or near a small number of communities with regularly-scheduled air transportation. The largest number of processors are located in Naknek along the Naknek River. Most of the other land-based facilities are in Dillingham, Egegik and Togiak.

Bristol Bay salmon processing is not an easy business. The list of companies buying and processing salmon in Bristol Bay changes from year to year. The number of large processors operating in Bristol Bay declined in the 1990s, reflecting consolidation in the industry forced by harvest volumes and lower profits. Many land-based processing plants closed and the number of floating processors brought into Bristol Bay each year to process salmon also declined sharply. This consolidation helped to make the industry more efficient and more profitable.

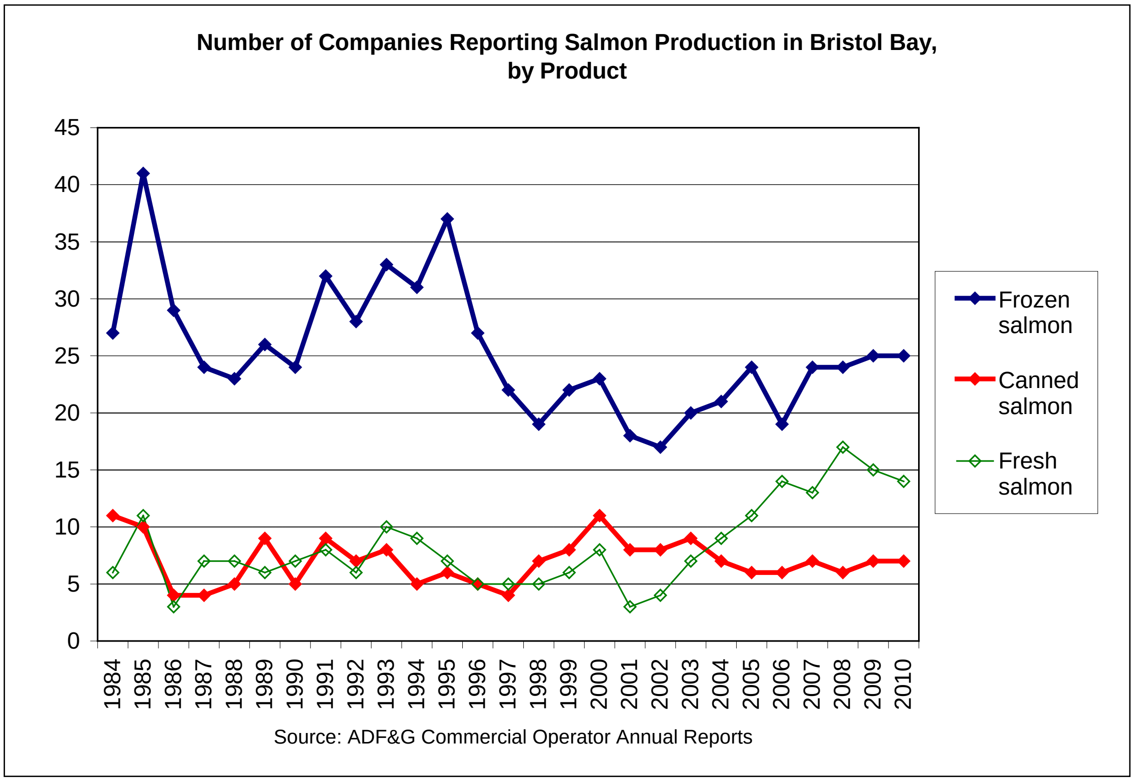


Figure 51. Number of Companies Reporting Salmon Production in Bristol Bay, by Product

Fish account for the largest share of costs of Bristol Bay processors. Other important costs include labor, fish tendering, packaging (boxes and cans), transportation of products and workers, utilities and taxes, maintenance, and costs of equipment and buildings.

Another important “cost” is the adjustment for the yield from the “round pound” weight of fish purchased from fishermen to the “processed pound” weight of fish products. In effect, for any given ex-vessel prices, the lower the yield, the higher the cost of fish per pound of final product weight.

Costs per pound vary between product forms and may also vary widely from year to year as fixed costs are spread over different volumes of salmon. Table 31 provides rough estimates of Bristol Bay salmon processing costs from an analysis for 1994 and 1995. Note that costs have likely risen considerably since these estimates were prepared, due to changes in costs of labor, energy and other factors. However, salmon ex vessel prices are highly variable and not directly tied to general changes in price levels. Therefore the Table 31 data is provided as a picture of two specific years, and not indexed to current price levels.

Table 31. Estimates of Bristol Bay Processor Costs, Prices and Profits

Estimates of Bristol Bay Processor Costs, Prices, and Profits: Mid-Range Estimates for 1994 and 1995

	Frozen Dressed		Frozen Round		Canned	
	1994	1995	1994	1995	1994	1995
Price paid to fishermen	$0.97	$0.75	$0.97	$0.75	$0.97	$0.75
+ Taxes and assessments	$0.03	$0.02	$0.03	$0.02	$0.03	$0.02
+ Tender cost	$0.17	$0.17	$0.17	$0.17	$0.17	$0.17
+ Costs of services to fishermen	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03
= Fish cost per round lb.	$1.20	$0.97	$1.20	$0.97	$1.20	$0.97
- Roe value per round lb. (= roe yeild x roe price)	$0.09	$0.09	$0.00	$0.00	$0.07	$0.07
= Fish cost per round lb., net of roe value	$1.11	$0.88	$1.20	$0.97	$1.13	$0.90
÷ Processing yield	74%	74%	97%	97%	59%	59%
= Fish cost per processed lb., net of roe value	$1.51	$1.20	$1.24	$1.00	$1.92	$1.53
+ Processing costs per processed lb.	$0.60	$0.60	$0.40	$0.40	$0.73	$0.73
+ Transportation and storage costs before sale	$0.00	$0.00	$0.00	$0.00	$0.10	$0.10
+ Other costs	$0.10	$0.10	$0.10	$0.10	$0.10	$0.10
= Processor's total cost	$2.21	$1.90	$1.74	$1.50	$2.85	$2.46
Average price received by processor	$2.45	$1.80	$2.20	$1.00	$2.71	$2.80
Profit or loss (= average price - total cost)						
per processed lb.	$0.24	-$0.10	$0.46	-$0.50	-$0.14	$0.34
per round lb.	$0.18	-$0.07	$0.45	-$0.49	-$0.08	$0.20

Note: Costs and prices can vary widely between processors. Any given processor's profits or lesses could be higher or lower than showin in this table.

Source: *Currents: A Journal of Salmon Market Trends*, University of Alaska Anchorage, Salmon Market Information Service, December 1995.

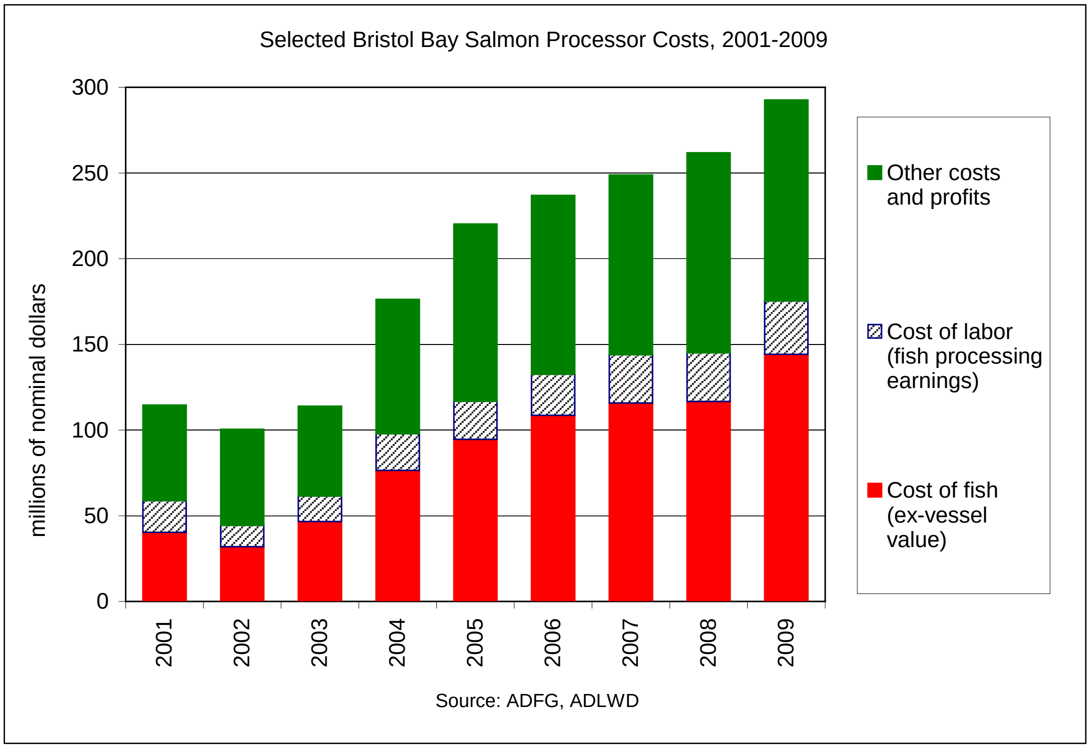


Figure 52. Selected Bristol Bay Salmon Processor Costs, 2001-2009

Most larger Bristol Bay salmon processors contract with tender vessels to transport salmon from fishing vessels at or near the best fishing areas to land-based or floating processing facilities. Tendering represents a significant cost for the industry. Many tender vessels are larger vessels used seasonally in other Alaska fisheries such as the Bering Sea crab fisheries. No data are available on the number of tender vessels used in the Bristol Bay fishery. A rough guess is that there are about fifty.

Fishermen delivering salmon to a tender. As fish are caught, they are placed in brailer bags in the hold of the fishing boat. Here, a brailer bag is being hoisted aboard a tender, where the fish are kept in refrigerated water during transport to the processor.

Photograph by Gabe Dunham

Fish are pumped from tenders into processing plants

Photograph by Gabe Dunham

Sockeye salmon entering a processing plant

Workers cleaning salmon

A processing line

Packaging is an important cost of fish processing

3.9 Bristol Bay Salmon Industry Employment

Challenges in Measuring Bristol Bay Salmon Industry Employment

Measuring employment in the Bristol Bay salmon industry is complicated by several factors. First, no employment data are collected for commercial fishing comparable to the employment data collected for most other industries. This is because commercial fishermen (both permit holders and crew) are considered self-employed, and they do not pay unemployment insurance. Employment data for most industries (including fish processing) are based on unemployment insurance reporting forms filed by employers. To make up for this significant gap in Alaska employment data, as discussed below, the Alaska Department of Labor and Workforce Development (ADLWD) Research and Analysis Division estimates monthly commercial fishing employment by multiplying the number of permits for which fish landings are reported each month by assumed average employment per permit fished (crew factors).

Second, the Bristol Bay salmon industry is highly seasonal. Most of the fishing and processing occurs between the middle of June and the middle of July, with smaller numbers of fishermen and processing workers engaged in smaller-scale fishing and processing as well as start-up and close-down activities earlier and later in the year. Thus a Bristol Bay fishing or processing job which typically lasts less than two months is not directly comparable to a year-round job in another industry. As discussed below, to provide a basis for comparing employment in the Bristol Bay salmon industry with year-round employment in other industries, we estimate "annual average employment," calculated as the total number of months worked divided by 12.

Third, the "Bristol Bay Region" for which ADLWD reports fish processing employment and estimated salmon fishing employment includes the Chignik salmon fishery—an important Alaska salmon fishery although much smaller than the Bristol Bay fishery. By way of comparison, between 2006 and 2010, expressed as a percentage of the Bristol Bay salmon fisheries, total pounds landed in the Chignik salmon fishery were 7.7% of Bristol Bay, earnings were 6.3% of Bristol Bay, and total permits fished were 2.4% of Bristol Bay. Thus ADLWD fish harvesting and processing employment estimates and data for the "Bristol Bay region" slightly overestimate employment for the Bristol Bay salmon fishery.

Fourth, estimates of fish processing employment are not available by fishery—because in reporting employment fish processing plants do not distinguish between the species of fish that their workers were processing during the reporting period. Thus fish processing employment estimates for the Bristol Bay region include some employment in processing other species such as herring. However, it is likely that fish processing employment data for the Bristol Bay region are overwhelmingly dominated by Bristol Bay salmon. For a comparison of the relative scale of the two fisheries, between 2006 and 2010, expressed as a percentage of the Bristol Bay salmon fisheries, total pounds landed in the Bristol Bay (Togiak) herring seine and gillnet fisheries 22.6% of pounds landed in the Bristol Bay salmon fisheries, earnings were 2.1% of earnings in the salmon fisheries, and the total permits fished were 2.6% of permits fished in the salmon fisheries. Note also that Bristol Bay herring processing is much less labor intensive than salmon processing because Bristol Bay herring are entirely frozen round for export.

Terminology for Measures of Employment

In the subsequent discussion, we use the following terms for different kinds of employment estimates:

Jobs:	The number of distinct work positions
Workers:	The number of different individuals who worked
Annual average employment	The number of months worked divided by 12

For example, suppose a permit holder fishes for two months with two crew members on board his boat. After one month one crew member leaves and is replaced by another crew member. The permit holder's operation would account for 3 jobs, 4 workers, and annual average employment of 0.5 (3 jobs x 2 months = 6 job months which is 6/12 or 0.5 job years).

Estimates of Bristol Bay Salmon Harvesting and Processing Employment

Table 32 (on the following page) summarizes available estimates of Bristol Bay salmon harvesting and processing employment from several different sources calculated in several different ways. Figure 53 (on the subsequent page) graphs several of the estimates shown in Table 32.

Estimated fishing jobs based on salmon permits fished (Rows 1-4)

A simple way to estimate Bristol Bay salmon fishing jobs is from Commercial Fisheries Entry Commission (CFEC) data for the number of permits fished and the Alaska Department of Labor and Workforce Development (ADLWD) assumption of three jobs for each drift gillnet and each setnet fishing operation.[16] Based on this methodology, between 2000 and 2010, the number of Bristol Bay salmon fishing jobs ranged between 5592 and 8232. The estimated number of jobs varied from year to year because the number of permits fished varied from year to year.

A problem with this method of estimating fishing jobs is that since the introduction of "permit stacking" in the drift gillnet fishery, there is no longer necessarily a direct relationship between the number of permits fished and the number of vessels fished. As discussed, the number of permits fished each year likely understates the number of permit holders who fished but likely overstates the number of vessels which fished (since some permit holders fished together on the same vessel).

CFEC reported that 1444 permits were fished in 2009, but only 1331 vessels were registered to fish during the season. This would imply that the number of permits fished overstated that number of vessels fished by 113, which would in turn imply that the estimates in Row 4 overstate the number of fishing jobs by 339. For the same reason, the estimates in rows 6 and 9-12 of Table 32 (discussed below) may also slightly overestimate the number of fishing workers.

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[16] According to a table of crew factors provided to Gunnar Knapp by ADLWD in 2004 (crewfactor.xls), ADLWD assumed crew factors of 3.0 for both the Bristol Bay drift gillnet and set gillnet fisheries.

Table 32. Indicators and Estimates of Bristol Bay Salmon Industry Fishing Processing Employment

Indicators and Estimates of Bristol Bay Salmon Industry Fishing and Processing Employment, 2000-2010

Measure	Row	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Estimated fishing jobs based on salmon permits fished (a)												
Permits fished, drift gillnet fishery	1	1,823	1,566	1,184	1,424	1,411	1,447	1,475	1,468	1,469	1,444	1,494
Permits fished, set gillnet fishery	2	921	834	680	761	795	829	844	835	850	843	861
Permits fished, total	3	2,744	2,400	1,864	2,185	2,206	2,276	2,319	2,303	2,319	2,287	2,355
Estimated number of fishing jobs (= permits fished x 3 jobs/permit fished)	4	8,232	7,200	5,592	6,555	6,618	6,828	6,957	6,909	6,957	6,861	7,065
ADLWD estimates of Bristol Bay region salmon fishing workers (b)												
Individuals who fished permits	5		2,412	1,867	2,196	2,210	2,286	2,340	2,239	2,245	2,309	
Total estimated workforce	6		6,969	5,334	6,324	6,294	6,444	7,020	6,717	6,735	9,236	
Ratio of estimated workforce to individuals who fished permits	7		2.89	2.86	2.88	2.85	2.82	3.00	3.00	3.00	4.00	
Estimated crew workers	8		4,557	3,467	4,128	4,084	4,158	4,680	4,478	4,490	6,927	
ADLWD estimates of Bristol Bay region salmon fishing workers by month (c)												
June	9		6,771	4,830	6,045	6,093	6,135	6,201	5,982	6,060	6,393	
July	10		7,098	5,514	6,465	6,513	6,750	6,936	6,891	6,969	6,768	
August	11		276	309	249	375	279	540	444	504	504	
September	12		0	0	0	84	15	3	0	12	54	
Bristol Bay region fish processing workers, all species (d)												
Total worker count	13		2,862	2,273	2,484	3,474	3,272	2,940	3,512	3,952	4,522	
Bristol Bay region food manufacturing employment (e)												
July	14			2,414	3,026	4,189	3,946	4,391	4,480			
Annual average	15			765	992	1,139	1,147	1,339	1,385			
Assumed total salmon industry workers												
Fishing (July employment) (Row 10)	16		7,098	5,514	6,465	6,513	6,750	6,936	6,891	6,969	6,768	
Processing (total worker count) (Row 13)	17		2,862	2,273	2,484	3,474	3,272	2,940	3,512	3,952	4,522	
Total	18		9,960	7,787	8,949	9,987	10,022	9,876	10,403	10,921	11,290	
Estimated annual average salmon industry employment												
Fishing (= total months of employment / 12)	19		1,179	888	1,063	1,089	1,098	1,140	1,110	1,129	1,143	
Fish processing (f)	20		475	366	409	581	532	483	566	640	764	
Total	21		1,654	1,254	1,472	1,669	1,631	1,623	1,675	1,769	1,907	

Sources and notes: (a) CFEC Salmon Basic Information Tables, http://www.cfec.state.ak.us/bit/MNUSALM.htm; (b) ADLWD, "Fish Harvesting Workforce and Gross Earnings by Species, 2001 - 2009," http://www.labor.state.ak.us/research/seafood/BristolBay/BBFHVWrkrErngSpec.pdf. Estimated crew workers= Total estimated workforce - Individuals who fished permits. (c) ADLWD, "Fish Harvesting Employment by Species and Month, 2000-2009, Bristol Bay Region," http://labor.alaska.gov/research/seafood/BristolBay/BBAvgMonthlyRegSpc.pdf; (d) ADLWD, "Bristol Bay Region Seafood Industry, 2003-2009, Processing," http://labor.alaska.gov/research/seafood/BristolBay/BBSFPOver.pdf. 2001 & 2002 data are earlier estimates formerly posted at the same website; (e) ADLWD, Quarterly Census of Employment and Wages Data, http://labor.alaska.gov/research/qcew/qcew.htm; (f) annual average fish processing employment estimated by assuming the same ratio of annual average employment to total worker count as the ratio of estimated annual average fishing employment to July fishing employment.

ADLWD estimates of Bristol Bay region salmon fishing workers (rows 5-8)

These are ADLWD estimates of the salmon harvesting workforce (number of workers) in the Bristol Bay region for the years 2001-2009.[17] Note that these include workers in the Chignik salmon fishery. The total estimated workforce (row 6) was estimated by multiplying the number

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[17] The estimates are posted at http://labor.alaska.gov/research/seafood/BristolBay/BBFHVWrkrErngSpec.pdf. A discussion of the methodology used to prepare the estimates is posted on the ADLWD website at:

of individuals who fished permits (row 5) by assumed crew factors for each fishery.[18] We calculated estimated crew workers (row 8) by subtracting individuals who fished permits (Row 5) from the total estimated workforce (row 6).

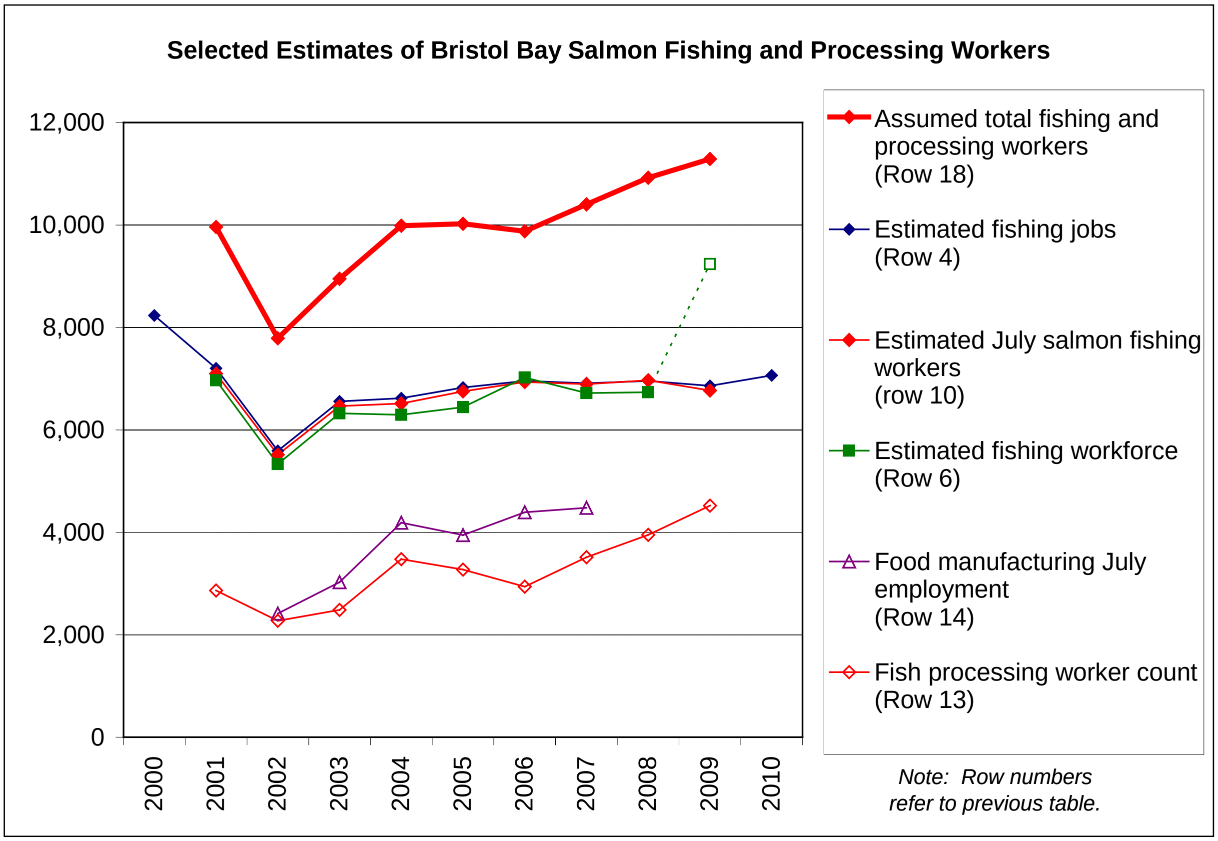

Figure 53. Selected Estimates of Bristol Bay Salmon Fishing and Processing Workers

<u>ADLWD estimates of Bristol Bay region salmon fishing workers by month (Rows 9-12)</u>

These are ADLWD estimates of the salmon harvesting workforce (number of workers) by month in the Bristol Bay region for the years 2001-2009.[19] The methodology used for these estimates

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http://labor.alaska.gov/research/seafood/Methodology.pdf. Additional discussion of the methodology is provided in Josh Warren and Rob Kreiger, “Fish Harvesting in Alaska (Alaska Economic Trends, November 2011); Josh Warren and Jeff Hadland, “Employment in Alaska’s Seafood Industry” (Alaska Economic Trends, November 2009); and Paul Olson and Dan Robinson, “Employment in the Alaska Fisheries: A special project estimates fish harvesting jobs” (Alaska Economic Trends, December 2004), These articles are posted on the ADLWD website at http://labor.alaska.gov/trends/.

[18] No documentation was provided as to what crew factors were used for these estimates. The ratio of estimated workforce to individuals who fished permits (Row 7) suggests that crew factors of 3.0 were used for the years 2006-2009. It is not clear why the ratio was lower for the years 2001-2005 (between 2.82-2.89) and much higher for 2009 (4.00), suggesting that different crew factors were used for these years. The estimate for 2009, based on a 25% higher crew factor of 4.0, is indicated with a dashed line in Figure 53.

[19] The estimates are posted at http://labor.alaska.gov/research/seafood/BristolBay/BBAvgMonthlyRegSpc.pdf.

was similar but not identical to that used to for the estimates of salmon fishing workers in rows 5-8), resulting in slightly higher estimates.[20]

Bristol Bay region fish processing workers, all species (Row 13)

These are ADLWD estimates of the total worker count for Bristol Bay region seafood processing.[21, 22]

Bristol Bay region food manufacturing employment (Rows 14 & 15)

These are the sum of ADLWD data for food manufacturing employment in Bristol Bay Borough, Lake and Peninsula Borough, and the Dillingham Census Area (the ADLWD's Bristol Bay region).[23] Table 33 provides the same detail in more detail, by month. Presumably, almost all food manufacturing in the Bristol Bay region is fish processing. It is not clear why the July food manufacturing employment (Row 14) is considerably larger than the total worker count for fish processing for the same region (Row 13).

Assumed total salmon industry workers (Rows 14 & 15)

For the purposes of this report, we assume that the total number of workers in the Bristol Bay salmon industry is July salmon fishing workers (Row 10) and the ADLWD total worker count (Row 13). The inconsistencies between the different estimates discussed above suggest that while these should be considered reasonable indicators of the general magnitude of the number rather than precise data. In general, it appears reasonable to assume that in recent years the total number of workers in Bristol Bay salmon fishing and processing has exceeded 10,000.

Estimated annual average salmon industry employment (Rows 19-21)

These are estimates of salmon industry annual average employment, or job months / 12. Again, these should be considered reasonable indicators of the general magnitude of annual average employment rather than precisely accurate data. In general, it appears reasonable to assume that in recent years average annual employment in Bristol Bay salmon fishing and processing has exceeded 1600.

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[20] According to notes provided with the estimates, for these estimates ". . . the permit itself is considered the employer. In other tables where a count of workers was estimated, the employer was considered to be the vessel, or permit holders for fisheries that did not typically use vessels. This means that a permit holder who makes landings under two different permits (in the same vessel) in the same month will generate two sets of jobs whereas for tables where the vessel is the employer there would be only one set of workers."

[21] The data are posted at http://labor.alaska.gov/research/seafood/BristolBay/BBSFPOver.pdf.

[22] The only information about how the data source or methodology is the following: "The Alaska Department of Labor and Workforce Development's Occupational Database (ODB) is the primary source of seafood processing employment data. The ODB contains quarterly information for all Alaska workers covered by unemployment insurance (UI)." (http://labor.alaska.gov/research/seafood/Methodology.pdf).

[23] Quarterly Census of Employment and Wages Data posted at http://labor.alaska.gov/research/qcew/qcew.htm.

Seasonality of Bristol Bay Fish Processing Employment

ADLWD monthly data for Bristol Bay food manufacturing employment provide an indication of the seasonality and geographic distribution of Bristol Bay salmon processing (Figure 54 and Table 33). Presumably salmon processing accounts for most but not all of Bristol Bay region food manufacturing employment. One indicator of this is that for the years 2001-2009, the total fish *harvesting* workforce for other fisheries for which ADLWD reported Bristol Bay region harvesting workforce estimates, expressed as a percentage of the salmon harvesting workforce estimates, averaged 5.5% for herring, 2.1% for halibut and 0.4% for sablefish.[24]

Bristol Bay region food manufacturing employment peaks in July, and is generally much higher during the months from May through September than at other times in the year. Note that a significant part of the work in fish processing occurs before the season starts (getting ready for processing) and after the season ends (closing down processing operations and preparing for the next season). Some people are employed throughout the year in activities such as plant maintenance and repair.

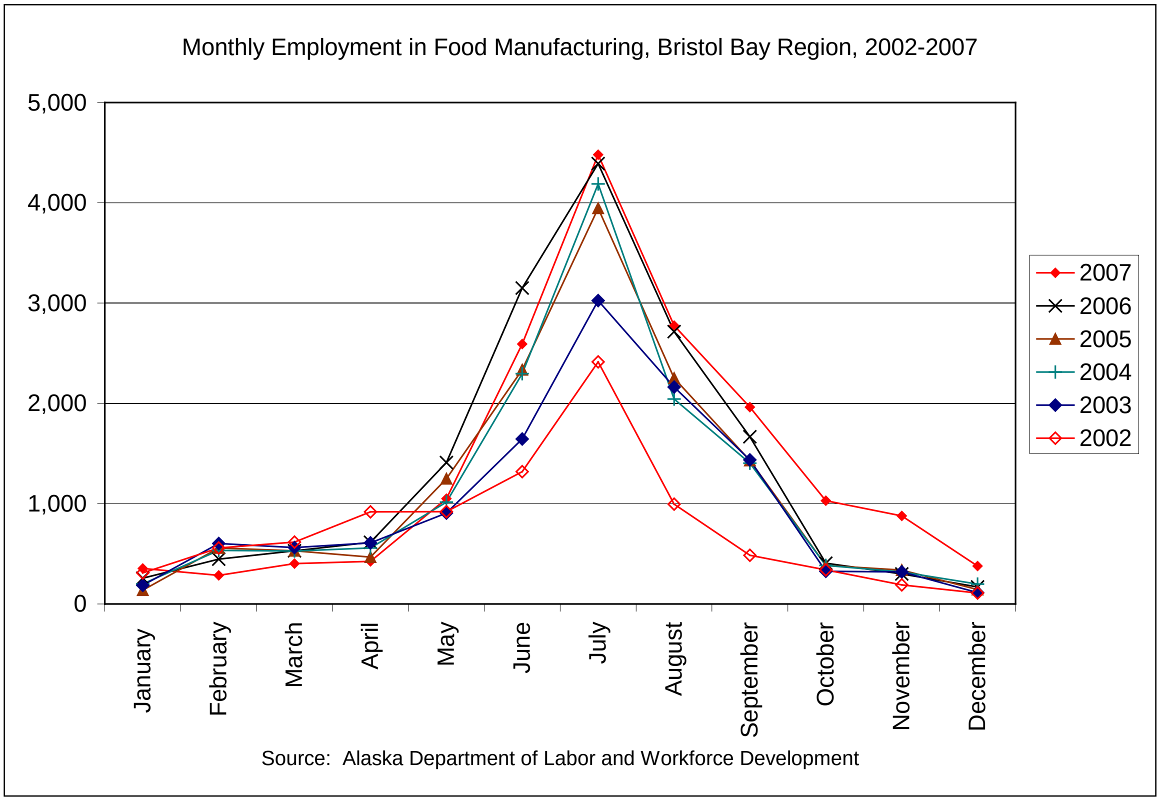

Figure 54. Monthly Employment in Food Manufacturing, Bristol Bay Region

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[24] ADLWD, "Fish Harvesting Workforce and Gross Earnings by Species, 2001-2009, Bristol Bay Region," http://labor.alaska.gov/research/seafood/BristolBay/BBFHVWrkrErngSpec.pdf.

Table 33. Monthly Employment in Food Manufacturing, by Borough or Census Area.

Monthly Employment in Food Manaufacturing, by Borough or Census Area, Bristol Bay Region, 2002-2010

Area	Month	2002	2003	2004	2005	2006	2007	2008	2009	2010
Bristol Bay Borough	*Units reporting*	*8*	*9*	*11*	*14*	*11*	*11*	*10*	*12*	*12*
	January	7	52	11	11	14	12			16
	February	8	56	10	12	13	11			19
	March	8	57	21	19	25	19			27
	April	441	197	81	81	113	73			96
	May	495	464	678	818	894	651			977
	June	713	1,115	1,299	1,365	1,957	1,635			1,819
	July	977	1,915	2,644	2,663	2,898	3,018			3,489
	August	325	1,291	1,250	1,424	1,471	1,661			1,738
	September	51	728	834	847	789	826			914
	October	42	41	46	68	61	671			92
	November	29	49	59	72	74	504			66
	December	34	22	46	51	53	188			59
	Average	**261**	**499**	**582**	**619**	**697**	**772**			**776**
Dillingham Census Area	*Units reporting*	*4*	*3*	*3*	*4*	*4*	*3*	*3*	*3*	*3*
	January	283	124	184	123	232	332			
	February	529	512	519	543	418	259			
	March	590	495	496	507	487	366			
	April	455	373	451	377	477	326			
	May	372	390	285	392	455	338			
	June	384	339	739	799	951	760			
	July	1,091	775	1,035	1,057	1,164	1,162			
	August	392	544	544	694	987	901			
	September	347	618	552	567	789	1,040			
	October	283	270	331	306	305	293			
	November	149	260	253	257	199	315			
	December	48	84	147	82	97	167			
	Average	**410**	**399**	**461**	**475**	**547**	**522**			
Lake and Peninsula Borough	*Units reporting*	*7*	*5*	*5*	*4*	*4*	*4*	*4*	*3*	*3*
	January	20	10	5	4	11	10	9		
	February	21	34	5	4	17	15	15		
	March	19	11	11	5	19	17	16		
	April	23	40	27	9	26	25	29		
	May	53	53	52	38	62	61	69		
	June	222	191	258	171	242	197	156		
	July	346	336	510	226	329	300	319		
	August	278	329	250	135	258	215	24		
	September	87	90	18	17	89	97	20		
	October	15	14	8	11	41	66	5		
	November	13	10	7	9	27	59	5		
	December	28	8	6	10	20	24	5		
	Average	**94**	**94**	**96**	**53**	**95**	**91**	**56**		
Total, Bristol Bay Region	Units reporting	*19*	*17*	*19*	*22*	*19*	*18*	*17*	*18*	*18*
	January	310	186	200	138	257	354	9		
	February	558	602	534	559	448	285	15		
	March	617	563	528	531	531	402	16		
	April	919	610	559	467	616	424	29		
	May	920	907	1,015	1,248	1,411	1,050	69		
	June	1,319	1,645	2,296	2,335	3,150	2,592	156		
	July	2,414	3,026	4,189	3,946	4,391	4,480	319		
	August	995	2,164	2,044	2,253	2,716	2,777	24		
	September	485	1,436	1,404	1,431	1,667	1,963	20		
	October	340	325	385	385	407	1,030	5		
	November	191	319	319	338	300	878	5		
	December	110	114	199	143	170	379	5		
	Average	**765**	**992**	**1,139**	**1,147**	**1,339**	**1,385**	**56**		

Source: Alaska Department of Labor and Workforce Development, Quarterly Census of Employment and Wages Data, historical data for 2002-2010, Excel file annual.xls, http://labor.alaska.gov/research/qcew/qcew.htm, downloaded November 27, 2011. Blank cells indicate data were not available.

3.10 Bristol Bay Salmon Industry Taxes

The Bristol Bay salmon industry pays millions of dollars annually in state, local and federal taxes. This section briefly describes these taxes and provides estimates, where available, of taxes paid in recent years.

Alaska Fisheries Business Tax

The Alaska Fisheries Business Tax (AS 43.75.015) accounts for the largest share of local and state taxes paid by the Bristol Bay salmon industry. Under the fisheries business tax, salmon processors pay the state:

> 5.0% of the ex-vessel value of salmon processed on floating facilities
>
> 4.5% of the ex-vessel value of salmon canned at shore-based facilities
>
> 3.0% of the ex-vessel value of other salmon processed at shore-based facilities
> (e.g. salmon processed frozen, fresh, or in other ways except for canning)

The State of Alaska does not publish data on fisheries business tax revenues for specific species and regions. Rows 1-4 of Table 34 provide a lower-bound estimate of tax obligations (before credits) of Bristol Bay salmon processors, assuming that processors pay a tax rate of 5.0% for a share of ex-vessel value equivalent to the share of canned salmon production in total Bristol Bay salmon production, and 3.0% of ex-vessel value on the remaining share of ex-vessel value. This estimate suggests that during the period 2000-2010, fisheries business tax obligations ranged from as low as $1.3 million in 2002 to $6.4 million. Fisheries business tax payments are directly proportional to ex-vessel value and thus highly sensitive to the effects of changes in catches and prices on ex-vessel value.

Actual tax obligations are likely higher than the lower-bound estimates in Row 4, since (a) the estimates do not take account of the higher tax rate (5.0%) on salmon processed on floating processing; and (b) the share of salmon which is canned is likely higher than the share of canned production in total production, because average yields are lower for canning.

Processors are entitled to credits against Fisheries Business Tax obligations up to certain limits for certain kinds of expenditures, including for example investments in salmon product development (AS 43.75.035); investments to improve salmon utilization (AS 43.75.036), and and contributions to the University of Alaska and other Alaska higher education institutions (AS 43.75.018). No data are available on the extent to which these tax credits reduce Bristol Bay fisheries business tax revenues.

Table 34. Selected Data and Estimates for Bristol Bay Salmon Taxes

Selected Data and Estimates for Bristol Bay Salmon Taxes

	Row	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Simple lower-bound estimate of fisheries business tax obligations												
Ex-vessel value of Bristol Bay salmon harvests ($ 000)	1	$84,014	$40,359	$31,898	$46,684	$76,461	$94,556	$108,570	$115,763	$116,717	$144,200	$180,818
Canned share (assumed tax rate = 5.0%)	2	37%	32%	49%	39%	34%	32%	34%	35%	28%	25%	27%
Non-canned share (assumed tax rate = 3%)	3	63%	68%	51%	61%	66%	68%	66%	65%	72%	75%	73%
Lower-bound estimate of fisheries tax obligation ($ 000)	4	$3,145	$1,467	$1,270	$1,760	$2,818	$3,439	$3,998	$4,287	$4,163	$5,061	$6,383
State of Alaska Shared Business Tax Payments to Bristol Bay Boroughs and Cities ($ 000) (a)												
Bristol Bay Borough	5	$1,440	$918	$494	NA	$451	$835	$1,178	$1,296	$1,564	$1,543	$1,797
Lake and Peninsula Borough	6	$357	$246	$162	NA	$113	$71	$99	$134	$138	$152	$215
Dillingham	7	$203	$176	$49	NA	$100	$154	$148	$184	$176	$187	$239
Egegik	8	$30	$176	$78	NA	$36	$29	$29	$74	$63	$63	$85
Total	9	$2,029	$1,517	$784	NA	$700	$1,089	$1,454	$1,687	$1,941	$1,944	$2,335

(a) Source: Alaska Department of Revenue, Annual Shared Taxes and Fees Reports, www.tax.alaska.gov. NA: Not available.

Fisheries Business Tax Refunds

The State of Alaska "refunds" a major share of Fisheries Business Tax revenues to Alaska local governments, as follows (AS 43.75.130):

> Cities receive 50% of the tax revenues collected in unified municipalities and in cities outside organized boroughs, and 25% of tax revenues collected in cities in organized boroughs
>
> Boroughs receive 50% of the tax revenues collected in areas of boroughs outside cities and 25% of the tax revenues collected in cities inside Boroughs.

Rows 5-9 of Table X-1 provide data on State of Alaska shared fisheries tax payments to Bristol Bay boroughs and cities. In total, these payments ranged from $700 thousand in 2004 to $2.3 million in 2010.

Local Government Taxes

Several local governments in the Bristol Bay region impose taxes on the ex-vessel value of salmon processed within their jurisdictions. In 2010, these included the following:[25]

Bristol Bay Borough: 4% fish taxEgegik: 3%
raw fish tax
Lake and Peninsula Borough: 2% raw fish tax
Pilot Point: 3% raw fish tax

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[25] Alaska Office of the State Assessor, 2010 Alaska Taxable, Table 2, Sales/Special Taxes and Revenues, http://www.dced.state.ak.us/dca/osa/osa_summary.cfm.

Local governments also impose property taxes on processing facilities. No data are published on Bristol Bay local government fish taxes or property taxes. However, it is likely that these taxes are comparable in magnitude to fisheries business taxes, and represent a major share of total local government tax revenues.

Federal Government Taxes

Like all U.S. industries, the Bristol Bay salmon industry pays federal taxes including corporate and individual income taxes paid by processing companies, processing workers, and fishermen. No data are available on federal taxes specifically attributable to the Bristol Bay salmon industry, although it is likely that they significantly exceed total taxes paid to the state and local governments.

3.11 Regional Distribution of Bristol Bay Permit Holders, Fishery Earnings, and Processing Employment

An important characteristic of the Bristol Bay commercial salmon industry is that shares of the participants in the industry—both fishermen and processing workers—do not live in the Bristol Bay region but rather in other parts of Alaska or other states and countries. In this section we review available data on trends in the regional distribution of permit holdings, earnings and processing employment between “local” residents of the Bristol Bay region, other Alaskans, and non-Alaskans.

The Bristol Bay Region

There are twenty-six communities in the Bristol Bay region the Commercial Fisheries Entry Commission (CFEC) considers “local” to the fishery for its analyses (Figure 55). Residents of these villages are considered “Bristol Bay residents” for the CFEC data presented below on permit holdings and earnings of Bristol Bay residents.

Residents of five additional villages on the south side of the Alaska Peninsula (Chignik City, Chignik Lagoon, Chignik Lake, Perryville and Ivanof) are also considered “Bristol Bay residents” for the Alaska Department of Labor and Workforce Development (ADLWD) data on seafood processing employment.

Figure 55. Bristol Bay Region Local Communities ***Source: www.visitbristolbay.org/bbvc/images/bb_map_large.jpg***

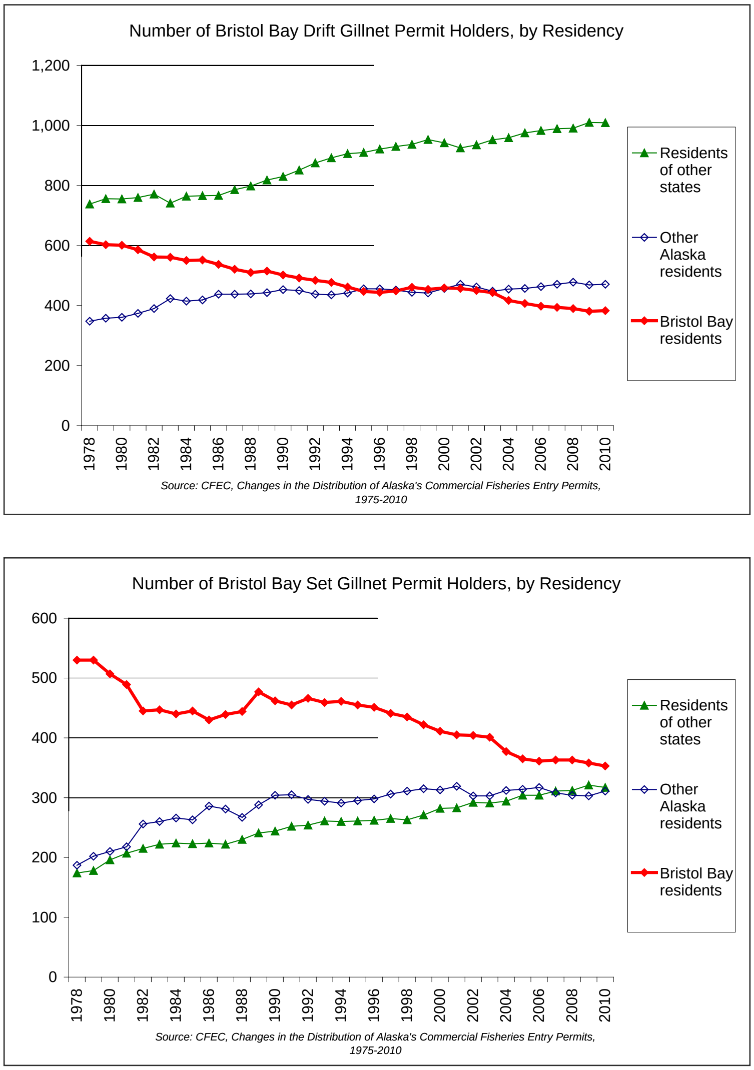
Regional Distribution of Permit Holders

Limited entry was implemented for most Alaska salmon fisheries in 1975, including the Bristol Bay drift gillnet and set gillnet fisheries. The permits were initially issued for free to individuals based on their degree of economic dependence upon the fishery and the extent of their past participation in the fishery. The purpose and effect of this initial allocation system was to ensure that significant numbers of rural local residents received permits in regions of Alaska with limited other economic opportunities, such as Bristol Bay (Knapp, 2011).

Soon after the implementation of limited entry a significant long-term decline began in the share of permits held by local residents in the Bristol Bay fisheries and many other rural Alaska fisheries. There has been a corresponding increase in the number of permits held by other Alaska residents as well as non-Alaska residents. This decline in local permits has been an important concern at both the regional and state level.

Between 1978 and 2010, the number of permits Bristol Bay drift gillnet permits held by local residents fell from 614 to 383 (Figure 56). The share of drift gillnet permits held by local residents fell from 36% to 21%.

Between 1978 and 2010, the number of permits Bristol Bay set gillnet permits held by local residents fell from 530 to 353. The share of permits held by local residents fell from 59% to 36%.



Number of Bristol Bay Drift Gillnet Permit Holders, by Residency

Source: CFEC, Changes in the Distribution of Alaska's Commercial Fisheries Entry Permits, 1975-2010

Number of Bristol Bay Set Gillnet Permit Holders, by Residency

Source: CFEC, Changes in the Distribution of Alaska's Commercial Fisheries Entry Permits, 1975-2010

Figure 56. Number of Bristol Bay Permit Holders by Residency

The decline in local permit ownership has come about as a result of both net permit transfers (sales and gifts) from residents of the region to non-local residents, as well as migration of permit holders out of the region. Initially net permit transfers played a far greater role, but migration of permit holders out of the region has also played an important role in recent years.

Regional Distribution of Fishery Earnings

Historically, Bristol Bay residents have had the lowest average earnings (gross revenues) per permit fished, while residents of other stages have had had the highest average earnings per permit fished.

For example, in 2007—the latest year for which CFEC earnings data by residency are available, in the Bristol Bay drift gillnet fishery, average earnings per permit fished were $44,604 for Bristol Bay residents, $66,191 for other Alaska residents, and $73,391 for non-Alaska residents (Figure 57).

In the Bristol Bay set gillnet fishery, average earnings per permit fished were $22,991 for Bristol Bay residents, $23,259 for other Alaska residents, and $25,333 for non-Alaska residents (Figure 57).

A variety of factors may contribute to these differences in average earnings per permit fished by residency. In the drift gillnet fishery, the vessels operated by Bristol Bay residents tend to be older and smaller, with lower average horsepower and fuel capacity than those of other Alaska residents or residents of other states (Table 35). A much smaller share of the vessels operated by Bristol Bay residents have refrigeration capacity. All of these differences may reflect less access to capital for Bristol Bay residents than for other Alaska residents or residents of other states. However, the reasons for differences in earnings between groups have not been studied in detail or conclusively explained.

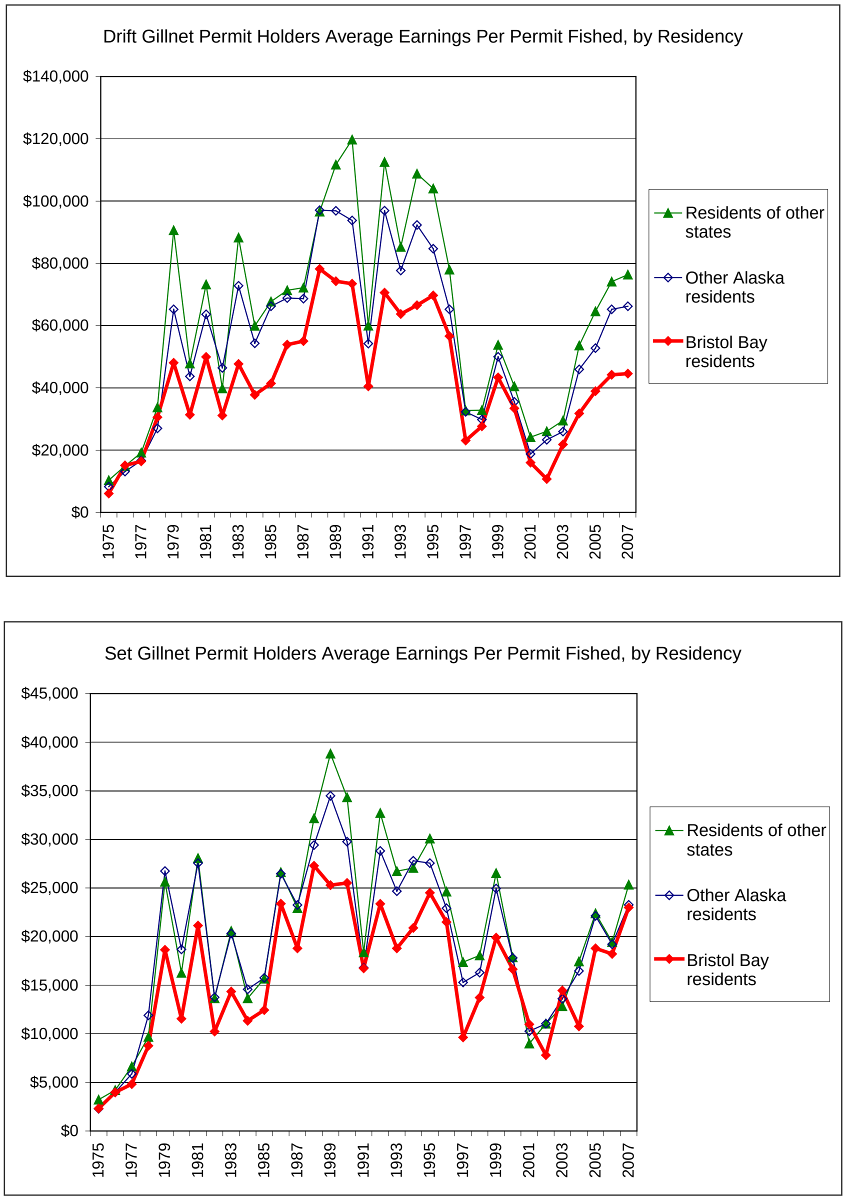


Figure 57. Permit Holders Average Earnings, by Residency

Table 35. Comparison of Vessels Used in the Bristol Bay Drift Gillnet Fishery, by Residency of Permit Holder

Comparison of Vessels Used in the Bristol Bay Drift Gillnet Fishery, by Residency of Permit Holder

	Group	1983	1988	1993	1998	2003	2008
Average age of vessels (years)	Bristol Bay Residents	9	11	14	18	22	26
	Other Alaska Residents	9	11	14	17	21	24
	Residents of Other States	11	12	13	16	20	24
	Average	10	11	14	17	21	25
Average horsepower of vessels	Bristol Bay Residents	239	279	282	294	287	337
	Other Alaska Residents	243	271	315	345	350	373
	Residents of Other States	252	286	335	368	372	382
	Average	245	278	311	336	336	364
Average displacement of vessels (gross tons)	Bristol Bay Residents	10	12	12	12	12	12
	Other Alaska Residents	12	13	13	13	14	15
	Residents of Other States	12	12	13	14	14	14
	Average	11	12	13	13	13	14
Average fuel capacity of vessels (gallons)	Bristol Bay Residents	239	288	282	294	287	299
	Other Alaska Residents	306	334	364	357	357	360
	Residents of Other States	283	311	348	352	350	364
	Average	276	311	331	335	331	341
Percent of vessels with refrigeration capacity	Bristol Bay Residents	0.5%	0.5%	2.3%	4.5%	5.5%	7.7%
	Other Alaska Residents	1.3%	2.3%	7.5%	13.7%	15.3%	20.8%
	Residents of Other States	0.5%	2.0%	8.1%	15.5%	17.8%	22.2%
	Average	0.8%	1.6%	6.0%	11.2%	12.9%	16.9%

Northern Economics. 2009. The Importance of the Bristol Bay Salmon Fisheries to the Region and its Residents. Report prepared for the Bristol Bay Economic Development Corporation. 193 pages. Data are from tables on pages 136 and 137 of report. Based on data provided by the Commercial Fisheries Entry Commission.

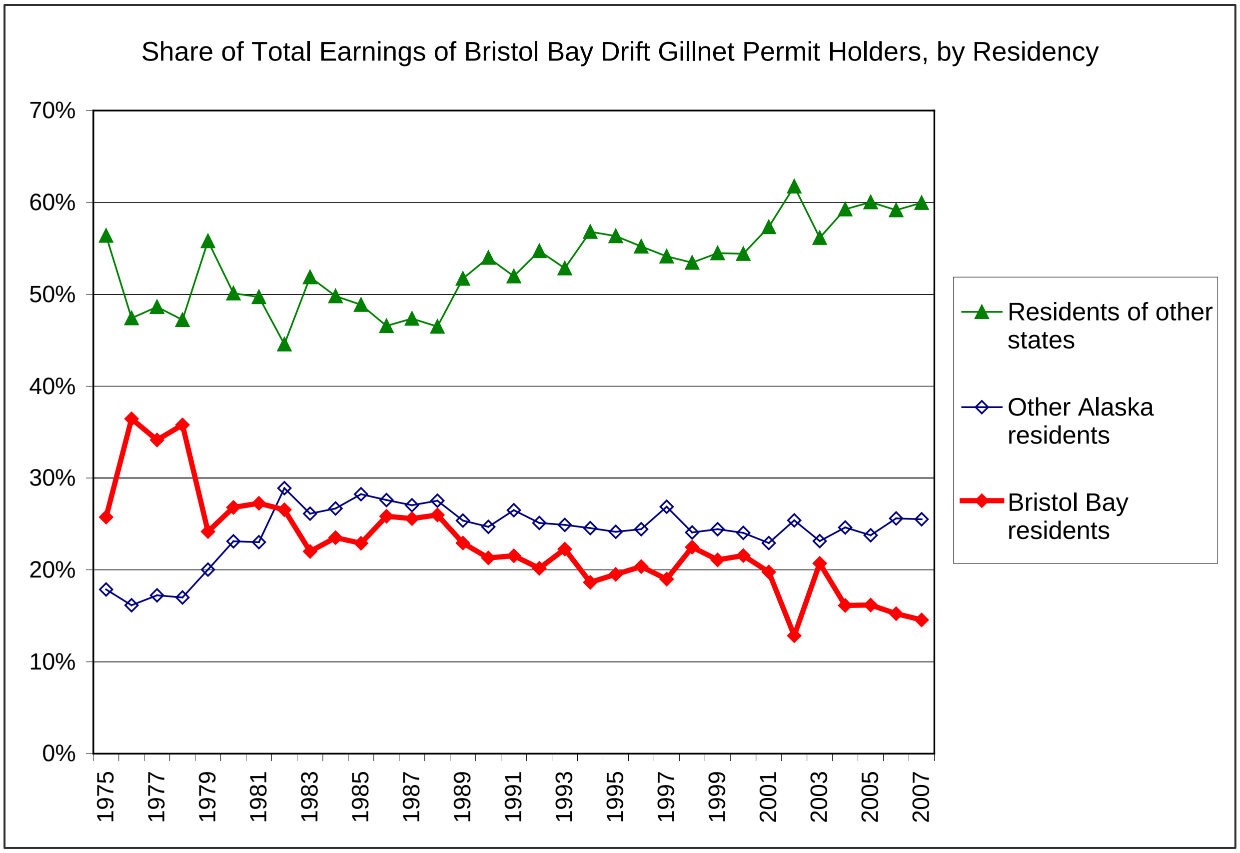


Figure 58. Share of Total Earnings of Bristol Bay Drift Gillnet Permit Holders, by Residency

Trends over time in the share of different groups in total earnings of Bristol Bay permit holders represent the combined effects of trends over time in each group's share of permit holdings as well as differences between groups in average earnings. In the drift gillnet fishery, the share of Bristol residents in total earnings fell from about 35% in the late 1970s to just 15% in 2007. The share of non-Alaska residents increased from less than 50% in the late 1970s to 60% in 2007 (Figure 58).

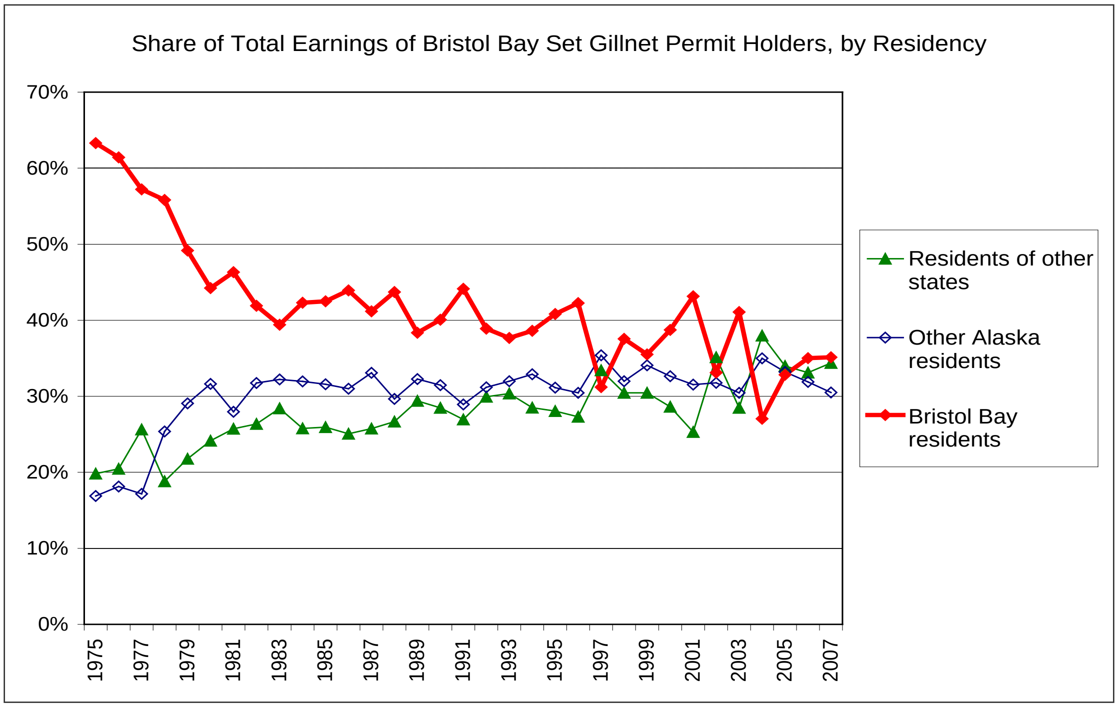


Figure 59. Share of Total Earnings of Bristol Bay Set Gillnet Permit Holders, by Residency

In the set gillnet fishery, the share of Bristol residents in total earnings fell from about 63% in the late 1970s to 35% in 2007. The share of non-Alaska residents increased from about 20% in the late 1970s to 34% in 2007 (Figure 59).

Regional Distribution of Processing Employment

Employment in Bristol Bay seafood processing is overwhelmingly dominated by residents of other states and countries. In 2009, according to Alaska Department of Labor and Workforce Development data, Bristol Bay residents accounted for less than 2% of Bristol Bay processing workers, and other Alaska residents accounted for only 12%. Residents of other states and countries accounted for 87%. (Processing employment data by residency are only available for the years 2004-2009).(Figure 59).

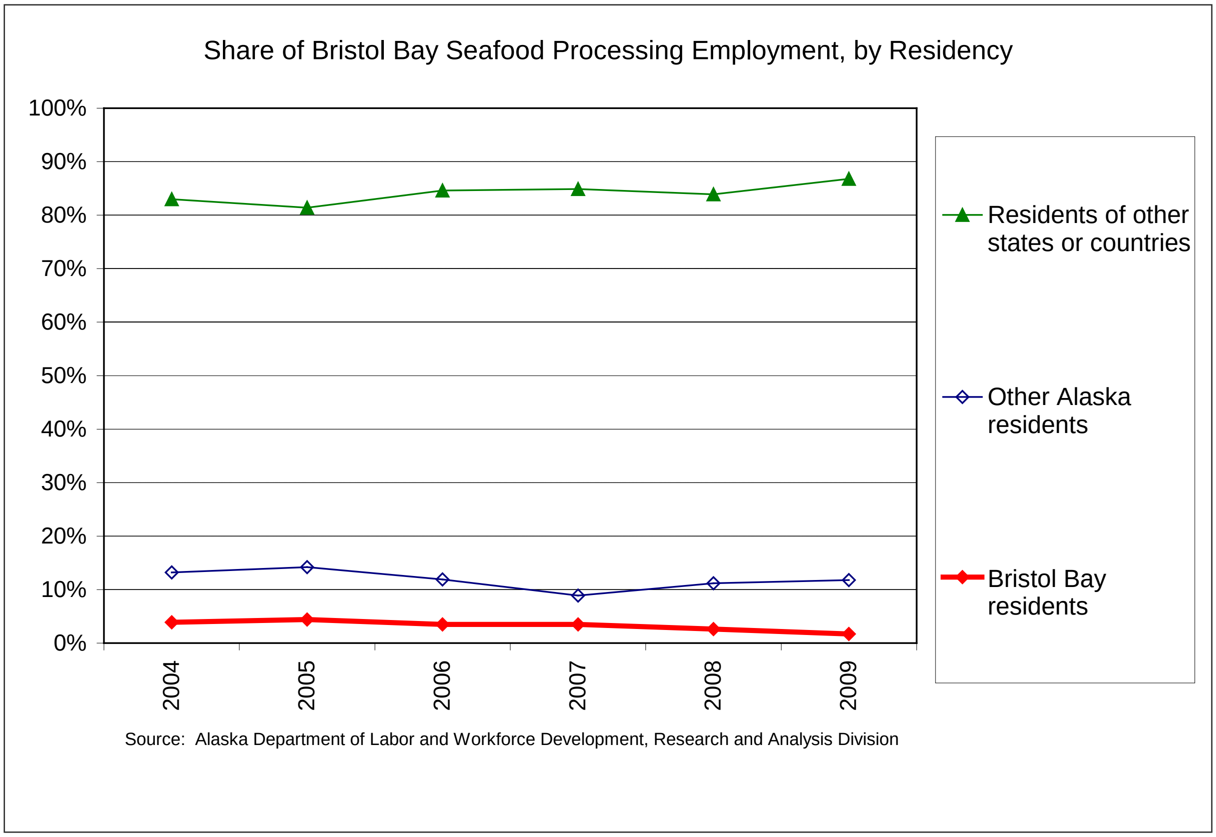
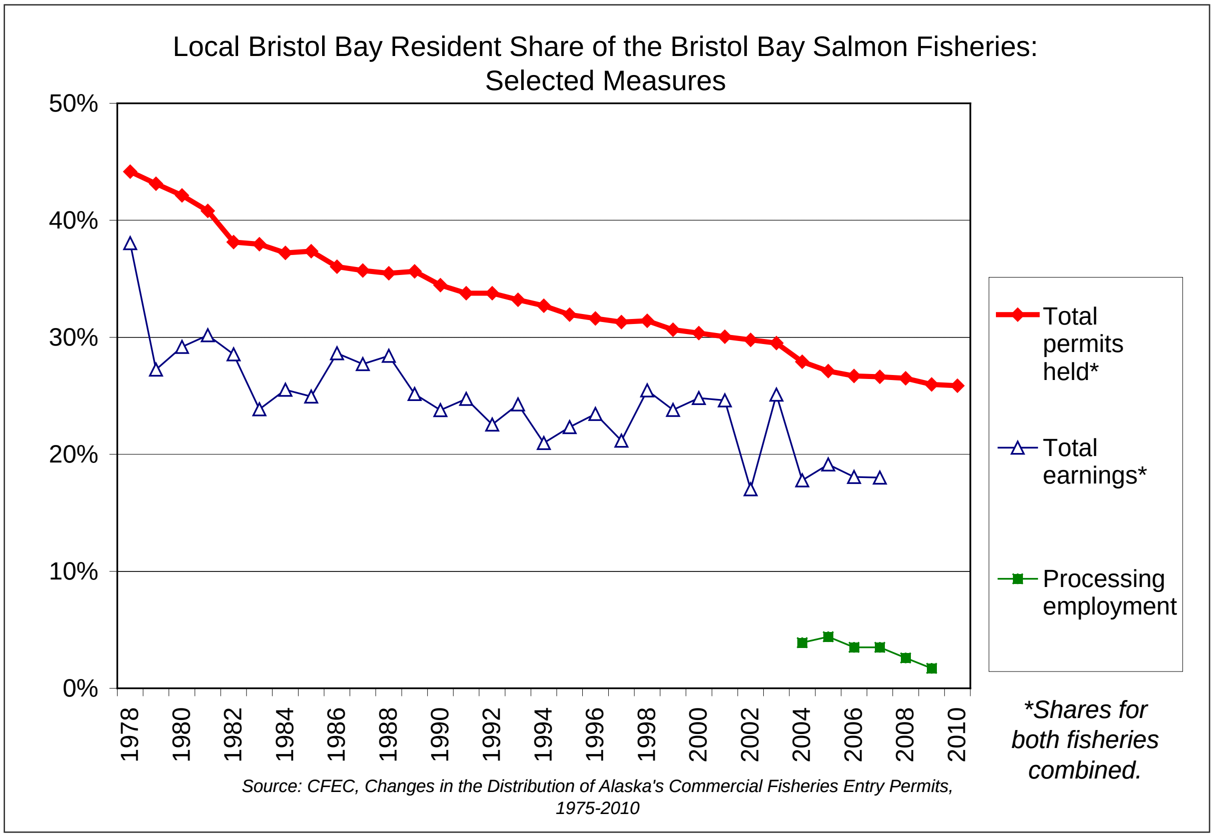


Figure 60. Share of Bristol Bay Seafood Processing Employment, by Residency

A Primarily Non-Local Fishery—With Widely Distributed Benefits

As is clear from the preceding figures, local residents account for a relatively small and declining share of the jobs and earnings in the Bristol Bay salmon industry (Figure 61). In contrast, non-Alaska residents account for relatively large and growing share of the jobs and earnings.



Source: CFEC, Changes in the Distribution of Alaska's Commercial Fisheries Entry Permits, 1975-2010

Figure 61. Local Bristol Bay Resident Share of Salmon Fisheries: Selected Measures

This does not mean, of course, that the Bristol Bay salmon fishery is unimportant as a source of jobs or income for local residents. As we discuss in greater detail previously, it remains very important. However, it is not as important for local residents as it might appear if one were to erroneously assume that all the jobs were held by local residents and all the income was earned by local residents.

Bristol Bay processing worker from Turkey

A different perspective is that the Bristol Bay fishery is not just economically important for a remote region of southwestern Alaska. Rather, it is of major economic importance for other parts of Alaska and other states, particularly the Pacific Northwest. Thousands of residents of other parts of Alaska and other states work in and earn significant income from participating in Bristol Bay fishing and processing. For example, as shown in Table 36, in 2010, 597 residents of other parts of Alaska, 656 residents of Washington, 125 residents of Oregon and 119 residents of California fished Bristol Bay salmon permits. They had gross earnings of $40 million (other Alaskans), $59 million (Washington residents), $10 million (Oregon residents, and $9.5 million (California residents).

Table 36. Participation and Gross Earnings in Bristol Bay Salmon Fisheries

Participation and Gross Earnings in Bristol Bay Salmon Fisheries, by Group, 2010

	Number of Fishermen Who Fished*			Estimated Gross Earnings ($1000)		
Group	Drift gillnet fishery	Set gillnet fishery	Total	Drift gillnet fishery	Set gillnet fishery	Total
Bristol Bay Residents, Total	**301**	**297**	**598**	**18,250**	**10,670**	**28,920**
Dillingham Census Area	202	183	385	11,170	6,451	17,620
Bristol Bay Borough	56	83	139	4,227	3,162	7,389
Lake and Peninsula Borough	43	31	74	2,854	1,057	3,911
Other Alaska Residents, Total	**359**	**238**	**597**	**31,215**	**8,858**	**40,074**
Anchorage	86	120	206	6,479	4,288	10,767
Kenai Peninsula Borough	86	44	130	7,968	1,685	9,652
Matanuska-Susitna Borough	38	42	80	3,593	1,504	5,097
Wrangell-Petersburg Census Area	18		18	2,445	0	2,445
Kodiak Island Borough	42	9	51	3,951	321	4,272
Other parts of Alaska	89	23	112	6,780	1,061	7,841
Alaska Residents, Total	**660**	**535**	**1195**	**49,466**	**19,528**	**68,994**
Other States and Countries, Total	**850**	**281**	**1131**	**84,671**	**11,494**	**96,165**
Washington	538	118	656	55,342	4,179	59,521
Oregon	87	39	126	8,383	1,618	10,001
California	87	32	119	8,058	1,449	9,507
Other States & Countries	138	92	230	12,888	4,249	17,136
TOTAL	**1510**	**816**	**2326**	**134,137**	**31,022**	**165,159**

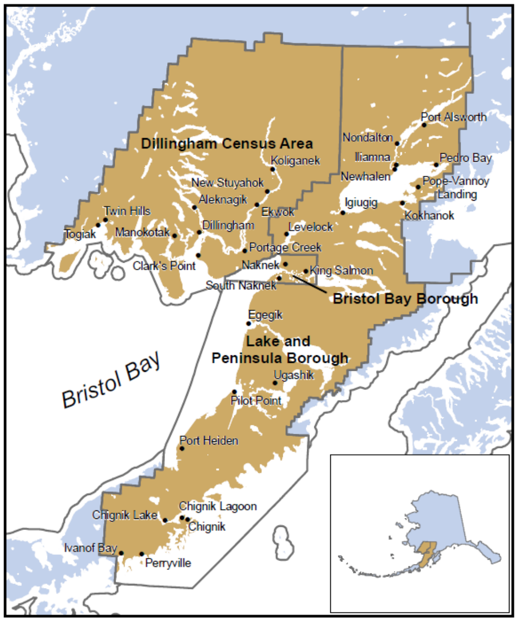
*Number of fishermen who made at least one landing as a permit holder.

Source: Commercial Fisheries Entry Commission, Fishery Participation and Earnings Statistics, 2010: http://www.cfec.state.ak.us/gpbycen/2010/mnu.htm.

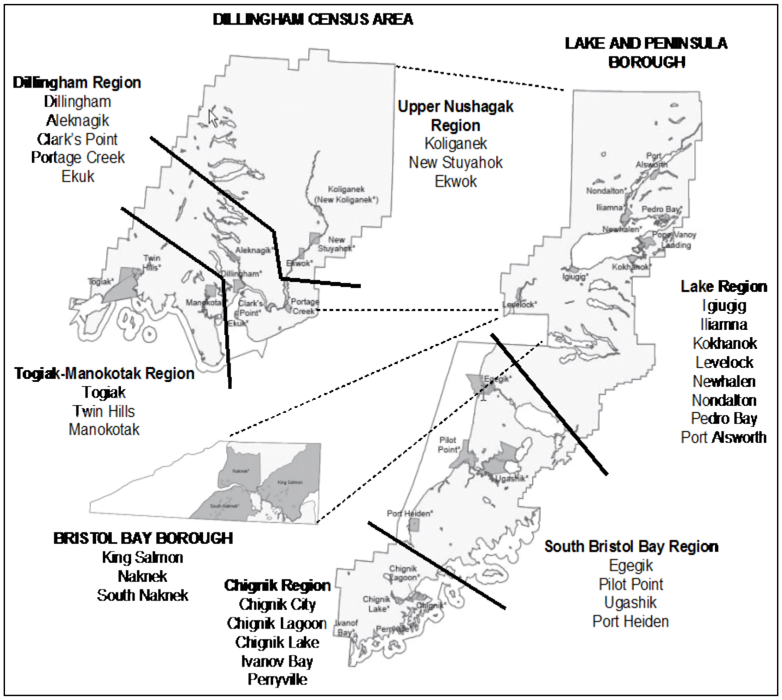
3.12 Distribution of Salmon Permits and Earnings within The Bristol Bay Region

Above, we discussed the distribution of Bristol Bay salmon permits and earnings between local residents of the Bristol Bay region and residents of other parts of Alaska and other states. In this section, we discuss the distribution of permits and earnings within the Bristol Bay region.

For this analysis, we used the Commercial Fisheries Entry Commission (CFEC) definition of the Bristol Bay region as the twenty-six communities within the Bristol Bay watershed. For the analysis in this section, we use the Alaska Department of Labor and Workforce Development (ADLWD) definition of the Bristol Bay region as the Bristol Bay Borough, the Lake and Peninsula Borough, and the Dillingham Census Area. The ADLWD definition is slightly larger because it includes five communities outside the Bristol Bay watershed (Chignik City, Chignik Lagoon, Chignik Lake, Perryville and Ivanof).



Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section



We further divide the Bristol Bay region into seven smaller regions, consisting of the groups of communities:

Bristol Bay Borough
Dillingham Region
Togiak-Manokotak Region
Upper Nushagak Region
Lake Region
South Bristol Bay Region
Chignik Region

We omit the Chignik Region from the figures because residents of the region have very little involvement with the Bristol Bay fishery.

Table 37 summarizes population, numbers of permit holders, and salmon fishery earnings for each community and region in 2000 and 2010. These data were used to calculate per capita permit holdings and earnings shown in Table 38 and Table 39. We used similar data to calculate Figure 62 through Figure 69 which show trends by region over time.

Table 37. Population, Permit Holders, and Salmon Earnings, by Community: 2000 & 2010

Population, Salmon Permit Holders, and Bristol Bay Salmon Earnings, by Community, 2000 & 2010

	Population		Drift gillnet permit holders		Set gillnet permit holders		Resident drift gillnet earnings ($000)		Resident set gillnet earnings ($000)	
	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010
BRISTOL BAY BOROUGH	**1257**	**997**	**63**	**63**	**117**	**101**	**$1,939**	**$4,227**	**$1,506**	**$3,162**
King Salmon	442	374	14	15	17	17	$589	$1,209	$291	$749
Naknek	678	544	37	38	70	69	$1,120	$2,695	$920	$2,184
South Naknek	137	79	12	10	30	15	$230	$323	$295	$229
DILLINGHAM CENSUS AREA	**4,922**	**4,847**	**326**	**262**	**231**	**199**	**$10,287**	**$10,913**	**$3,901**	**$6,246**
Dillingham Region	**2800**	**2614**	**167**	**142**	**115**	**97**	**$6,284**	**$6,855**	**$2,005**	**$3,032**
Aleknagik	221	219	19	15	9	6	$530	$752	$131	$174
Clarks Point	75	62	8	7	5	4	$329	$0	$68	$117
Dillingham	2,466	2,329	139	120	101	87	$5,425	$6,103	$1,806	$2,742
Ekuk	2	2	0	0	0	0	-	-	-	-
Portage Creek	36	2	1	0	0	0	-	-	-	-
Togiak-Manokotak Region	**1277**	**1333**	**107**	**80**	**106**	**97**	**$2,918**	**$3,222**	**$1,811**	**$3,213**
Manokotak	399	442	28	24	44	35	$847	$696	$646	$1,547
Togiak	809	817	72	53	60	62	$2,071	$2,526	$1,165	$1,666
Twin Hills	69	74	7	3	2	0	$0	$0	$0	$0
Upper Nushagak Region	**783**	**834**	**52**	**40**	**10**	**5**	**$1,084**	**$836**	**$85**	**$0**
Ekwok	130	115	5	3	0	0	$117	-	-	-
Koliganek	182	209	14	16	3	2	$300	$456	-	-
New Stuyahok	471	510	33	21	7	3	$667	$380	$85	-
LAKE AND PEN. BOROUGH	**1,823**	**1,631**	**86**	**57**	**64**	**45**	**$1,454**	**$2,018**	**$436**	**$599**
Lake Region	**986**	**953**	**36**	**28**	**32**	**27**	**$371**	**$865**	**$109**	**$499**
Igiugig	53	50	4	3	0	1	-	-	-	-
Iliamna	102	109	8	9	7	6	$116	$450	$51	$215
Kokhanok	174	170	4	3	4	6	$76	$0	$0	$143
Levelock	122	69	8	4	6	2	$130	$189	$0	$0
Newhalen	160	190	6	6	2	4	$49	$226	$0	$141
Nondalton	221	164	4	2	8	4	-	-	$57	-
Pedro Bay	50	42	1	0	2	3	-	-	-	-
Port Alsworth	104	159	1	1	3	1	-	-	-	-
South Bristol Bay Region	**346**	**291**	**49**	**28**	**31**	**17**	**$1,083**	**$1,152**	**$328**	**$100**
Egegik	116	109	23	10	15	7	$494	$468	$222	$100
Pilot Point	100	68	9	8	11	5	$232	$0	$106	$0
Port Heiden	119	102	15	8	3	3	$357	$684	$0	$0
Ugashik	11	12	2	2	2	2	-	-	-	-
Chignik Region	**456**	**362**	**1**	**1**	**1**	**1**	**-**	**-**	**-**	**-**
Chignik	79	91	0	0	0	0	-	-	-	-
Chignik Lagoon	103	78	0	0	0	0	-	-	-	-
Chignik Lake	145	73	1	1	1	1	-	-	-	-
Ivanof Bay	22	7	0	0	0	0	-	-	-	-
Perryville	107	113	0	0	0	0	-	-	-	-
BRISTOL BAY, TOTAL (a)	**8003**	**7475**	**475**	**382**	**412**	**345**	**$13,679**	**$17,158**	**$5,843**	**$10,007**
BRISTOL BAY, TOTAL (b)	**7547**	**7113**	**474**	**381**	**411**	**344**	**$13,679**	**$17,158**	**$5,843**	**$10,007**

(a) Total includes the Chignik Region; (b) Total excludes the Chignik Region. Note: "-" indicates that earnings data were confidential and not reported. Sources: U.S. Censuses, 2000 and 2010; CFEC.

Bristol Bay Population Trends

Figure 62 and Figure 63 show population trends for the Bristol Bay region. Note that the population data should be considered estimates rather than precise data. They are based on the decennial United States censuses conducted in 1980, 1990, 2000 and 2010, and were estimated for intervening years by the Alaska Department of Labor and Workforce Development. In addition, given the seasonality of the Bristol Bay area employment and the fact that much of the workforce is non-resident, it is difficult to define or measure population precisely. It is most useful to focus on long-term population trends and relative populations of different regions rather than short-term changes which may result from changes in how the data were estimated rather than actual population changes.

In general, the population of the Bristol Bay area increased rapidly during the 1980s, grew more slowly during the 1990s, and declined gradually during the 2000s. The total 2010 population was about 7500.

Of the six regions within the Bristol Bay area (excluding Chignik) the Dillingham Region has by far the largest population and the south Bristol Bay region has by far the smallest.

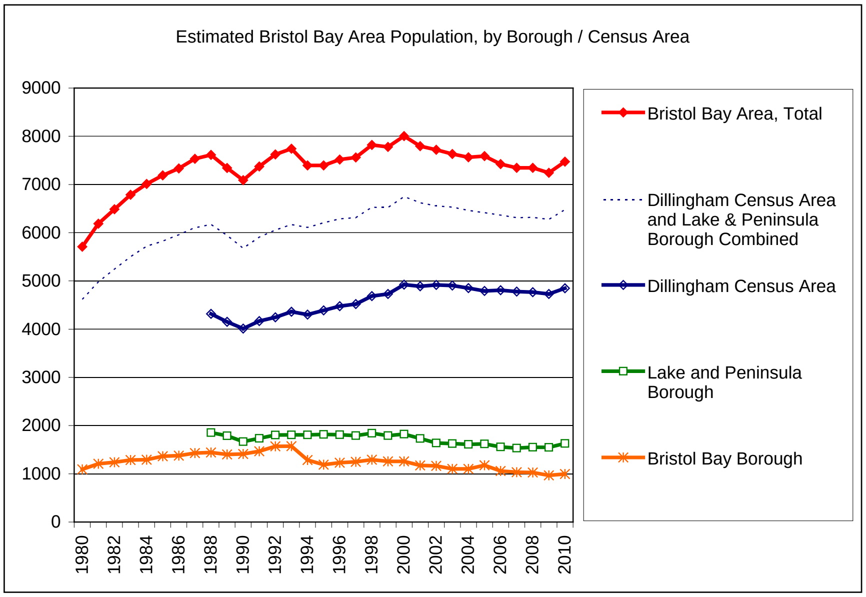


Figure 62. Estimated Bristol Bay Area Population, by Area

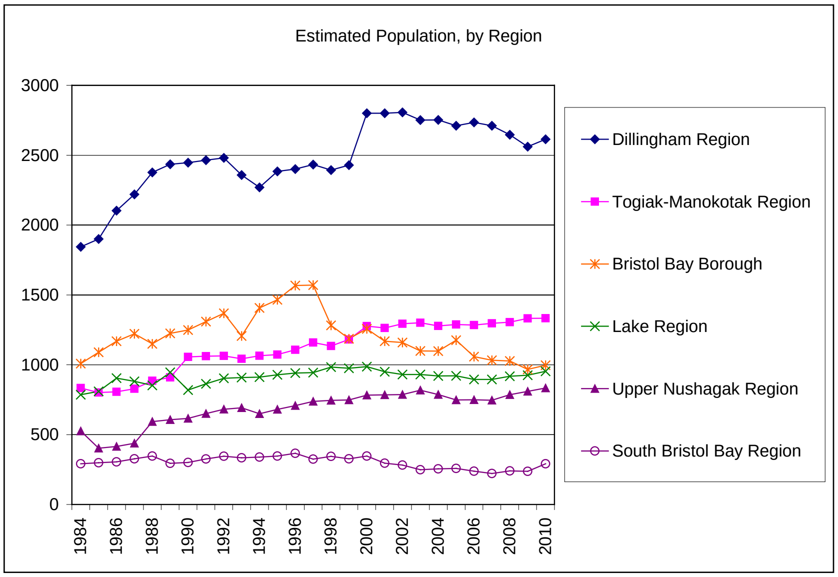


Figure 63. Estimated Population by Region

Permit Holders

Figure 64 shows the number of drift gillnet permit holders by region for the years 1984-2010. The number is highest for the Dillingham Region, followed by the Togiak-Manokotak Region. The number of drift gillnet permit holders has declined in all regions since 1984. The rate of decline has been somewhat less for the Bristol Bay Borough, particularly since 2000.

Figure 65 shows number of drift gillnet permit holders per 100 residents, by region. This measure is equal to per capita permit holdings multiplied by 100.
By adjusting for differences in population over time and between regions, it provides a way of comparing the relative degree of participation by residents in the drift gillnet fishery over time and between regions.

Because the Bristol Bay population is currently higher than it was in the early 1980s, permit holdings per 100 residents have declined relatively more sharply than total permit holdings, and have fallen by about half since 1984 in all regions except the Bristol Bay Borough.

In 2010, the number of permit holders per 100 residents was highest in the South Bristol Bay Region (10) and lowest in the Lake Region (3). Thus the degree of participation in the drift gillnet fishery varies between these regions by

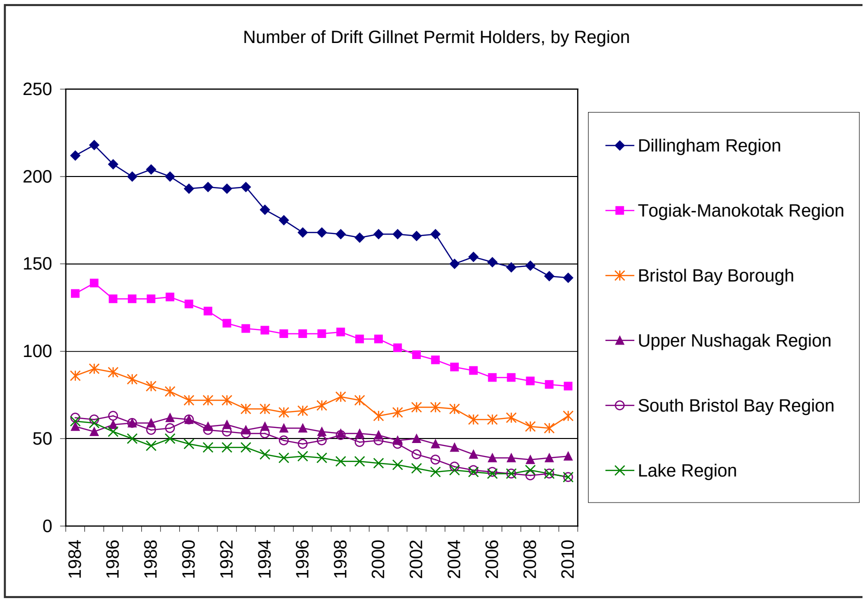


Figure 64. Number of Drift Gillnet Holders, by Region

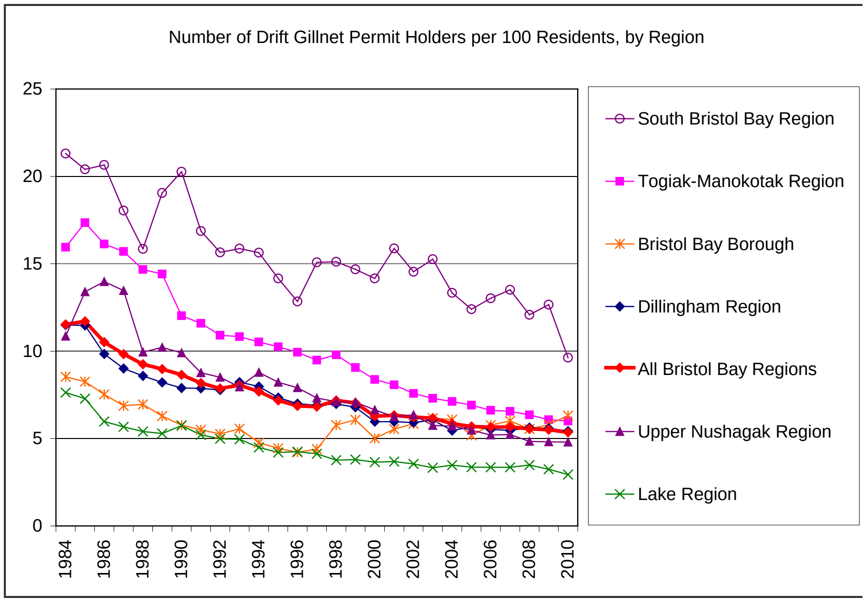


Figure 65. Number of Drift Gillnet Holders per 100 Residents, by Region

a factor of 3.

Figure 66 shows the number of set gillnet permit holders by region for the years 1984-2010. The number is highest for the Bristol Bay Borough, Togiak-Manokotak Region, and Dillingham Region, and is much lower for the other three regions. Since 1984, the number of set gillnet permit holders has declined in four regions (Bristol Bay Borough, Dillingham Region, Lake Region, and South Bristol Bay Region). However, the declines have generally not been as steep as the declines in the number of drift gillnet permit holders. The number of set gillnet permit holders has stayed about the same in the Togiak-Manokotak Region. It is very small in the Upper Nushagak Region.

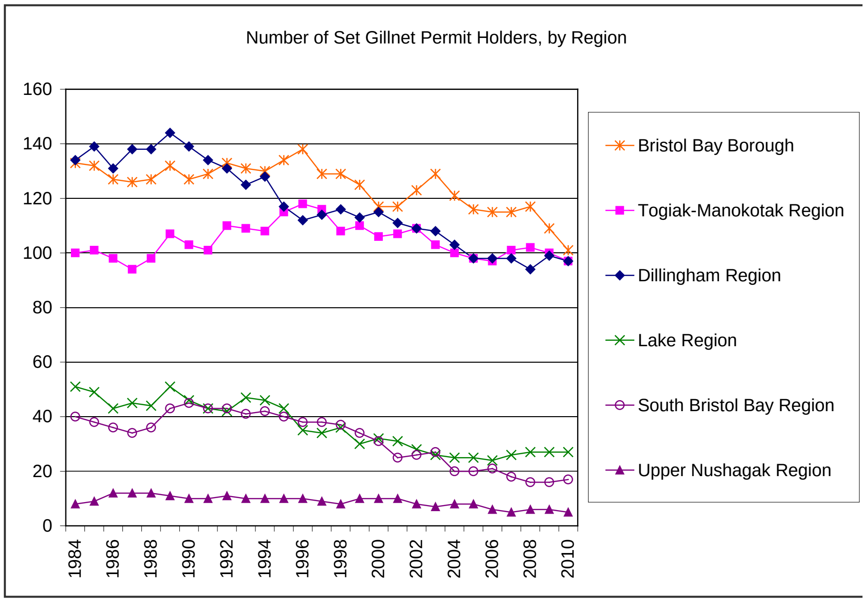


Figure 66. Number of Set Gillnet Holders, by Region

Figure 67 shows number of set gillnet permit holders per 100 residents, by region. In general, the number of set gillnet permit holders per 100 residents has trended downward in all regions except for the Bristol Bay Borough.

There is wide variation between regions in the degree of participation in the set gillnet fishery, from as high as 10 permit holders per 100 residents in the Bristol Bay Borough to as low as 1 in the Upper Nushagak Region.

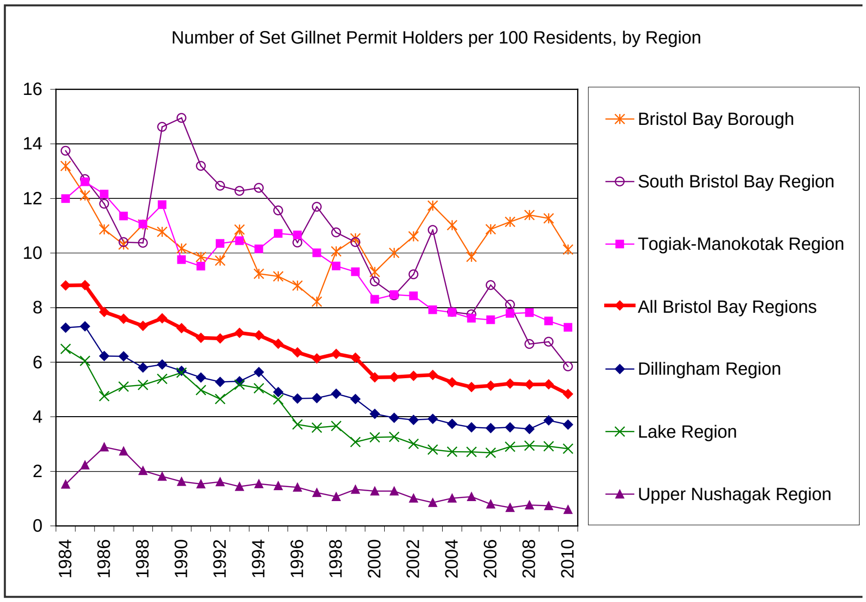


Figure 67. Number of Set Gillnet Permit Holders per 100 Residents, by Region

Just as there is wide variation between regions in the numbers of permit holders per 100 residents, there is also wide variation between individual communities within regions and within the Bristol Bay watershed as a whole (Table 38). In 2010, some communities, such as Ekwok and Nondalton, had fewer than 5 permit holders (drift and set gillnet combined) per 100 residents. Others communities, such as Naknek and South Naknek, had 20 or more.

Table 38. Salmon Permit Holders per 100 Residents, by Community

Salmon Permit Holders Per Hundred Residents, by Community, 2000 & 2010

	Drift gillnet permit holders per hundred residents		Set gillnet permit holders per hundred residents		Total permit holders per hundred residents	
	2000	2010	2000	2010	2000	2010
BRISTOL BAY BOROUGH	**5**	**6**	**9**	**10**	**14**	**16**
King Salmon	3	4	4	5	7	9
Naknek	5	7	10	13	16	20
South Naknek	9	13	22	19	31	32
DILLINGHAM CENSUS AREA	**7**	**5**	**5**	**4**	**11**	**10**
Dillingham Region	**6**	**5**	**4**	**4**	**10**	**9**
Aleknagik	9	7	4	3	13	10
Clarks Point	11	11	7	6	17	18
Dillingham	6	5	4	4	10	9
Ekuk	0	0	0	0	0	0
Portage Creek	3	0	0	0	3	0
Togiak-Manokotak Region	**8**	**6**	**8**	**7**	**17**	**13**
Manokotak	7	5	11	8	18	13
Togiak	9	6	7	8	16	14
Twin Hills	10	4	3	0	13	4
Upper Nushagak Region	**7**	**5**	**1**	**1**	**8**	**5**
Ekwok	4	3	0	0	4	3
Koliganek	8	8	2	1	9	9
New Stuyahok	7	4	1	1	8	5
LAKE AND PEN. BOROUGH	**5**	**3**	**4**	**3**	**8**	**6**
Lake Region	**4**	**3**	**3**	**3**	**7**	**6**
Igiugig	8	6	0	2	8	8
Iliamna	8	8	7	6	15	14
Kokhanok	2	2	2	4	5	5
Levelock	7	6	5	3	11	9
Newhalen	4	3	1	2	5	5
Nondalton	2	1	4	2	5	4
Pedro Bay	2	0	4	7	6	7
Port Alsworth	1	1	3	1	4	1
South Bristol Bay Region	**14**	**10**	**9**	**6**	**23**	**15**
Egegik	20	9	13	6	33	16
Pilot Point	9	12	11	7	20	19
Port Heiden	13	8	3	3	15	11
Ugashik	18	17	18	17	36	33
Chignik Region	**0**	**0**	**0**	**0**	**0**	**1**
Chignik	0	0	0	0	0	0
Chignik Lagoon	0	0	0	0	0	0
Chignik Lake	1	1	1	1	1	3
Ivanof Bay	0	0	0	0	0	0
Perryville	0	0	0	0	0	0
BRISTOL BAY, TOTAL (a)	**6**	**5**	**5**	**5**	**11**	**10**
BRISTOL BAY, TOTAL (b)	**6**	**5**	**5**	**5**	**12**	**10**

(a) Total includes the Chignik Region; (b) Total excludes the Chignik Region. Sources: U.S. Censuses, 2000 and 2010; CFEC.

Salmon Fishery Earnings

Figure 68 and Figure 69 show total and per capita salmon fishery earnings for Bristol Bay regions. Note that trends in fishery earnings for each region, as well as differences between regions, reflect the combined effects of three factors: (1) trends in overall catches, prices and value of the fishery; (2) trends in the number of permit holders in each region; and (3) trends in average catch shares of permit holders within each region.

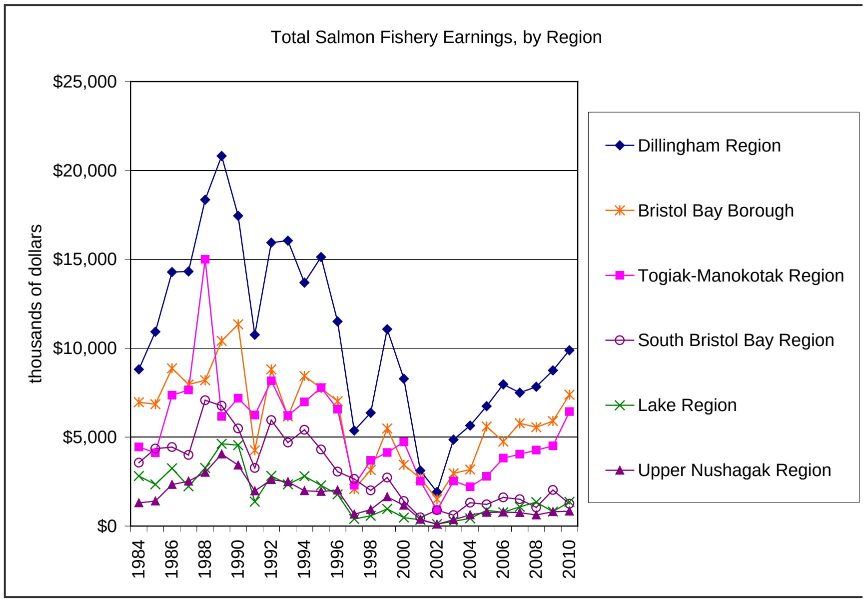


Figure 68. Total Salmon Fishery Earnings, by Region

The combined effect of the decline in total value of the fishery as well as a decline in the number of permit holders was a dramatic decline in salmon fishery earnings and per capita earnings for all regions between the late 1990s and 2002. Note that this effect would appear even more dramatic if adjusted for the inflation which occurred during this period of time.

Between 2002 and 2010, both earnings and per capita earnings have recovered significantly in all regions. However, except for the Bristol Bay Borough, per capita earnings were well below the levels of the 1980s, particularly for the Lake Region and Upper Nughagak Region.

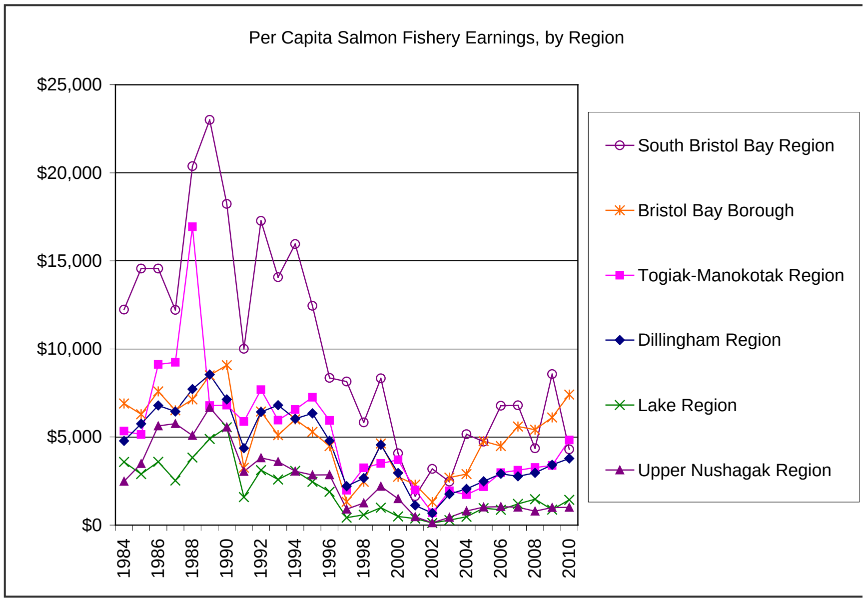


Figure 69. Per Capita Salmon Fisheries Earnings, by Region

Just as there is wide variation between regions in per capita salmon fishery earnings, there is also wide variation between individual communities within regions and within the Bristol Bay watershed as a whole

(Table 39). In 2010, per capita salmon fishery earnings in some communities, such as Kokhanok and Newhalen, were less than $2000. Presumably they were much lower in other communities, such as Nondalton and Ekwok, for which earnings data were confidential due to the small number of permit holders. In other communities, such as Naknek, South Naknek, Iliamna and Port Heiden, they per capita earnings exceeded $6000. Thus there is clearly wide variation within the Bristol Bay watershed in the extent to which communities and regions participate in and benefit economically from Bristol Bay salmon fisheries.

Table 39. Bristol Bay Salmon Fishery Earnings, by Community

Bristol Bay Salmon Fishery Per Capita Earnings, by Community, 2000 and 2010

	Drift gillnet fishery per capita earnings		Set gillnet fishery per capita earnings		Total salmon fishing per capita earnings	
	2000	2010	2000	2010	2000	2010
BRISTOL BAY BOROUGH	**$1,542**	**$4,240**	**$1,198**	**$3,172**	**$2,740**	**$7,411**
King Salmon	$1,334	$3,232	$657	$2,004	$1,991	$5,236
Naknek	$1,652	$4,954	$1,357	$4,015	$3,009	$8,969
South Naknek	$1,675	$4,093	$2,154	$2,892	$3,829	$6,986
DILLINGHAM CENSUS AREA	**$2,090**	**$2,252**	**$793**	**$1,289**	**$2,882**	**$3,540**
Dillingham Region	**$2,244**	**$2,623**	**$716**	**$1,160**	**$2,960**	**$3,783**
Aleknagik	$2,399	$3,435	$591	$794	$2,990	$4,229
Clarks Point	$4,385	$0	$901	$1,882	$5,286	$1,882
Dillingham	$2,200	$2,620	$733	$1,177	$2,933	$3,798
Ekuk						
Portage Creek						
Togiak-Manokotak Region	**$2,285**	**$2,417**	**$1,418**	**$2,410**	**$3,703**	**$4,828**
Manokotak	$2,123	$1,576	$1,619	$3,500	$3,742	$5,075
Togiak	$2,560	$3,091	$1,440	$2,039	$4,000	$5,131
Twin Hills	$0	$0	$0	$0	$0	$0
Upper Nushagak Region	**$1,384**	**$1,002**	**$109**	**$0**	**$1,494**	**$1,002**
Ekwok	$900					
Koliganek	$1,649	$2,182				
New Stuyahok	$1,416	$745	$181		$1,597	
LAKE AND PEN. BOROUGH	**$798**	**$1,237**	**$239**	**$367**	**$1,037**	**$1,604**
Lake Region	**$377**	**$908**	**$110**	**$524**	**$487**	**$1,432**
Igiugig						
Iliamna	$1,137	$4,127	$504	$1,975	$1,640	$6,102
Kokhanok	$435	$0	$0	$842	$435	$842
Levelock	$1,067	$2,743	$0	$0	$1,067	$2,743
Newhalen	$309	$1,191	$0	$740	$309	$1,931
Nondalton						
Pedro Bay						
Port Alsworth						
South Bristol Bay Region	**$3,129**	**$3,960**	**$947**	**$343**	**$4,076**	**$4,302**
Egegik	$4,261	$4,296	$1,911	$915	$6,173	$5,211
Pilot Point	$2,316	$0	$1,058	$0	$3,375	$0
Port Heiden	$2,998	$6,705	$0	$0	$2,998	$6,705
Ugashik						
Chignik Region						
Chignik						
Chignik Lagoon						
Chignik Lake						
Ivanof Bay						
Perryville						
BRISTOL BAY, TOTAL (a)	**$1,709**	**$2,295**	**$730**	**$1,339**	**$2,439**	**$3,634**
BRISTOL BAY, TOTAL (b)	**$1,813**	**$2,412**	**$774**	**$1,407**	**$2,587**	**$3,819**

(a) Total includes the Chignik Region; (b) Total excludes the Chignik Region. Blank cells indicate that earnings data were confidential and not reported. Sources: U.S. Censuses, 2000 and 2010; CFEC.

3.13 Economic Measures of the Bristol Bay Salmon Industry

There is no single or best economic measure for the Bristol Bay fishery. Which measure is appropriate depends upon the question being asked.

For example, if we want to know how the Bristol Bay salmon fishery compares in scale with other fisheries, we should look at total harvests or ex-vessel or wholesale value. If we want to know how it affects the United States balance of payments, we should look at estimated net exports attributable to the fishery. If we want to know how much employment the industry provides for residents of the local Bristol Bay region, Alaska or the United States, we should look at estimated employment in fishing and processing for residents of these regions. If we want to know the net economic value attributable to the fishery, we should look at estimated profits of Bristol Bay fishermen and processors. These different measures vary widely in units, in scale, and how economically "important" they make the fishery appear.

In this section, we summarize selected economic measures of the Bristol Bay commercial fishery for recent years. These include harvests, gross ex-vessel and wholesale value, estimated export value, direct employment and earnings in fishing and processing by region of residency, and limited entry prices and total estimated limited entry permit value. We present tables of each of these measures for the years 2000-2010. Where data are available, we present graphs for longer periods, showing dollar values in both nominal and real (inflation-adjusted) prices expressed in 2010 dollars. Blank cells in the tables indicate that data were not available as of November 2011. Refer to earlier sections in this report for more detailed discussions of each measure.

Harvests

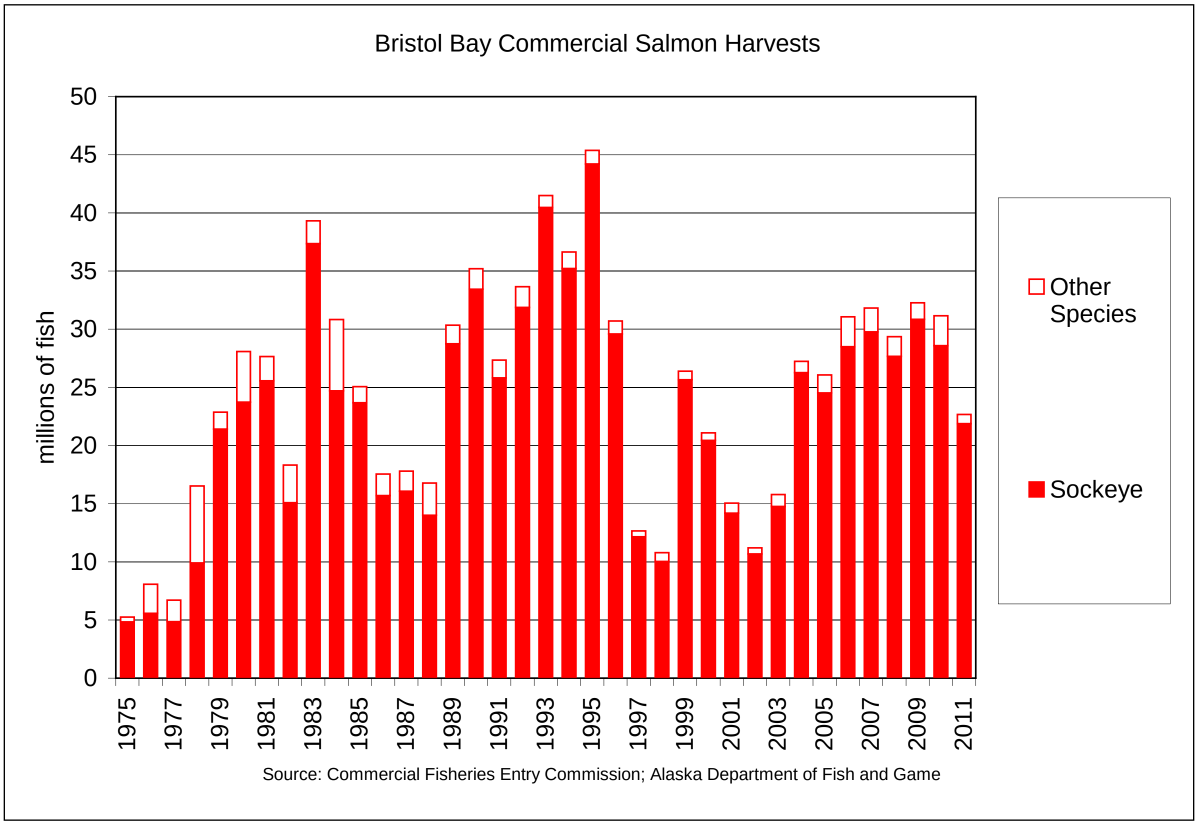
The Bristol Bay salmon fishery is a world-scale commercial salmon fishery. Between 2000 and 2010, Bristol Bay averaged 60% of total Alaska sockeye salmon harvests (by volume), 45% of world sockeye salmon harvests, 18% of all Alaska wild salmon harvests, 7% of all world wild salmon harvests, and 2% of all world salmon production (wild and farmed combined).

Table 40. Economic Measures of Bristol Bay Salmon Industry: Sockeye Salmon Harvests

Economic Measures of the Bristol Bay Salmon Industry: Sockeye Salmon Harvests

Measure	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg.	Range
Harvests													
Millions of fish	21	14	11	15	26	25	28	30	28	31	29	23	11 - 31
Millions of pounds	125	96	65	93	152	155	165	173	160	183	170	140	65 - 183
Bristol Bay harvest volume as a share of:													
Alaska sockeye salmon	61%	56%	48%	50%	59%	58%	69%	62%	71%	71%	74%	62%	48% - 74%
World sockeye salmon	45%	40%	28%	38%	47%	47%	49%	47%	52%	55%		45%	28% - 55%
Alaska wild salmon (all species)	18%	12%	10%	13%	19%	16%	22%	18%	23%	25%		18%	10% - 25%
World wild salmon (all species)	7%	5%	4%	5%	8%	7%	8%	7%	9%	7%		7%	4% - 9%
World wild & farmed salmon (all species)	3%	2%	1%	2%	3%	3%	3%	3%	3%	3%		2%	1% - 3%

Sources: Alaska Department of Fish and Game, National Marine Fisheries Service, FAO.


Bristol Bay Commercial Salmon Harvests

Source: Commercial Fisheries Entry Commission; Alaska Department of Fish and Game

Figure 70. Bristol Bay Commercial Salmon Harvests

Gross Ex-Vessel Value and First Wholesale Value

During the period 2000-2010, Bristol Bay sockeye salmon harvests had an average annual real ex-vessel value to fishermen of $101 million (expressed in 2010 $). During this period of time, the value was generally increasing, from a low or $39 million in 2002 to $181 million in 2010. The real first wholesale value of salmon products processed from Bristol Bay sockeye salmon in Bristol Bay was more than twice as high as harvest value, averaging $234 million for the period 2000-2010, and increasing from $124 million in 2002 to $390 million in 2010.

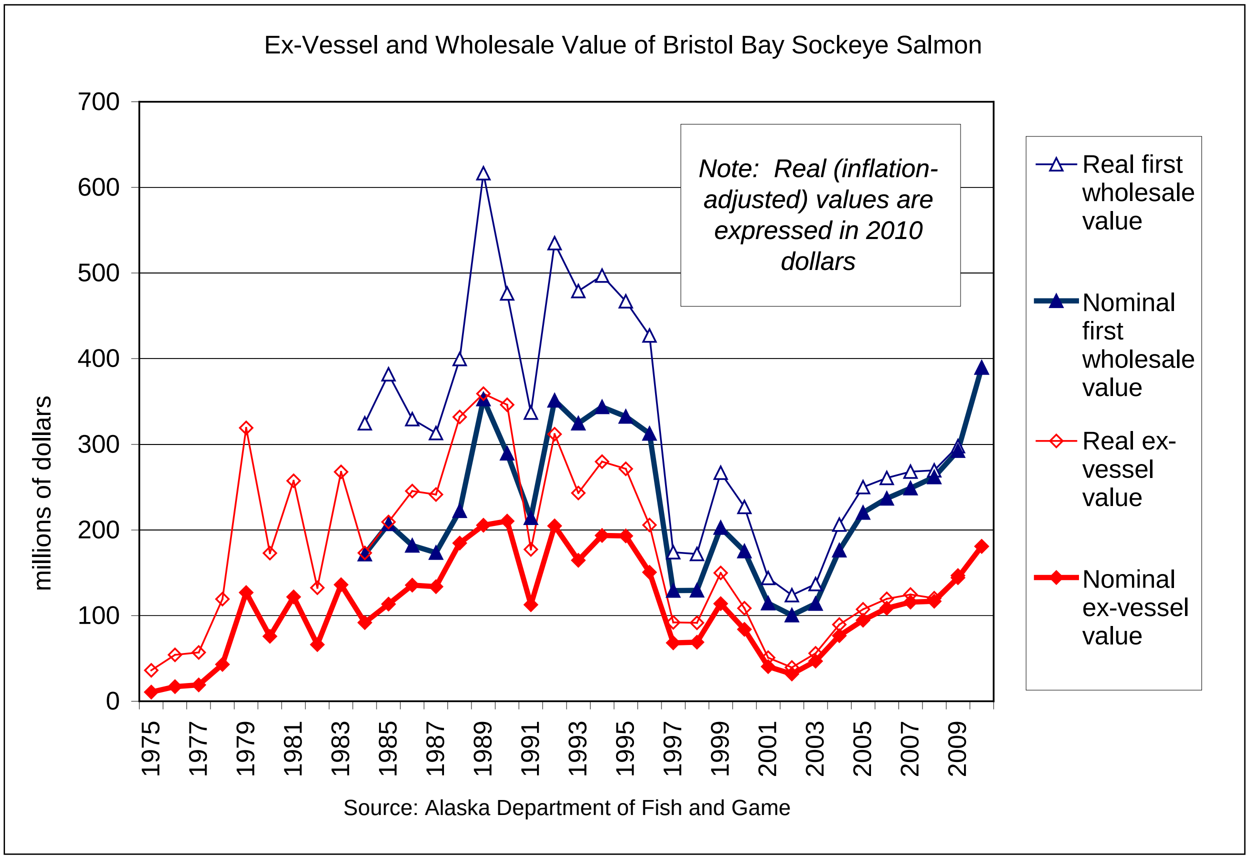
Table 41. Economic Measures of Bristol Bay Salmon Industry: Sockeye Value

Economic Measures of the Bristol Bay Salmon Industry: Sockeye Salmon Ex-Vessel Value and First Wholesale Value

Measure	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg.	Range
Ex-Vessel Value ($ mllions)													
Nominal value (not inflation-adjusted)	80	40	32	48	76	95	109	116	117	144	181	94	32 - 181
Real value (inflation adjusted, 2010 $)	104	51	39	57	90	107	119	125	120	147	181	104	39 - 181
First wholesale value													
Nominal value (not inflation-adjusted)	175	115	100	114	176	220	237	249	262	293	390	212	100 - 390
Real value (inflation adjusted, 2010 $)	227	144	124	137	206	250	261	268	270	298	390	234	124 - 390
Bristol Bay sockeye salmon share of:													
Alaska wild salmon ex-vessel value (all species)	23%	14%	16%	19%	24%	24%	28%	24%	22%	29%	25%	23%	14% - 29%
World wild salmon ex-vessel value (all species) *	12%	6%	6%	8%	13%	12%	13%	11%	10%	9%		10%	6% - 13%
United States fish & shellfish landed value (all species)	2%	1%	1%	1%	2%	2%	2%	2%	2%	3%	3%	2%	1% - 3%
Rank of Naknek-King Salmon among U.S. ports in annual landed value	21	49	87	58	12	8	8	7	7	4	4	24	87 - 4

* Valued at average prices of Alaska wild salmon, by species.

Sources: Alaska Department of Fish and Game, National Marine Fisheries Service, FAO.



Source: Alaska Department of Fish and Game

Figure 71. Ex-Vessel and Wholesale Value of Bristol Bay Sockeye Salmon

Between 2000 and 2010, Bristol Bay averaged 23% of the ex-vessel for all Alaska wild salmon, an estimated 10% of the harvest value of world wild salmon harvests, and 2% of the value of U.S. fish and shellfish landings of all species combined.

As ex-vessel value increased dramatically between 2003 and 2010, the Bristol Bay port of Naknek-King Salmon rose from a rank of 87th to 4th among all U.S. ports in annual landed value (ex-vessel value, or value paid to fishermen, of fish landed in the port).

Export Value of Bristol Bay Salmon Products

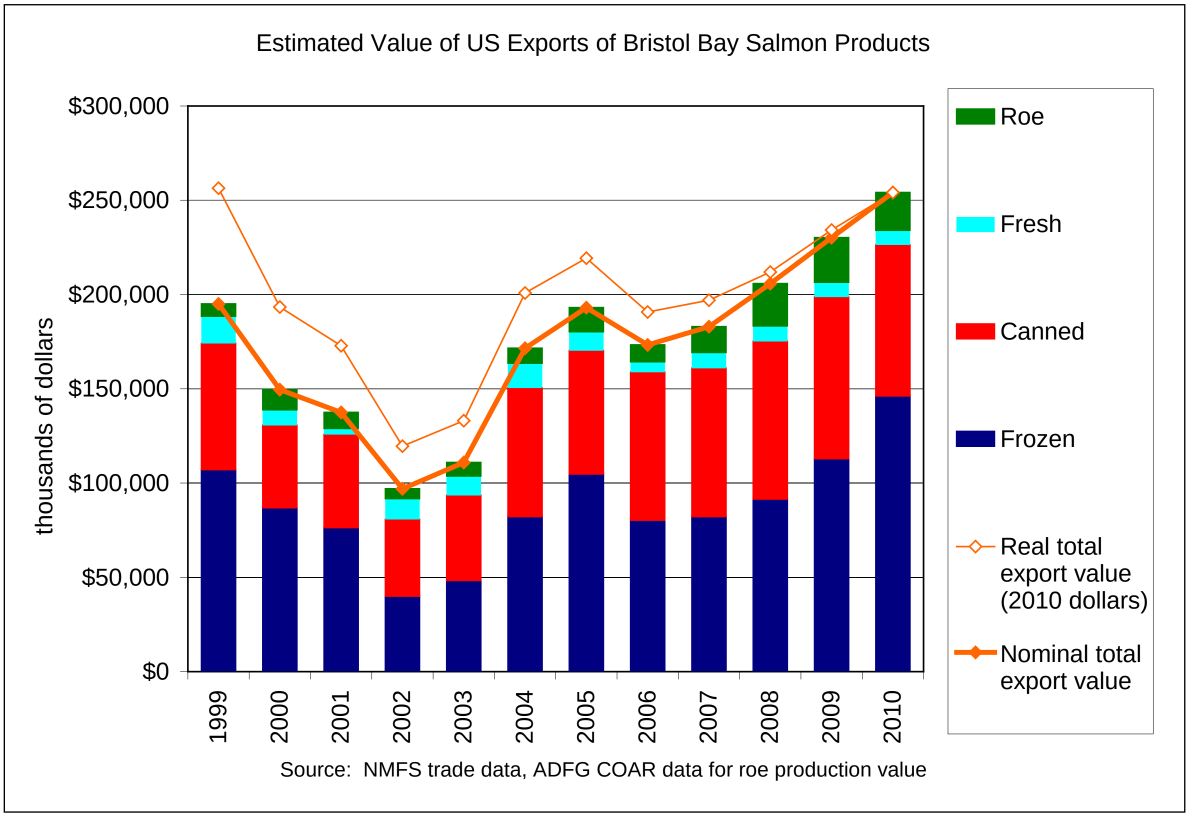
During the period 2000-2010, the value of Bristol Bay salmon products exported from the United States averaged $173 million for the years 2000-2010, and was $254 million in 2010.

Table 42. Economic Measures of the Bristol Bay Salmon Industry: Export Value.

Economic Measures of the Bristol Bay Salmon Industry: Estimated Export Value of Bristol Bay Sockeye Salmon Products

Measure	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg.	Range
Nominal value of exports (millions of dollars)													
Canned	44	49	41	45	68	65	79	79	84	86	80	65	41 - 86
Frozen	8	3	11	10	13	10	5	8	8	8	8	8	3 - 13
Fresh	87	76	40	48	82	105	80	82	92	113	146	87	40 - 146
Roe	11	8	5	7	8	13	9	14	22	24	20	13	5 - 24
Total	150	137	97	111	172	193	173	183	206	230	254	173	97 - 254
Real value of exports (millions of 2010 $)													
Canned	57	62	50	54	80	74	86	85	86	87	80	73	50 - 87
Frozen	11	4	14	12	15	11	6	9	8	8	8	10	4 - 15
Fresh	112	96	49	58	96	119	88	89	94	115	146	97	49 - 146
Roe	14	11	6	8	9	14	10	15	23	24	20	14	6 - 24
Total	193	173	120	133	201	219	191	197	212	234	254	193	120 - 254

Note: The value of US exports of Bristol Bay sockeye salmon products was estimated as the total value of US sockeye salmon exports multiplied by the share of Bristol Bay sockeye in total Alaska sockeye salmon havests. The value of Bristol Bay sockeye salmon roe exports was assumed to be equal to the first wholesale value of sockeye salmon roe production. The data source for US exports was the National Marine Fisheries Serivce Foreign Trade in Fisheries Products website.


Estimated Value of US Exports of Bristol Bay Salmon Products

Source: NMFS trade data, ADFG COAR data for roe production value

Figure 72. Estimated Value of US Exports of Bristol Bay Salmon Products

Employment

During the period 2001-2009, estimated peak employment in the Bristol Bay salmon industry averaged 6,656 fishermen and 3,255 processing workers, for average total peak employment of 9,911.

Because the fishery occurs almost entirely in June and July, estimated annual average employment is only about one-sixth as high as peak employment. During the period 2001-2009, estimated annual average employment averaged 1,093 in fishing and 535 in processing, for a total of 1,628 annual average jobs.

During this period Bristol Bay salmon annual average fishing employment averaged 15% of Alaska statewide annual average fishing employment. Peak Bristol Bay commercial fishing employment averaged 33% of peak statewide Alaska commercial fishing employment. Put differently, in July—the busiest month for Alaska commercial fishing—about one third of all the people fishing commercially in Alaska were fishing in Bristol Bay. Bristol Bay fish processing accounted for an average of 14% of the individuals who worked in Alaska fish processing.

Table 43. Economic Measures of the Bristol Bay Salmon Industry: Employment

Economic Measures of the Bristol Bay Salmon Industry: Employment

Measure	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg.	Range
Estimated peak employment or number of workers											
Peak (July) fishing employment	7,098	5,514	6,465	6,513	6,750	6,936	6,891	6,969	6,768	6,656	5,514 - 7,098
Number of fish processing workers	2,862	2,273	2,484	3,474	3,272	2,940	3,512	3,952	4,522	3,255	2,273 - 4,522
Total	9,960	7,787	8,949	9,987	10,022	9,876	10,403	10,921	11,290	9,911	7,787 - 11,290
Estimated annual average employment											
Fishing	1,179	888	1,063	1,089	1,098	1,140	1,110	1,129	1,143	1,093	888 - 1,179
Fish processing	475	366	409	581	532	483	566	640	764	535	366 - 764
Total	1,654	1,254	1,472	1,669	1,631	1,623	1,675	1,769	1,907	1,628	1,254 - 1,907
Bristol Bay share of estimated Alaska total											
Annual average fishing employment	15%	12%	14%	15%	15%	16%	15%	16%	16%	15%	12% - 16%
Peak (July) employment in fishing	33%	30%	33%	33%	33%	35%	34%	34%	34%	33%	30% - 35%
Number of fish processing workers	13%	11%	11%	16%	15%	13%	15%	17%	19%	14%	11% - 19%

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Division.

Limited Entry Permit Prices and Values

Limited entry permit prices provide a measure of the value to the marginal permit holder of the present and future right to participate in the fishery. Economic theory suggests that this will be the marginal permit holder's present discounted present value of expected future profits from the fishery. During the period 2002-2010 Bristol Bay permit prices increased from $19,700 to $102,100 for drift gillnet permits and from $11,900 to $28,700 for set gillnet permits. The dramatic recovery in permit prices reflects a dramatic increase in profitability of the fishery and expectations of continued profitability.

The total value of Bristol Bay permits—calculated as the number of permits multiplied by the permit price—provides an estimate of the total present discounted value of expected future profits from the fishery. During the period 2000-2010 the estimated total value of Bristol Bay permits (both fisheries combined) ranged from $48 million to $218 million.

Multiplying the total value of a permit by the rate of return a permit holder demands on a permit investment provides a measure of the annual profit permit holders expect to earn. We do not know the rate of return demanded by permit holders. However, it is likely that it is between 5% and 20% (Hupert et al 1996). This suggests that in 2010 annual expected profits from Bristol Bay commercial fishing between $10.9 million and $43.7 million. Note that this does not include expected profits from fish processing.

Table 44. Economic Measures of the Bristol Bay Salmon Industry: Permit Prices and Values. (Source: www.cfec.state.ak.us/bit/MNUSALM.htm)

Economic Measures of the Bristol Bay Salmon Industry: Permits Prices and Values

Measure	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg.	Range
Number of permanent permits issued													
Drift gillnet fishery	1858	1,861	1,863	1,861	1,857	1,859	1,859	1,861	1,863	1,863	1,863	1,861	1,857 - 1,863
Set gillnet fishery	1,007	1,008	1,004	999	988	988	985	983	979	982	982	991	979 - 1,008
Total	1,007	2,869	2,867	2,860	2,845	2,847	2,844	2,844	2,842	2,845	2,845	2,683	1,007 - 2,869
Average nominal permit price ($)													
Drift gillnet fishery	80,500	34,700	19,700	29,300	37,000	51,200	75,000	79,400	89,800	78,300	102,100	61,545	19,700 - 102,100
Set gillnet fishery	32,400	25,300	11,900	12,600	14,700	15,100	22,400	24,000	27,400	28,200	28,700	22,064	11,900 - 32,400
Estimated total nominal value ($ millions) (a)													
Drift gillnet fishery	149.6	64.6	36.7	54.5	68.7	95.2	139.4	147.8	167.3	145.9	190.2	114.5	36.7 - 190.2
Set gillnet fishery	32.6	25.5	11.9	12.6	14.5	14.9	22.1	23.6	26.8	27.7	28.2	21.9	11.9 - 32.6
Total	182.2	90.1	48.6	67.1	83.2	110.1	161.5	171.4	194.1	173.6	218.4	136.4	48.6 - 218.4
Implied annual nominal profits ($ millions) (b) assuming permit holders demand a rate of return of:													
5%	9.1	4.5	2.4	3.4	4.2	5.5	8.1	8.6	9.7	8.7	10.9	6.8	2.4 - 10.9
10%	18.2	9.0	4.9	6.7	8.3	11.0	16.1	17.1	19.4	17.4	21.8	13.6	4.9 - 21.8
15%	27.3	13.5	7.3	10.1	12.5	16.5	24.2	25.7	29.1	26.0	32.8	20.5	7.3 - 32.8
20%	36.4	18.0	9.7	13.4	16.6	22.0	32.3	34.3	38.8	34.7	43.7	27.3	9.7 - 43.7

(a) Calculated as average permit price x number of permanent permits issued. (b) Estimated total value x assumed rate of return demanded. Source: Commercial Fisheries Entry Commission, Salmon Basic Information Tables.

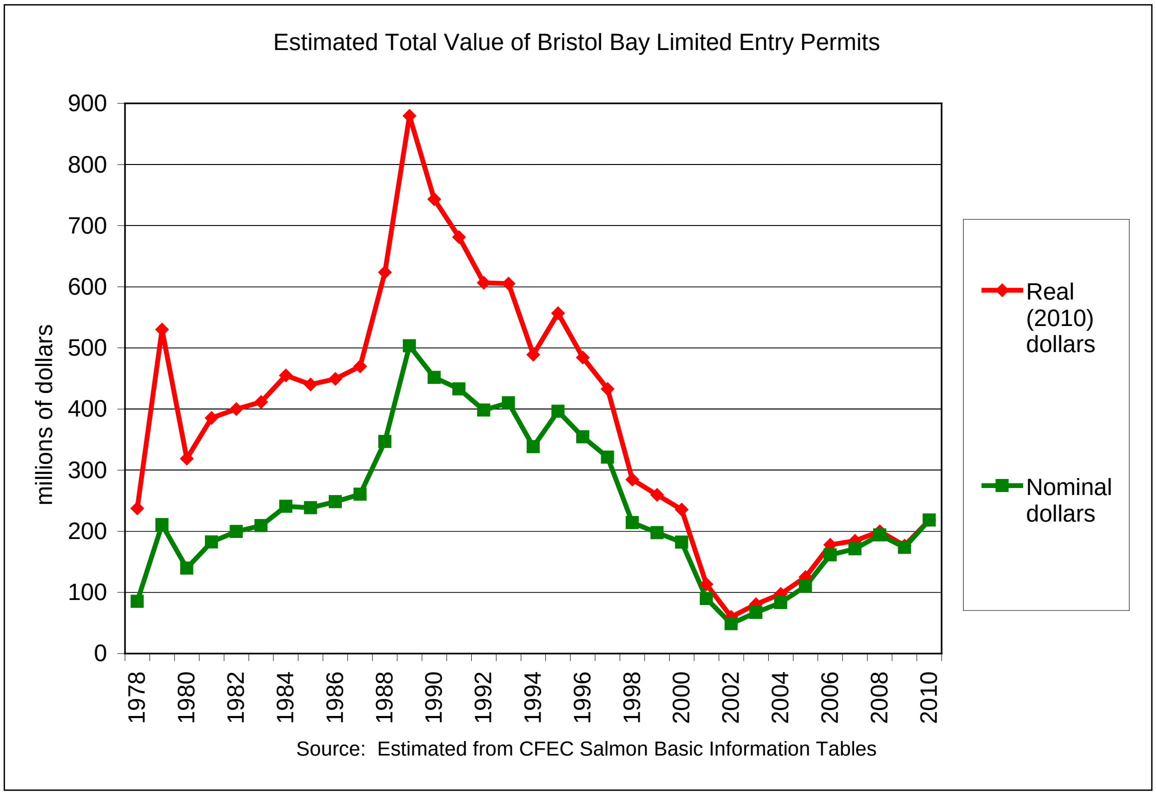


Figure 73. Estimated Total Value of Bristol Bay Limited Entry Permits

3.14 Bristol Bay Commercial Fisheries: Summary

The Bristol Bay sockeye salmon fishery is one of the world's largest and most valuable wild salmon fisheries. Between 2006 and 2010, the Bristol Bay salmon industry averaged:

- Annual harvests of 31 million salmon (including 29 million sockeye salmon)
- 51% of world sockeye salmon harvests
- Annual "ex-vessel" value to fishermen of $129 million
- Annual first wholesale value after processing of $268 million.
- 26% of the "ex-vessel" value to fishermen of the entire Alaska salmon harvest.
- Seasonal employment of more than 6800 fishermen and 3700 processing workers.

Participation in the Bristol Bay salmon fishery is limited to holders of limited entry permits and their crew. There are approximately 1860 drift gillnet permits for fishing from boats and approximately 1000 set net permits for fishing from the shore. The driftnet fishery accounts for about 80% of the harvest. Most of the harvest is processed by about ten large processing companies in both land-based and floating processing operations which employ mostly non-resident seasonal workers.

Bristol Bay Salmon Harvests

Sockeye salmon account for about 94% of the volume of Bristol Bay salmon harvests and an even greater share of the value. Total catches vary widely from year to year. Between 1980 and 2010, Bristol Bay sockeye salmon harvests ranged from as low as 10 million fish to as high as 44 million fish. Harvests can vary widely from year to year. Annual pre-season forecasts are subject to a wide margin of error.

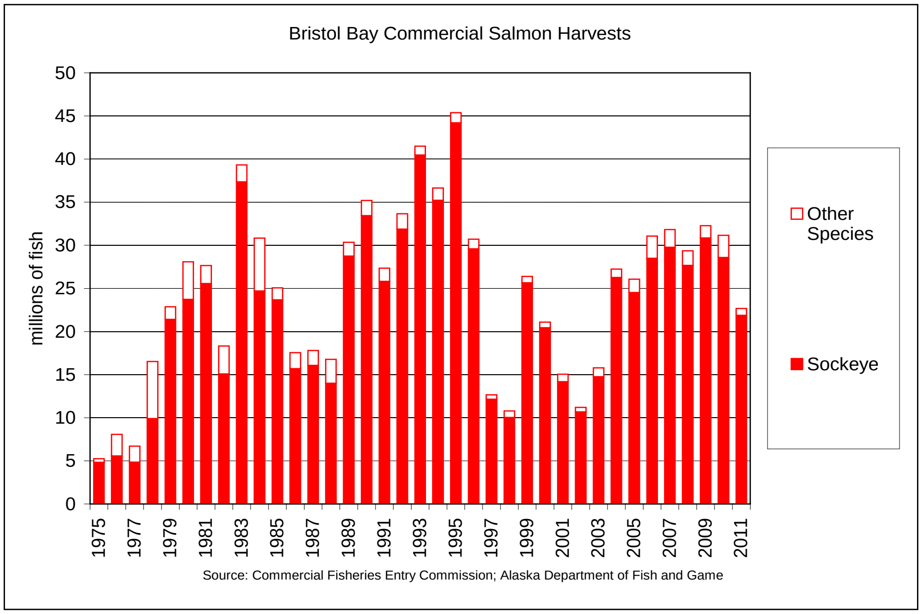


Figure 74. Bristol Bay Commercial Salmon Harvests

There are no formal long-term forecasts of future Bristol Bay harvests. The variability and uncertainty of annual salmon returns are important factors influencing how the fishery is managed and how fish are harvested, processed and marketed.

The Bristol Bay commercial salmon fishery harvests salmon which spawn in and return to numerous rivers over a broad area. For management purposes, the fishery is divided into five fishing districts. Catches in each district vary widely from year to year and over longer time periods of time, reflecting wide variation in returns to river systems within each district (Table). There is no obvious way to characterize the relative share of the Bristol Bay commercial salmon fishery attributable to particular river systems or to the individual streams and lakes that make up each river system.

Table 45. Distribution of Harvests for Bristol Bay Fishing Districts, 1986-2010

Distribution of Harvests for Bristol Bay Fishing Districts, 1986-2010

Measure	District	Minimum	10th percentile	Mean	90th percentile	Maximum	Standard deviation
Harvests (millions of fish)	Naknek-Kvichak	0.6	2.7	8.0	15.3	20.3	5.0
	Nushagak	1.7	2.7	5.1	8.0	11.1	2.3
	Egegik	2.3	4.0	8.3	13.3	21.6	4.3
	Ugashik	0.5	1.5	2.8	4.5	5.0	1.3
	Togiak	0.1	0.2	0.5	0.8	0.8	0.2
Share of total harvests (%)	Naknek-Kvichak	5%	18%	30%	46%	52%	11%
	Nushagak	9%	10%	22%	32%	45%	10%
	Egegik	16%	21%	34%	48%	62%	11%
	Ugashik	3%	7%	11%	15%	32%	5%
	Togiak	0%	1%	2%	4%	6%	1%

Source: Alaska Department of Fish and Game, Bristol Bay Annual Management Reports

Currently there is particular interest in the significance of fisheries resources of river systems in the Nushagak and Kvichak districts, because of potential future resource development in these watersheds. Over the period 1986-2010, the Naknek-Kvichak catches ranged from as low as 5% to as high as 52% of total Bristol Bay catches; Nushagak district catches ranged form as low as 9% to as high as 45% of total Bristol Bay catches. For most of the past decade, the combined Nushagak and Naknek-Kvichak districts have accounted for about 60% of the total Bristol Bay commercial sockeye harvest.

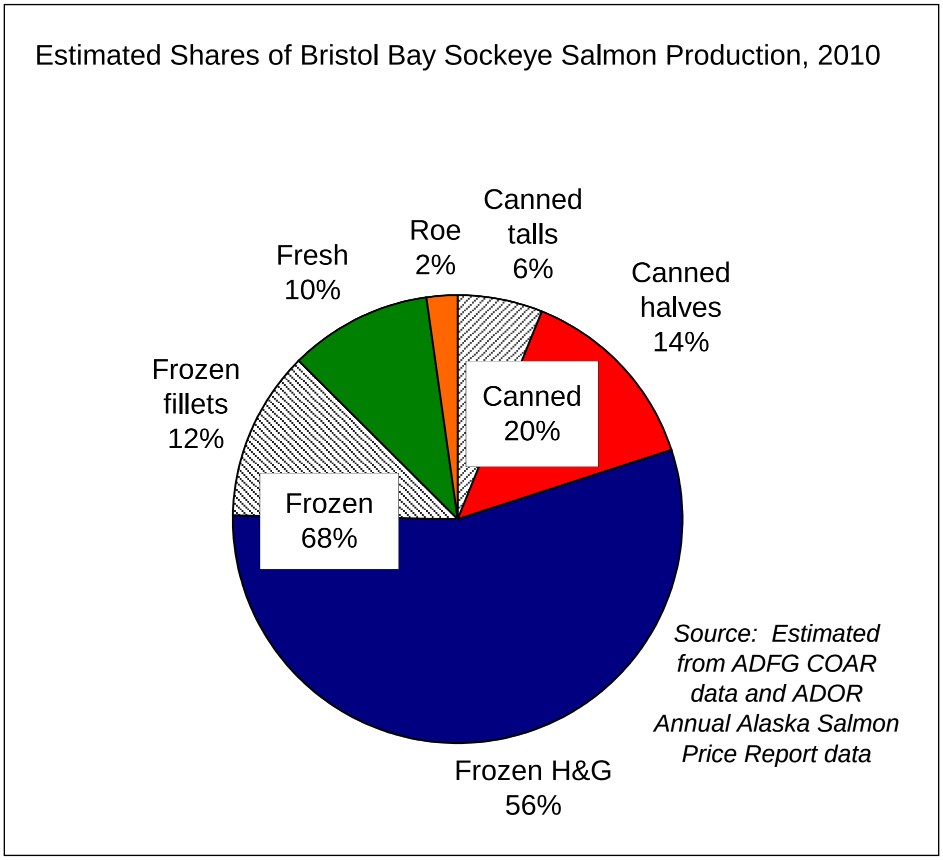
In general, a decline in salmon returns associated with any particular river system might have a relatively small effect on *average* catches over a long period of time in the Bristol Bay fishery. But it might have a much larger effect on catches in those years when the river system would have contributed a relatively larger share of total harvests. For example, if a particular river system accounts for an average of 1% of the return on average but 10% of the return in some years, the loss of that system would reduce catches by only 1% on average but would reduce catches in some years by 10%. Put differently, a decline in catches from any particular river system would increase the variability in catches in the fishery and the overall economic risk associated with the fishery.

An inherent question here is whether 51% of the world’s sockeye are caught in Bristol Bay because that is where the fish are or because that is where the boats go. One could envision circumstances where the boats prefer to go to areas that are more safe/convenient (more sheltered, closer to port, etc.) and there are enough fish available there that they don’t need to go elsewhere. It is not clear if severe degradation of the Bristol Bay commercial fishery may necessarily result in the total loss of 51% of the world’s harvest, but rather displace it to other areas (possibly even in another area of AK). However, such changes in the Alaska and Bristol Bay fishery could result in more dangerous working conditions, negatively affect Alaska native participation in the fishery; and will change the Alaska commercial fishery market structure. Evaluating such impacts is beyond the scope of this baseline assessment.

Bristol Bay Salmon Production and Markets

Most Bristol Bay salmon is processed into either frozen or canned salmon. Traditionally most frozen salmon has been frozen headed and gutted (H&G) for further processing elsewhere, particularly in Japan. However, in recent years production of frozen salmon fillets in the Bristol Bay region has increased.

Formerly almost all Bristol Bay frozen salmon was exported to Japan as frozen headed and gutted salmon. Over the past decade exports of frozen head and gutted salmon to Japan have declined while exports have increased to Europe and to China (for reprocessing into fillets). Most Bristol Bay canned salmon is exported, primarily to the United Kingdom and Canada.



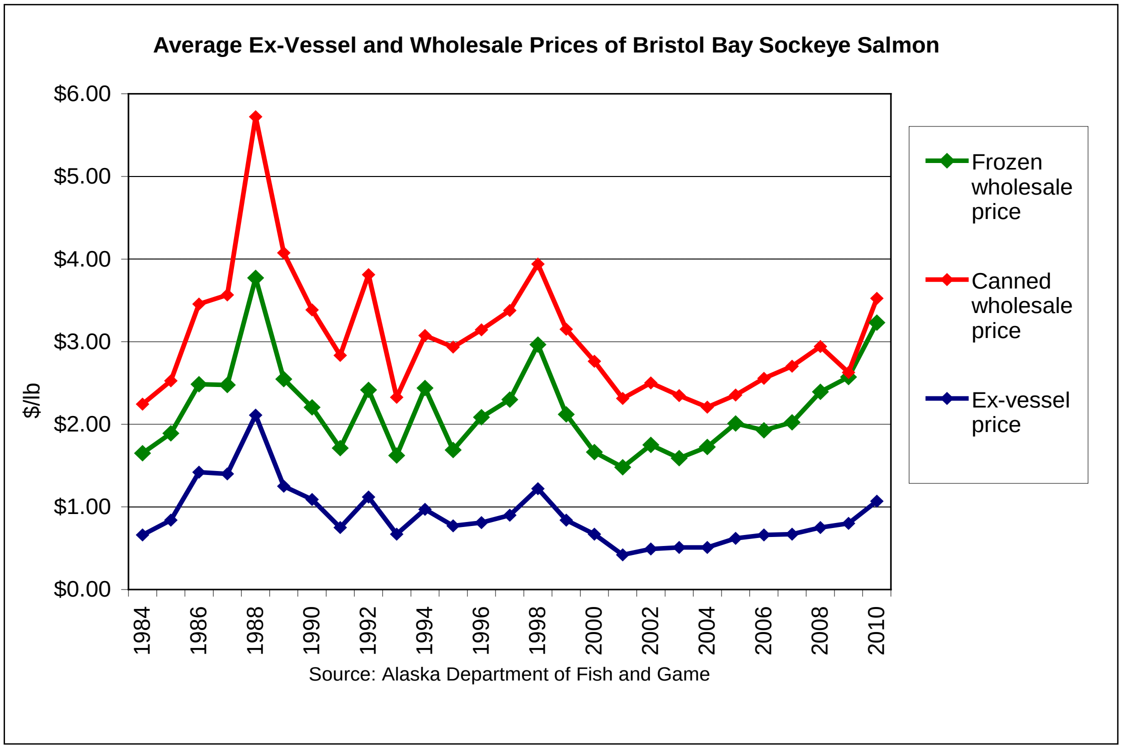
Estimated Shares of Bristol Bay Sockeye Salmon Production, 2010

Source: Estimated from ADFG COAR data and ADOR Annual Alaska Salmon Price Report data

Figure 75. Estimated Shares of Bristol Bay Sockeye Salmon Production, 2010

Bristol Bay Salmon Prices and Value

Ex-vessel prices paid to fishermen and first wholesale prices received by processors in the Bristol Bay salmon fishery have varied widely over the past three decades, reflecting dramatic changes in world salmon markets during this period.



Source: Alaska Department of Fish and Game

Figure 76. Average Ex-Vessel and Wholesale Prices of Bristol Bay Sockeye Salmon

Strong Japanese demand from frozen sockeye salmon drove a sharp rise in Bristol Bay salmon prices during the 1980s. Competition from rapidly increasing farmed salmon production drove a protracted and dramatic decline in prices between 1988 and 2001, which led to an economic crisis in the industry. Growing world salmon demand, a slowing of farmed salmon production growth, diversification of Bristol Bay salmon products and markets, and improvements in quality have driven a strong recovery in prices over the past decade. Many other factors, such as changes in wild salmon harvests, exchange rates, and global economic conditions have also affected prices. In general, changes in ex-vessel prices paid to fishermen have reflected changes in first wholesale prices paid to processors.

Changes in prices, harvests and production have combined to drive dramatic changes in the ex-vessel and first wholesale value of Bristol Bay salmon over the past three decades . Adjusted for inflation (expressed in 2010 $), the real ex-vessel value paid to fishermen fell from $359 million in 1988 to $39 million in 2002, and rose to $181 million in 2010. The real first wholesale value of Bristol Bay salmon production fell from $616 million in 1988 to $124 million in 2002, and then rose to $390 million in 2010.

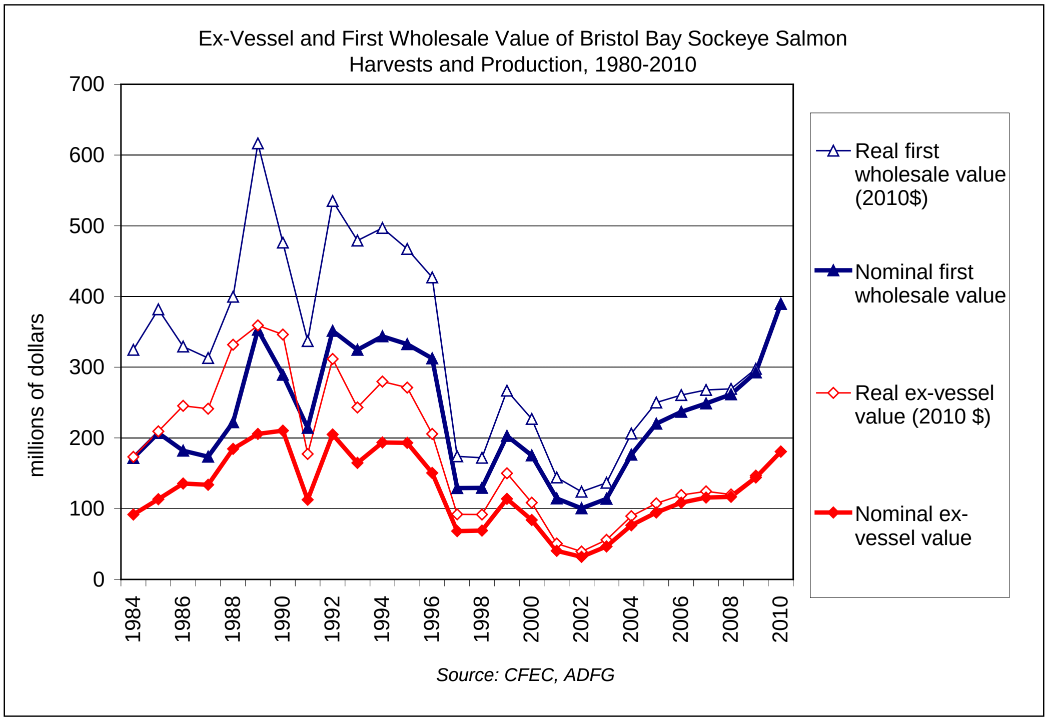


Figure 77. Ex-Vessel and First Wholesale Value 1980-2010

Bristol Bay Salmon Industry Employment

The number of Bristol Bay permits fished each year has varied over time depending on economic conditions in the fishery. Over the past decades, between about 1200 and 1500 drift gillnet permits and between about 700 and 900 set gillnet permits were fished each year.

On average, for each permit fished, about three people were engaged in fishing (the permit holder and two crew members). The estimated total number of people working in fishing during the Bristol Bay season ranged from about 5500 to 7100. Because most of the commercial harvest occurs within a period of a few weeks in late June and early July, annual average employment in the fishery is much smaller than peak employment, ranging from about 900 to 1200 over the past decade.

Over the past decade Bristol Bay fish processors employed between about 2300 and 4500 workers, with annual average employment ranging from about 360 to 760. Together, about 7,800-11,300 people worked seasonally in fishing and processing, for combined annual average employment of 1200 to 1900.

Geographic Distribution of Bristol Bay Salmon Fishery Participation and Earnings

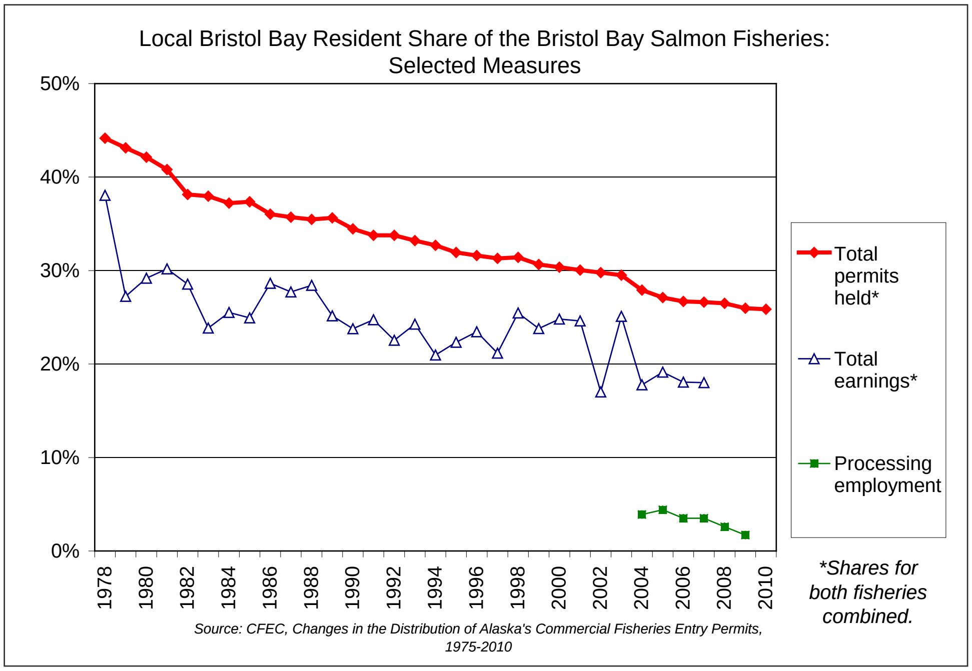
Local residents of the Bristol Bay region account for a relatively small and declining share of employment and earnings in the Bristol Bay salmon industry. Non-Alaska residents account for a relatively large and growing share of employment and earnings.

Table 46. Geographic Distribution of Bristol Bay Salmon Industry Employment and Earnings.

Geographic Distribution of Bristol Bay Salmon Industry Employment and Earnings: Selected Measures

	Measure by Residency				Share of Total		
Measure	Bristol Bay region residents	Other Alaska residents	Residents of other states or countries	Total	Bristol Bay region residents	Other Alaska residents	Residents of other states or countries
Permit holders, drift gillnet fishery	383	471	1,009	1,863	21%	25%	54%
Permit holders, set gillnet fishery	353	311	317	982	36%	32%	32%
Permit holders, total	736	782	1,326	2,845	26%	27%	47%
Earnings, drift gillnet fishery (2007) ($000)	$14,273	$25,020	$58,821	$98,115	15%	26%	60%
Earnings, set gillnet fishery (2007) ($000)	$6,989	$6,071	$6,840	$19,900	35%	31%	34%
Earnings, total (2007) ($000)	$21,262	$31,091	$65,661	$118,014	18%	26%	56%
Processing workers (2009)	76	529	3,916	4,521	2%	12%	87%
Processing workers' earnings (2009) ($000)	$1,000	$3,025	$27,162	$31,187	3%	10%	87%

Sources: Gho, Marcus, K. Iverson, C. Farrington, and N. Free-Sloan, "Changes in the Distribution of Alaska's Commercial Fisheries Entry Permits, 1975 – 2010," CFEC Report 11-3N (2011); Permit holder earnings: Iverson, Kurt, "Permit Holdings, Harvests, and Estimated Gross Earnings by Resident Type in the Bristol Bay Salmon Gillnet Fisheries," CFEC Rpt 09-1N (2009); Processing workers and earnings: Alaska Department of Labor and Workforce Development estimates, http://labor.alaska.gov/research/seafood/seafoodbristol.htm.



*Shares for both fisheries combined.

Source: CFEC, Changes in the Distribution of Alaska's Commercial Fisheries Entry Permits, 1975-2010

Figure 78. Local Bristol Bay Resident Share of Bristol Bay Salmon Fisheries.

This does not mean, of course, that the Bristol Bay salmon fishery is unimportant as a source of jobs or income for local residents. It remains very important—but not as important as it would be if all the jobs were held by local residents and all the income were earned by local residents.

A different perspective is that the Bristol Bay fishery is not just economically important for a remote region of southwestern Alaska. Rather, it is of major economic importance for other parts of Alaska and other states, particularly the Pacific Northwest. Thousands of residents of other parts of Alaska and other states work in and earn significant income from participating in Bristol Bay fishing and processing.

Distribution of Salmon Permits and Earnings within the Bristol Bay Region

Within the Bristol Bay region, there is wide variation in the extent to which residents of different communities participate in and derive income from the Bristol Bay salmon fisheries. In 2010, the number of permits held per 100 residents ranged from as high as 16 in the Bristol Bay Borough to as low as 5 in the Upper Nushagak Region. Per capita salmon fishery earnings ranged from more than $7000 in the Bristol Bay Borough to only $1000 in the Upper Nushagak Region.

Table 47. Relative Indicators of 2010 Salmon Fishery Participation and Earnings.

Relative Indicators of 2010 Salmon Fishery Participation and Earnings, Bristol Bay Watershed Regions

	Number of permit holders per 100 residents			Per capita salmon fishery earnings		
	Drift gillnet fishery	Set gillnet fishery	Combined fisheries	Drift gillnet fishery	Set gillnet fishery	Combined fisheries
Bristol Bay Borough	6	10	16	$4,240	$3,172	$7,411
Togiak-Manokotak Region	6	7	13	$2,417	$2,410	$4,828
South Bristol Bay Region	10	6	15	$3,960	$343	$4,302
Dillingham Region	5	4	9	$2,623	$1,160	$3,783
Lake Region	3	3	6	$908	$524	$1,432
Upper Nushagak Region	5	1	5	$1,002	*	$1,002
Bristol Bay Watershed	**5**	**5**	**10**	**$2,412**	**$1,407**	**$3,819**

* Confidential. Sources: U.S. Censuses, 2000 and 2010; CFEC.

Economic Measures of the Bristol Bay Salmon Industry

There are many potential economic measures of the Bristol Bay salmon industry. Which measure is most useful depends upon the question being asked. For example, if we want to know how the Bristol Bay salmon fishery compares in scale with other fisheries, we should look at total harvests or ex-vessel or wholesale value. If we want to know how it affects the United States balance of payments, we should look at estimated net exports attributable to the fishery. If we want to know how much employment the industry provides for residents of the local Bristol Bay region, Alaska or the United States, we should look at estimated employment in fishing and processing for residents of these regions. If we want to know the net economic value attributable to the fishery, we should look at estimated profits of Bristol Bay fishermen and processors. These different measures vary widely in units, in scale, and how economically "important" they make the fishery appear.

Table 48. Selected Economic Measures of the Bristol Bay Salmon Industry, 2000-2010.

Selected Economic Measures of the Bristol Bay Salmon Industry, 2000-2010

Measure	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg.	Range
Sockeye Salmon Havests													
Millions of fish	21	14	11	15	26	25	28	30	28	31	29	23	11 - 31
Millions of pounds	125	96	65	93	152	155	165	173	160	183	170	140	65 - 183
Bristol Bay harvest volume as a share of:													
Alaska sockeye salmon	61%	56%	48%	50%	59%	58%	69%	62%	71%	71%	74%	62%	48% - 74%
World sockeye salmon	45%	40%	28%	38%	47%	47%	49%	47%	52%	55%		45%	28% - 55%
Alaska wild salmon (all species)	18%	12%	10%	13%	19%	16%	22%	18%	23%	25%		18%	10% - 25%
World wild salmon (all species)	7%	5%	4%	5%	8%	7%	8%	7%	9%	7%		7%	4% - 9%
World wild & farmed salmon (all species)	3%	2%	1%	2%	3%	3%	3%	3%	3%	3%		2%	1% - 3%
Gross Value ($ mllions)													
Ex-vessel value	80	40	32	48	76	95	109	116	117	144	181	94	32 - 181
First wholesale value	175	115	100	114	176	220	237	249	262	293	390	212	100 - 390
Total value of US exports of Bristol Bay salmon products	150	137	97	111	172	193	173	183	206	230	254	173	97 - 254
Workers													
Peak (July) fishing employment		7,098	5,514	6,465	6,513	6,750	6,936	6,891	6,969	6,768		6,656	5,514 - 7,098
Number of fish processing workers		2,862	2,273	2,484	3,474	3,272	2,940	3,512	3,952	4,522		3,255	2,273 - 4,522
Total		9,960	7,787	8,949	9,987	10,022	9,876	10,403	10,921	11,290		9,911	7,787 - 11,290
Estimated annual average employment													
Fishing		1,179	888	1,063	1,089	1,098	1,140	1,110	1,129	1,143		1,093	888 - 1,179
Fish processing		475	366	409	581	532	483	566	640	764		535	366 - 764
Total		1,654	1,254	1,472	1,669	1,631	1,623	1,675	1,769	1,907		1,628	1,254 - 1,907
Average permit price ($ 000)													
Drift gillnet fishery	81	35	20	29	37	51	75	79	90	78	102	62	20 - 102
Set gillnet fishery	32	25	12	13	15	15	22	24	27	28	29	22	12 - 32
Estimated total permit value ($ millions)													
Drift gillnet fishery	149.6	64.6	36.7	54.5	68.7	95.2	139.4	147.8	167.3	145.9	190.2	114.5	36.7 - 190.2
Set gillnet fishery	32.6	25.5	11.9	12.6	14.5	14.9	22.1	23.6	26.8	27.7	28.2	21.9	11.9 - 32.6
Total	182.2	90.1	48.6	67.1	83.2	110.1	161.5	171.4	194.1	173.6	218.4	136.4	48.6 - 218.4

Economic impacts and net economic value of the Bristol Bay salmon industry are not necessarily proportional to harvests or gross value, particularly in the short run. Put differently, economic impacts and net economic value are disproportionately affected by changes in value. A 1% change in harvests results in less than a 1% change in fishing and processing employment—particularly if it is unexpected. In contrast, because many of the costs of the fishery are fixed, a 1% change in value results in more than a 1% change in profits and net economic value. For these reasons, short term changes in future fish harvests would likely have less-than-proportional or greater-than-proportional economic effects. Longer-term changes in fish harvests would tend to have proportional economic effects as the scale of the fishing and processing industry changed over time.

Future Economic Importance of the Bristol Bay Salmon Industry

It is impossible to predict the future economic importance of the Bristol Bay salmon industry with certainty. Historically, catches, prices and value have varied dramatically both from year to year and over longer-term periods of time. They are likely to continue to vary.

No particular recent year or period is necessarily a good indicator of future Bristol Bay catches and value. However, it seems likely that future catches, prices and values will fall within the wide range experienced between 1980 and 2010.

Table 49. Distribution of Selected Economic Measures for the Bristol Bay Commercial Salmon Fishing Industry, 1980-2010

Distribution of Selected Economic Measures for the Bristol Bay Commercial Salmon Fishing Industry, 1980-2010

Measure	Minimum	10th percentile	Mean	90th percentile	Maximum	Standard deviation
Total sockeye salmon harvest (million fish)	10.0	14.0	24.8	35.2	44.2	8.8
Total sockeye salmon harvest (million pounds)	57.7	87.8	145.6	195.5	243.6	48.8
Ex-vessel price paid to fishermn ($/lb)	$0.53	$0.61	$1.31	$2.18	$3.79	$0.70
Average first wholesale price, frozen H&G salmon ($/lb)	$1.48	$1.64	$2.18	$2.73	$3.77	$0.54
Average first wholesale price,canned salmon ($/lb)	$2.21	$2.32	$3.05	$3.86	$5.72	$0.76
Total ex-vessel value ($ millions)	39.3	89.5	184.0	311.8	359.2	90.5
Total first wholesale value ($ millions)	123.9	160.8	324.8	486.2	616.5	131.2
Drift gillnet permit price ($ thousands)	24.3	43.6	180.5	311.6	434.7	106.1
Set gillnet permit price ($ thousands)	14.7	17.2	54.2	83.6	107.2	27.0
Estimated total permit value ($ millions)	60.0	113.3	375.6	623.6	879.5	212.0

Note: All prices and values are adjusted for inflation to real 2010 dollars. 10th and 90th percentiles are interpolated. Estimated total permit value calculated by mulltiplying average permit prices by the number of permanent permits renewed. First wholesale prices and values are for the years 1984-2010. Data are from Alaska Department of Fish and Game and Commercial Fisheries Entry Commission.

3.15 Appendix: Data Sources

A rich variety of data exists for the Bristol Bay commercial salmon fishery. However, the data can be difficult and confusing to work with, for a number of reasons. Some data are not published, and are available only upon request from Alaska state government agencies. Many data series are available only for limited periods of time: some have been discontinued and are not available for recent years; others have been collected or published only beginning relatively recently and are not available for earlier years. Many data series are inconsistent: reports published by the same agency in different years may provide different data for the same series. Preliminary data (particularly for prices and values) are often revised later, sometimes substantially. Some kinds of data are confidential except when aggregated for minimum threshold numbers of permit holders, processors or other firms. Some kinds of data are proprietary (particularly price data gathered by private market information services). Most importantly, what data mean, how they were collected or estimated, and how reliable they are is often unclear. For all these reasons, pulling together the variety of data presented in this report was a significant task, building on a variety of research conducted over many years, much of it devoted to finding data sources and learning what they meant (and didn't mean).

The purpose of this appendix is to document, as best practical, the sources for the analysis, both for the benefit of readers and for other researchers. The appendix provides details on the data sources for all of the text references, graphs and tables in this report, except where the source is obvious or reported in detail in the text.

This section begins with a description of the major data sources for this report (those used multiple times), listed in alphabetical order of the names used to refer to them.

This section then describes the sources for all data provided in the report, text, figures and tables, except where the source information is provided in the report or is otherwise clear. These are listed in the chronological order in which they appear in the report.

The final section of the appendix provides the price index data used to convert selected prices and values in the report from "nominal" dollars (not adjusted for inflation) to "real" dollars (adjusted for inflation).

Researchers wishing more detailed information about data sources may contact Gunnar Knapp at Gunnar.Knapp@uaa.alaska.edu or 907-786-7717.

Major Data Sources for This Report

Below are descriptions of the major data sources used in this report (those used multiple times), listed in alphabetical order of the names used to refer to them (shown in **bold font**). Website addresses were current as of October 2011 for all data found online.

ADFG Annual Run Forecasts and Harvest Projections. Each year the Alaska Department of Fish and Game publishes a report on "Run Forecasts and Harvests Projections for Alaska Salmon Fisheries" for the current year, which also includes a review of the salmon fisheries for the previous season. This report includes forecasts for the coming season of commercial sockeye salmon harvests in Bristol Bay. The reports for the most recent years are available at the "Commercial Salmon Fisheries Forecasts" website:

http://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmonforecast

Reports for earlier years available on the Alaska Department of Fish and Game "Fishing and Subsistence" Publications Searchable Database at:

http://www.adfg.alaska.gov/sf/publications/

To find them, search for the following: Report = All Reports; Field = Title; Operator = Contains; Search String = Forecast. Then scroll through several pages out output until you come to "Commercial Fisheries Reports."

ADFG Bristol Bay Annual Management Reports. These are detailed reports for each salmon season compiled by Alaska Department of Fish and Game Division of Commercial Fisheries Bristol Bay area management staff. Each report also contains an extensive data appendix with dozens of tables of catches and escapements by district, day, gear type, etc. The reports are available on the Alaska Department of Fish and Game "Fishing and Subsistence" Publications Searchable Database at:

http://www.adfg.alaska.gov/sf/publications/

To find them, search for the following: Report = Commercial Fisheries Annual Management Reports; Field = Title; Operator = Contains; Search String = Bristol Bay.

ADFG Bristol Bay Salmon Season Summaries. These are news releases prepared by compiled by Alaska Department of Fish and Game Division of Commercial Fisheries Bristol Bay area management staff after each Bristol Bay salmon season after each salmon season which summarize catches and preliminary ex-vessel price information. The news releases are available on the ADFG Bristol Bay website at:

http://www.cf.adfg.state.ak.us/region2/finfish/salmon/salmhom2.php

ADFG Commercial Operator Annual Report (COAR) Data. In April of every year, all Alaska fish processors are required to submit "Commercial Operator Annual Reports" to the Alaska Department of Fish and Game. In these reports they are required to report the total volume of fish purchased, by species and area; the total amount paid for fish purchased, by species and area; the total volume (weight) of production, by product, species and area; and the total first wholesale value of production. Information about the COAR reporting forms is at:

http://www.adfg.alaska.gov/index.cfm?adfg=fishlicense.coar

The COAR data are not posted on the internet or published regularly by ADF&G (which is unfortunate), but are available by special request from ADF&G. The data used for this report were provided on August 2, 2011 to Gunnar Knapp and were saved as Excel file "Statewide and regional COAR production 1984-2011 provided by ADFG 8-2-11.xls." Average "first wholesale prices" were calculated by dividing first wholesale value by production volume.

ADFG Alaska Commercial Salmon Harvests and Ex-vessel Values Reports. These reports provide summary annual data for each of 11 Alaska salmon harvest areas. The data include average fish weight, average price per pound, numbers of fish, harvest volume in pounds, and estimated value in dollars. Prices for the most recent year are generally preliminary estimates based on fish tickets and reports from area managers. Prices for earlier years are generally based on "Commercial Operators Annual Report and area staff reports." The reports are available at:

http://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmoncatch

ADFG Salmon Ex-Vessel Price Time Series by Species 1984-2008. This is a two-page table of ex-vessel prices by species, 1984-2008, for the following areas: Cook Inlet, Kodiak, Alaska

Peninsula, Bristol Bay, Prince William Sound, Southeast, and Statewide. Original source is cited as the Commercial Operator Annual Reports database.
http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/catchval/blusheet/84-08exvl.pdf

ADLWD Bristol Bay Region Fishing and Seafood Industry Data. The Alaska Department of Labor and Workforce Development (ADLWD) Research and Analysis Division posts a variety of economic information for the Bristol Bay Seafood Industry on its “Bristol Bay Region Fishing and Seafood Industry Data” website at:

http://labor.alaska.gov/research/seafood/seafoodbristol.htm.

ADOR Annual Salmon Price Reports. Every year, “large” Alaska salmon processors (those with sales exceeding 1 million pounds in the previous calendar year) are required to report sales volumes and first wholesale values for major salmon product categories to the Alaska Department of Revenue. Annual statewide summary reports of these data are available on the Alaska Department of Revenue’s Tax Division Reports website at:

http://www.tax.alaska.gov//programs/reports.aspx

Once on this page, click on “Alaska Salmon Price/Production.” Note that the “Annual Salmon Price Reports” differ from (and sometimes are inconsistent with the “Annual Salmon Production Reports” and “Monthly Salmon Price Reports” which are also available at the same website.

ADOR Canned Salmon Wholesale Price Reports. For many years prior to 2001, the Alaska Department of Revenue prepared “Canned Salmon Average Wholesale Reports.” These reported monthly statewide average prices for canned salmon, by species, compiled from information reported by Alaska salmon processors. The University of Alaska Anchorage Institute of Social and Economic Research (ISER) maintains a collection of these reports beginning with the period April 1-September 30, 1983.

ADOR Monthly Salmon Price Reports. Every four months, large Alaska salmon processors (those with sales exceeding 1 million pounds in the previous calendar year) are required to submit salmon price reports to the Alaska Department of Revenue for the following four-month periods: January-April, May-August , and September-December.
The reports include sales volumes and first wholesale values for major salmon product, by area and month. Summaries of the data from these reports, for each four-month period, are available on the Alaska Department of Revenue’s Tax Division Reports website at:

http://www.tax.alaska.gov//programs/reports.aspx.

Once at this page, click on “Alaska Salmon Price/Production.” Note that these “Monthly Salmon Price Report” differ from (and sometimes are inconsistent with the “Annual Salmon Price Reports” and the “Annual Salmon Production Reports” which are also available at the same website. Data are not reported for product-area-month combinations for which fewer than three processors reported sales.

CFEC Basic Information Tables. The Commercial Fisheries Entry Commission (CFEC) posts "Basic Information Tables" for each Alaska salmon fishery on its website at:

http://www.cfec.state.ak.us/bit/MNUSALM.htm

These tables provide a useful summary of trends since 1975 in each salmon fishery for numbers of permits issued/renewed, numbers of permits fished, total pounds harvested, average pound harvested, gross earnings, average earnings, and average annual permit prices. The most recent data currently available are for 2010.

CFEC Data for Alaska Salmon Harvests 1980-2005. 1980-2005: CFEC Alaska Salmon Summary Data 1980-2005 061113. These are Commercial Fisheries Entry Commission data for Alaska commercial salmon harvest (number of fish, pounds, earnings, and price), by species, for the years 1980-2005. This file was prepared by the Commercial Fisheries Entry Commission on March 31, 2005, in response to a request by Professor Gunnar Knapp of the University of Alaska Anchorage Institute of Social and Economic Research (ISER). The data was provided as an Excel file named SWPrices.xls, containing the worksheet of this file named "Original data." Professor Knapp maintains a copy of the file named "CFEC_Alaska_Salmon_Summary_Data _1980-2005.xls." The data were calculated from CFEC fish ticket database. The harvest and earnings figures include set and drift gill net, test fishing, confiscated and educational permit harvests, and any other harvest where the product was sold.

CFEC Data for Bristol Bay Salmon Harvests 1975-2003. These are Commercial Fisheries Entry Commission data for Bristol Bay commercial salmon harvests for the years 1975-2003, provided by Kurt Iverson, June 9, 2004, as file BBayEarnHarv1.xls. The data were calculated from CFEC fish ticket database. The harvest and earnings figures include set and drift gill net, test fishing, confiscated and educational permit harvests, and any other harvest where the product was sold.

CFEC Quartile Tables. The Commercial Fisheries Entry Commission (CFEC) posts annual "Quartile Tables" for each Alaska salmon fishery on its website at:

http://www.cfec.state.ak.us/quartile/mnusalm.htm

These tables show the number of permit holders and average earnings per permit holder in each "quartile group"—calculated by ranking permit holdings in each year by earnings, and then dividing them into four "quartile" groups with equal total earnings. The first quartile has the smallest number of permit holders with the highest average earnings; the fourth quartile has the highest number of permit holders with the lowest average earnings.

CFEC Permit and Fishing Activity Data. The Commercial Fisheries Entry Commission (CFEC) posts annual data on permit and fishing activity by year, state, census area and Alaska city on its website at:

http://www.cfec.state.ak.us/fishery_statistics/earnings.htm

For each state, census area and city in which permit holders reside, and for each fishery for which residents held permits, data include the number of permits issued, number of permit holders, number of permits with recorded landings, total pounds landed and estimated gross earnings. Earnings data are confidential for fisheries in which fewer than four permit holders in a census area or community had landings.

FAO FishstatJ Database. FAO FishstatJ is software for fishery statistical time series developed by the Food and Agricultural Organization of the United Nations (FAO) Fisheries and Aquaculture Department, based in Rome. The software is designed to be used with global datasets for capture (wild) fisheries catches and aquaculture production, by species, country and year. The software and the global datasets can be downloaded from the FAO Fisheries and Aquaculture Department website at:

http://www.fao.org/fishery/statistics/software/fishstatj/en

NMFS Commercial Fishery Landings Database. The National Marine Fisheries Service (NMFS) Office of Science and Technology maintains an online database of US Commercial Fishery Landings (volume and value) by state, species and year. Customized datasets for Alaska and other states may be downloaded from NMFS Commercial Fishery Landings webite at:

http://www.st.nmfs.noaa.gov/st1/commercial/index.html

NMFS Foreign Trade in Fisheries Products Data. The National Marine Fisheries Service posts very detailed data online about U.S. exports and imports of fisheries products at:

http://www.st.nmfs.noaa.gov/st1/trade/

The export data in this report were calculated from the "Monthly Trade Data by Product, Country/Association" option at this website.

NMFS Major Ports Data. The National Marine Fisheries Service publishes an annual report entitled *Fisheries of the United States* which provides a wide variety of useful data on United States fisheries. A regular table in this report (on page 7 in recent years), entitled "Commercial Fishery Landings and Value at Major U.S. Ports," lists the value and volume of landings for the top 50 United States ports (ranked by value). The *Fisheries of the United States* reports are available at:

http://www.st.nmfs.noaa.gov/st1/publications.html

Data Sources for Report Text, Figures and Tables

Below are descriptions of the sources for data provided in the report text, figures and tables. Except where text sources are given below, the data in the text is from the same sources as the adjacent figures and tables in the same sections of the report. Except where text sources are given below, all of the material discussed in the "Overview" and "Summary" sections of the report is discussed in greater detail in corresponding sections of the report. Refer to the body of the report for more details as well as sources for information presented in the “Overview” and “Summary” sections.

Page 52. *“Annual harvests of 31 million salmon . . .”* Source: ADFG Alaska Commercial Salmon Harvests and Exvessel Values Reports.

Page 52. *“51% of world sockeye salmon harvests.”* Source: See discussion below of sources for Figure 22 (World Sockeye Supply).

Page 52. *“Annual ex-vessel” value to fishermen of $129 million.”* Source: ADFG Alaska Commercial Salmon Harvests and Exvessel Values Reports.

Page 52. “Annual first wholesale value . . . of $268 million.” ADFG Commercial Operator Annual Report (COAR) Data.

Page 52. *“26% of the ex-vessel value . . .“* Source: ADFG Alaska Commercial Salmon Harvests and Exvessel Values Reports.

Page 52. *“Seasonal employment of more than 6800 fishermen and 3700 processing workers.”* Source: See sources for Table 36, page 112.

Figure 11. Bristol Bay Commercial Salmon Harvests. Sources: 1975-2003: CFEC Data for Bristol Bay Salmon Harvests; 2004-2010: ADFG Alaska Commercial Salmon Harvests and Exvessel Values Reports; 2011: ADFG 2011 Bristol Bay Salmon Season Summary (9/26/2011).

Page 57. *“The average weight of a Bristol Bay sockeye salmon is typically about 6 pounds. . . . average weights varied from as low as 5.3 pounds to as high as 6.7 pounds.”* Data sources are the same as for Figure 11.

Figure 12. Bristol Bay Fishing Districts. Average annual harvests for the years 1991-2010 were calculated from the same data used for Figure 13.

Figure 13. Bristol Bay Commercial Sockeye Salmon Harvests, by District. Sources: 1986-1989: *ADFG Bristol Bay Annual Salmon Management Report*, 2006, Appendix A3.–Sockeye salmon commercial catch by district, in numbers of fish, Bristol Bay, 1990–2010; 1990-2010: *ADFG Bristol Bay Annual Salmon Management Report*, 2010, Appendix A3.–Sockeye salmon commercial catch by district, in numbers of fish, Bristol Bay, 1990–2010. 2011: *ADFG Bristol Bay Salmon Season Summary*, 2011.

Figure 14. Share of Bristol Bay Commercial Sockeye Salmon Harvest, by District. *Same sources as for* Figure 13.

Figure 15. Naknek-Kvichak District Sockeye Salmon Harvests, by River of Origin. Compiled from ADFG Bristol Bay Annual Management Reports for each year (usually tables 18, 19 or 20).

Table 27. Comparison of Bristol Bay Drift Gillnet and Set Gillnet Fisheries (2006-10 Averages). Source: CFEC Basic Information Tables.

Figure 16. Bristol Bay Salmon Harvests, by Fishery. Source: CFEC Basic Information Tables.

Figure 17. World Sockeye Salmon Supply. Bristol Bay: Sources are the same as for Figure 16. Other Alaska: Calculated by subtracting Bristol Bay data from Alaska data. Alaska data: 1980-2005: CFEC Data for Alaska Salmon Harvests 1980-2005; 2006-2009: ADFG Alaska Commercial Salmon Harvests and Exvessel Values Reports. Lower 48: NMFS Commercial Fishery Landings Database, data for Washington, Oregon and California; Canada, Russia and Japan: FAO FishstatJ Database.

Figure 18. Alaska Salmon Supply. Bristol Bay sockeye: Sources are the same as for Figure 11. Other Alaska sockeye: Calculated by subtracting Bristol Bay data from Total Alaska data. Total Alaska data: 1980-2005: CFEC Data for Alaska Salmon Harvests 1980-2005; 2006-2009: ADFG Alaska Commercial Salmon Harvests and Exvessel Values Reports.

Figure 19 World Salmon and Trout Supply. Wild salmon: Sources are the same as for Figure 17. Farmed salmon and farmed trout: FAO FishstatJ Database. Includes only farmed production of Atlantic, Coho and Chinook salmon. Includes only farmed rainbow trout farmed in a "mariculture" (saltwater) environment.

Figure 20. Bristol Bay Sockeye Preseason Projection and Annual Commercial Catch. Preseaon Projections: 1990-2005: ADFG Bristol Bay Annual Management Reports; Beginning 2006: ADFG Annual Run Forecasts and Harvest Projections. Actual harvests: same sources for Figure 11.

Figure 21 Bristol Bay Sockeye Salmon Harvests, 1895-2009. 1893:-1997: Byerly, Mike; Beatrice Brooks, Bruce Simonson, Herman Savikko and Harold Geiger. 1999. *Alaska Commercial Salmon Catches*, 1878-1997. Alaska Department of Fish and Game Regional Information Report No. 5J99-05. March 1999. 1998-2003: CFEC Data for Bristol Bay Salmon Harvests 1975-2003. 2004-2011: ADFG Alaska Commercial Salmon Harvests and Exvessel Values Reports.

Figure 22. Bristol Bay Sockeye Salmon Production. ADFG Commercial Operator Annual Report (COAR) Data.

Figure 23. Share of Sockeye Salmon Production in Bristol Bay. ADFG Commercial Operator Annual Report (COAR) Data.

Table 28. Sales of Selected Sockeye Salmon Products by Major Bristol Bay Salmon Processors. ADOR Annual Salmon Price Reports.

Figure 24. Bristol Bay Sockeye Salmon Harvests and Production. Harvests: See sources for Figure 11. Production: ADFG Commercial Operator Annual Report (COAR) Data.

Figure 25. Monthly Sale Volume of Bristol Bay Salmon Products. ADOR Monthly Salmon Reports

Figure 26. Alaska Frozen Sockeye Production and U.S. Frozen Sockeye Exports. ADFG Commercial Operator Annual Report (COAR) Data; NMFS Foreign Trade in Fisheries Products Data.

Figure 27. Estimated End-Markets for Alaska Frozen Sockeye Salmon. Sources: ADFG Commercial Operator Annual Report (COAR) Data; NMFS Foreign Trade in Fisheries Products Data. The estimates for the "USA" were calculated by subtracting exports from Alaska production as reported in the COAR data. For the years 1989-1992 reported exports exceeded reported Alaska production. The estimate for the USA was assumed to be zero for these years. This is almost certainly an underestimate. In reality, some frozen sockeye production undoubtedly went to the US market, but the production and export data suggest that the amount going to the US market was relatively low, with most of the production being exported.

Figure 28. Alaska Canned Sockeye Production and U.S. Canned Sockeye Exports. Sources: ADFG Commercial Operator Annual Report (COAR) Data; NMFS Foreign Trade in Fisheries Products Data.

Figure 29. Average Ex-Vessel Price of Bristol Bay Sockeye Salmon. See data sources for Figure 11. Real prices calculated using Anchorage CPI, as discussed below.

Figure 30. Average Wholesale and Ex-Vessel Prices of Bristol Bay Sockeye Salmon. Ex-vessel prices: See data sources for Figure 11. Wholesale Prices: ADFG Commercial Operator Annual Report (COAR) Data.

Figure 31. Average Monthly First Wholesale Prices. Sources: ADOR Monthly Salmon Price Reports

Figure 32. Average Wholesale and Ex-Vessel Prices, Bristol Bay and Rest of Alaska. Rest-of-Alaska wholesale and ex-vessel prices were calculated by dividing Rest -of -Alaska value by Rest-of-Alaska volume. Rest-of-Alaska wholesale value and volume were calculated by subtracting Bristol Bay wholesale value and volume from total Alaska wholesale value and volume, as reported in ADFG Commercial Operator Annual Report (COAR) Data. Rest-of-Alaska ex-vessel value and volume were calculated by subtracting Bristol Bay ex-vessel value and volume (from sources for Figure 16, page 61) from total Alaska ex-vessel value and volume. Sources for total Alaska ex-vessel value and volume were: 1980-2005: CFEC Data for Alaska Salmon Harvests 1980-2005; 2006-2009: ADFG Alaska Commercial Salmon Harvests and Ex vessel Values Reports.

Figure 33. Average Ex-Vessel Prices of Sockeye Salmon, Selected Alaska Areas. Sources: ADFG Alaska Commercial Salmon Harvests and Exvessel Values Reports.

Figure 34. Japanese Red-Fleshed Salmon Imports, May-April. Sources: Japanese monthly import data reported in *Bill Atkinson's News* Report (a weekly compilation of articles and

information from the Japanese seafood industry press, translated into English, published until 2006 by industry analyst Bill Atkinson) and Japanese import data reported on the National Marine Fisheries Service "Fishery Market News" website at: http://www.st.nmfs.noaa.gov/st1/market_news/index.html.

Figure 35. Japanese Red-Fleshed Frozen Salmon Imports & Wild Sockeye Wholesale Prices. Japanese red-fleshed salmon imports are data for May-April, from the same sources as for Figure 34. Sockeye wholesale price data are average prices for the period May-April, from the same sources as for Figure 36.

Figure 36. Japanese Wholesale Prices and Bristol Bay Prices for Sockeye Salmon. Source for ex-vessel price: see sources for Figure 11. Source for average first wholesale price: ADFG Commercial Operator Annual Report (COAR) Data. Sources for Japanese monthly wholesale prices: January 1980-December 1989: Tokyo Central Wholesale Market reports, average price for all frozen sockeye. January 1990-April 2002. Suisan Tsushin (Seafood News), Marine Products Power Data Book, 2002. Beginning May 2002: Japanese frozen market salmon prices posted on www.fis.com and the predecessor "Seaworld" website (data are prices reported for the first day of the month). Monthly wholesale prices in yen/kilo converted to prices in $/lb using monthly Japanese exchange rate data reported on the website of the Federal Reserve Bank of St. Louis (series EXJPUS, available at: http://research.stlouisfed.org/fred2/series/EXJPUS).

Figure 37. Average United States Import Prices of Selected Farmed Salmon Products. Source: NMFS Foreign Trade in Fisheries Products data.

Figure 38. U.S. Wholesale Prices for Selected Wild and Farmed Salmon Products. Prices are from Urner Barry's *Seafood Price-Current*, a twice-weekly market report for U.S. seafood wholesale prices. Data shown in the figure are "low" reported prices for the first reporting date of the month. Products are as follows: "Fresh farmed Atlantic, whole fish": Northeast, Domestic and Canadian Atlantic, 6-8 lbs; "Fresh farmed Atlantic, pinbone-out fillets": Fob Miami, Chilean Atlantic Fillets, Scale-on/Standard, C Trim/Premium,Pinbone out, 2-3 lbs; "Frozen H&G wild sockeye": Red/Sockeye, Gillnet, 4-6 lbs. Information on *Seafood Price-Current* is at www.urnerbarry.com.

Figure 39. Monthly Average Wholesale Case Prices for Alaska Canned Sockeye Salmon. Data through August 2000: ADOR Canned Salmon Wholesale Price Reports (statewide data for canned sockeye salmon). Data beginning September 2000: ADOR Monthly Salmon Price Reports (data for Bristol Bay canned sockeye salmon).

Figure 40. Estimated Chilled and Unchilled Shares of Bristol Bay Salmon Harvests. Northern Economics, *2010 Bristol Bay Processor Survey*. Prepared for Bristol Bay Regional Seafood Development Association, February 2011. Available at: http://www.bbrsda.com/layouts/bbrsda/files/documents/ bbrsda_reports/BB-RSDA%202010%20Survey%20Final%20Report.pdf

Figure 41. Ex-Vessel and First Wholesale Value of Bristol Bay Sockeye Salmon Harvests and Production, 1984-2010. Ex-vessel value: Same data sources as for Figure 11. Wholesale value: ADFG Commercial Operator Annual Report (COAR) Data.

Figure 42. Distribution of Nominal Value of Bristol Bay Sockeye Salmon. Sources for ex-vessel value and wholesale value are the same as for Figure 46, page 94. Value to processors after deducting payments to fishermen was calculated by subtracting ex-vessel value from wholesale value.

Figure 43. Distribution of Value of Bristol Bay Sockeye Salmon. Calculated from data used for Figure 42.

Figure 44. Number of Limited Entry Permits Issued and Fished in Bristol Bay. Source: CFEC Basic Information Tables.

Figure 45. Average Gross Earnings of Bristol Bay Drift Gillnet Permit Holders, by Quartile. Source: CFEC Quartile Tables.

Figure 46. Average Gross Earnings of Bristol Bay Set Gillnet Permit Holders, by Quartile. Source: CFEC Quartile Tables.

Figure 47. Average Prices Paid for Bristol Bay Limited Entry Permits. Source: CFEC Basic Information Tables.

Figure 48. Average Permit Prices and Total Earnings: Bristol Bay Drift Gillnet Fishery. Source: CFEC Basic Information Tables.

Figure 49. Average Permit Prices and Total Earnings: Bristol Bay Drift Gillnet Fishery. Source: CFEC Basic Information Tables.

Figure 51. Number of Companies Reporting Salmon Production in Bristol Bay, by Product. Source: ADFG Commercial Operator Annual Report (COAR) Data.

Figure 52. Selected Bristol Bay Salmon Processor Costs, 2001-2009. “Cost of labor” data are ADLWD Bristol Bay Region Fishing and Seafood Industry Data. They are from the column titled “Seafood Processing Wages” in a table named “Bristol Bay Region Seafood Industry 2003-2009” (as well as earlier versions of the same table no longer posted online) posted at:

http://labor.alaska.gov/research/seafood/BristolBay/BBoverall.pdf

The data are also accessible by clicking on “Harvesting and Processing Workers and Wages” at the ADLWD Bristol Bay Region Fishing and Seafood Industry Data website. “Cost of fish” are ex-vessel values from the same data sources as Figure 11. “Other costs and profits” were calculated by subtracting “cost of labor” and “cost of fish” from wholesale value, as reported in ADFG Commercial Operator Annual Report (COAR) Data.

Figure 54. Monthly Employment in Food Manufacturing, Bristol Bay Region, 2002-2007. Alaska Department of Labor and Workforce Development, Quarterly Census of Employment and Wages Data, historical data for 2002-2010, Excel file annual.xls, downloaded November 27, 2011 from:

http://labor.alaska.gov/research/qcew/qcew.htm

Table 34. Selected Data and Estimates for Bristol Bay Taxes. Ex-vessel value of Bristol Bay salmon harvests: see data sources for Figure 11. Canned and non-canned share of production: ADFG Commercial Operator Annual Report (COAR) Data.

Figure 56. Number of Bristol Bay Permit Holders by Residency. Source: Gho, Marcus, K. Iverson, C. Farrington, and N. Free-Sloan, *Changes in the Distribution of Alaska's Commercial Fisheries Entry Permits, 1975 – 2010*, CFEC Report 11-3N (2011), Appendix C. Available at:

http://www.cfec.state.ak.us/RESEARCH/12-1N/12-1N.htm

Figure 57. Permit Holders Average Earnings, by Residency. Source: Kurt Iverson, *CFEC Permit Holdings, Harvests, and Estimated Gross Earnings by Resident Type in the Bristol Bay Salmon Gillnet Fisheries*, CFEC Report 09-1N (February, 2009). Available at:

http://www.cfec.state.ak.us/RESEARCH/09_1N/09_1N.pdf.

Figure 58. Share of Total Earnings of Bristol Bay Drift Gillnet Permit Holders, by Residency. *Same source as for Figure 57.*

Figure 58. Share of Total Earnings of Bristol Bay Set Gillnet Permit Holders, by Residency. *Same source as for Figure 57.*

Figure 60. Share of Bristol Bay Seafood Processing Employment, by Residency. Source: ADLWD Bristol Bay Region Fishing and Seafood Industry Data, posted at:

http://labor.alaska.gov/research/seafood/seafoodbristol.htm

In particular, see the following tables:

(A) “Bristol Bay Region Seafood Industry, 2003-2009, Processing" at:
http://labor.alaska.gov/research/seafood/BristolBay/BBSFPOver.pdf

(B) “Local Seafood Processing Workforce, 2003-2009, Bristol Bay Region" at:
http://labor.alaska.gov/research/seafood/BristolBay/BBSFPLocal.pdf

The number and percentage of residents of other states or countries was calculated from data in (A). The number and percentage of Bristol Bay residents was calculated from data in (B). The share of “Other Alaska residents” was calculated as the residual.

Figure 61. Local Bristol Bay Resident Share of Salmon Fisheries: Selected Measures. Source for local resident share of total permits held: Gho, Marcus, K. Iverson, C. Farrington, and N. Free-Sloan, *Changes in the Distribution of Alaska's Commercial Fisheries Entry Permits, 1975 – 2010*, CFEC Report 11-3N (2011), Appendix C. Available at:

http://www.cfec.state.ak.us/RESEARCH/12-1N/12-1N.htm

Source for local resident share of total earnings: Iverson, Kurt, CFEC Permit Holdings, Harvests, and Estimated Gross Earnings by Resident Type in the Bristol Bay Salmon Gillnet Fisheries, CFEC Report 09-1N (2009). Available at:

http://www.cfec.state.ak.us/RESEARCH/09_1N/09_1N.pdf

Source for local resident share of processing employment: Alaska Department of Labor and Workforce Development, "Local Seafood Processing Workforce, 2003-2009, Bristol Bay Region," available at:

http://labor.alaska.gov/research/seafood/BristolBay/BBSFPLocal.pdf
Table 37. Population, Permit Holders, and Salmon Earnings, by Community: 2000 & 2010. Source for population: U.S. Census, 2000 and 2010, in "Alaska Population Estimates by Borough, Census Area, City and Census Designated Place (CDP), 2000-2011," Excel spreadsheet available on website of Alaska Department of Labor and Workforce Development, Research and Analysis Division at:

http://labor.alaska.gov/research/pop/popest.htm

Source for numbers of permit holders and earnings: CFEC Permit and Fishing Activity Data.

Figure 63. Estimated Bristol Bay Population, by Area and Region. Data for 2000-2010 are from "Alaska Population Estimates by Borough, Census Area, City and Census Designated Place (CDP), 2000-2011," Excel spreadsheet available on website of Alaska Department of Labor and Workforce Development, Research and Analysis Division, at:

http://labor.alaska.gov/research/pop/popest.htm

Data for 1984-1999 are from Northern Economics, *The Importance of the Bristol Bay Salmon Fisheries to the Region and its Residents*, Report prepared for the Bristol Bay Economic Development Corporation (October 2009), Tables A1-A12.

Figure 63 [TOP FIGURE]. Estimated Bristol Bay Population, by Area. Data for 2000-2010 are from "Alaska Population Estimates by Borough, Census Area, City and Census Designated Place (CDP), 2000-2011," Excel spreadsheet available on website of Alaska Department of Labor and Workforce Development, Research and Analysis Division. Data for 1984-1999 are from Northern Economics, *The Importance of the Bristol Bay Salmon Fisheries to the Region and its Residents*, Report prepared for the Bristol Bay Economic Development Corporation (2009), Tables A1-A12.

Figure 63 [BOTTOM FIGURE]. Estimated Population by Region. Data for 2000-2010 are from "Alaska Population Estimates by Borough, Census Area, City and Census Designated Place (CDP), 2000-2011," Excel spreadsheet available on website of Alaska Department of Labor and Workforce Development, Research and Analysis Division. Data for 1984-1999 are from Northern Economics, *The Importance of the Bristol Bay Salmon Fisheries to the Region and its Residents*, Report prepared for the Bristol Bay Economic Development Corporation (2009), Tables A1-A12.

Figure 65 [TOP FIGURE]. Number of Drift Gillnet Holders, by Region. Source: CFEC Permit and Fishing Activity Data.

Figure 65 [BOTTOM FIGURE]. Number of Drift Gillnet Holders per 100 Residents, by Region. Calculated by dividing data for number of drift gillnet holders, shown in Figure 65 [TOP FIGURE], by data for estimated population by region, from the same sources as for Figure 63 [BOTTOM FIGURE].

Figure 67 [TOP FIGURE]. Number of Set Gillnet Holders, by Region. Source: CFEC Permit and Fishing Activity Data.

Figure 67 [BOTTOM FIGURE]. Number of Set Gillnet Holders per 100 Residents, by Region. Calculated by dividing data for number of set gillnet holders, shown in Figure 67 [TOP FIGURE], by data for estimated population by region, from the same sources as for Figure 63 [BOTTOM FIGURE].

Table 38. Salmon Permit Holders per 100 Residents, by Community. Calculated by dividing data for number of permit holders by community, from CFEC Permit and Fishing Activity Data, by data for population by community, from the same sources as for Figure 63 [BOTTOM FIGURE].

Figure 69 [TOP FIGURE]. Total Salmon Fishery Earnings, by Region. Source: CFEC Permit and Fishing Activity Data.

Figure 69 [BOTTOM FIGURE]. Per Capita Salmon Fisheries Earnings, by Region. Calculated by dividing data for total salmon fisheries earnings, shown in Figure 69 [TOP FIGURE], by data for estimated population by region, from the same sources as for Figure 63 [BOTTOM FIGURE].

Table 39. Bristol Bay Salmon Fishery Earnings, by Community, 2000 and 2010. Calculated by dividing data for salmon fishery earnings by community, from CFEC Permit and Fishing Activity Data, by data for population by community, from the same sources as for Figure 63 [BOTTOM FIGURE].

Table 40. Economic Measures of Bristol Bay Salmon Industry: Sockeye Salmon Harvests. *Same sources as for* Figure 11, Figure 17, Figure 18 *and* Figure 19.

Figure 70. Bristol Bay Commercial Salmon Harvests. *Same sources as for Figure 16.*

Table 41. Economic Measures of Bristol Bay Salmon Industry: Sockeye Value. Source for ex-vessel value is the same as for Figure 11. Source for first wholesale value is ADFG Commercial Operator Annual Report (COAR) Data. Source for Bristol Bay ex-value used in calculation of Bristol Bay sockeye salmon shares of value is the same as for Figure 11. Source of Alaska wild salmon ex-vessel value used to calculate Bristol Bay share of Alaska wild salmon ex-vessel value is the same as for Alaska data for Figure 17. World wild salmon harvest value estimated by multiplying world wild salmon harvests (from the same sources as for Figure 17) by Alaska average ex-vessel prices (from the same sources as for Figure 17). Source for United States Fish and Shellfish Landed Value is NMFS, *Fisheries of the United States*, various years, available at:

http://www.st.nmfs.noaa.gov/st1/publications.html

Source for "Rank of Naknek-King Salmon among U.S. ports in annual landed value" is NMFS Major Ports Data.

Figure 71. Ex-Vessel and Wholesale Value of Bristol Bay Sockeye Salmon. *Same sources as for Figure 46.*

Table 41. Economic Measures of the Bristol Bay Salmon Industry: Export Value. Source for U.S. export value is NMFS Foreign Trade in Fisheries Products Data. Source for estimated share of Bristol Bay sockeye in total Alaska sockeye salmon harvests is the same as for Figure 18. Source for first wholesale value of sockeye salmon roe production is ADFG Commercial Operator Annual Report (COAR) Data.

Figure 72. Estimated Value of US Exports of Bristol Bay Salmon Products. *Same sources as for Table 41.*

Table 43. Economic Measures of the Bristol Bay Salmon Industry: Employment. Source for estimated peak employment and estimated annual average employment is Table 43. Source for Alaska totals used to calculate Bristol Bay share is the Alaska Department of Labor and Workforce Development (ADLWD) Research and Analysis Division website for "Statewide Data, Fishing and Seafood Industry" at:

http://labor.alaska.gov/research/seafood/seafoodstatewide.htm

Table 44. Economic Measures of the Bristol Bay Salmon Industry: Permit Prices and Values. Source for permits issued and permit prices is CFEC Basic Information Tables.

Figure 74. Bristol Bay Commercial Salmon Harvests. *Same sources as for* Figure 11.

Table 45. Distribution of Harvests for Bristol Bay Fishing Districts. See the data sources for Figure 13 for the sources for harvests by district used to calculate the distribution data shown in the table.

Figure 75. Estimated Shares of Bristol Bay Sockeye Salmon Production, 2010. Frozen, Canned, Fresh and Roe share estimated from ADFG Commercial Operator Annual Report (COAR) Data. Frozen fillet and frozen H&G shares and canned talls and canned halves shares estimated from the shares of these products in frozen production and canned production reported in ADOR Annual Salmon Price Reports.

Figure 76. Average Ex-Vessel and Wholesale Prices of Bristol Bay Sockeye Salmon. *Same sources as for* Figure 30.

Figure 77. Ex-Vessel and First Wholesale Value of Bristol Bay Sockeye Salmon Production, 1980-2010. *Same sources as for* Figure 41.

Figure 78. Local Bristol Bay Resident Share of Bristol Bay Salmon Fisheries: Selected Measures. *Same sources as for* Figure 61.

Table 47. Relative Indicators of 2010 Salmon Fishery Participation and Earnings, Bristol Bay Watershed Region. *Calculated from data in* Table 37.

Table 48. Selected Economic Measures of the Bristol Bay Salmon Industry. *Selected data from* Table 40-Table 44.

Table 49. Distribution of Selected Economic Measures for the Bristol Bay Commercial Salmon Fishing Industry. Sources for distribution calculations are as follows: Harvest, ex-vessel price, and ex-vessel value: Same data sources as for Figure 11. First wholesale prices and first wholesale value: ADFG Commercial Operator Annual Report (COAR) Data. Permit prices and estimated permit value: CFEC Basic Information Tables.

Price Index Data for Converting from Nominal Dollars to Real Dollars

The Anchorage Consumer Price Index (CPI) was used to convert selected “nominal” price and value data (not adjusted for inflation) presented in this report to “real” price and value data (adjusted for inflation).

Anchorage and US Consumer Price Indexes

Year	Anchorage CPI	US CPI	Adjustment factor to convert to 2010 dollars using: Anchorage CPI	Adjustment factor to convert to 2010 dollars using: US CPI
1980	85.500	82.400	2.282	2.646
1981	92.400	90.900	2.112	2.399
1982	97.400	96.500	2.004	2.260
1983	99.200	99.600	1.967	2.189
1984	103.300	103.900	1.889	2.099
1985	105.800	107.600	1.844	2.027
1986	107.800	109.600	1.810	1.990
1987	108.200	113.600	1.804	1.920
1988	108.600	118.300	1.797	1.843
1989	111.700	124.000	1.747	1.759
1990	118.600	130.700	1.645	1.668
1991	124.000	136.200	1.574	1.601
1992	128.200	140.300	1.522	1.554
1993	132.200	144.500	1.476	1.509
1994	135.000	148.200	1.446	1.471
1995	138.900	152.400	1.405	1.431
1996	142.700	156.900	1.368	1.390
1997	144.800	160.500	1.348	1.359
1998	146.900	163.000	1.328	1.338
1999	148.400	166.600	1.315	1.309
2000	150.900	172.200	1.293	1.266
2001	155.200	177.100	1.257	1.231
2002	158.200	179.900	1.234	1.212
2003	162.500	184.000	1.201	1.185
2004	166.700	188.900	1.171	1.154
2005	171.800	195.300	1.136	1.117
2006	177.300	201.600	1.101	1.082
2007	181.237	207.342	1.077	1.052
2008	189.497	215.303	1.030	1.013
2009	191.744	214.537	1.018	1.016
2010	195.144	218.056	1.000	1.000
2011	201.427	224.939	0.969	0.969

(a) Anchorage CPI: Consumer Price Index for Anchorage Municipality; (b) US CPI: United States Consumer Price Index, All Urban Consumers. Source: U.S. Dept. of Labor, Bureau of Labor Statistics (BLS), downloaded March 15, 2012 from Alaska Department of Labor & Workforce Development website: http://labor.alaska.gov/research/cpi/cpi.htm.

For any given year, the adjustment factor to convert from nominal dollars to real dollars is the Anchorage CPI for 2010 (195.144) divided by the Anchorage CPI for the year. For example, a nominal price of $1.00 in 1990 would have a “real” 2010 value of (195.144 / 118.600) x $1.00 = 1.645 x $1.00 = $1.64.

This report uses the Anchorage CPI rather than the US CPI because it is the only available measure of inflation for Alaska, and it is the most appropriate measure for accounting for the effects of inflation *for Alaskans*. The table above also shows the corresponding alternative adjustment factors using the US CPI. In practice, using the US CPI would have resulted in very similar "real" prices and values, and would not have resulted in any meaningful changes in any of the analysis or conclusions of this report. The source for both the Anchorage CPI and the US CPI was the U.S. Dept. of Labor, Bureau of Labor Statistics (BLS). These data are available on the Alaska Department of Labor & Workforce Development website at http://labor.alaska.gov/research/cpi/cpi.htm.

4.0 Economic Significance of Healthy Salmon Ecosystems in the Bristol Bay Region: Summary Findings

The purpose of this section is to assess the economic significance of commercial activities that are dependent on ecosystems in the Bristol Bay watershed and important to the regional economy and to the state economy of Alaska. The study region consists of the Bristol Bay Borough, the Dillingham Census Area, and the Lake and Peninsula Borough. This economic significance analysis measures how many annual average jobs and how much personal income was generated in Alaska by expenditures associated with the Bristol Bay commercial salmon industry, subsistence activities, as well as various types of recreational activities dependent on Bristol Bay salmon ecosystems. We divide recreation into sport fishing, sport hunting, and non-consumptive use, based on the primary activity reported by visitors to the Bristol Bay region.

For 2009, we estimate that about 6,300 annual average jobs are attributable to the wild salmon ecosystem in the Bristol Bay region. Residents of Alaska hold more than 80 percent of all jobs. About 60 percent of all Alaskans working in the Bristol Bay region live in other parts of Alaska. About 20 percent of all jobs are held by non-residents from outside Alaska. At the peak of the summer season, there are almost 15,000 jobs in the Bristol Bay region associated with the commercial salmon fishery and recreation industries. In 2009, the total payroll traceable to this economic activity amounts to more than $282 million of which $182 million went to Alaska residents, and more than $100 million was received by non-residents from outside Alaska working seasonally in the commercial salmon fishery, recreation industries, or service providing industries. About $77 million went to local residents of the Bristol Bay region.

The commercial fishing industry provides the biggest contribution to the economic significance of the Bristol Bay ecosystem. In terms of the overall direct employment in the region, half of all jobs are in the fishing industry, followed by government (32 percent), recreation (15 percent), and mineral exploration (3 percent). The largest recreation related contributor of direct jobs in the region is the non-consumptive recreational use sector providing 9 percent of the overall employment followed by sport fishing (5 percent) and sport hunting (1 percent).

Table 50. Estimated Economic Significance of Bristol Bay Ecosystems

	Total	Residents			Non-Residents
		Non-local	Local	Total	
Direct jobs					
Peak	**14,227**	4,365	2,273	6,639	7,587
Commercial fish	***11,572***	*3,251*	*1,089*	*4,341*	*7,231*
Recreation	***2,655***	*1,114*	*1,184*	*2,298*	*356*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Annual average	**2,811**	914	585	1,499	1,313
Commercial fish	***1,897***	*530*	*177*	*707*	*1,190*
Recreation	*914*	*384*	*408*	*792*	*123*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Multiplier Jobs	**3,455**	2,008	1,447	3,455	-
Total jobs (annual average)	**6,266**	2,922	2,032	4,954	1,313
Direct wages ($000)	**$166,632**	$40,149	$31,048	$66,199	$100,435
Commercial fish	***$134,539***	*$22,698*	*$17,608*	*$40,307*	*$94,233*
Recreation	***$32,093***	*$12,451*	*$13,440*	*$25,892*	*$6,202*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Multiplier wages	**$115,976**	$69,250	$46,724	$115,976	-
Total wages	**$282,608**	$104,399	$77,772	$182,175	$100,435

Note, table does not include jobs related to mineral exploration, commercial trapping, commercial fisheries other than salmon, or government.

4.1 Introduction

The purpose of this section is to assess the economic significance of commercial activities that are dependent on ecosystems in the Bristol Bay watershed and important to the regional economy and to the state economy of Alaska.
“Economic significance” refers to how many annual average jobs and how much personal income was generated in Alaska by expenditures associated with the Bristol Bay commercial salmon industry as well as various types of recreational activities and subsistence activities dependent on Bristol Bay ecosystems. Thus it represents the jobs and income supported by a healthy Bristol Bay ecosystem. The study region consists of the Bristol Bay Borough, the Dillingham Census Area, and the Lake and Peninsula Borough. An economic significance analysis is different from an economic impact analysis that quantifies the change in management policy or some factor influencing the use of natural resources in the region. This analysis does not attempt to quantify any changes in the ecosystem, rather seeks to estimate economic activity dependent on a healthy Bristol Bay ecosystem.

Note the following important limitations of this analysis: the analysis does not measure the net economic value of the natural resources occurring in the Bristol Bay region to Alaska and/or the U.S. as a whole. For example, we do not measure the economic value visitors and non-visitors to the region place on preservation of fish, wildlife, and wilderness within the Bristol Bay region. Second, the analysis shows the contributions to the regional economy of Bristol Bay and the rest of Alaska but excludes the contributions occurring in other states of the U.S. or other parts of the world. Fourth, the model shows only a one-year-snapshot of the economy. The analysis is based on data sources of earlier years that have been adjusted to reflect 2009 conditions or they are based on 2009 data. Given the large annual variations that occur in catches for the commercial salmon fishery and for visitation and expenditures related to tourism, the estimated economic significance for 2009 is not necessarily representative of historical or future economic significance.

The following sections of the report first describe the methods used to quantify the economic significance of economic activity in the Bristol Bay region. We then provide a brief regional economic overview followed by the multiplier results for each economic activity. The rationale and uncertainties related to assumptions relevant for the analysis are also discussed. Information about all data sources used is also provided.

Except where noted, all values are expressed in 2009 dollars and where necessary were adjusted using the Anchorage Consumer Price Index, the only available measure of inflation for Alaska. We report employment estimates for residents of three different regions: the local Bristol Bay region (local), other parts of Alaska (non-local residents), and residents of other states or countries (non-residents).

Note, for the purpose of this study, we report peak employment as a point estimate of the maximum count of workers observed, and state all other employment estimates (including multiplier jobs) in terms of *annual average jobs*. For example, six jobs held for 2 month of the year in commercial salmon fishing would result in one annual average job.

4.2 Methods

An economic significance analysis measures the importance of economic activity occurring in a region to the regional and statewide economies. We use jobs and income as two measures to show this significance. To conduct this analysis, we first identify the expenditures and jobs directly associated with the primary economic activity of the region including commercial fishing, recreation, and subsistence. We then calculate the additional expenditures, annual average jobs, and payroll generated by dollars re-circulating through the economy to support industries located in the region and elsewhere in Alaska. These effects are commonly referred to as multiplier effects. Note that these effects are only measuring trade flows in dollars and do not account for non-market trade flows such as bartering and the exchange of goods and services related to subsistence activity.

The process by which purchases by an industry or by households stimulate purchases by other businesses and households is known as the multiplier effect. For this study, we measure multiplier effects for indirect and induced employment and wages. Indirect effects occur when primary industry purchases inputs to their operation from support sectors. For example, fishing boat captains purchase diesel fuel from local gas stations. Induced effects consist of the additional jobs and payroll created when employees of the primary and support industries spend their personal income on consumer goods and services. For example, the manager of the local gas station, where the fishermen purchased fuel, buys bread from the local bakery.

In order to appropriately calculate the effects of re-circulating dollars through the economy, we use a regional Input-Output model developed by University of Alaska Anchorage Economics Professor Scott Goldsmith for the state of Alaska. Models are an imperfect representation of the real world and while they are essential for understanding reality, they should not be confused with that reality itself (Hilborn and Mangel, 1997). Thus the model results we represent are suggestive rather than definitive. If we wished to definitively measure the economic significance of the Bristol Bay ecosystem, we would need to conduct a very large and comprehensive survey of all the economic activity originating from the region and the payment flows that they generate. Such a study would be far outside the scope of this analysis both in terms of its cost as well as the time that it would take to complete.

We refer to the model used in this analysis as the ‘ISER Input-Output model” (Goldsmith, 2000). The model reflects the simplified economic structure of the Alaska economy, consisting of four regions, with the Southwest region encompassing the Bristol Bay study area. Since the model represents the structure of the entire region of Southwest Alaska, it is dominated by the larger urban area (Kodiak and Dutch Harbor), where most of the jobs are located. Other more rural communities, such as those of the Bristol Bay region, have a more rudimentary market economy. As a consequence, the Input-Output model may overstate the local economic activity in a rural area compared to what that spending may actually generate locally In other words, in rural areas, the local jobs multiplier tends to be overstated. However, this slight distortion averages out across the region of Southwest Alaska and statewide. Thus, the aggregate regional effects across Southwest Alaska and the state-wide Alaska economy can be considered more accurate than the estimated local effects within the Bristol Bay region.

Similarly to variation of economic activity within a region, there is also variation among regions. For example, Anchorage serves as the trade and service center for the state. Thus, any spending occurring in rural parts of the state has economic effects in the rural region and in the Southcentral region, where Anchorage is located. An important feature of the ISER Input-Output model is that wages paid in Anchorage can be attributed back to expenditures made in rural areas.

Another important characteristic of the ISER Input-Output model is that it establishes supply constraints. In Alaska, inter-industry purchases mainly occur with services and raw materials that are supply-constrained due to resource scarcity and the limited availability of capital and labor to extract the raw materials. "Off-the-shelf" Input-Output models developed primarily for other less resource-dependent states, such as IMPLAN, do not take this characteristic into account, and potentially overestimate multiplier effects within Alaska (MIG, 2011). Another important attribute of the Alaska economy is that inter-industry purchases are less important in Alaska compared to more mature economies. The absence of a developed manufacturing sector in Alaska means that most goods must be purchased outside the state, creating large leakages and small indirect multiplier effects.

Despite the outlined advantages of the ISER Input-Output model, there remain many challenges to the analysis. One of these challenges is that the economic structure depends in large part on determining where the workers reside when they are not working. Many workers, particularly in the commercial fishing industry, don't live in the Bristol Bay region. These workers only come to the region for a two to four months long period in the summer but live elsewhere the rest of the year.

Another challenge is that there is no Input-Output model currently available that incorporates subsistence activity as an industry. Current Input-Output models solely reflect market economies and their sectors and ignore non-market sectors such as household work or subsistence activity. Due to the importance of subsistence to the regional economy of the Bristol Bay region, we believe that ideally the subsistence sector would be incorporated into input-output analysis of the economies of rural Alaska regions such as Bristol Bay where it is an important part of the economy. However, this kind of research would require additional effort and time far beyond the scope of this analysis.

Sections 4.8 and 4.9 further discuss data sources used and the implications of assumptions made on overall results. Due to a lack of certain kinds of data and other sources of uncertainty further discussed in the appendix, the reader should interpret the estimated impacts as suggestive rather than definitive.

The following two tables show how many jobs and income are associated with $1 million in 2009 spending in Southwest Alaska. For example, $1 million dollars of in-state spending on air transportation in Southwest Alaska creates approximately six jobs in Southwest Alaska and one job in Southcentral Alaska (Table 51). In addition, this spending generates $344,000 in payroll in Southwest Alaska and $54,000 in payroll in Southcentral Alaska (Table 52).

Table 51. Annual average jobs associated with $1 million in spending in each sector in Southwest Alaska, 2009

	SOUTH EAST I	SOUTH CENTRAL II	SOUTH WEST III	NORTH IV	STATE TOTAL
Agriculture and AFF Services	0.0	0.9	5.5	0.0	**6.3**
Forestry	0.0	0.3	4.2	0.0	**4.4**
Fishing	0.0	0.2	4.2	0.0	**4.3**
Crude Petroleum and Natural Gas	0.0	0.9	0.6	0.0	**1.5**
Other Mining	0.0	0.9	4.2	0.0	**5.1**
New Construction	0.0	0.0	4.1	0.0	**4.1**
Maintenance and Repair	0.0	4.0	10.2	0.0	**14.1**
Food and Kindred Products	0.0	0.2	5.3	0.0	**5.5**
Paper and Allied Products	0.0	0.0	5.0	0.0	**5.0**
Chemicals and Petroleum Processing	0.0	0.1	1.1	0.0	**1.2**
Lumber and Wood Products	0.0	0.0	5.6	0.0	**5.7**
Other Manufacturing	0.0	0.4	8.4	0.0	**8.8**
Railroads	0.0	0.2	4.1	0.0	**4.3**
Local and Interurban Transit	0.0	0.2	11.7	0.0	**12.0**
Motor Freight and Warehousing	0.0	1.1	10.2	0.0	**11.2**
Water Transportation	0.0	0.3	4.4	0.0	**4.7**
Air Transportation	0.0	1.0	6.4	0.0	**7.4**
Pipelines	0.0	0.1	3.7	0.0	**3.8**
Transportation Services	0.0	0.3	6.8	0.0	**7.2**
Communication	0.0	1.3	6.1	0.0	**7.4**
Electric, Gas, Water, and Sanitary	0.0	0.8	2.7	0.0	**3.5**
Wholesale Trade	0.0	4.6	10.0	0.0	**14.6**
Retail Trade	0.0	12.3	30.4	0.0	**42.7**
Finance	0.0	4.0	9.2	0.0	**13.2**
Insurance	0.0	2.1	8.9	0.0	**11.0**
Real Estate	0.0	0.9	0.7	0.0	**1.6**
Hotels, Lodging, Amusements	0.0	1.9	15.0	0.0	**16.9**
Personal Services	0.0	2.0	24.2	0.0	**26.3**
Business Services	0.0	6.4	20.2	0.0	**26.6**
Eating and Drinking	0.0	8.5	26.8	0.0	**35.3**
Health Services	0.0	4.8	18.8	0.0	**23.6**
Miscellaneous Services	0.0	4.6	15.1	0.0	**19.7**
Federal Government Ent	0.0	0.4	6.3	0.0	**6.7**
State & Local Government Ent	0.0	0.1	8.3	0.0	**8.4**

Table 52. Annual payroll associated with $1 million in spending in each sector in Southwest Alaska, 2009

	SOUTH EAST I	SOUTH CENTRAL II	SOUTH WEST III	NORTH IV
Agriculture and AFF Services	$ -	$ 43,276	$ 274,635	$ -
Forestry	$ -	$ 13,755	$ 209,563	$ -
Fishing	$ -	$ 8,821	$ 209,563	$ -
Crude Petroleum and Natural Gas	$ -	$ 150,128	$ 92,746	$ -
Other Mining	$ -	$ 72,014	$ 326,900	$ -
New Construction	$ -	$ 254	$ 254,526	$ -
Maintenance and Repair	$ -	$ 243,764	$ 626,678	$ -
Food and Kindred Products	$ -	$ 7,446	$ 181,843	$ -
Paper and Allied Products	$ -	$ 524	$ 165,218	$ -
Chemicals and Petroleum Processing	$ -	$ 12,003	$ 97,505	$ -
Lumber and Wood Products	$ -	$ 1,092	$ 211,898	$ -
Other Manufacturing	$ -	$ 15,244	$ 299,200	$ -
Railroads	$ -	$ 16,082	$ 296,407	$ -
Local and Interurban Transit	$ -	$ 5,409	$ 269,956	$ -
Motor Freight and Warehousing	$ -	$ 35,723	$ 336,974	$ -
Water Transportation	$ -	$ 21,311	$ 316,516	$ -
Air Transportation	$ -	$ 54,410	$ 344,270	$ -
Pipelines	$ -	$ 4,718	$ 268,972	$ -
Transportation Services	$ -	$ 14,772	$ 296,132	$ -
Communication	$ -	$ 87,937	$ 423,144	$ -
Electric, Gas, Water, and Sanitary	$ -	$ 55,677	$ 186,376	$ -
Wholesale Trade	$ -	$ 227,652	$ 494,997	$ -
Retail Trade	$ -	$ 365,739	$ 904,797	$ -
Finance	$ -	$ 206,101	$ 476,973	$ -
Insurance	$ -	$ 108,765	$ 463,912	$ -
Real Estate	$ -	$ 29,189	$ 23,538	$ -
Hotels, Lodging, Amusements	$ -	$ 46,021	$ 360,382	$ -
Personal Services	$ -	$ 44,267	$ 526,104	$ -
Business Services	$ -	$ 298,171	$ 940,459	$ -
Eating and Drinking	$ -	$ 151,775	$ 479,206	$ -
Health Services	$ -	$ 197,932	$ 785,286	$ -
Miscellaneous Services	$ -	$ 172,055	$ 565,071	$ -
Federal Government Ent	$ -	$ 25,818	$ 403,554	$ -
State & Local Government Ent	$ -	$ 5,415	$ 360,384	$ -
Households	$ -	$ 9,129	$ 22,931	$ -

Source: ISER Input-Output Model (Goldsmith, 2000).

4.3 Regional Economic Overview

The economy of the Bristol Bay Region depends on three main activities (basic sectors)—publicly funded services through government and non-profits, commercial activity associated with the use of natural resources (mainly commercial fishing and recreation), and subsistence. Subsistence is a non-market activity in the sense that there is no exchange of money associated with the subsistence harvest. However, local participants invest a significant portion of their time and income to participate in subsistence and the harvest has considerable economic value and their expenditures have significant economic effects.

Public services and commercial activities bring money into the economy (basic sectors) and provide the basis for a modest support sector. The support sector (non-basic sector) consists of local businesses that sell goods and services to the basic sectors including the commercial fishing industry, the recreation industry, the government and non-profit sectors. The support sector also sells goods and services to participants in subsistence activities.

The relative importance within the regional economy of government as contrasted with commercial fishing and recreation can be measured by the annual average employment in each sector. In 2009, more than two thousand jobs were directly associated with government spending from federal, state, and local sources. Commercial fishing and recreation accounted for approximately three thousand or 57 percent of total basic sector jobs (Table 53). Since much of the recreation is using public lands and resources, a share of the government sector; for example administration of the federal and state parks and wildlife refuges, is directly related to providing jobs and opportunities in the recreation sector. Accordingly, the estimate of recreation-dependent jobs is conservative.

The annual spending of federal dollars in the region is another indicator of the importance of the government sector in the region. Table 54 shows that in 2009, $119 million in federal spending flowed into the three labor market areas of the Bristol Bay region.

The support sector depends on money coming into the regional economy from outside mainly through government, commercial fishing, and recreation. The relative dependence of the support sector on the three main sectors is difficult to measure. One reason for this is that government employment is stable throughout the year, while employment in commercial fisheries and recreation vary seasonally. Due to the seasonal stability of government jobs, the payroll spending of people employed in government is likely to contribute more to the stability of support sector jobs in the region than their share of basic sector jobs indicates.

Table 53. Employment Count by Place of Work in the Bristol Bay Region, 2009

	Annual Average	Summer	Winter	Swing
Total jobs count	**6,648**	16,386	3,792	12,594
Basic	**5,490**	14,877	2,430	12,447
Fish harvesting	**1,409**	6,909	-	6,909
Fish processing	**1,374**	4,480	354	4,126
Recreation	**432**	1,297	-	1,297
Government & Health	**2,039**	1,712	2,056	(344)
Mineral Exploration	**197**	450	70	380
Non-basic	**1,406**	1,509	1,362	147
Construction	**61**	92	55	37
Trade/Transportation/Leisure	**634**	717	593	124
Finance	**155**	142	162	(20)
Other wage & salary	**239**	241	235	6
Non-basic self employed	**317**	317	317	-
Resident jobs count	**4,675**	10,351	3,225	7,126

Note, estimates based on ISER Input-Output Model (Goldsmith, 2000).

Note, fish harvesting and processing include other fisheries but salmon, thus employment numbers cannot be compared with other tables shown in this report. Summer and winter employment shown, are point estimates that either show the maximum or minimum job count. Swing refers to the difference between maximum and minimum. See Appendix B for sources used.

Table 54. Federal Spending in the Bristol Bay Region, 2009 ($000)

	Bristol Bay	Dillingham	Lake & Pen	Total
Total	$49,600	$54,345	$16,013	**$119,958**
Retirement	$6,934	$6,764	$545	**$14,243**
Other direct to individuals	$1,930	$10,235	$4,799	**$16,964**
Grants	$32,867	$32,467	$7,878	**$73,212**
Procurement	$4,440	$1,005	$857	**$6,302**
Wages	$3,430	$3,874	$1,934	**$9,238**

Source: U.S. Department of Commerce (2009).

Table 55. Estimated Residence of Workers in the Bristol Bay Region 2009

	Local	Other Alaska	Outside Alaska	Total
Bristol Bay				
State government	24	14	9	**47**
Local government	126	12	18	**156**
Private sector	273	332	1,916	**2,521**
Sum	**423**	**358**	**1,943**	**2,724**
Dillingham				
State government	90	24	8	**122**
Local government	877	66	94	**1,037**
Private sector	1,033	270	728	**2,031**
Sum	**2,000**	**360**	**830**	**3,190**
Lake & Pen				
State government	7	7	3	**17**
Local government	417	105	66	**588**
Private sector	179	322	685	**1,186**
Sum	**603**	**434**	**754**	**1,791**
Total Private	**1,485**	**924**	**3,329**	**5,738**
Share	26%	16%	58%	**100%**

Source: ADOL (2009). Note, this is a count of workers (unique individuals) and not a measure of Full Time Equivalent or annual average jobs. Also, the table includes processing workers but excludes harvesters in the commercial fishery (private sector).

The estimated personal income in the region varies by borough/census area. The Bureau of Economic Analysis (BEA) reports more than $58,000 as the 2009 per capita personal income for the Bristol Bay Borough. Per capital personal income in the Lake and Peninsula Borough or in the Dillingham Census Area is approximately equal to $35,000 (Table 56). For comparison, the 2009 per capita personal income in Anchorage amounts to $48,598.

The commercial salmon fishery provides above average income to seasonal workers and residents of the region. Because of the large amounts of income received by seasonal workers that do not reside in the Bristol Bay region, BEA applies the *Alaskan seasonal worker adjustment*. This residence adjustment lowers the income generated in the region by the amount that is believed to be received by people working in Bristol Bay but not residing in the region. In part, it is a subjective measure for the amount of income flowing out of the Bristol Bay Borough to other areas of Alaska and to Washington State, Oregon, and California (BEA, 2007). Thus, the per capita income measures stated here are uncertain and should be viewed as suggestive rather than definitive.

Table 56. Estimated Personal Income in the Bristol Bay Region, 2009 (000$)

	Bristol Bay	Dillingham	Lake & Pen	Total
Wages	$57,018	$96,654	$27,551	**$181,223**
+ Supplements to wages	$16,694	$28,021	$9,164	**$53,879**
+ Proprietor income	$9,421	$16,194	$2,605	**$28,220**
= Earnings by place of work	$83,133	$140,869	$39,320	**$263,322**
- Contributions for government social insurance	$8,799	$14,820	$3,736	**$27355**
+ Residence adjustment	-$39,175	-$4,530	-$1,055	**-$44,760**
= Net earnings by place of residence	$35,159	$121,519	$34,529	**$191,207**
+ Dividends	$7,382	$20,314	$7,980	**$35,676**
+ Transfers	$9,189	$35,764	$11,981	**$56,934**
= Personal Income	$51,730	$177,597	$54,490	**$283,817**
Population	881	4,957	1,485	**7,323**
Per Capita Income	$58,717	$35,828	$36,694	**$38,757**

Source: BEA (2009).

4.4 Commercial Salmon Fisheries

The largest share of jobs and income generated in the Bristol Bay region comes from commercial salmon fishing, including drift gillnet and set gillnet fisheries. The commercial salmon fishery is described in detail in Section 3 of this report. Here we provide a brief summary description prior to presenting estimates of the economic significance of the industry.

The number of commercial fishing jobs and income varies from year to year due to the varying size and value of the salmon harvest. For example, the ex-vessel value paid to fishermen fell from a peak of $214 million in 1989 to $32 million in 2002, and recovered to $148 million in 2009. The 2009 harvest was 192 million pounds. The whole sale value of these fish amounted to $300.2 million.[26]

At the peak of the 2009 commercial salmon fishery, about 1,000 local residents and 6,000 seasonal workers from outside the region participated in the commercial salmon fishery's harvest. In addition, approximately 4,500 non-local processing workers came to the Bristol Bay region. At the peak of the season approximately 11,500 workers had jobs in harvesting and processing combined. About 4,300 of these workers were Alaska residents and approximately 7,200 came from outside the state.

We estimate that total income to harvesters in 2009 was approximately $103 million of which permit holders received $72 million (70 percent) and $31 million went to crew members. Alaskans participating directly in harvesting and processing earned approximately $40 million amounting to 42 percent of total direct wages. Local residents of the Bristol Bay region earned $17.6 million (12 percent) of total direct income in processing and harvesting combined.
The commercial salmon season is highly seasonal. Almost all fishing and processing activity occurs between June and August. For the purpose of our analysis, we assume that each seasonal fishing job lasts two months. Therefore, six seasonal jobs equate to one annual average job.

The in-state spending by harvesters, processors, and workers in the region and in other places of Alaska created additional jobs in other sectors of the economy through the multiplier effect. We estimate that on an annual average basis, 1,586 additional jobs (754 locally and 832 in the rest of Alaska) and $54.7 million in indirect wages were traceable to commercial fisheries. These jobs were in the trade, service, finance, and other support industries. Jobs created outside of the state are not included in these estimates.

In 2009, the total income traceable to commercial salmon fishing in Bristol Bay equaled $189 million. Accounting for the short two months summer season in commercial salmon fishing, the 11,500 direct commercial salmon fishing jobs translate to approximately 1,900 jobs on an annual average basis. With the addition of multiplier jobs, about 3,500 annual average jobs would be attributable to the commercial salmon fishing industry (Table 57).

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[26] Estimates of some year-specific commercial fishery total harvest and total sales vary slightly within this report. This is due to differences in how these data are aggregated and reported by the Alaska Fish and Game, and the point in time these statistics were accessed during the preparation of this report.

Table 57. Estimated Economic Significance of Commercial Fishing

	Total	Residents			Non-Residents
		Non-local	Local	Total	
Direct jobs					
Peak	**11,572**	3,251	1,089	4,341	7,231
Harvesting	***7,050***	*2,694*	*1,013*	*3,708*	*3,342*
Processing	***4,522***	*557*	*76*	*633*	*3,889*
Annual average	**1,897**	530	177	707	1,190
Harvesting	***1,143***	*437*	*164*	*601*	*542*
Processing	***754***	*93*	*13*	*106*	*648*
Multiplier Jobs	**1,586**	832	754	1,586	-
Total jobs (annual average)	**3,483**	1,362	931	2,293	1,190
Direct wages ($000)	**$134,539**	$22,698	$17,608	$40,307	$94,233
Harvesting	***$103,354***	*$19,645*	*$16,609*	*$36,255*	*$67,100*
Processing	***$31,185***	*$3,053*	*$999*	*$4,052*	*$27,133*
Multiplier wages	**$54,705**	$28,101	$26,604	$54,705	-
Total wages	**$189,244**	$50,799	$44,212	$95,012	$94,233

Note, estimates based on ISER Input-Output Model (Goldsmith, 2000).

4.5 Recreation

The second largest portion of jobs and income generated by spending dependent on Bristol Bay salmon resources comes from the recreation sector which directly employs approximately 2,600 workers during peak season translating to about 900 annual average jobs with an annual payroll of more than $32 million. Most recreational visits occur during the summer months, creating a peak in economic activity that largely coincides with the peak of the commercial salmon fishery. Recreational activity concentrates in Katmai National Park and Preserve, Lake Clark National Park and Preserve as well as the National Wildlife Refuges: Alaska Peninsula/Becharof, Ixembek, and Togiak. Sport fishing activity occurs mainly in the Nushagak and Naknek River watersheds, whereas sport hunting occurs predominately in the Mulchatna River watershed. Visitors travel to Alaska by air, ferry, highway, and cruise ship. Each of these travel markets has distinct visitor attributes, demographics and regional impacts. Visitation to Southwest Alaska is primarily driven by independent travelers who predominately arrive by air. Statewide visitation declined 5.8 percent between 2008 and 2009 as a result of the recession following the collapse of financial markets in late 2008. Cruise passenger volume remained essentially the same in 2009 because ship deployment decisions require a longer lead time than air. In contrast, air visitor traffic decreased by 15 percent in 2009.

The rebound in Alaska visitation in 2010 was led by independent travelers arriving by air, and to a lesser extent road, ferry, and international visitors. This rebound is expected to continue in 2011 and again be comprised primarily of independent travelers. These independent visitors tend to visit Alaska's more remote regions, while cruise visitors primarily visit the marine accessible Southeast region and the Southcentral and Interior regions including Denali National Park and Preserve. Katmai National Park and Preserve in Southwest Alaska showed a rebound in visitor numbers in 2010 after declines in 2008 and 2009, based on National Park Service Commercial Use Authorization permit report data. Among those that reported boosts in independent-visitor traffic are lodges, tour operators, and campgrounds, according to the Alaska Travel Industry Association.

We estimate that there were approximately 40,964 non-consumptive recreation visitors to Southwest Alaska in 2009 of which approximately 10 percent were Alaska residents. Visitor related spending amounted to approximately $173.3 million in 2009. The average spending per visitor and the average length of stay are higher in Southwest Alaska compared to respective statewide averages. Based on the Alaska Visitor Statistics Program (2011), non-residents visiting Southwest Alaska spent $2,873 per visitor and stayed 12.9 nights whereas the statewide average visitor spent $992 and stayed 9.1 nights. Fay and Christensen (2010) estimate per visitor spending in Katmai to amount to $2,332. Also, recreational expenditures occurring inside Katmai NPP are relatively high for a remote Alaska park because of the location of Brooks Camp and concession businesses located inside the park. Based on the visitor spending reported by the Alaska Visitor Statistics Program (2011) and Fay and Christensen (2010), we estimate non-consumptive visitor spending in the Bristol Bay region to equal $2,548 per visitor and year.

Among all recreational users of the region, non-residents spent the largest amount, equaling $149.5 million or 86 percent of total spending. Alaskans from outside the region spent an estimated $18.9 million, whereas locals had the smallest amount equaling $4.9 million in recreation related expenditures. The per-visitor expenditures to destinations in Southwest Alaska are higher compared to other locations in Southcentral Alaska because most travelers go by air to the more remote locations such as Bristol Bay, whereas the largest portion of visitors to Southcentral Alaska come to Alaska by cruise ship.

Table 58. Estimated Recreational Visitors and Expenditures in the Bristol Bay Region, 2009

	Local residents	Non-local residents	Non-residents	**Total**
Visitors				
Non-consumptive	-	4,506	36,458	**40,964**
Sport fishing	13,076	3,827	12,464	**29,367**
Sport hunting	-	1,319	1,323	**2,642**
Total	**13,076**	**9,652**	**50,245**	**72,973**
Spending per visitor				
Non-consumptive	-	$2,548	$2,548	
Sport fishing	$373	$1,582	$3,995	
Sport hunting	-	$1,068	$5,170	
Spending ($million)				
Non-consumptive	-	$11.5	$92.9	**$104.4**
Sport fishing	$4.9	$6.0	$49.8	**$60.7**
Sport hunting	-	$1.4	$6.8	**$8.2**
Total	**$4.9**	**$18.9**	**$149.5**	**$173.3**

Note that some visitors combine fishing with non-consumptive use activities. These visitors are included here in sport fishing. Cost of travel to Alaska for non-residents not shown. Annual spending per non-consumptive visitor is the weighted average of visitor spending related to Katmai and other locations in the Bristol Bay Region.

The local economic impact of visitor spending occurs primarily through local purchases of goods and services. This effect is captured in the multiplier jobs and wages in . The multiplier jobs are held in the transportation, accommodation, and trade sectors of the economy. A large share of these jobs is located outside the Bristol Bay region in Southcentral Alaska where most of the goods and services originate from. The jobs in these sectors are more likely to be filled by Alaska residents who live where they work, and they are more likely year-round rather than seasonal jobs.

For 2009, we estimate the total annual average number of jobs that are traceable to recreational visits to the Bristol Bay region to equal 2,715 with total payroll of $90.8 million. On an annual average basis, the majority (44 percent) of the 914 direct jobs were held by local residents of the region followed by other Alaska residents (384 jobs). Other Alaskans either moved into the region to fill a job during the summer season, or their job was located in Anchorage and attributable to recreation occurring in the Bristol Bay region. A smaller share of total jobs (13 percent) was taken by non-residents. Also, some of the indirect jobs in transportation, trade, and accommodations were probably filled by non-residents rather than residents. Important to note is that due to a lack of data, the distribution of jobs and income by residency is uncertain. However, total employment and total income estimates are more robust measures.

Note, since many of the goods and services consumed in Alaska, are produced outside of Alaska and consequently have economic effects elsewhere, these spillover effects are not part of this economic analysis.

Table 59. Estimated Economic Significance of All Recreation

	Total	Residents			Non-Residents
		Non-local	Local	Total	
Direct jobs					
Peak	**2,655**	1,114	1,184	2,298	356
Non-cons.	***1,669***	*735*	*741*	*1,475*	*193*
Sport Fish	***854***	*328*	*383*	*712*	*142*
Sport Hunt	***132***	*51*	*60*	*111*	*21*
Annual average	**914**	384	408	792	123
Non-cons.	***575***	*253*	*255*	*509*	*67*
Sport Fish	***294***	*113*	*132*	*245*	*49*
Sport Hunt	***45***	*18*	*21*	*38*	*7*
Multiplier Jobs	**1,801**	1,129	672	1,801	-
Total jobs (annual average)	**2,715**	1,513	1,080	2,593	123
Direct wages ($000)	**$32,093**	$12,451	$13,440	$25,892	$6,202
Non-cons.	***$19,107***	*$7,823*	*$7,925*	*$15,748*	*$3,359*
Sport Fish	***$11,279***	*$4,020*	*$4,777*	*$8,797*	*$2,482*
Sport Hunt	***$1,707***	*$608*	*$738*	*$1,347*	*$361*
Multiplier wages	**$58,672**	$39,380	$19,290	$58,672	-
Total wages	**$90,765**	$51,831	$32,730	$84,564	$6,202

Note, estimates based on ISER Input-Output Model (Goldsmith, 2000). All direct jobs are in the Bristol Bay region. Multiplier jobs are divided between Bristol Bay and Southcentral Alaska. Multiplier jobs are assumed to be all taken by residents of the region where they occur. Peak and annual average direct wages are assumed to be equal.

4.5.1 Non-Consumptive Use

Most of recreational spending in the Bristol Bay region is related to non-consumptive use, for example wildlife viewing of coastal brown bears and bird species, or kayaking and camping activities. For this part of the analysis we estimate visitation based on the most recent studies of non-resident visitors to the state and two studies that estimated visitation and economic impacts related to Katmai National Park and Preserve. On an annual basis including summer and winter visitation, approximately 2,300 residents and 18,900 non-residents visited Katmai NPP. Other areas in the Bristol Bay region received approximately 2,300 resident visitors and 19,000 non-resident visitors. Note, these estimates exclude visitation where sport fishing or sport hunting was in part or the primary activity of choice. After adjusting the per capita expenditures to 2009 dollars we estimate per person expenditures to amount to $2,245 annually for Katmai NPP and $2,873 per person annually for visiting other destinations in the Bristol Bay region.

To be consistent with the expenditure data for sport fishing and hunting, we assume that the visit to the Bristol Bay region was the primary reason for their visit to Alaska. For these visitors we include all their instate spending in the calculation of multiplier jobs and income.

We estimate a total of 1,681 annual average jobs to be attributable to non-consumptive use of natural resources in the Bristol Bay region with a payroll of $54.8 million. The main proportion (57 percent) of jobs are held by residents of Alaska that do not live in the Bristol Bay region either because they move to Bristol Bay for the summer months to fill a seasonal job or because they work in Anchorage for a supplier of goods and services to the Bristol Bay region. The total income generated in 2009 for residents of Alaska amounted to $51.4 million.

Table 60. Estimated Economic Significance of Non-Consumptive Use

	Total	Residents			Non-Residents
		Non-local	Local	Total	
Direct jobs					
Peak	**1,669**	735	741	1,475	193
Annual average	**575**	253	255	509	67
Multiplier Jobs	**1,106**	703	403	1,106	-
Total jobs (annual average)	**1,681**	956	658	1,615	67
Direct wages ($000)	**$19,107**	$7,823	$7,925	$15,748	$3,359
Multiplier wages	**$35,668**	$24,059	$11,608	$35,668	-
Total wages	**$54,775**	$31,882	$19,533	$51,416	$3,359

Note, estimates based on ISER Input-Output Model (Goldsmith, 2000). All direct jobs are in the Bristol Bay region.

4.5.2 Sport Fishing

The second largest share of total recreational expenditures in the Bristol Bay region is associated with sport fishing, either as the only or as the primary activity of the visitor. Non-residents account for 53 percent of visitors that fish in the region and spend 82 percent of total sport fish related expenditures attributable to the region, excluding travel to Alaska. Non-residents are most likely to hire guides and stay at local lodges. Alaska residents account for 47 percent of visitation and spend 10 percent of total sport-fish-related expenditures. We also include spending on sport fishing by local residents, even though that spending does not bring in money from outside the region to the Bristol Bay region. If there would not be any sport fishing opportunities in the region, that local spending could likely shift to other areas outside the region and thus provides the rationale for including it in our calculations.

At the peak of the fishing season in July, employment in sport fishing reaches 854 direct seasonal jobs. The annual average employment traceable to sport fishing in the region amounts to approximately 300 annual average jobs, of which almost half are taken by local residents. The total estimated payroll attributable to sport fishing activities in the Bristol Bay region amounts to $31.4 million in 2009. We estimate that about a third of total payroll went to local residents of the Bristol Bay region. After counting for multiplier jobs, more than 900 annual average jobs are traceable to sport fishing occurring in the Bristol Bay region.

Table 61. Estimated Economic Significance of Sport Fishing

	Total	Residents			Non-Residents
		Non-local	Local	Total	
Direct jobs					
Peak	**854**	328	383	712	142
Annual average	**294**	113	132	245	49
Multiplier Jobs	**608**	371	237	608	-
Total jobs (annual average)	**902**	484	368	853	49
Direct wages ($000)	**$11,279**	$4,020	$4,777	$8,797	$2,482
Multiplier wages	**$20,118**	$13,339	$6,779	$20,118	-
Total wages	**$31,397**	$17,359	$11,556	$28,915	$2,482

Note, estimates based on ISER Input-Output Model (Goldsmith, 2000). All direct jobs are in the Bristol Bay region.

4.5.3 Sport Hunting

Compared to other recreation activities, sport hunting accounts for the smallest share of total recreational expenditures (3 percent) and the fewest visitors overall (5 percent) (Table 58). The larger per person expenditure of $3,122 per visitor is related to higher travel costs. In addition, non-residents are by law required to hire local guide services which adds to the cost for hunting, including air service to remote hunting locations. Sport hunters are also more likely to hire commercial operators for sport hunting. Of the 125 total annual average jobs in Alaska attributable to sport hunting, most are taken by residents of the state with the majority of workers residing outside the Bristol Bay region. The total payroll attributable to spending traceable to sport hunting in the Bristol Bay region is more than $4 million, with the majority going to non-local residents of Alaska residing in the Southcentral region of Alaska.

Table 62. Estimated Economic Significance of Sport Hunting

	Total		Residents		Non-Residents
		Non-local	Local	Total	
Direct jobs					
Peak	**132**	51	60	111	21
Annual average	**45**	18	21	38	7
Multiplier Jobs	**87**	55	32	87	-
Total jobs (annual average)	**132**	73	53	125	7
Direct wages ($000)	**$1,707**	$608	$738	$1,347	$361
Multiplier wages	**$2,886**	$1,982	$903	$2,886	-
Total wages	**$4,593**	$2,590	$1,641	$4,233	$361

Note, estimates based on ISER Input-Output Model (Goldsmith, 2000). All direct jobs are in the Bristol Bay region.

4.6 Subsistence

Subsistence is an important component of the regional economy even though it is not part of the market economy. Consequently there is no official measure for employment or the amount of payroll associated with the pursuit of subsistence resources. However, there remains a link between subsistence and the market economy in form of equipment, goods, and services purchased by households participating in subsistence. Typically these purchases include boats, rifles, nets, snow mobiles, and fuel used exclusively to take part in subsistence activities.
Data on expenditures related to subsistence activities in the Bristol Bay region is not publically available. Our estimate of $3,054 per household relies on data from a survey conducted in 1993 in the North Slope Borough (North Slope Borough, 1993; Goldsmith, 1998). Although, income, employment opportunities, and subsistence methods used in the North Slope Borough are different, there is evidence that suggests the estimate is justified. The results of a 1980s subsistence survey in Western Alaska communities are consistent with the 1993 North Slope estimate (Peterson et al., 1992).

A large share of the 68 multiplier jobs occurs in the Southcentral region (47 jobs) with more than $1.8 million in payroll. Local multiplier jobs amount to approximately 16 and an annual payroll of $830,000. The small number of multiplier jobs that are generated by household spending on equipment is also affected by the limited capacity of local businesses to supply goods and services.

Table 63. Estimated Economic Significance of Subsistence

	Total		Residents		Non-Residents
		Non-local	Local	Total	
Direct jobs					
Peak	**Non-mkt.**	Non-mkt.	Non-mkt.	Non-mkt.	Non-mkt.
Annual average					
Multiplier Jobs	**68**	47	21	68	-
Total jobs (annual average)	**68**	47	21	68	-
Direct wages ($000)	**Non-mkt.**	Non-mkt.	Non-mkt.	Non-mkt.	Non-mkt.
Multiplier wages	**$2,599**	$1,769	$830	$2,599	-
Total wages	**$2,599**	$1,769	$830	$2,599	-

Note, estimates based on ISER Input-Output Model (Goldsmith, 2000). All direct jobs are in the Bristol Bay region.

4.7 Conclusions

In 2009, the Bristol Bay salmon ecosystem supported more than 6,000 annual average jobs with a payroll of $282 million. Non-residents of Alaska held one fifth of all jobs and received one third of all income generated, about $100 million. Alaskans held approximately 5,000 jobs (80 percent of all jobs) and earned $182 million, one third of total income. Local residents of the Bristol Bay region held about a third of all jobs and earned almost $78 million (28 percent) of total income traceable to the Bristol Bay salmon ecosystem (Table 64).

The majority of jobs held by Alaskans are taken by residents from other regions of Alaska, particularly by harvesters in the commercial salmon fishery. More than half of all jobs are held by workers in the support industries for commercial fishing and recreation, which are mainly located in Southcentral Alaska. Multiplier wages amount to about a third of total income generated.

The regional economy is primarily driven by the commercial salmon industry, followed by tourism and participation in subsistence, considered to be a non-market economic activity. The economy of the Bristol Bay is a mixed cash-subsistence economy, where subsistence activity requires labor inputs without exchange of money for the labor performed. Subsistence creates non-cash jobs to local residents of the region who are pursuing subsistence activities to support their families' need for food. The subsistence economy provides a direct link between the health of the Bristol Bay salmon ecosystem and human well-being. Subsistence is integral to the local way of life in the Bristol Bay region. However, even though it is an important part of the regional economy, work related to subsistence similar to household work, is not officially measured and neither is it subject to an exchange of money for the work performed. Thus, in the context of this study which is solely focused on market values, we are unable to quantify the economic significance of subsistence in the sense of direct jobs and income. Thus we present these jobs as non-market jobs. However, we present multiplier jobs resulting from subsistence-related spending on capital equipment and gasoline for example. These expenditures are necessary inputs to participating in subsistence activities and are included under multiplier jobs and wages (Table 64).

Table 64. Estimated Economic Significance of Bristol Bay Ecosystems

	Total	Residents Non-local	 Local	 Total	Non- Residents
Direct jobs					
Peak	**14,227**	4,365	2,273	6,639	7,587
Commercial fish	***11,572***	*3,251*	*1,089*	*4,341*	*7,231*
Recreation	***2,655***	*1,114*	*1,184*	*2,298*	*356*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Annual average	**2,811**	914	585	1,499	1,313
Commercial fish	***1,897***	*530*	*177*	*707*	*1,190*
Recreation	*914*	*384*	*408*	*792*	*123*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Multiplier Jobs	**3,455**	2,008	1,447	3,455	-
Total jobs (annual average)	**6,266**	2,922	2,032	4,954	1,313
Direct wages ($000)	**$166,632**	$40,149	$31,048	$66,199	$100,435
Commercial fish	***$134,539***	*$22,698*	*$17,608*	*$40,307*	*$94,233*
Recreation	***$32,093***	*$12,451*	*$13,440*	*$25,892*	*$6,202*
Subsistence	***non-mkt.***	*non-mkt.*	*non-mkt.*	*non-mkt.*	*non-mkt.*
Multiplier wages	**$115,976**	$69,250	$46,724	$115,976	-
Total wages	**$282,608**	$104,399	$77,772	$182,175	$100,435

Note, estimates based on ISER Input-Output Model (Goldsmith, 2000). All direct jobs are in the Bristol Bay region.

4.8 Key Assumptions and Uncertainties

Description	Potential Bias	Sensitivity relative to overall results
GENERAL		
The ISER Alaska Input-Output model consists of four regions. The Bristol Bay region is only part of one of these regions, the Southwest region. Larger communities outside Bristol Bay such as Kodiak and Dutch Harbor are part of the Southwest region.	The expenditures related to economic activity in the Bristol Bay region overestimate the employment generated in the region and underestimate the employment generated in other regions. The bias in overall Alaska economic impact is unknown.	Moderate
The commodity by industry matrix is part of the Input-Output model and allocates commodity expenditures among costs of goods, transportation margins, trade margins, and to industries, based on statewide averages.	Transportation and trade margins may be higher for purchases made in small, rural parts of Alaska than for the state as a whole. This would result in an underestimate of the transportation and trade share of the total economic impact. Bias in overall Alaska economic impact is unknown.	Moderate
Composition of household expenditures is based on statewide averages.	The composition of rural household expenditures may be different from the state average, which is heavily weighted by urban households. Bias in overall Alaska economic impact is unknown.	Moderate
COMMERCIAL FISHING		
Unrepresentative base year for harvest and ex-vessel value estimates	Given the large annual variations that occur in catches for the commercial salmon fishery the estimated economic significance for 2009 is not necessarily representative of historical or future economic significance.	High
Assumptions about the level of expenditures per harvester and processor	Unknown	Moderate
Assumptions about the composition of harvester and processor purchases	Unknown	Moderate
Assumption about the regional allocation of expenditures by	Unknown	Moderate

Description	Potential Bias	Sensitivity relative to overall results
harvesters and processors		
Assumption about the residence of harvesters and processor employees	Unknown	Moderate
Travel cost related to non-resident and Alaska resident travel between place of residence and place of work in Bristol Bay.	While we consider the in-state economic impact of all earnings for harvesters' and processors' earnings, we ignore the in-state cost of travel between place of residency and place of work for participants in the commercial fishing industry.	Negligible
RECREATION: NON-CONSUMPTIVE USE		
Assumptions about the number of local resident visitors, non-local residents, and non-residents	Underestimate due to the potentially higher number of resident visitors (Fix, 2010).	Moderate
Assumptions about the level of expenditures per trip	Underestimate. Other sources state higher per trip expenditures for Southwest Alaska destinations ranging from $3,068 to $3,760 per person and trip (Colt and Dugan, 2005; Littlejohn and Hollenhorst, 2007).	Moderate
Regional allocation of non-consumptive expenditures	Unknown	Negligible
Assumption about the regional allocation of guide, charter, and lodge purchases.	Unknown	Negligible
Assumption about the residence of guide, charter, and lodge employees	Unknown	Negligible
RECREATION: SPORT FISHING & HUNTING		
Assumptions about the number of trips by local residents, non-local residents, and non-residents	Given the annual variations that occur in the number of visitors to Southwest Alaska the estimated economic significance for 2009 is not necessarily representative of historical or future economic significance.	Moderate
Assumptions about the level of expenditures per trip	Given the national recession and worldwide economic slump the annual variations in visitor expenditures, the estimated economic significance for 2009 is not necessarily representative of historical or future economic	Moderate

Description	Potential Bias	Sensitivity relative to overall results
	significance.	
Regional allocation of sport fishing and sport hunting expenditures	Unknown	Negligible
Assumption about the regional allocation of guide, charter, and lodge purchases.	Unknown	Negligible
Assumption about the residence of guide, charter, and lodge employees	Unknown	Negligible
Capital expenditures related to residents' boats, cabins, and other equipment	We ignore capital expenditures related to equipment due to the difficulty of apportioning a usage-share to specifically sport fishing or hunting in the Bristol Bay region.	Moderate
SUBSISTENCE		
Assumption of number of households engaged in subsistence activities	Unknown	Moderate
Assumption about the level of expenditures on subsistence per household	Unknown. Estimate is from the North Slope of Alaska where there is a different subsistence culture compared to Bristol Bay. Similar subsistence surveys in Western Alaska indicate that the estimate used is justified. The direction of bias is unknown.	Moderate
Assumptions about the composition of subsistence related expenditures	Unknown	Negligible
Assumption about the regional allocation of subsistence-related expenditures	Unknown	Negligible

Source: adapted from Goldsmith et al. (1998).

4.9 Data Sources

(Methods).
Expenditures that are excluded from the Input-Output modeling exercise are tax revenues generated through locally occurring economic activity, expenditures associated with natural resource management, and the commercial trapping industry. In addition, the study excludes the economic importance of herring fisheries in the Bristol Bay region. Compared to salmon, herring fisheries in Bristol Bay are much smaller amounting to $2.5 million in ex-vessel value in 2009 compared to salmon with $148 million (CFEC, 2009). We do not evaluate mineral exploration because it is not dependent on healthy ecosystems in the Bristol Bay region.

(Regional Economic Overview). There are three data sources related to jobs reported in the Bristol Bay region. The Alaska Department of Labor and Workforce Development offers annual average employment for wage earners (ADOL, 2009e) and information on participation in the commercial fisheries such as crew shares and processor employment (ADOL, 2009a-c). The third data source is an annual count of proprietors provided by the U.S. Bureau of Economic Analysis (BEA, 2009). Data from ADOL does not include fishing employment, but BEA provides an estimate of proprietors (including fish harvesters and other proprietors) in the region. Since ADOL data is measured in annual average jobs and the BEA data is a count of workers, we adjust the proprietor data to reflect seasonality assuming a six week harvesting season. Proprietors include local resident crew and local resident captains which are based on crew factors from ADOL (2004) and resident share of crew from ADOL (2009c). In addition, we use information on the number of local permits fished from CFEC (2009) to get an estimate of the number of local captains participating in the fishery. It is important to note that the ADOL data only provides employment estimates by place of work. The BEA proprietor data is based on income tax returns, thus the BEA proprietors counted in our analysis are only the ones that show a business address in the Bristol Bay region. Our analysis does not include businesses registered elsewhere in Alaska or out of state. Consequently, the proprietor data used in this study and shown in Table 2 is an underestimate of the jobs that likely exist. For this reason, employment estimates in Table 2 are not comparable to employment estimates elsewhere in the report.

(Commercial fisheries). For this study we divide the commercial fisheries sector into harvesting and processing. For the **harvest sector**, harvest data by residency of permit holder came from the Commercial Fisheries Entry Commission’s Basic Information Tables (CFEC, 2009). Residency of captains is based on Iverson (2009). Residency of crew is unknown but was inferred from crew license data available at ADOL (2009a) for all commercial fisheries in the Bristol Bay region. ADOL (2009a) shows that local captains hire 1.46 local crew in all of Bristol Bay’s commercial fisheries. Since the salmon fisheries are by far the largest fisheries in the region we assume that each local captain hires 1.46 local crew with the remainder of crew members coming from other places in Alaska. Non-local captains are assumed to hire exclusively non-local crew and non-resident captains exclusively non-resident crew. The crew size for Bristol Bay commercial salmon fisheries amounts to three including the skipper and is the same in the set net and drift gill net fisheries (ADOL 2004). Crew shares for the set net and drift gill net fisheries are based on a ten year average proportion of crew shares to gross earnings as stated in Schelle et al. (2004). In addition, Schelle et al. (2004) provides expenditure categories for harvesters for the drift gillnet fishery. Due to a lack of data on expenditures in the set gill net fishery, we assume costs to be about half of what they are in the drift gill net fishery with lower insurance, moorage and storage and other boat related expenses due to the much smaller boats being used for set net operations. We further allocate these expenditures within a commodity by industry matrix to form a final demand vector that is passed to the ISER I-O Model following Goldsmith (2000). For the **processing sector,** we assume that 95 percent of the harvest is processed in the Bristol Bay region, including on-shore and off-shore processing. For simplicity, the Input-Output model assumes processor expenditures for off-shore processing to be similar to on-shore processing. Residency of processing workers is from ADOL (2009). Wholesale value for salmon roe and non-roe combined are from ADF&G (2009). Average processor yield is calculated based on the combined net product weight stated in ADF&G (2009) and pounds harvested (CFEC, 2009). Note, all direct jobs are in the Bristol Bay region. Multiplier jobs are divided between Bristol Bay and Southcentral Alaska. Multiplier jobs are assumed to be all taken by residents of the region where they occur. Peak and annual average direct wages are assumed to be equal.

(Recreation).
No comprehensive analysis has been completed on the economic significance of recreation and tourism in Southwest Alaska. One of the greatest challenges is estimating visitor volume for residents and non-residents. A number of separate studies provide some indication of pertinent levels and patterns of visitation activities. Non-resident visitation, length of stay, and expenditure per visitor to Southwest Alaska are from McDowell Group (2007a). Bluemink (2010) and the Alaska Travel Industry Association provided information on current trends in visitation and so did the National Park Service Commercial Use Authorization permit report data (National Park Service, 2010).

For this study we separated visitor impacts by residency and by type of activity. For **sport fishing and sport hunting**, Duffield and Neher (2002), estimated visitor volume and expenditures for sport fishing and sport hunting based on license data and visitor specific expenditure data from ADF&G (2009b). In addition, Duffield et al. (2007) conducted a lodge survey in the Bristol Bay region that offered detailed angler expenditure categories by residency, as well as expenditure detail for lodges and guiding outfits. After adjusting for inflation, we develop separate final demand vectors for sport hunting and fishing by residency. The analysis follows Goldsmith (2000) and Duffield et al. (2007). According to ADF&G's hunting regulations, the sport hunting season for moose, caribou and bear is mainly in the fall months and varies by area. For the calculation of annual average jobs, we assume the main season for sport hunting to be three months long (ADF&G, 2011).

We define **non-consumptive** users as those who reported wildlife viewing, camping, kayaking, hiking, or photography as their primary purpose of their visit. We adjust the most recent 2006 summer and winter visitor estimate for Southwest Alaska excluding Kodiak by applying the 2006-2009 percent difference in air travelers for Alaska overall (McDowell Group, 2007a & 2007b). The trend in air travelers to Alaska serves as the best indicator for changes to visitation in Southwest Alaska for two reasons. First, visitors to rural Alaska are mainly independent travelers, and second they primarily arrive by air in comparison to the statewide largest share of visitors who arrive by cruise ship. The Southwest Alaska region closely matches the Bristol Bay

study region with the exception of Kodiak and the Aleutian Islands. Our analysis excludes Kodiak but includes an insignificant portion of visitors to the Aleutian Islands.
Since Alaska Visitor Statistics Program counts out-of-state visitors only, we calculate visitor volume originating within the state based on Littlejohn and Hollenhorst (2007) and Colt and Dugan (2005) resident share of between ten and eleven percent. We treat visitation to Katmai NPP separate from other areas of the Bristol Bay region. Visitor volume and expenditure for Katmai NPP are from Fay and Christensen (2010) and for the remaining Bristol Bay area are from McDowell Group (2007a). We net out sport fishing and hunting visitation in Katmai NPP using Littlejohn and Hollenhorst (2007) and for the rest of the region by applying the McDowell Group (2007a and 2007b) estimate. We assume equal expenditures for residents and non-residents because the non-resident per person expenditure estimate in both cases does not include the cost of travel to and from Alaska. For the expenditure categories associated with non-consumptive use, we modeled the final demand vector based on Fay and Christensen (2010). These expenditures categories include transportation within Alaska, food, lodging, guiding services, supplies, licenses, etc. For most non-residents all in-state travel expenditures are included, based on the assumption that the primary reason for the travel to Alaska is the visit the Bristol Bay region. We allocated these expenditures within a commodity by industry matrix to form the final demand vector that’s then passed to the ISER I-O Model developed by Goldsmith (2000). For all of these estimates, we paid special attention to the potential for double counting and addressed those issues.

Note, all direct jobs are in the Bristol Bay region but the residency of workers and the location where these workers spend their income is difficult to trace. Multiplier jobs are divided between Bristol Bay and Southcentral Alaska. Multiplier jobs are assumed to be all taken by residents of the region where they occur. Peak and annual average direct wages are assumed to be equal.

(Subsistence).
We estimate **annual expenditures related to subsistence** activities for households based on the only publically available source (North Slope Borough, 1993) and adjust for inflation to 2009$. This estimate is justified as results from similar subsistence surveys are similar (Peterson et al., 1992). We assume that every household in the region participates in subsistence activities with varying degrees of involvement and expense. We assume Native households to be participating in subsistence extensively resulting in the entire per household expenditure, whereas Non-Native households are assumed to be less involved with about a quarter of expenditures related to subsistence activities compared to Native households as indicated by North Slope Borough (1993). Due to the lack of data, the economic significance is quite small if compared to commercial fishing or non-consumptive use, both in terms of the market jobs and the payroll generated. For the **expenditure categories** related to subsistence, we assume maintenance and repair of boats and trucks to amount to 10% of total annual expense each, purchase of boats and trucks (10% each), hunting equipment (7%), fuel, repair, and parts (13% each).

Note, all direct jobs are in the Bristol Bay region. Multiplier jobs are divided between Bristol Bay and Southcentral Alaska. Multiplier jobs are assumed to be all taken by residents of the region where they occur. Peak and annual average direct wages are assumed to be equal.

5.0 Bristol Bay Net Economic Values

The second general accounting framework under which ecosystem services can be measured is the Net Economic Value (NEV) framework. Net economic value is the value of a resource or activity that is over and above regular expenditures associated with engaging in an activity or visiting a resource area. The framework for this accounting perspective is the standard federal guidelines for estimating net economic benefits in a system of national accounts (Principles and Standards, U.S. Water Resources Council 1985). EPA (2010) is a more recent and complementary set of guidelines.

5.1 Commercial Fisheries

In addition to the regional economic impact of commercial fish harvest in the Bristol Bay, the commercial fishery has a net economic value related to the expected differences over time between the *ex vessel* revenues and the costs of participating in this fishery. One method for estimating this value is to look at the market prices for commercial fishing permits in the Bristol Bay. Bristol Bay commercial fishing permits are of two types, drift net permits and set net permits. Regulations closely control many aspects of this permitted commercial harvest, including types of nets, size of boats, areas fished, and start and end dates of season. The value of holding one of these perpetual commercial permits is reflected in the prices that these permits command when they are transferred between owners. These market prices reflect the value that commercial operators place on their right to fish the region. That value in turn is a judgment of the value of the net income stream that would reasonably be expected from operating the permit given current and expected future salmon harvest levels and salmon prices.

In 2011, there were 1,862 salmon drift net permits in the Bristol Bay fishery and 981 salmon set net permits in the fishery. Every year a portion of these permits are sold and change hands. Since 1991, an annual average of 155 drift net permits and 89 set net permits have been sold and changed hands in the Bristol Bay fishery.[27] Permit transfers each year generally account for approximately 8% to 10% of all issued salmon permits in the fishery.

The Commercial Fish Entry Commission also reports average permit transfer prices annually (and monthly) for the Bristol Bay salmon fishery.[28] Over the period from 1991-2011 the average sales price for Bristol Bay drift net permits has been $149,000 (in constant 2011 dollars). The average price for set net permits over the same period has been $42,200. The 95% confidence interval on the mean drift net price for this period ranges from $105,500 to $192,700. For the set net permit transfers, the 95% C.I. on the mean sales price was between $28,700 and $55,700.[29] Table 65 presents the estimated 95% C.I. range of total Bristol Bay drift and set net salmon permit value based on the 1991-2011 permit transfer data. For both types of permits it is

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[27] The Alaska Fish and Game Commercial Fish Entry Commission publishes annual data on permit transfers at, http://www.cfec.state.ak.us/RESEARCH/12-1N/12-1N.htm

[28] A long time series of monthly and annual permit transfer prices is continuously updated at, http://www.cfec.state.ak.us/pmtvalue/mnusalm.htm

[29] Over the period 1991-2011, a total of 3,246 Bristol Bay drift net salmon permits and 1,867 set net salmon permits were reported sold by the Commercial Fish Entry Commission.

estimated that the total value of the permits ranges from approximately $225 million to $414 million.

In order to be comparable to other annual net economic values in this analysis (such as sport fishing or sport hunting) the market value of commercial fishing permits must be converted into an annual value reflecting expected annual permit-related net income. The market value of the permits can be annualized using an appropriate amortization (or discount) rate. The decision to sell a commercial fishing permit at a given price is an individual (or private) decision. In deciding on an acceptable sales price, a permit holder considers past profits from operating the permit, risk associated with future operation of the permit (both physical and financial), and many other factors. All these considerations weigh on how heavily a permit seller discounts (reduces) potential future profits from fishing the permit in order to arrive at a lump-sum value for the permit. Huppert et al. (1996) specifically looked at Alaska commercial salmon permit operations and sales and estimated the individual discount rate on drift net permit sales in the Bristol Bay and surrounding fisheries. This discount rate was estimated from both profitability and permit sales price data. Huppert et al. estimated the implied discount rate appropriate for annualizing permit sales prices in this setting at 13.52%. This estimate was consistent with previous estimates for the fishery.[30] Use of the 13.52% discount rate from Huppert results in an estimated annual permit net profit or net income associated with Bristol Bay commercial salmon fishing of between $30.4 million and $55.9 million.

Table 65. Current Bristol Bay Salmon Fishing Permit Numbers and sale prices, 2011

Permit type	***Number of permits***	***Current market value***		***Total***	
		Lower Value - 95% Confidence Interval	***Upper Value - 95% Confidence Interval***	***Lower Value - 95% Confidence Interval***	***Upper Value - 95% Confidence Interval***
Salmon (Drift net)	1862	105,500	192,700	196,500,000	358,800,000
Salmon (Set net)	981	28,700	55,700	28,100,000	54,700,000
Total				224,600,000	413,500,000
Estimated annual net income (at 13.52% real discount rate)				**$30,400,000**	**$55,900,000**

Just as there is an implied net economic value associated with the fishing aspect of the Bristol Bay commercial salmon fishery, as outlined above, there is also a net economic value associated with expected future profits from investments in fish processing facilities in the region. Data on Bristol Bay salmon processor average aggregate profit levels is not published. Table 31, above, shows estimated profit (loss) margins for two years. Clearly, as with permit prices, processor

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[30] Huppert, Ellis and Nobel (1996) estimated the real discount rate associated with sales of Alaska drift gill-net commercial permits of 13.52%. Karpoff (1984) estimated the discount rate from sales of Alaska limited entry permits at 13.95%.

profits are highly variable year-to-year. The average value-added associated with salmon processing for the Bristol Bay fishery is generally equal to or more than the ex-vessel value. Salmon processors in the Bristol Bay fishery have an “oligopsony” market structure, in that a small number of buyers of raw fish exist in the market. Additionally, these buyers are largely “price makers” in that they set the price paid per pound to fishermen each season. Given the unique relationship between fisherman that the small number of processors in the Bristol Bay, it is estimated that processors derive profits (net economic value) equal to that earned by fishermen. Therefore, for the purposes of this report it is estimated that the NEV for salmon producers is equal to that for the fishing fleet.

A second estimate of estimated annual net income for the Bristol Bay commercial salmon harvest and processing sectors is derived from data presented in a 2003 study of the industry (Link et al. 2003). The 2003 report, titled “An analysis of options to restructure the Bristol Bay salmon fishery”, includes estimates of both Bristol Bay harvester and processor annual profits (net income) for the period 1990-2001. These estimates can be scaled to 2011 values using both changes in general price levels (CPI-U) and changes in harvester permit values. The table below (Table 66) shows the estimation of 2011 harvester and processor net income estimated from the Link et al. (2003) report.

Use of this second set of net income estimates and assumptions leads to a calculation of estimated harvest and processing sector net income that is near the upper 95% bound of the estimates calculated in this report. While the analysis based on 1990-2001 data presented above does suggest that the Table 65 analysis significantly undervalues the harvest sector, while the assumption of an equal processing sector net income somewhat overvalues the processing sector. The net effect is that the range of values for the combined harvest and processing sectors include values significantly below the estimate developed by the second (Table 66) analysis above. For purposes of presenting a conservative range of value estimates for the commercial salmon sector, an estimate of total harvester and processor net incomes from $60.8 to $111.8 million is used.

Table 66. Estimation of Total 2011 Net Income for the Bristol Bay Salmon Harvest and Processing Sectors based on Reported 1990-2001 Net Income (Link et al. 2003).

Parameter	**Assumption/operation**	**Value**
(A) BB Commercial Salmon Harvester Sector Average Annual Net Income Estimation		
Average 1990-2001 harvest sector net income	Data from Link et al (2003). Table 12 (p.43).	$93.7 million
Average annual BB commercial salmon fishing sector net income (1990-2001) in 2011 dollars	Annual values updated to 2011 dollars using CPI-U	$113.15 million
Adjusted 2011 profitability based on differences between 1990-2001 average permit values and 2011 permit values	The correlation between profitability in year X and permit sales price in year x+1 for this period is 0.857. Based on this observed close relationship, net income is scaled by the ratio of 2011 permit prices to the average 1990-2001 price, or by 79.27%	$89.69 million
(B) BB Salmon Processing Sector Average Annual Net Income Estimation		
Average BB net income of the salmon processing sector for the years 1990-2001 in 2011 $. (Link et al. 2003)	There is no observed correlation between processor profits and permit prices (r=0.053). Average processor profits are assumed to be a constant 23.3% of harvester profits (the average ratio observed in the 1990-2001 data by Link (2003))	$20.90 million
(C)Estimated Sum of Harvest and Processing Sectors Average Annual Net Income		
Total estimated annual harvester and processor net income (2011$) derived from 1990-2001 data		$110.59 million
(D) Estimated Range of Harvest and Processing Sector Average Annual Net Income		
Range of estimates developed in this analysis		$60.8 to $111.8 million

5.2 Subsistence Harvest

The Alaska Department of Fish and Wildlife, Division of Subsistence reports that most rural families in Alaska depend on subsistence fishing and hunting. ADF&G surveys of rural communities find that from 92% to 100% of sampled households used fish, 79% to 92% used wildlife, 75% to 98% harvested fish, and 48% to 70% harvested wildlife. Because subsistence foods are widely shared, most residents of rural communities make use of subsistence foods during the course of the year. The subsistence food harvest in rural areas constitutes about 2% of the fish and game harvested annually in Alaska. Commercial fisheries harvest about 97% of the statewide harvest, while sport fishing and hunting take about 1%. Though relatively small in the statewide picture, subsistence fishing and hunting provide a major part of the food supply of rural Alaska (Subsistence in Alaska, a 2000 Update http://www.subsistence.adfg.state.ak.us/download/subupd00.pdf).

The Alaskan subsistence harvest is not traditionally valued in the marketplace. Because the subsistence resources are not sold, no price exists to reveal the value placed on these resources within the subsistence economy. The prices in external markets, such as Anchorage, are not really relevant measures of subsistence harvest value. The supply/demand conditions are unique to the villages, many of which are quite isolated. Native preferences for food are strongly held and often differ from preferences in mainstream society. Additionally, because these are highly vertically-integrated economies, substantial value-added may occur before final consumption (such as drying, or smoking fish and meats). In their research on estimating the economic value of subsistence harvests, Brown and Burch (1992) suggest that these subsistence harvests have two components of value, a product value, and what they call an "activity value." The product value is essentially the market value of replacing the raw subsistence harvest. The activity value would primarily include the cultural value of participating in a subsistence livelihood. The activity value component is also associated with the value of engaging in subsistence harvest and food processing activities. This activity value would include maintaining cultural traditions associated with a subsistence livelihood.

Duffield (1997) estimated the value per pound of Alaskan subsistence harvest though use of a cross-sectional hedonic model of community-specific harvest per capita and community per capita income levels. This "wage-compensating differential model" essentially estimates the average tradeoff across communities between per-capita subsistence harvest (in pounds of usable harvest) and per capita income levels. In essence, residents of rural Alaskan communities tradeoff the opportunity to have higher income in a less rural environment with the opportunity to harvest larger amounts of subsistence resources in more rural communities.

There is a substantial economics literature that utilizes the hedonic wage, or wage compensating differential model. For example, estimates of the trade-off of wages and workplace risk of mortality are the basis of the statistical value of life estimates widely used in regulatory analysis of ambient air and other standards (EPA 2008). There is also a literature that relates wages and amenity values as revealed through choice of location (e.g. Henderson 1982, Clark and Khan 1988). These later models are generally applied to intercity data sets, such as across U.S. Standard Metropolitan Statistical Areas (SMSA) These models are also used to estimate the benefits and costs of climate change (e.g. Maddison and Bigano 2003).

The application of a compensating wage model to a cross-section of Alaska Villages and towns is consistent with the view that these Alaska cash-subsistence economies are not just a transitory phase in economic development. Rather the village economies represent an equilibrium that is a function of individual choice of where to live and work (Wolfe and Walker 1987; Kruse 1991).

Wolfe and Walker (1987) were the first to estimate a statistical relationship between wage income and subsistence livelihoods using harvested usable pounds as a measure of subsistence productivity. Wolfe and Walker were interested in factors that influenced subsistence productivity, including construction of roads, settlement activity and income. The data was based on extensive surveys of Alaska villages undertaken by the applied anthropology group at Alaska Fish and Game, Division of Subsistence. Duffield (1997) used the Wolfe and Walker dataset for 98 villages in a compensating wage specification to inform subsistence harvest valuation in the context of the Exxon Valdez oil spill litigation. Hausman (1993), who represented the defendant in the case (Exxon) also estimated a compensating wage model using the Wolfe and Walker dataset. Hausman introduced the use of applying an instrumental variable approach to estimating the model, since wages and subsistence harvests are jointly determined.

Hausman's (1993) estimate of the value of subsistence harvests (1982 dollars) was $33.60 per pound and Duffield's (1997) was quite similar at $32.46. The estimated Hausman and Duffield harvest income models are now based on 30 year-old data. Indexing these results using average Alaska personal income per capita suggests that were this same relationship to hold today, total subsistence harvest NEV would be on the order of $75.58 per pound. In order to avoid making the assumption that the income—harvest relationship observed in the early 1980s was still valid, the Duffield (1997) model was updated using the most recently available per capita income,[31] subsistence harvest,[32] education,[33] and cost of living data[34] for the 90 communities included in both the Hausman and the Duffield models.

The updated estimated wage compensating differential model shown in Table 66 uses a two-stage least squares methodology and a linear specification. The two-stage least squares method is used to statistically address the fact that income and harvest levels in the communities are at least partly co-determined. The first stage of the model uses an instrumental variable (the percent of adults in each community with 4 or more years of college education) along with the remaining regional indicator variables to predict adjusted gross income per capita for each community. This predicted income level then was used in the second stage regression. The model explains 54% of the observed variation in harvest levels across communities, and a large majority of the 14 explanatory variables are significant at the 90% level of confidence or greater. The implied value per pound of subsistence harvest is calculated from the parameter estimate for Adjusted Gross Income Per Capita. The implied value per pound is the negative inverse of the income parameter (-0.01162). [(1/-0.01162)*-1 = $86.06]

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[31] American Community Survey 5-year averages 2006-2010 (Table B19301) www.census.gov/acs/

[32] Alaska Fish and Game Department of Subsistence , http://www.adfg.alaska.gov/sf/publications/

[33] American Community Survey 5-year averages 2006-2010 (Table GCT1502) www.census.gov/acs/

[34] McDowell Group, Alaska Geographic Differential Survey: 2008.

Table 67. Estimated Two-Stage Least Squares Wage Compensating Differential Model of Subsistence Harvest in 90 Alaska Communities (Duffield 1997).

Variable	**Parameter Estimate**
Intercept	936.45 (137.89)***
Adjusted Gross Income Per Capita	-0.01162 (0.0051)**
Alaska Peninsula	-174.227 (119.08)
Copper Basin	-522.132 (86.37)***
Kenai Peninsula	-448.975 (120.61)***
Kodiak	-465.551 (111.31)***
North Slope	227.2387 (172.49)
NW Arctic	-112.557 (227.61)
N Cook Inlet	-548.580 (230.87)**
Prince William Sound	-248.607 (173.95)
South East	-314.787 (103.27)**
South West	-265.364 (101.56)**
Upper Tanana	-514.022 (130.35)***
Urban	-590.972 (169.66)***
West	-22.1552 (105.28)
Observations	90
R-Squared	0.536
Endogenous Variable	Adjusted Per Capita personal income (BEA 2010) (adjusted to Anchorage dollars using cost-of-living index)
Instrumental Variable	% of adults with 4 or more years of college (plus region indicator variables)

*=significant at 90% confidence level; **=significant at 95% confidence level; ***=significant at 99% confidence level.

One difference between the Hausman and Duffield models and the updated subsistence model is in the per capita income measure used. Hausman and Duffield both used Alaska Department of Revenue data on community level adjusted gross income (AGI). However, Duffield's updated model utilized average community per capita personal income. This second measure is the more appropriate income measure in that it includes certain amounts that are deducted from total income in the calculation of AGI. The updated income measure is consistently larger than the Alaska AGI originally used, with the latter being on average an estimated 70% of the former.[35] The magnitude of the income measure used is directly proportional to the estimated value of subsistence harvest NEV per pound calculated from the estimated model income parameter. For purposes of this report, a range of values in the following analysis uses both the estimated $86.06 value, based on the updated dataset and adjusted per capita personal income, and a lower bound estimate of $60.24 per pound ($86.06*0.70) based on the assumption of consistently using Alaska AGI.

Based on both the Hausman (1993) and Duffield (1997) analyses, in principle the correct way to value subsistence harvests is to use the compensating wage differential approach. With reference to the Brown and Burch (1992) perspective, the compensating wage estimate includes both product and activity value. Duffield (1997) also reports a replacement cost estimate of just product values for subsistence harvests at $13.28 per pound.[36] In 2009 dollars, this product value is estimated at $18.86 per pound.[37]

Table 67 shows the accounting of ADF&G Division of Subsistence estimates of total annual subsistence harvest in most communities in Bristol Bay. This total has been adjusted to include population in the region not included in the ADF&G subsistence harvest estimates. In total, we estimate that about 2.6 million usable pounds of subsistence harvest per year occur in the Bristol Bay region. Valued at an estimated range of $60.24 to $86.06 per pound, this harvest results in an estimated net economic value annually for subsistence harvest of between $154.4 and $220.6 million (Table 69).

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[35] http://www.irs.gov/uac/SOI-Tax-Stats---Historical-Data-Tables "Table 4. Comparison of Personal Income in the National Income and Product Accounts (NIPA) with Adjusted Gross Income (AGI). For Specified Tax Years, 1990-2005).

[36] This value is the simple average of the replacement cost of lost harvest between two definitions of households in the Duffield (1997) paper. p. 109, Table 4.

[37] It should be noted that a significant component of subsistence harvest in some communities is marine mammals, a resource with a very high market replacement cost.

Table 68. Estimated Total Annual Bristol Bay Subsistence Harvest (usable pounds of harvest)

Bristol Bay Area Community /year of harvest data	Total Usable Pounds Raw Subsistence Harvest
Aleknagik 1989	64,824
Clark's Point 1989	75,020
Dillingham 1984	563,618
Egegik 1984	41,856
Ekwok 1987	91,655
Igiugig 2005	27,100
Iliamna 2004	51,121
King Salmon 2008	117,062
Kokhanok 2005	115,600
Koliganek 2005	187,891
Levelock 2005	36,363
Manokotak 2000	131,716
Naknek 2008	143,616
New Stuyahok 2005	198,390
Newhalen 2004	131,480
Nondalton 2004	58,712
Pedro Bay 2004	12,852
Pilot Point 1987	26,112
Port Alsworth 2004	21,147
Port Heiden 1987	41,616
South Naknek 2008	21,172
Ugashik 1987	9,768
Togiak City 2000	200,982
Twin Hills 2000	36,926
Total surveyed communities	2,406,599
Un-surveyed communities (estimated)	156,714
Total including un-surveyed areas	**2,563,313**

Source: Estimates of community-specific subsistence harvest levels are contained within the Subsistence Technical Report Series, available at, http://www.adfg.alaska.gov/sf/publications/

It should be noted that although the total annual value of subsistence harvests implied by the wage compensating differential model is large, simply the market replacement cost of these resources is fully 32% of the lower-bound estimate and 22% of the upper-bound estimate. In addition to simply procuring the usable pounds of raw subsistence harvest, many of these resources have substantial value-added in the form of processing by drying, smoking, or other preserving, cleaning, or other processing methods. This value-added is also captured within the context of the wage compensating differential model.

Another perspective on the revealed economic significance of subsistence harvests in Bristol Bay is seen by comparing the implied NEV associated with subsistence activities and reported per capita income in the region. For the 7,475 Bristol Bay residents (74% of who are Native Alaskan) subsistence harvests valued at $60.24 per pound imply that the value of these harvests are about 34% of their total combined per capita 2009 personal income (as reported by BEA) plus estimated total subsistence value. Valued at $86.06 per pound, subsistence harvest value is about 42% of total income and subsistence value. Another component of subsistence value is the relative effort or allocation of time put into the subsistence sector instead of spending time in the cash income sector. The effort put into the subsistence sector is estimated to be the same or more than the full-time equivalent jobs included in the cash sector.

Table 69. Estimated Net Economic Annual Value of Bristol Bay Area Subsistence Harvest

Estimates of Subsistence Value	Per Pound Value	Total Subsistence Harvest	Total Annual Value (Million 2009 $)
Value based on Harvested Product Value	$18.86	2,563,313	$48.3
Value based on Wage Compensating Differential Approach (Adjusted to AK DOR AGI income measure))	$60.24	2,563,313	$154.4
Value based on Wage Compensating Differential Approach (Based on BEA per capita personal income measure)	$86.06	2,563,313	$220.6

5.3 Sport Fishing Net Economic Value

In addition to the direct expenditures that Bristol Bay area sport anglers make each year, there is substantial net economic value attached to the trips these anglers take to the region. A measure of the net economic value of sport fishing trips is the amount anglers are willing to pay over and above the costs of their trips. The 2005 Bristol Bay angler survey asked respondents a series of questions relating to what they spent on their fishing trip, and how much, if any, more they would have been willing to spend to have the same experience. This willingness to pay is also referred to as net economic benefit. There is a large economics literature on estimating sport fishing net economic benefits (Rosenberger and Loomis 2001). The method for estimating these benefits here is contingent valuation using the so called “payment card” question format.

Respondents were presented with a set of amounts ranging from $0 to $2,000, and asked to mark the greatest additional increase in spending they would have made to take the same trip. Table 72 shows the mean willingness to pay estimate for the two groups. The net economic value from the survey data was estimated using an interval estimation model.

Following questions on their trip expenditures, survey respondents were asked whether they felt their trip was worth more than the amount they actually spent. Those who answered “yes” were then asked, “What is the largest increase over and above your actual costs that you would have paid to be able to fish your primary destination?" Respondents were presented with a series of dollar amounts ranging from $10 to $2,000. Table 70 shows the percentage of both resident and nonresident Bristol Bay anglers who responded that they would have paid the various additional amounts to take their Bristol Bay fishing trip.

Table 70. Responses to Current Trip Net Economic Value Question

	NONRESIDENTS	***RESIDENTS***
	Percent	**Percent**
Willing to Pay More	**63.0%**	**73.3%**
$ 10	1.1%	0%
$ 25	0.3%	2.1%
$ 50	0.2%	3.6%
$ 100	6.2%	16.5%
$ 250	16.2%	20.5%
$ 500	15.9%	7.5%
$ 750	2.5%	3.6%
$ 1,000	9.1%	0%
$ 1,500	3.7%	0%
$ 2,000	2.3%	3.6%
Other amount	4.3%	15.7%

The estimates of willingness to pay models based on the Table 70 data were developed using a maximum likelihood interval approach (Welsh and Poe 1998). As noted, respondents were asked to choose the highest amount he or she was willing to pay from a list of possible amounts. It was inferred that the respondent's true willingness to pay was some amount located in the interval between the amount the respondent chose and the next highest amount presented. The SAS statistical procedure LIFEREG was used to estimate the parametric model of willingness to pay based on the underlying payment card responses.

Table 71 shows the estimated parametric willingness to pay for trips to Bristol Bay fisheries. Nonresident anglers state their trip was worth approximately $500 more, on average, than they actually paid. Resident Bristol Bay anglers stated they were willing on average to pay an additional $352 for their most recent trip. These estimates are similar to other estimates for Alaska sport fishing (Duffield et al. 2002; Jones and Stokes 1987).

Table 71: Estimated Mean Willingness to Pay for Anglers' Recent Trip to Bristol Bay

Statistic	*Non-residents*	*Residents*
Estimated mean willingness to pay in addition to trip costs for those willing to pay more	$793	$480
Percent of respondents willing to pay more for their trip	63.0%	73.3%
Net willingness to pay for Bristol Bay fishing trips for all anglers	$500	$352

The net economic value per trip estimates shown in Table 71 were calculated from the results of a bivariate statistical model of the payment card response data using a variant of survival analysis to examine censored interval data. The chi-square test of significance for the key parameters from these models show the estimated coefficients to be statistically significant.

Based on an estimated annual use level of 12,464 trips for nonresidents, and 16,903 trips for Alaska residents, we estimate that the annual net economic value of fishing trips in the Bristol Bay region is approximately $12.2 million.

Table 72. Estimated Willingness to Pay for Sportfishing Fishing in the Bristol Bay Region

	Residents	***Nonresidents***
Estimated mean net willingness to pay	$ 352	$ 500
Estimated number of trips/year	16,903	12,464
Total estimated Net Economic Value	$5,950,093	$6,228,350
Total annual value		$12,178,443

5.4 Sport Hunting Net Economic Value

As in the case of sport fishing, there is additional value associated with sport hunting, above what is actually spent on the activity. Table 73 details the estimation of annual net economic value of big game hunting in the Bristol Bay region. Table 73 utilizes ADF&G estimates of hunter numbers in the game management units associated with the Bristol Bay area, and on estimates of net willingness to pay per trip for hunting (from Miller and McCollum 1994, adjusted to current, 2009 dollars). It is estimated that nonresident net economic value of Bristol Bay hunting is approximately $1 million annually. The annual net economic value of big game hunting in the Bristol Bay region for Alaska residents is estimated at about $380,000. Therefore the total annual estimated net economic value of big game hunting in this region is $1.4 million.

Table 73. Estimated annual big game hunting net economic value for Bristol Bay region

Species / Statistic	*Nonresidents*			*Non-local residents*		
	trips	Value/ trip	NEV	Trips	Value/ trip	NEV
Moose	352	$581	$ 204,549	291	$ 268	$ 77,998
Caribou	230	$ 640	$ 147,298	311	$ 250	$ 77,892
Brown bear	741	$ 897	$ 665,028	717	$ 307	$ 220,535
	Total		$ 1,017,000			$ 376,000

5.5 Wildlife Viewing and Tourism Net Economic Value

The 1991 study by McCollum and Miller estimated the net economic value of wildlife watching trips in Alaska. These values adjusted to current dollars results in an estimated value per trip of $199. Using the 40,164 visitor trips to the region we estimate a 2009 net economic value of wildlife watching of about $8.1 million.

5.6 Total Net Economic Value and Present Value and Inter-temporal Issues

Commercial salmon fishery net economic values for fishermen are derived by annualizing the total value of the perpetual permits to fish the Bristol Bay waters held by fishermen. The value of these permits is reflected in the prices paid for them when they are exchanged in an open market and reported by the Commercial Fish Entry Commission. These are on the order of $156,000 for a drift gillnet permit in 2011, and have been as high as $200,000 as recently as 1993.

The total value of Bristol Bay permits—calculated as the number of permits multiplied by the permit price—provides an estimate of the total present discounted value of expected future profits from the fishery. Based on 1991-2011 average permit sales prices (in constant 2011 dollars) the estimated 95% confidence interval on the total value of Bristol Bay permits (both drift net and set net fisheries combined) was between $224.6 million and $413.5 million.

Multiplying the total value of a permit by the rate of return a permit holder demands on a permit investment provides a measure of the annual profit permit holders expect to earn. Using a 13.52% amortization (or discount) rate estimated by Huppert et al. (1996) suggests that annual expected profits (net economic value) from Bristol Bay commercial fishing is currently between $30.4 million and $55.9 million. Note that this does not include expected profits from fish processing.

Net income for the processing sector is more difficult to estimate. Relative to the fishing sector, with ex-vessel value of $181 million in 2010, the processing sector provides an approximately equal value added of $209 million in 2010 (first wholesale value of $390 million in 2010 less the cost of buying fish at the ex-vessel cost of $181 million (Figure 79). However, information on profits or net income for this sector is difficult to obtain. For purposes of this report, net income in the processing sector is assumed to be equal to the value for the fishing fleet.

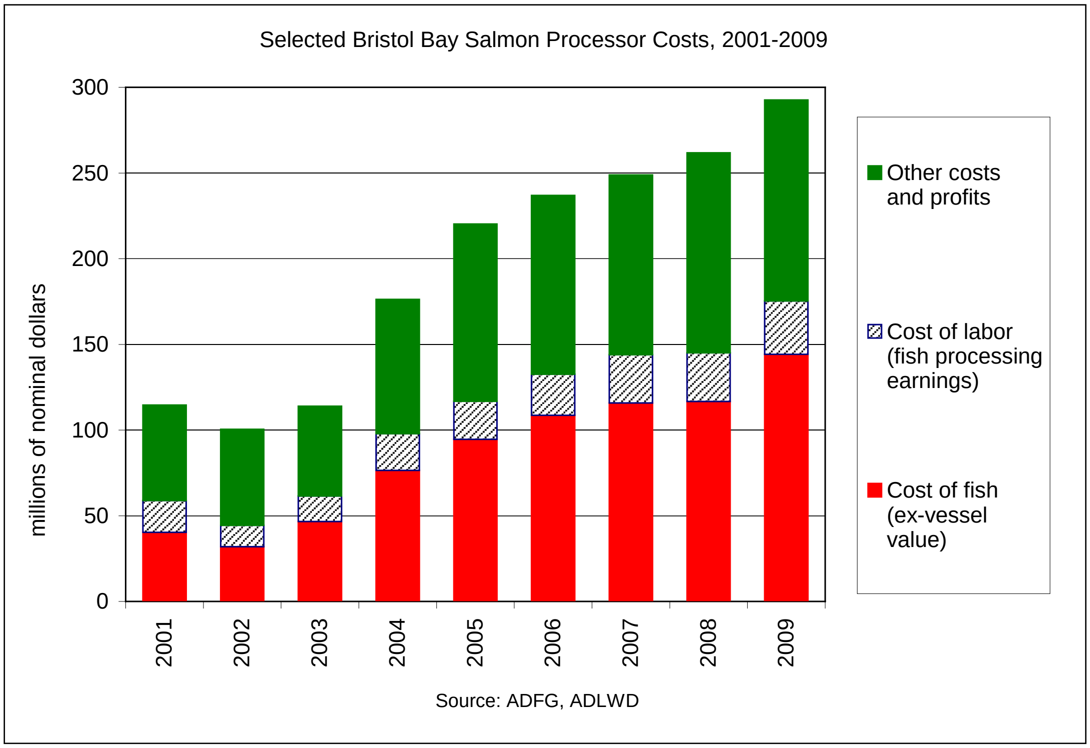

Figure 79. Selected Bristol Bay Salmon Processor Costs: 2001-2009

The sportfish net economic values are angler recreational benefits (consumer surplus) in Duffield et al. (2007). These estimates are consistent with values from the extensive economic literature on the value of sportfishing trips (for example Duffield, Merritt, and Neher 2002). Sport hunting values are based on studies conducted in Alaska by McCollum and Miller (1994). Annual direct use net economic values for recreation use of the Bristol Bay area is estimated to be $22.1 million, including $12.2 million for sport fishing, $1.8 million for sport hunting, and $8.1 million for wildlife viewing and other tourism. In addition to recreationist's net benefits, net income (producer's surplus) is recognized by the recreation and tourism industry. This is a component that remains to be estimated.

Subsistence harvests are valued based on the willingness-to-pay revealed through tradeoffs of income and harvest in choice of residence location (Duffield 1997).

Based on the National Research Council panel on guidelines for valuation of ecosystem services (NRC 2005), it is important to include intrinsic or passive use values (aka "non-use" values) in any net economic accounting of benefits (Figure 80).

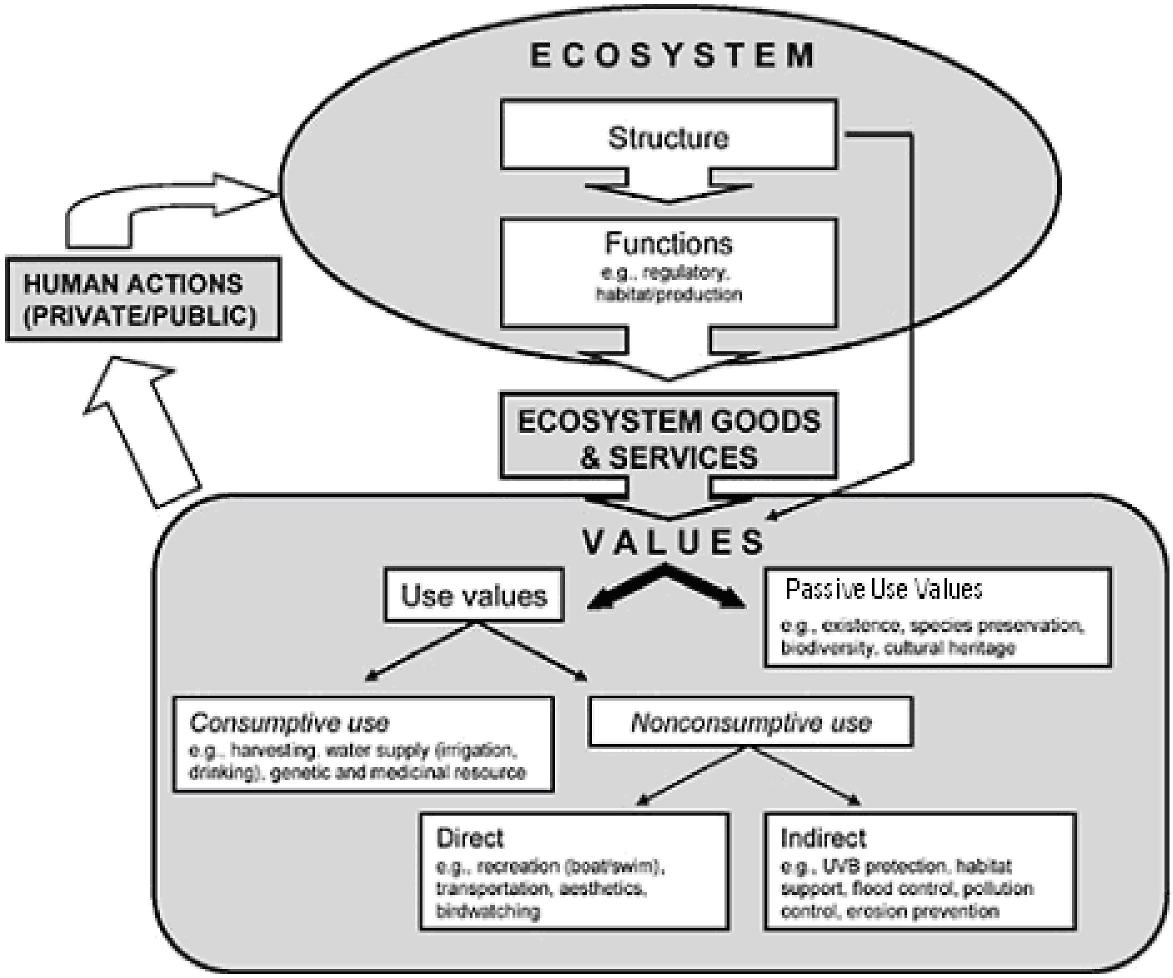

Figure 80. Flows of Ecosystem Services (adapted from (National Research Council 2005))

A major unknown is the total value related to existence and bequest motivations for passive use values. Goldsmith et al. (1998) estimated the existence and bequest value for the federal wildlife refuges in Bristol Bay at $2.3 to $4.6 billion per year (1997 dollars). There is considerable uncertainty in these estimates, as indicated by the large range of values. Goldsmith's estimates for the federal wildlife refuges are based on the economics literature concerning what resident household populations in various areas (Alberta, Colorado) (Adamowicz et al. 1991; Walsh et al. 1984; Walsh et al. 1985) are willing to pay to protect substantial tracts of wilderness. Similar literature related to rare and endangered fisheries, including salmon, could also be applied here. It is possible that from a national perspective the Bristol Bay wild salmon ecosystems and the associated economic and cultural uses are sufficiently unique and important to be valued as highly as wilderness in other regions of the U.S. Goldsmith et al.'s (1998) estimates assume that a significant share of U.S. households (91 million such households) would be willing to pay on the order of $25 to $50 per year to protect the natural environment of the Bristol Bay federal wildlife refuges. The number of these households used in Goldsmith's analysis is based on a willingness to pay study (the specific methodology used was contingent valuation) conducted by the State of Alaska Trustees in the Exxon Valdez oil spill case (Carson et al. 1992). These methods are somewhat controversial among economists, but when certain guidelines are followed, such studies are recommended for use in natural resource damage regulations (for example, see Ward and Duffield 1992). The findings of the Exxon Valdez study were the basis for the $1 billion settlement between the State and Exxon in this case. Willingness-to-pay analyses have also been upheld in court (Ohio v. United States Department of Interior, 880 F.2d 432-474 (D.C. Cir.1989)) and specifically endorsed by a NOAA-appointed blue ribbon panel (led by several Nobel laureates in economics) (Arrow et al. 1993).

While the primary source of passive use values for Bristol Bay are likely to be with national households (lower 48), it is important to note that the Alaska natives living in Bristol Bay also likely have significant passive use values for the wild salmon ecosystem. For example, Boraas (2011) quotes Bristol Bay natives in saying “We want to give to our children the fish, and we want to keep the water clean for them…It was a gift to us from our ancestors, which will then be given to our children.) (Boraas p. 33).

Goldsmith’s estimates for just the federal refuges may be indicative of the range of passive use values for the unprotected portions of the study area. However, there are several caveats to this interpretation. First, Goldsmith et al. estimates are not based on any actual surveys to calculate the contingent value specific to the resource at issue in Bristol Bay. Rather, they are based on inferences from other studies a method referred to as benefits transfer. Second, these other studies date from the 1980’s and early 1990’s and the implications of new literature and methods have not been examined. Additionally, the assumptions used to make the benefits transfer for the wildlife refuges may not be appropriate for the larger Bristol Bay study area which includes not only the wildlife refuge, but also two large national parks. This topic is an area for future research.

Table 74. Summary of Bristol Bay Wild Salmon Ecosystem Services, Net Economic Value per Year (Million 2009 $)

Ecosystem Service	Low estimate	High estimate
Commercial salmon fishery		
Fishing Fleet	$30.4	$55.9
Fish Processing	$30.4	$55.9
Sport fishing	$12.2	$12.2
Sport hunting	$1.4	$1.4
Wildlife viewing / tourism	$8.1	$8.1
Subsistence harvest	$154.4	$220.6
Total Direct Use Value	**$236.90**	**$354.10**

Table 74 details the estimates of annual net economic values for the major sectors tied to the Bristol Bay Ecosystem. The scope of this characterization report is to use existing data, information, and estimates to provide a comprehensive picture of the economic structure and associated values related to the Bristol Bay Ecosystem. The estimates shown in the table are based on a variety of sources and methods, and based on data and estimates from a range of years. These estimates have been presented in constant 2009 dollars.

Differences in net economic values across sectors are driven by several factors, including the number of individuals impacted, the type of market structure, and the scope of resources and resource services included in the estimates. For instance, the estimates for subsistence NEV are between 38% and 73% higher than for the commercial salmon fishery (and processing) sectors. These two sectors have several key differences, however. The market for commercial salmon is highly competitive, with other fisheries (as well as farmed salmon) providing strong price competition and thus keeping profits and implied NEV low in the sector. Additionally, the estimates of commercial fishery NEV are based on commercial fishing permit sales prices. These sales of generally less than 10% of active permits in a given year represent "marginal" prices, rather than the "average permit value" to all permit holders. Those permit holders who do not sell value their permits more highly than those who do. The commercial fishery NEV estimates, therefore, are based on conservative marginal values while the subsistence values are less conservative "average" values. A third difference between these estimates is that the commercial fishery NEV is narrowly tailored to salmon fishing and processing, while the subsistence harvest NEV includes all resources used (including land and marine mammals, fish, shellfish, and plants). Salmon harvest only accounts for about one-half of all Bristol Bay subsistence harvest (in usable raw harvest weight).

The estimates in Table 74 are for annual net economic values. Since these are values for renewable resource services that in principle should be available in perpetuity, it is of interest to also consider their present value (e.g. total discounted value of their use into the foreseeable future). Recent literature (OMB 2003; EPA 2010; Weitzman 2001) provides some guidance on the use of social discount rates for long term (intergenerational) economic comparisons.

The controlling guidance document for discounting in Federal cost benefit analysis, OMB Circular A-4 (2003), generally requires use of discount rates of 3% and 7%, but allows for lower, positive consumption discount rates, perhaps in the 1 percent to 3 percent range, if there are important intergenerational values. The circular states,

> "Special ethical considerations arise when comparing benefits and costs across generations. Although most people demonstrate time preference in their own consumption behavior, it may not be appropriate for society to demonstrate a similar preference when deciding between the well-being of current and future generations. Future citizens who are affected by such choices cannot take part in making them, and today's society must act with some consideration of their interest.
>
> One way to do this would be to follow the same discounting techniques described above and supplement the analysis with an explicit discussion of the intergenerational concerns (how future generations will be affected by the regulatory decision). Policymakers would be provided with this additional information without changing the general approach to discounting.
>
> Using the same discount rate across generations has the advantage of preventing time-inconsistency problems. For example, if one uses a lower discount rate for future generations, then the evaluation of a rule that has short-term costs and long-term benefits would become more favorable merely by waiting a year to do the analysis. Further, using the same discount rate across generations is attractive from an ethical standpoint. If one expects future

> generations to be better off, then giving them the advantage of a lower discount rate would in effect transfer resources from poorer people today to richer people tomorrow.
>
> Some believe, however, that it is ethically impermissible to discount the utility of future generations. That is, government should treat all generations equally. Even under this approach, it would still be correct to discount future costs and consumption benefits generally (perhaps at a lower rate than for intragenerational analysis), due to the expectation that future generations will be wealthier and thus will value a marginal dollar of benefits or costs by less than those alive today. Therefore, it is appropriate to discount future benefits and costs relative to current benefits and costs, even if the welfare of future generations is not being discounted. Estimates of the appropriate discount rate appropriate in this case, from the 1990s, ranged from 1 to 3 percent per annum." (p. 35)

The key question in deciding on an appropriate discount rate or range of rates for analysis is whether the Bristol Bay ecosystem is a resource of intergenerational significance. Clearly, this resource base and ecosystem that has been relied on for thousands of years by Alaska natives, and now has a long-term significance to a growing number of nonnatives, is the very definition of an intergenerational resource.

Weitzman (2001), conducted an extensive survey of members of the American Economic Association, and suggests a declining rate schedule, which may be on the order of 4 percent (real) in the near term and declining to near zero in the long term. He suggests a constant rate of 1.75% as an equivalent to his rate schedule. Weitzman's work is cited both in the EPA guidance (EPA 2000) and in OMB guidance (*Circular A-4* (2003)). Table 75 shows the estimated net present value in perpetuity of direct use values within the Bristol Bay Ecosystem. The table shows a range of alternative discount rates from the standard "intragenerational" rates of 7% and 3% to the more appropriate "intergenerational" rates for the Bristol Bay case of 1.75% and 1.0%. The entire range of NPV estimates in the table is from $3.4 to $35.4 billion. The range of estimated direct use NPV of the resource using the more appropriate intergenerational discount rates is from $13.5 to $35.4 billion. These estimates may be quite conservative as they do not include estimates of passive use values held by those living outside the Bristol Bay Region, but are limited to direct economic uses of the wild salmon ecosystem services.

Table 75. Estimated Net Present Value of Bristol Bay Ecosystem Net Economic Use Values and Alternative Assumed Perpetual Discount Rates

Estimate		**Net Present Value (million 2009 $)**			
	Annual Value	**7% Discount**	**3% Discount**	**1.75% Discount**	**1% Discount**
Low Estimate	$236.9	$3,384	$7,897	$13,537	$23,690
High Estimate	$354.1	$5,059	$11,803	$20,234	$35,410

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AN ASSESSMENT OF POTENTIAL MINING IMPACTS ON SALMON ECOSYSTEMS OF BRISTOL BAY, ALASKA

VOLUME 3—APPENDICES E-J

Appendix F: Biological Characterization: Bristol Bay Marine Estuarine Processes, Fish and Marine Mammal Assemblages

Biological Characterization: An Overview of Bristol, Nushagak, and Kvichak Bays; Essential Fish Habitat, Processes, and Species Assemblages

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PREFACE

The Bristol Bay watershed supports abundant populations of all five species of Pacific salmon found in North America (sockeye, Chinook, chum, coho, and pink), including nearly half of the world's commercial sockeye salmon harvest. This abundance results from and, in turn, contributes to the healthy condition of the watershed's habitat. In addition to these fisheries resources, the Bristol Bay region has been found to contain extensive deposits of low-grade porphyry copper, gold, and molybdenum in the Nushagak and Kvichak River watersheds. Exploration of these deposits suggests that the region has the potential to become one of the largest mining developments in the world.

The potential environmental impacts from large-scale mining activities in these salmon habitats raise concerns about the sustainability of these fisheries for Alaska Natives who maintain a salmon-based culture and a subsistence lifestyle. Nine federally recognized tribes in Bristol Bay along with other tribal organizations, groups, and individuals have petitioned the U.S. Environmental Protection Agency (EPA) to use its authority under the Clean Water Act to restrict or prohibit the disposal of dredged or fill material from mining activities in the Bristol Bay watershed. In response to these petitions and to better understand the potential impacts of large-scale mining, the EPA is conducting an assessment of the biological and mineral resources of the Bristol Bay watershed to inform future government decisions related to protecting and maintaining the physical, chemical, and biological integrity of the watershed. As part of this process, the EPA requested assistance from National Marine Fisheries Service (NMFS) as the agency responsible for the nation's living marine resources.

The EPA assessment focuses on salmon populations, their habitat, and the supporting ecosystem processes in the Nushagak and Kvichak watersheds. Under Section 305(b)(2) of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson Stevens Act), NMFS has designated the region's fresh and marine waters as Essential Fish Habitat (EFH) for anadromous salmon, groundfish, and other invertebrate species. EFH for salmon consists of the aquatic habitat necessary to support a long-term sustainable salmon fishery and salmon contributions to healthy ecosystems. Natural wild salmon populations are currently stable and abundant, and their habitat at the ecosystem scale, from headwater streams through marine processes, is functionally intact.

This report summarizes our current understanding of the region's oceanic and freshwater influence on the nearshore areas of Nushagak and Kvichak Bays; of the invertebrate, fish, and marine mammal assemblages found east of 162° West longitude; and of the range and distribution of Bristol Bay salmon. This report also highlights our understanding of the trophic contribution of Bristol Bay salmon both as smolt leaving the watersheds and as returning adults and our understanding of the importance of estuaries and nearshore habitat as nutrient rich nursery areas for numerous marine species.

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ABSTRACT

This report summarizes our current understanding of Bristol Bay as Essential Fish Habitat (EFH) for salmon at various life stages as well as for other species of marine invertebrates, fish, and marine mammals. As an ecosystem, the currently healthy habitat of the bay both supports and results from the interactions between natural processes and the presence and abundance of all five species of Pacific salmon. As a keystone species, Bristol Bay salmon facilitate energy and nutrient transport to and from the inner bay's terrestrial watersheds and the marine ecosystems of the eastern Bering Sea. Outbound migrations of billions of salmon smolts provide nutrition to numerous trophic levels and marine species, and salmon returning in their adult phase provide a valuable nutrient source to marine mammals and subsidize watersheds in the form of salmon-derived nutrients.

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BRISTOL BAY

Overview

Bristol Bay is a large, shallow sub-arctic bay (Buck et al. 1974, Straty 1977, Straty and Jaenicke 1980, NOAA 1997 and 1998, Wilkinson 2009). Its benthic topography is essentially flat, with an average gradient of 0.02 percent and a maximum depth of approximately 70 meters at the 162° West longitude line (Moore 1964, Buck et al. 1974). The substrate throughout the bay consists of silts and mud and vast aggregates of sand, gravel, cobble, and boulder (Sharma et al. 1972, NOAA 1987; see Smith and McConnaughey 1999 for a detailed description of benthic substrate).

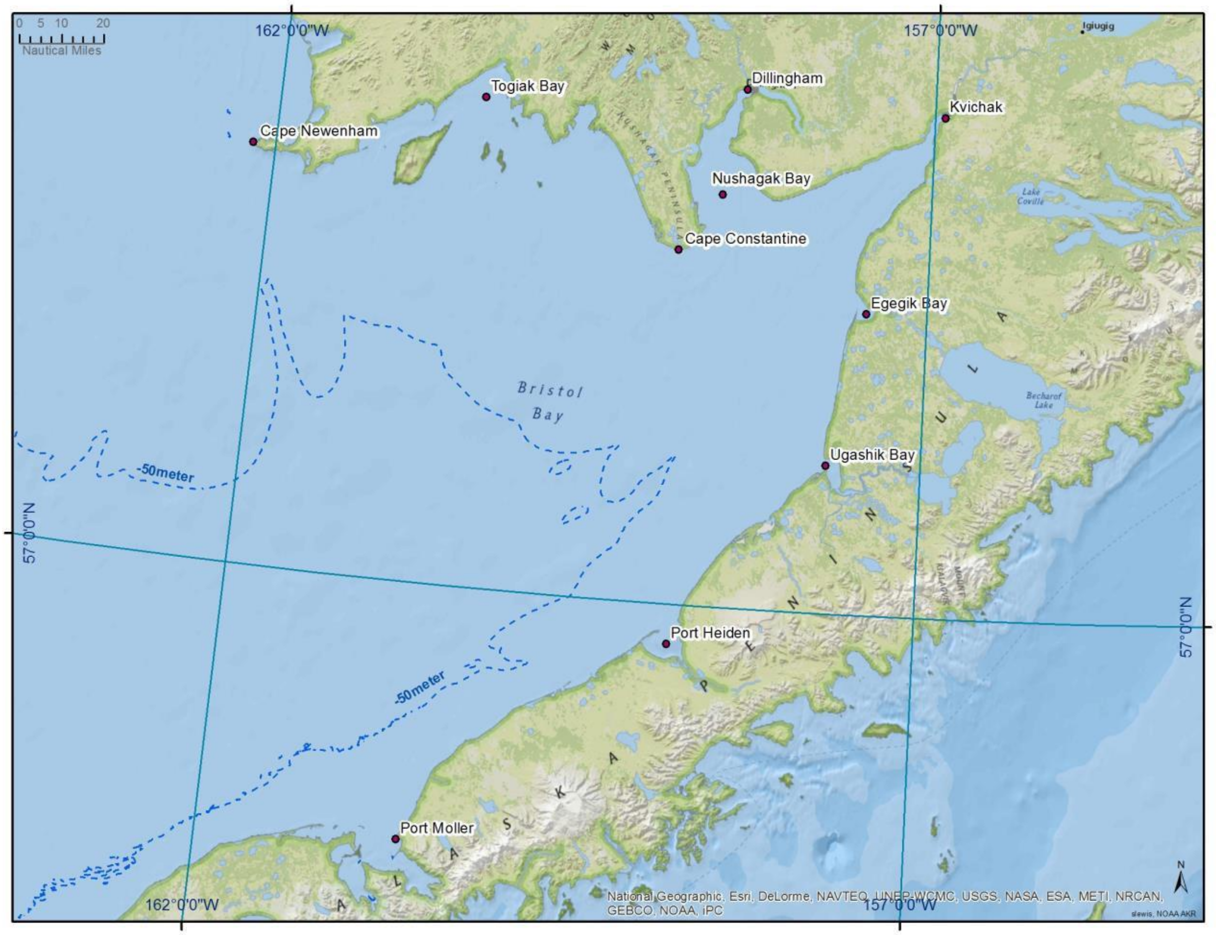

Fig1. Bristol Bay. Waters east of the 162° West longitude line are defined by the North Pacific Fishery Management Council as the Bristol Bay No-Trawl-Zone Protected Area.

The chemical properties of Bristol Bay waters are highly variable and constantly shift under the influence of dramatic currents, tide cycles, and severe weather events from the Bering Sea in the west and the influence of terrestrial freshwater discharges from Nushagak River, Kvichak River, and a number of other, smaller rivers in the east.

Earlier literature distinguishes the inner bay from the outer bay by physical properties such as salinity, temperature, and turbidity (Buck et al. 1974, Straty 1977, Straty and Jaenicke 1980). More recent investigations, however, distinguish different parts of the bay by depth, with an inner or coastal domain from the shoreline to 50 meters deep, a middle domain from 50 to 100 meters deep, and outer domain beyond the 100-meter contour (Kinder and Coachman 1978, Kinder and Schumacher 1981, Coachman 1986, Schumacher and Stabeno 1998, Stabeno et al. 2001**).**

Inner bay processes are continuously fed large volumes of fresh water from numerous watersheds, with salinity increasing toward the 162° West longitude line, while currents from the eastern Bering Sea move through the bay in a counter-clockwise gyre under the influence of tides ranging from 3 to 23 feet (Buck et al. 1974, Straty 1977, Straty and Jaenicke 1980).

Marine Influence

Bristol Bay is essentially an extension of the eastern Bering Sea. Flood tides from the North Pacific enter the eastern Bering Sea through several Aleutian Island passes contributing to the Aleutian North Shore Current (Schumacher et al. 1979, Reed and Stabeno 1994, Stabeno et al. 2002 and Stabeno et al. 2005). East of Unimak Pass, the marine current flows northeast as the Bering Coastal Current along the Alaska Peninsula and into Bristol Bay where it turns in a counter-clockwise gyre (Kachel 2011, pers. comm.). The majority of this current diverts north near the 50-meter contour and eventually flows west and then north around Cape Newenham toward Nunivak and Pribilof Islands (Coachman 1986). Part of the current, however, continues east and delivers marine nitrates, carbon, phosphates, and silica into the inner bay. These mix with fresh water discharges and dissolved organic material from several river systems at the eastern end of the bay (Buck et al. 1974, Stockwell et al. 2001, Kachel et al. 2002, Coyle and Pinchuk 2002, Stabeno and Hunt 2002, Ladd et al. 2005).

Fresh Water Influence

Estuarine characteristics of Nushagak and Kvichak Bays are the result of continual freshwater runoff from several watersheds (Straty 1977, Buck 1974, Straty and Jaenicke 1980). Four large rivers flow into Nushagak Bay: the Igushik, Snake, Wood-Tikchik and Nushagak; and three rivers flow into Kvichak Bay: the Naknak, Alagnak, and Kvichak. The discharge of these rivers contributes to the estuarine character of these bays (Buck et al. 1974). Of the rivers that drain into the inner domain, we measure the discharge of only two, the Nushagak and Kvichak Rivers, which together drain 22,172 square miles (14,190,134 acres) of watershed (USGS 2011). The Nushagak River has a mean annual discharge of 28,468 cubic feet per second (CFS) based on readings from the Nushagak River gauge (USGS No. 15302500, 23,645 cfs) and the Wood River gauge (USGS No. 15303000, 4,823 cfs). The Kvichak River has a mean annual discharge of 17,855 cfs based on readings from the USGS gauge (15300500) located at the outlet of Lake Iliamna. If these three gauges represent an accurate estimate, the total discharge is 46,323 cfs, or approximately 33,536,000 acre feet squared per year. This fresh water influence dominates Nushagak and Kvichak Bays between April and November creating the characteristic estuarine water chemistry. Other sources of fresh water also discharge into Bristol Bay and influence the water quality, but their flows are not monitored and cannot be currently included in estimates.

Out-welling freshwater contributions are significantly higher in spring and summer when winter snow and ice melt and rains are prevalent. As a result, summer ebb tide currents often considerably exceed the flood tides. Discharge from the watersheds keeps the waters of Nushagak and Kvichak Bays colder in early spring; however, by mid-summer these temperatures reverse with warmer terrestrial discharges (Buck et al. 1974). Furthermore, the counter-clockwise current pushes freshwater discharge from Kvichak Bay into Nushagak Bay which maintains a slightly lower salinity. Generally, lower sea surface salinity measurements are observed in Nushagak Bay than in Kvichak Bay (Radenbaugh 2011, pers. comm.).

Because of this seasonal terrestrial freshwater influence, Nushagak and Kvichak Bays exhibit the lowest salinity and greatest temperature fluctuation in Bristol Bay (Buck et al. 1974, Straty and Jaenicke 1980). Similar temperature and salinity gradients have been observed in the inner domain (temperature 11.4 °C, salinity 28.9%) and the middle domain (temperature 7.4 °C, salinity 32.7%) (NOAA 1987). Marine characteristics then dominate off shore. More recent analyses and descriptions of oceanographic currents and nutrients generally describe shallow, wind-driven, well-mixed, homogenous, nutrient-laden waters (Coyle and Pinchuk 2002, Kachel et al. 2002, Stabeno and Hunt 2002).

Bristol Bay - Fish and Invertebrate Assemblages

Nushagak and Togiak Bays

Recent mid-water surveys in Nushagak Bay have found the dominant species in numbers and biomass to include bay shrimp (*Crangon alaskensis*) and Gammarid amphipods and mysiids (*Gammarus* sp.) and confirm the presence of walleye pollock (*Theragra chalcogramma*, a marine pelagic species) and flatfish species (*Pleuronectiformes*) such as yellowfin sole (*Limanda asper*a) in this nearshore habitat (depths less than 30m), along with numerous other fish and invertebrate species (Radenbaugh 2010, pers. comm.). Additional surveys specific to Nushagak Bay shore line at low tide captured over 6,000 fish of 17 species. Two species accounted for 95% of the total catch: rainbow smelt and pond smelt (*Hypomesus olidus*) (Johnson 2012).

Recent surveys conducted in both Nushagak and Togiak Bays encountered over 40 fish and invertebrate species (Olmseth 2009). Most captured individuals were less than 20 cm in length. Of these species, shrimp (*Crangonidae*) and rainbow smelt (*Osmerus mordax*) were the most abundant species encountered, occurring in almost every trawl and beach seine, and were especially dominant in very shallow water with mud and silt bottoms. Forage fish species identified by these surveys were salmon smolt (*Salmonidae*), capelin (*Osmeridae*) and Pacific herring (*Clupeidae*), as well as poachers (*Agonidae*), sculpin (*Cottoidea*), flatfish (*Pleuronectidae* and *Bothidae*), and greenling (*Hexagraaidae*).

Nearshore

In addition to the surveys of Nushagak and Togiak Bays, surveys of other nearshore waters of Bristol Bay document forage fish species such as Pacific herring, eulachon (*Thaleichthys pacificus*), capelin, and rainbow smelt (Warner and Shafford 1981, Mecklenburg et al. 2002, Bernard 2010). In an evaluation of historical data, Gaichas and Aydin (2010) found that salmon smolts rank as one of the top ten nearshore forage fish. Pacific herring are also known to spawn in nearshore waters of Togiak Bay and along the northern shoreline of the Alaska Peninsula (Bernard 2010). Sand lance (*Ammodytes hexapterus*) have been found in particular abundance in these nearshore waters of the Alaska Peninsula (McGurk and Warburton 1992).

Surveys conducted to characterize the presence and distribution of forage fish species in Bristol Bay nearshore waters also identified several species of groundfish: Pacific cod (*Gadus macrocephalus*) and walleye pollock, as well as juvenile sockeye salmon (*Oncorhynchus nerka*) (Isakson et al. 1986, Houghton 1987). During one phase of these surveys, juvenile sockeye salmon were more abundant than any forage fish or juvenile ground fish species encountered. Present again, though in fewer numbers, were Pacific herring, capelin, pond and surf smelt, and eulachon. The presence, abundance, and biodiversity of these species in Bristol Bay nearshore habitat support our current understanding of these areas as nutrient rich fish nurseries.

Similar surveys of nearshore habitat conducted in neighboring Alaskan waters further illustrate the complexity and diversity of fish and invertebrate assemblages (Norcross et al. 1995, Abookire et al. 2000, Abookire and Piatt 2005, Arimitsu and Piatt 2008, Thedinga et al. 2008, Johnson et al. 2010). Anadromous species, as well as groundfish, forage fish, and invertebrate species, are all well represented in many of these nearshore areas in a variety of different habitat and substrate types and water conditions.

Offshore

Fisheries surveys of the offshore waters of Bristol Bay have been conducted since the 1930s. The AFSC has conducted annual surveys in the eastern Bering Sea offshore and outer Bristol Bay waters since 1982 using standardized gear and repeatable methods. These surveys identify numerous groundfish species inhabiting the eastern Bering Sea and Bristol Bay, generally deeper than the 15-20m contour (Lauth 2010)[1]. The more common species represented in the surveys are cod and pollock (*Gadidae*); fifteen species of flatfish (*Pleuronectiformes*); forage fish species such as herring, eulachon, capelin, smelts, sand lance, and sandfish; and dozens of other species well represented, such as skate (*Rajidae*), poachers (*Psychrolutidae*), greenling (*Hexagrammos*), rockfish (*Scorpaenidae*), sculpin (*Cottidae*), crab (*Cancer*), and salmon. In Table 1 we identify all species known to inhabit these waters.

The hundreds of fish species and invertebrate species that inhabit Bristol Bay waters contribute to trophic levels at various life stages; tides and currents transport and distribute larval marine fish and invertebrate species from offshore to nearshore nursery areas (Norcross et al. 1984, Lanksbury et al. 2007). The relationship between marine and nearshore processes and species presence in Bristol Bay has been well documented in the life histories of species such as walleye pollock, red king crab (*Paralithodes camtschaticus*), and yellowfin and rock sole. Larval forms of each species are transported and concentrated in nutrient-rich nearshore habitat. These four species illustrate relevant examples of recognized marine species with population segments that in a larval or juvenile phase rely on nearshore marine habitat (depths less than 30 m) for refuge and nutrition.

Walleye pollock are generally recognized as a pelagic species spawning in open marine waters (Bailey et al. 1999). As Coyle (2002) notes, pollock in their larval and juvenile forms are known to be transported into nearshore nursery zones: the current carries the eggs and larvae along the north shore of the Alaska Peninsula and into the nearshore nursery zones of Bristol Bay (Napp et al. 2000). A recent investigation of trophic interactions shows that juvenile pollock feed on euphasiid and mysiid populations nearshore, especially mysiids, which have been shown to be more abundant in the diets of pollock found in the northern nearshore zones than those found in deep water (Aydin 2010).

Bristol Bay is also home to the second-largest population of red king crab (Dew and McConnaughey 2005, Chilton et al. 2010). Although red king crab of both genders and several stages of maturity occur throughout central Bristol Bay, immature larvae and juveniles are often concentrated along nearshore areas. The Aleutian North Shore and Bering Coastal currents transport larval king crab from the eastern Bering Sea to inner Bristol Bay (Dew and McConnaughey 2005). Larval red king crab (smaller than 2 mm) settle in cobble and gravel substrates of Kvichak Bay[2] (Armstrong et al. 1981, McMurray 1984, Loher et al. 1998); juveniles are present along the nearshore zone in the Togiak district (Armstrong et al. 1993,

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[1] All species were found east of the 162° West longitude line and in waters deeper than 15m. Because the surveys represent a snap shot of species present at a particular time, they may not represent complete species diversity. Also, because standardized trawl gear mesh is size selective, juvenile and larval specimens of a species may not be well represented. It is important to note that salmon species at any life stage may not be well represented due to seasonality of surveys and species migration.

[2] Larval red king crab were present on substrates less than 70 to 80 feet (approximately 21 to 24 meters) at mean low water in Kvichak Bay.

Olmseth 2009). These juvenile phases inhabit nearshore rocks, shell hash, or a variety of biological cover in shallow depths (from 5 to 70 meters).

Yellowfin and rock sole are among several species of flatfish that inhabit the eastern Bering Sea and for which nearshore substrates (depths less than 30 meters) in Bristol Bay are optimal habitat (McConnaughey and Smith 2000, Lauth 2010; Table 1). Life histories of these species and other flatfish take advantage of the same currents that transport larvae into nearshore nursery areas (Nichol 1998, Wilderbuer et al. 2002, Norcross and Holladay 2005, Lanksbury et al. 2007, Cooper et al. 2011). Larval and juvenile yellowfin sole are abundant in shallow nearshore areas along the northern shore and Togiak Bay (Olmseth 2010, Nichol 1998, Wilderbuer et al. 2002).

These findings for Pollock, red king crab, and yellowfin and rocksole substantiate our understanding of nearshore and estuary zones as nutrient rich fish nurseries, providing juvenile fish species with greater forage opportunity in the form of abundant invertebrate populations.

Bristol Bay – Salmon

The ecological role of Bristol Bay salmon is complex. Salmon facilitate energy and nutrient exchange across multiple trophic levels from terrestrial headwaters through estuarine and marine ecosystems. Each species migrates through these waters at slightly different times depending on life history and watershed of origin. Because of their abundance, distribution, and overall economic importance, Bristol Bay sockeye salmon have been more extensively studied than other salmonids in the region. Generally, once in marine waters juvenile salmon spend their first summer in relatively shallow waters on the southeastern Bering Sea shelf, feeding, growing and eventually moving offshore into the Bering Sea basin and North Pacific Ocean (Meyers et al. 2007, Farley et al. 2011, Farley 2012, pers. comm.).

Range and Distribution

The Magnuson-Stevens Act defines EFH as “waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” For salmon, EFH consists of those fresh and marine waters needed to support healthy stocks in order to provide long-term sustainable salmon fisheries. Because of the broad range and distribution of salmon in Alaskan waters, all marine waters over the continental shelf in the Bering Sea extending north to the Chukchi Sea and over the continental shelf throughout the Gulf of Alaska and in the inside waters of the Alexander Archipelago are defined as EFH for all juvenile salmon (Echave et al. 2011). EFH for immature and mature Pacific salmon (*Oncorhynchus spp*) includes nearshore and oceanic waters, often extending well beyond the shelf break (Echave et al. 2011).

In their emigration phase, anadromous juvenile salmon occupy shallows of estuaries and nearshore zones, although timing, duration, and abundance vary throughout the year depending on species, stock, and life history stage (Groot and Margolis 1991, Quinn 2005). Nearshore and estuarine habitats act as transition zones supporting osmoregulatory changes (the physiological changes by which smolt adapt between fresh and salt water) (Hoar 1976 and 1988, Clarke and Hirano 1995, Dickhoff et al. 1997). Studies have shown that sub-yearling salmon in the Pacific Northwest move repeatedly between zones of low and high salinity, and although no studies have yet shown Bristol Bay salmon to behave similarly, the Pacific Northwest studies suggest that such behavior may be integral to the survival and growth of young salmon (Healey 1982, Levings 1994, Levings and Jamieson 2001, Simenstad et al. 1982, Simenstad 1983, Thom 1987).

The eastern Bering Sea shelf is an important nursery ground for juvenile and sub-adult Bristol Bay sockeye salmon (Farley et al. 2009). Early models of eastern Bering Sea and North Pacific salmon stocks describe migrations and broad distributions to the south and east in winter and spring and to the north and west in summer and fall (French et al. 1975, French et al. 1976, Rogers 1987, Burgner 1991, Shuntov et al. 1993). These studies were the first to suggest that population migrations crossed the Aleutian Island chain into the North Pacific (Myers et al. 1996, Myers 2011 pers. comm.). Recent investigations incorporating genetic (DNA) and scale pattern analysis validate these observations (Bugaev 2005, Farley et al. 2005, Habicht et al. 2005, Habicht et al. 2007, Myers et al. 2007). Investigations conducted in autumn 2008 and winter 2009 substantiate the migration of juvenile Bristol Bay sockeye salmon from the Eastern Bering Sea shelf to the North Pacific, south of the Aleutian Island chain (Habicht et al. 2010, Farley et al. 2011, Seeb et al. 2011):

> In their first oceanic summer and fall, juveniles are distributed on the eastern Bering Sea shelf, and by the following spring immature salmon are distributed across a broad region of the central and eastern North Pacific. In their second summer and fall, immature fish migrate to the west in a band along the south side of the Aleutian chain and northward through the Aleutian passes into the Bering Sea. In subsequent years, immature fish migrate between their summer/fall feeding grounds in the Aleutians and Bering Sea and their winter habitat in the North Pacific. In their last spring, maturing fish migrate across a broad, east-west front from their winter/spring feeding grounds in the North Pacific, northward through the Aleutian passes into the Bering Sea, and eastward to Bristol Bay. (Farley et al. 2011)

More than 55% of ocean age-1 sockeye salmon sampled during the 2009 winter survey in the North Pacific were from Bristol Bay stocks. These broad seasonal shifts in distribution likely reflect both genetic adaptations and behavioral responses to environmental cues (e.g., prey availability and water temperature) that are mediated by bioenergetic constraints (Farley et al. 2011). This extensive range and distribution suggest that Bristol Bay sockeye salmon contribute to the trophic dynamics in the Bering Sea as well as the North Pacific.

Salmon Contribution to Trophic Levels

A recent evaluation was conducted by the AFSC Ecosystem Modeling Team to assess the contribution of Nushagak and Kvichak River sockeye salmon to trophic dynamics of the eastern Bering Sea shelf and North Pacific ecosystems (Gaichas and Aydin 2010). Using estimates of outbound salmon smolt survival and adult returns, researchers calculate that these two rivers account for nearly 70% (56,000 of 81,100 tons) of adult salmon biomass in the eastern Bering Sea. In the open ocean, sockeye salmon represent 47% of total estimated salmon biomass present in the eastern subarctic gyre (Aydin et al. 2003). Bristol Bay sockeye salmon from the Nushagak and Kvichak Rivers compose 26% of total sockeye salmon biomass and 12% of total salmonid biomass in the entire eastern subarctic gyre. The Nushagak and Kvichak Rivers produce a significant portion of all salmon in offshore marine ecosystems and the majority of salmon on the eastern Bering Sea shelf, thus producing the majority of juveniles and returning adults in the salmon biomass (Gaichas and Aydin 2010). The AFSC's evaluation indicates sockeye salmon from these river systems rank among the top ten forage groups, comparable to Pacific herring or eulachon as a nutritional source for other marine species in the Bering Sea and North Pacific. One study supports this rational indicating that outbound salmon smolt export substantial levels of nitrogen and phosphorus seaward (Moore and Schindler 2004).

Returning adult salmon enrich watersheds in the form of salmon-derived nutrients (Gende et al. 2002, Schindler et al. 2003, Wilson et al. 2004), and these nutrients are flushed back into estuaries by out-welling[3] river waters. Salmon-derived nutrients are transported in the form of partial and whole salmon carcasses or particulates and dissolved nutrients (carbon, nitrogen and phosphorous) moving from watersheds back to the estuaries. Early studies identified the flow of salmon carcasses out of the coastal watersheds into marine estuaries as a result of high precipitation events (Brickell and Goering 1970, Richey et al. 1975). Salmon-derived nutrients stimulate primary production in estuaries where nitrogen and phosphorus are often limiting nutrients (Rice and Ferguson 1975). Estuarine algae use dissolved nutrients, in turn feeding copepods which feed juvenile salmon (Fujiwara and Highsmith 1997). One investigation identified several species of marine invertebrates feeding on salmon carcasses (Reimchen 1994). Stationary whole salmon carcasses were completely consumed in a week. Gende (2004) estimated that 43% of the tagged salmon carcasses washed into the study estuary within days. More recent investigations conducted in Alaskan waters suggest that 60% of the total nutrient or biomass transported into the watershed by salmon may be transported back to the estuary (Johnston et al. 2004, Mitchell and Lamberti 2005).

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[3] Terrestrial freshwater runoff from large river systems and watersheds drains into marine estuaries. In referenced literature, this runoff is often referred to as "outflow" or "outwelling." Outwelling freshwater chemistry, temperature, and nutrient plumes influence marine estuary chemistry, productivity, and salinity gradients.

In Nushagak and Kvichak Bays, nutrients liberated from tens of millions of decomposing adult salmon likely have a significant influence on estuarine trophic interactions and biodiversity in the manner discussed above. Estuarine processes such as primary and secondary production and countless marine fish and invertebrate species benefit from this mass transport of nutrients. Numerous studies indicate that marine estuarine vegetation and larval and juvenile invertebrate and fish populations benefit from enrichment of nutrients flushed back into the marine estuaries. The influence of outwelling freshwater and nutrients from watersheds and terrestrial river systems on marine estuaries and processes can be substantial.

Bristol Bay - Marine Mammals

The eastern Bering Sea supports numerous species of marine mammals including whales (*Cetacea*) of the suborders Odontoceti (toothed whales and porpoise) and Mysticeti (baleen whales). Several species of seals (pinnipeds) are also represented (*Otariidae*, *Phocidae*, and *Odobenidae*) in these waters (Allen and Angliss 2011). Of marine mammals present in the eastern Bering Sea, twenty species occur in Bristol Bay waters in significant numbers and regularity (Table 2). Three species of baleen whale (fin, right and humpback whales) and one pinniped species (Western Distinct Population Segment Steller sea lion) found in Bristol Bay are listed as endangered under the Endangered Species Act. The seven species we discuss below are those Bristol Bay marine mammals known to feed on salmon.

In Bristol Bay, the presence of marine mammals and their prey species is highly variable depending on the season and location within the bay. For example, the presence and feeding habitats of sea lions or fur seals are difficult to identify because of variations in their seasonal range, in whether they are at sea or in rookeries, and in the migratory patterns of their prey. Less is known about pinniped prey selection in the open ocean because scat and stomach content studies are only conducted while specimens are on the rookery. Thus, the only prey species represented in dietary analysis are prey species near the rookeries.

Some marine mammal diet data show seasonal dependence on salmon. Several studies demonstrate that salmon are a prominent nutritional source for several marine mammal species (Pauly et al. 1998a). Many marine mammals, especially pinniped and ondontocete species, prey on adult and juvenile salmon in nearshore and estuary zones.

Pinnipeds

*Steller Sea lion*s

Steller Sea lion predation on salmon has been confirmed by data from scat and stomach content studies from which researchers have estimated the level of consumption and frequency of occurrence (NMFS 1992, Merrick 1995, Merrick et al. 1997, Sinclair and Zeppelin 2002, Trites and Donnelly 2003, Jemison 2011, pers. comm.). Depending on seasonal range and migratory patterns, salmon ranked high as a selected prey species in Steller sea lion diets (Sinclair and Zeppelin 2002). The endangered western stock of Steller sea lions relies on salmon during summer; salmon rank second in frequency of occurrence in summer diets in regions sampled between 1990 and 1998 (Sinclair and Zeppelin 2002). These regions include the Bering Sea shelf and waters surrounding the Aleutian Islands, where salmon were noted to increase in diets during winter due to out-migrating sub-adult Bristol Bay salmon (Sinclair and Zeppelin 2002).

Fur seals

Fur seals also feed on salmon throughout the Pacific range, from California to Alaska (Perez and Bigg 1986). One more recent investigation conducted to determine prey species of northern fur seals in the Pribilof Islands indicates salmon composed part of the diet of fur seals on St. George and St. Paul Islands (Sinclair et al. 2008). Pacific salmon had a mean annual frequency of occurrence of 14.4%, and 10% in any one year on St. George and St. Paul Islands respectively. Similar nutrition studies of eastern Bering Sea northern fur seals indicate salmon rank second among fish in frequency of occurrence for animals on both Pribilof Islands from late July through September, 1990-2000 (Gudmundson et al. 2006).

Harbor seals

Harbor seals also are found throughout Bristol Bay and the eastern Bering Sea and prey upon species of Pacific salmon (Jemison et al. 2000, Small et al. 2003, Allen and Angliss 2011, Jemison 2011, pers. comm.). The Bristol Bay population of harbor seals numbers approximately 18,000 seals and is increasing (Allen and Angliss 2013). Lake Iliamna supports a year-round population of harbor seals, which are currently included as part of the Bristol Bay stock. The number of seals residing in Lake Iliamna is relatively small; aerial surveys of hauled-out harbor seals count as many as 321 (which counts do not reflect absolute abundance) (Mathisen and Kline 1992, Small 2001, Burns et al. 2012; Migura 2013, pers. Comm.). Although this population has colonized Lake Iliamna from Bristol Bay via the Kvichak River, no scientific evidence shows that harbor seals migrate to and from Bristol Bay. However, some residents and Alaska Native subsistence hunters in the Iliamna Lake area say that harbor seals are seen within the entire expanse of the Kvichak River and migrate between the lake and Bristol Bay (Migura 2013, pers. Comm.). Harbor seals have also been identified in the Nushagak and Wood River systems. In the Wood River system, harbor seals are observed in Lake Aleknagik (B. Andrew 2011, pers. comm., D. Chythlook 2011, pers. comm., Tinker 2011, pers. comm.).

Spotted seals

Spotted seals have also been sighted in Bristol Bay. Other spotted seals tagged in Alaskan and Russian sectors of the Bering Sea show clear seasonal preference for nearshore habitat and associated fisheries, which suggests that spotted seals sighted in Bristol Bay may have a persistent presence there. These populations feed mostly on salmon, saffron cod (*Eleginus gracilus*), and herring (Burkanov 1989, Lowery et al. 2000).

Whales: Toothed Whales

Beluga whales

Beluga whales are abundant in Bristol Bay waters primarily from spring through fall near the mouths of the Kvichak, Nushagak, Wood, and Igushik rivers. Early studies document the importance and contribution of sockeye salmon for beluga nutrition (Brooks 1955). Lensink (1961) notes that belugas fare poorly in Bristol Bay when migratory (anadromous) fish are not available. In addition to following the general movements of its prey, belugas appear to feed specifically where their prey species are most concentrated. The frequency of occurrence of salmon species in beluga stomachs is correlated with the abundance of each species during their respective migrations (Brooks 1955). Studies conducted by Brooks in the 1950s further indicate that beluga whales feed on both juvenile and adult salmon, as well as on several other forage fish and invertebrate species (Klinkhart 1966).

From 1993 to 2005, the beluga population increased in abundance by 4.8% per year, and while thresholds of prey abundance needed for belugas to thrive are not fully understood, the larger size of red salmon runs before and during the period covered by aerial surveys may partially explain the increased beluga numbers (Lowry et al. 2008). Belugas are well known to travel up these regional rivers in pursuit of salmon. They have been seen feeding on salmon in the Kvichak River past Levelock to the Igiugig Flats (Cythlook and Coiley 1994, G. Andrew 2011, pers. comm.). Traditional knowledge also indicates that beluga whales have also been seen in Lake Illiamna (M. Migura 2013, pers. comm.). In summer, belugas are routinely observed in the Nushagak River (P. Andrew 2011, pers. comm.). In the Wood River system, belugas have been observed in Lake Aleknagik (Fried et al. 1979, B. Andrew 2011, pers. comm, Tinker 2011, pers. comm).

Killer whales

Killer whales also inhabit Bristol Bay waters. They have been seen in nearshore waters and frequent the lower river reaches chasing and preying upon salmon and beluga whales (Frost and Lowry 1981, Frost et al. 1992, Allen and Angliss 2011, Quakenbush 2011, pers. comm.). In a recent observation (July 17, 2002), killer whales displayed cooperative feeding behaviors near the Nushagak spit. A pod formed a circle with their tails facing toward the center, flukes slapping on the surface of the water. A male killer whale emerged through the center of the circle with a mouth full of salmon (Tinker 2011, pers. comm.). In the Nushagak River, killer whales have been observed chasing both belugas and coho (*Oncorhynchus kisutch*) salmon (D. Cythlook 2011, pers. comm.). In late fall, in the absence of beluga whales, killer whales pursue late-run and fall coho up the Nushagak River (P. Andrew 2011, pers. comm.).

Although they are opportunistic feeders, fish-eating killer whales outside of Bristol Bay show an affinity for salmon. In Prince William Sound, the results of a 14-year study of the diet and feeding habits of killer whales identify two non-associating groups of killer whale, termed resident and transient (Bigg et al. 1987). The resident groups (fish-eaters) appear to prey principally on salmon, preferring coho (*O. kisutch*) over other more abundant salmon species (Saulitis et al. 2000). Another distinct population of Alaskan fish-eating killer whales off the coast of British Columbia moves seasonally to target salmon populations (Nichol and Shackleton 1996). Field observations of predation and stomach content analysis of stranded killer whales collected over a 20-year period document 22 species of fish and one species of squid that dominated the diet of fish-eating resident-type killer whales (Ford et al. 1998). Despite the diversity of fish species taken in these studies, fish-eating resident killer whales showed a clear preference for salmon: 96% of fish taken were salmonids. Of the six salmonid species identified, by far the most common was Chinook (*Oncorhynchus tshawytscha*) representing 65% of the total sample. The second most common was pink at 17% (*Oncorhynchus gorbuscha*), followed by chum (6%) (*Oncorhynchus keta*), coho (6%), sockeye (4%), and steelhead (2%) (*Oncorhynchus mykiss*) (Ford et al. 1998). Although a separate population, Bristol Bay killer whales may have similar feeding behaviors.

Sperm whales

Sperm whales are also known to prey upon salmon and have been sighted, however infrequently, in Bristol Bay. Sperm whales feed primarily on mesopelagic squid in the North Pacific, but have also been documented consuming salmon as well as several other species of fish (Tomilin 1967, Kawakami 1980).

Whales: Baleen Whales: Humpback Whales

Investigations of baleen whale food habits in the North Pacific and Bering Sea have documented species such as humpbacks targeting small schooling fish populations. Salmon were among numerous species of fish identified (Nemoto 1959, Tomilin 1967, Kawamura, 1980). More recently, humpback whales have been observed off Cape Constantine in Bristol Bay in the spring of year, presumably feeding on schooling herring and possibly outmigrating salmon smolts (D. Cythlook 2011, pers. comm.). In southeast Alaska, humpback whales have been observed preying upon both wild and hatchery outbound salmon smolts as well as adult pink salmon (Straley et al. 2010, Straley 2011, pers. comm.). Humpback whales have been shown to exhibit site fidelity to feeding areas, and return year after year to the same feeding locations (Baker et al. 1987, Clapham et al. 1997). There is very little interchange between feeding areas (Baker et al. 1986, Calambokidis et al. 2001, Waite et al. 1999, Urban et al. 2000. The humpback whales observed off Cape Constantine may reasonably be assumed to exhibit a similar site fidelity for purposes of feeding.

Discussion

The primary purpose of this report is to identify the range, distribution, and trophic contribution of salmon originating from the Nushagak and Kvichak watersheds and bays. In a broader context, this report also presents information on known species assemblages and environmental influences on the estuarine and marine habitat. This report also attempts to acknowledge other habitat attributes that influence nearshore and estuary conditions and are important to salmon smolt physiology and to the trophic dynamics that support the abundance and resilience of current salmon populations.

Habitat Condition

The abundance, resilience, and stability of regional salmon populations are at once a product of and contribute to the currently healthy habitat, which includes the water quality. Natural ecosystem and hydro-geomorphic processes in the region remain functionally intact from headwater tributaries through marine waters. Salmon are abundant at various life history stages, which abundance influences and contributes to the productivity of other fisheries at multiple trophic levels. At their current abundance, salmon influence habitat condition in these watersheds by providing a rich source of nutrition to a broad range of invertebrates, fish, and marine mammals, as well as to countless terrestrial flora and fauna. Salmon enrich watersheds and influence water chemistry.

Water

Fish habitat includes not only structure such as hard substrate, reefs or rock, and vegetation such as eel grass or kelp, but also—and it seems odd to have to say so—the water itself. The success and abundance of a species are largely determined by the quality of the water, its temperature, its salinity, and its chemical composition, which includes the availability of nutrients necessary for life. If nutrient sources, forage opportunities, and prey are diminished, the habitat itself is changed, and all the dynamics of the food web are thus altered.

Nushagak and Kvichak Bays resemble other Alaskan estuaries as subarctic and allochthonous (turbid) in nature. As discussed above, these waters are dominated by seasonal freshwater runoff from snow melt and rains. Turbidity in the bays minimizes photosynthesis, primary production, and associated algal blooms; however, nutrient is carried in outwelling discharge of detritus, dissolved organic material, and salmon-derived nutrients. These materials provide the essential nutrients and energy for lower trophic levels supporting assemblages of minute bacteria, fungi and algae, through larval stages of plankton, invertebrates, juvenile fish and salmon smolt. The abundance and availability of nutrient sources at the lower trophic levels are essential to the survival of salmon smolt in their early estuarine and marine phase. Successful smolt survival is reflected years later in the strength of returning adult runs and escapement.

Estuaries

Although no studies to date have been conducted specifically identifying the importance of estuarine habitat to salmon smolt in Nushagak and Kvichak Bays, a number of other studies conducted in Alaska and the Northwest document several attributes of estuaries important to juvenile salmon smolt (Murphy et al. 1984, Heifetz et al. 1989, Johnson et al. 1992, Thedinga et al. 1993 and 1998, Koski and Lorenz 1999, Halupka et al. 2003, Koski 2009). Cited studies identify estuaries as an often preferred habitat choice for coho salmon, providing increased food and growth, expanding their nursery area, and increasing overall production from the watershed.

The high productivity of some estuarine habitats in Alaska and the Northwest allows an array of life history patterns (Healey 1983). One such pattern involves rearing in both rivers and estuaries, allowing salmon to migrate and rear in estuaries for a summer and in some cases return and over-winter in rivers (Reimers 1971, Murphy et al. 1984, 1997, Harding 1993, Koski and Lorenz 1999, Miller and Sadro 2003, M. Wiedmer 2013, pers. comm.). Being able to move between estuary and river increases feeding opportunities, allows smolt to achieve critical size (as discussed below), and supports osmoregulatory change in their early marine phase. The dominant freshwater influence of Nushagak and Kvichak Bays supports osmoregulatory adjustment prior to entry into the highly saline marine phase. It should also be recognized that smolt outmigration coincides with increased freshwater influence in these estuaries. Similar studies and literature of northwest salmon substantiate the importance of estuarine habitat to salmon smolt survival (Rich 1920, Healey 1982, Levy 1992, Thorpe 1994, Groot and Margolis 1998, Bottom 2005, Quinn 2005, Koski 2009).

Studies focused on flatfish species in other regions further identify the importance of estuarine habitat as fish nurseries. Disproportionate numbers of juvenile flatfish from estuarine habitat compose adult populations found in nearshore marine waters (Brown 2006). In this instance, although estuarine habitat composes only about 6% of the available juvenile habitat, the estuary appears to be the source of approximately half of the adult fish collected in the region. These results validate previous findings further explaining the linkage between estuarine and nearshore habitats for other species (Yamashita et al. 2000, Forrester and Swearer 2002, Gillanders et al. 2003). As noted in this review, these nearshore waters are “fish nurseries” supporting numerous species in their larval and juvenile life history stages.

Salmon Food Habits

Studies of the feeding habits of North Pacific salmon in general (that is, not specific to Bristol Bay salmon) show that the species’ feeding habits vary by species, life stage, region, and seasonal prey availability. Prey species repeatedly identified were euphausiids, hyperiids, amphipods, copepods, pteropods, and chaetognaths. Egg, larval, and juvenile stages of numerous forage fish, groundfish, and invertebrate species were also identified. Landingham and Sturdevant (1997) report that the prey spectrum for juvenile salmon species was composed of 30 taxa. The six taxa groups of most importance were calanoid copepods, hyperiid amphipods, euphausiids, decapods, larval tunicates and fishes. Other studies identify similar prey assemblages: euphausiids, hyperiids, amphipods, copepods, pteropods, chaetognaths, and polychaetes (Auburn and Ignell 2000, Orsi et al. 2000, Powers et al. 2006, Weikamp and Sturdevant 2008). Food habit studies conducted in Cook Inlet and Knik Arm further illustrate the importance of nearshore invertebrate prey assemblages for salmon smolt (Houghton 1987, Moulton 1997, summarized in USFWS 2009). Brodeur and Pearcy (1990) describe prey of all five North Pacific salmon and ocean-phase trout in all regions where they occur.

These studies analyzed stomach-content data and reveal that juvenile salmon ingest substantial quantities of food while in nearshore and estuary habitat. Salmon smolts tended to be well nourished and in some cases demonstrated prolonged estuarine residence time feeding extensively on plentiful larval invertebrate and juvenile fish species. Although these studies are not specific to Bristol Bay, the salmon prey species identified in these studies are also abundant in the Nushagak and Kvichak Bays.

Salmon Critical Size

The importance of abundant prey opportunities during the transition from fresh to marine waters, especially in the early marine phase, has been illustrated in “critical size” discussions. Earlier studies suggest that more slowly growing salmon smolt experience greater size-selective predation (Parker 1968, Willette et al. 1999). Smolt that fail to achieve a critical threshold size by late spring and early summer commonly fail to survive their first winter (Mahnken et al. 1982). Stunted smolt suffer protein-energy deficiency and are more likely to become prey for other marine species. Salmon smolt need to reach a critical size and strength to survive their first year in the open ocean (Beamish 2001 and 2004). Studies of Bristol Bay salmon in their marine phase in the eastern Bering Sea again suggest that reduced growth during their first year at sea may lead to substantial mortality (Moss et al. 2005, Farley et al. 2007). Greater nutrition and prey availability lead to larger juvenile salmon which gain a survival advantage over smaller individuals (Farley et al. 2007, Farley et al. 2011).

Trophic Contribution

Salmon-derived nutrients subsidize watersheds with organic nutrients such as carbon, nitrogen, and phosphorus, first in the form of whole carcasses and large solids and later as dissolved particulates (Willson et al. 1998, Cederholm et al. 1999, Gende et al. 2002, Naiman et al. 2002). Salmon carcasses, which are considerably enriched in carbon and nitrogen, contribute to primary production in freshwater streams, lakes, and estuaries (Stockner 1987, Cederholm et al. 1989 and 2000, Kline et al. 1990 and 1993, Bilby et al. 1996, Wipfli et al. 1998). As discussed above, marine estuaries and nearshore zones benefit from seasonal pulses of these nutrients. Terrestrial and aquatic species, from invertebrates and insects to mammals, as well as aquatic and riparian vegetation, also receive benefit from these seasonal pulses (Reimchen 1994, Wilson and Halupka 1995, Bilby et al. 1996 and 1998, Ben-David et al. 1997 and 1998, Wipfli et al. 1998, Cederholm et al. 1999, Gende and Wilson 2001, Helfield and Naiman 2001, Chaloner et al 2002, Chaloner and Wipfli 2002, Darimont and Reimchen 2002, O'Keefe and Edwards 2002, Reimchen et al. 2002 and 2003, Darimont et al. 2003, Mathewson et al 2003, Johnston et al. 2004, Lessard and Merritt 2006, Moore et al. 2007, Christie 2008, Christie and Reimchen 2008, Janetski 2009).

Coastal watersheds drain to the ocean-influencing estuaries and nearshore coastal zones (Kennish 1992, Caddy 1995 and 2000, Milliman 2010, Dade 2012). Watershed and riparian processes influence downstream estuaries through the transport of terrestrial and freshwater nutrients (Murphy 1984, Jauquet et al. 2003, Jonsson and Jonsson, 2003, Cak 2008, Von Biela 2013). Nutrient metabolism in estuaries can be strongly influenced by freshwater river inputs of organic and inorganic material (Hopkinson 1995, Kennish 2002). Some studies have demonstrated the importance of terrestrial-generated carbon to juvenile and adult bottom-dwelling marine fish species in periods of even moderate river discharge (Darnaube 2005). Recently, these nutrient sources have been identified as contributing to coastal estuaries and trophic interaction in Arctic zones as well (Dunton 2006 and 2012, Von Biela 2013).

Salmon-derived nutrients influence and contribute to estuary production of seasonal larval and juvenile plankton, invertebrate and fish species. One early study to suggest the influence of these nutrients on estuary water chemistry was conducted in Port Walther, Alaska (Brickell and Goering 1970). This study found that after spawning and dying in Sashin Creek, salmon carcasses were flushed into the estuary and elevated levels of organic nitrogen. Richey (1975) observed similar flushing of salmon carcasses into estuaries. Reimchen (1994) observed entire salmon carcasses rapidly consumed by several species of estuarine invertebrates. Gende (2004) reports that 43% of tagged carcasses in one watershed washed into the estuary within days. Fujiwara (1997) presents evidence suggesting that dissolved nutrients fuel estuarine productivity and associated bacteria and algae, which in turn increase the numbers of harpacticoid copepods that serve as primary prey for outbound juvenile salmon. Estimates of recent nutrient transport indicate that substantial amounts of salmon-derived nutrients (46%-60%) move directly back to the estuary (Mitchell and Lamberti 2005). A similar study suggests that bivalves also benefit from these nutrients (Chow 2007).

The results of this research indicate an influence of salmon-derived nutrients on trophic productivity in marine estuaries. These studies also suggest a positive feedback mechanism in salmon production, given that decomposing adult salmon subsidize lower trophic levels and provide prey species to their outbound offspring (Fujiwara and Highsmith 1997, Gende et al. 2004). As Aydin (2010) explains, “Mysiids, as an inshore zooplankton (appearing in diets primarily in shallow waters of Bristol Bay) have a nitrogen isotope ($\delta 15N$) level higher than deepwater forage fish.” This strong nitrogen signal was observed in euphausiid and walleye pollock inhabiting northern Bristol Bay nearshore waters. This unusually high nitrogen signal may result from the seasonal increase of freshwater discharge and dissolved organic matter (a seasonal terrestrial nutrient pulse from salmon) carried on currents along the northern shore of Bristol Bay. In addition, smolt emigration theoretically exports more nutrients out of the watersheds than previously recognized, and salmon in sub-adult and adult phases in the eastern Bering Sea and North Pacific also contribute to marine mammal diets.

Summary

Pacific salmon are a keystone species providing nutrients that influence the habitat condition of terrestrial, estuarine and marine ecosystems (Willson and Halupka 1995; Cedarholm et al.1999; Helfield and Naiman 2001; Piccolo et al. 2009). Due to their life history, anadromy, range, and distribution, Bristol Bay salmon represent a link between fresh water and marine systems. Discharges of seasonal freshwater transport dissolved organic matter to the estuary. The freshwater discharge facilitates osmoregulatory adaption in salmon smolts, providing a buffer to highly saline marine conditions. The estuary provides rich foraging opportunities and a rearing environment that allow smolt to achieve the size essential for survival in the early marine phase. At the beginning of their life cycle, emigrating smolt from rivers contribute to estuarine and marine productivity as a forage fish species. At the end of their life cycle, adult salmon provide the nutrients that influence productivity from watersheds through the estuary. These nutrient sources provide a feedback mechanism to their outbound offspring fueling lower trophic levels, from minute bacteria and fungi to a multitude of plankton, invertebrate, fish, and marine mammal species.

Bristol Bay provides EFH for salmon at various life stages as well as other marine species. The Nushagak and Kvichak estuaries provide nutrient-rich transition zones where salmon smolt can achieve critical size while acclimating to the marine environment. At an ecosystem level, from the head water tributaries through the marine environment, the healthy habitat of the bay both supports and results from the interactions between natural processes and the presence and abundance of Bristol Bay salmon.

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Tables

Table 1: Fish and Invertebrate Species List

Species listed have been identified in the NOAA-AFSC Bering Sea Trawl Surveys between 1982-2010 (Lauth 2010).

FISH SPECIES

Common Name	***Scientific Name***
	Salmonidae
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Steelhead	*Oncorhynchus mykiss*
	Gadidae
Pacific cod	*Gadus macrocephalus*
Walleye pollock	*Theragra chalcogramma*
Arctic cod	*Boreogadus saida*
Saffron cod	*Eleginus gracilis*
	Anoplopomatidae
Sablefish	*Anoplopoma fimbria*
	Osmeridae
Eulachon	*Thaleichthys pacificus*
Capelin	*Mallotus villosus*
Rainbow smelt	*Osmerus mordax*
Smelt unident	*Osmeridae*
	Clupeidae
Pacific herring	*Clupea pallasi*
	Ammodytidae
Pacific sand lance	*Ammodytes hexapterus*
	Trichodontidae
Pacific sandfish	*Trichodon trichodon*
	Pleuronectidae
Pacific halibut	*Hippoglossus stenolepis*

Yellowfin sole	*Limanda aspera*
Northern rock sole	*Lepidopsetta polyxystra*
Rock sole unident.	*Lepidopsetta sp.*
Flathead sole	*Hippoglossoides elassodon*
Dover sole	*Microstomus pacificus*
Rex sole	*Glyptocephalus zachirus*
Butter sole	*Isopsetta isolepis*
Sand sole	*Psettichthys melanostictus*
Starry flounder	*Platichthys stellatus*
Alaska plaice	*Pleuronectes quadrituberculatus*
Arrowtooth flounder	*Atheresthes stomias*
Kamchatka flounder	*Atheresthes evermanni*
Longhead dab	*Limanda proboscidea*
Sanddab unident.	*Citharichthys sp.*
	Scorpaenidae
Northern rockfish	*Sebastes polyspinis*
	Rajidae
Big skate	*Raja binoculata*
Bering skate	*Bathyraja interrupta*
Starry skate	*Raja stellulata*
Alaska skate	*Bathyraja parmifera*
Aleutian skate	*Bathyraja aleutica*
	Hexagrammos
Whitespotted greenling	*Hexagrammos stelleri*
Rock greenling	*Hexagrammos lagocephalus*
Kelp greenling	*Hexagrammos decagrammus*
Smooth lumpsucker	*Aptocyclus ventricosus*
Greenling unident.	*Hexagrammidae*
	Psychrolutidae
Sawback poacher	*Leptagonus frenatus*
Gray starsnout	*Bathyagonus alascanus*
Sturgeon poacher	*Podothecus accipenserinus*
Aleutian alligatorfish	*Aspidophoroides bartoni*
Arctic alligatorfish	*Ulcina olrikii*
Warty poacher	*Chesnonia verrucosa*
Bering poacher	*Occella dodecaedron*

	Anarhichadidae
Wolf-eel	*Anarrhichthys ocellatus*
Bering wolffish	*Anarhichas orientalis*
	Gymnocanthus sp.
Threaded sculpin	*Gymnocanthus pistilliger*
Arctic staghorn sculpin	*Gymnocanthus tricuspis*
Armorhead sculpin	*Gymnocanthus galeatus*
Northern sculpin	*Icelinus borealis*
Sculpin unident.	*Cottidae*
	Artediellus sp.
Hookhorn sculpin	*Artediellus pacificus*
Irish lord	*Hemilepidotus sp.*
Red Irish lord	*Hemilepidotus hemilepidotus*
Yellow Irish lord	*Hemilepidotus jordani*
	Triglops sp. Ribbed
sculpin	*Triglops pingeli*
Brightbelly sculpin	*Microcottus sellaris*
Warty sculpin	*Myoxocephalus verrucosus*
Great sculpin	*Myoxocephalus polyacanthocephalus*
Plain sculpin	*Myoxocephalus jaok*
	Myoxocephalus sp.
Pacific staghorn sculpin	*Leptocottus armatus*
Antlered sculpin	*Enophrys diceraus*
Spinyhead sculpin	*Dasycottus setiger*
Crested sculpin	*Blepsias bilobus*
Eyeshade sculpin	*Nautichthys pribilovius*
Sailfin sculpin	*Nautichthys oculofasciatus*
Bigmouth sculpin	*Hemitripterus bolini*
Thorny sculpin	*Icelus spiniger*
Spatulate sculpin	*Icelus spatula*
	Liparis sp.
Variegated snailfish	*Liparis gibbus*
Snailfish unident.	*Liparidinae*

	Stichaeidae
Daubed shanny	*Lumpenus maculatus*
Snake prickleback	*Lumpenus sagitta*
Decorated warbonnet	*Chirolophis decoratus*
Bearded warbonnet	*Chirolophis snyderi*
Polar eelpout	*Lycodes turneri*
	Cryptacanthodidae
Giant wrymouth	*Cryptacanthodes giganteus*

INVERTEBRATE SPECIES

Common Name	***Scientific Name***
Octopus	
	Octopodidae sp.
Common Octopus	*Octopoda*
Eastern Pacific bobtail	*Rossia pacifica*
Crab	
	Cancer sp.
Oregon rock crab	*Cancer oregonensis*
Graceful decorator crab	*Oregonia gracilis*
Tanner crab	*Chionoecetes bairdi*
Circumboreal toad crab	*Hyas coarctatus*
Pacific lyre crab	*Hyas lyratus*
Snow crab	*Chionoecetes opilio*
Hybrid tanner crab	*Chionoecetes hybrid*
Helmet crab	*Telmessus cheiragonus*
Hermit crab unident.	*Paguridae*
	Pagurus sp.
Sponge hermit	*Pagurus brandti*
Aleutian hermit	*Pagurus aleuticus*
Splendid hermit	*Labidochirus splendescens*
Knobbyhand hermit	*Pagurus confragosus*
Fuzzy hermit crab	*Pagurus trigonocheirus*
Bering hermit	*Pagurus beringanus*
Alaskan hermit	*Pagurus ochotensis*
Longfinger hermit	*Pagurus rathbuni*
Widehand hermit crab	*Elassochirus tenuimanus*
Hairy hermit crab	*Pagurus capillatus*

Purple hermit	*Elassochirus cavimanus*
Wrinkled crab	*Dermaturus mandtii*
	Hapalogaster sp.
Fuzzy crab	*Hapalogaster grebnitzkii*
Red king crab	*Paralithodes camtschaticus*
Horsehair crab	*Erimacrus isenbeckii*

Shrimp

	Pandalus sp.
Ocean shrimp	*Pandalus jordani*
Alaskan pink shrimp	*Pandalus eous*
Humpy shrimp	*Pandalus goniurus*
Shrimp unident.	*Hippolytidae*
	Lebbeus sp.
Spiny lebbeid	*Lebbeus groenlandicus*
	Crangon sp.
Abyssal crangon	*Crangon abyssorum*
Twospine crangon	*Crangon communis*
Ridged crangon	*Crangon dalli*
Sevenspine bay shrimp	*Crangon septemspinosa*
Crangonid shrimp unident.	*Crangonidae*
	Argis sp.
Arctic argid	*Argis dentata*
	Sclerocrangon sp.
Sculptured shrimp	*Sclerocrangon boreas*
Kuro argid	*Argis lar*

Clams, Mussels, Scallop, Cockles

	Mytilidae sp.
Northern horse mussel	*Modiolus modiolus*
	Mytilus sp. Blue
mussel	*Mytilus edulis*
Weathervane scallop	*Patinopecten caurinus*
Arctic hiatella	*Hiatella arctica*
Arctic roughmya	*Panomya norvegica*
	Yoldia sp.
Crisscrossed yoldia	*Yoldia seminuda*
Northern yoldia	*Yoldia hyperborea*
Discordant mussel	*Musculus discors*
Boreal astarte	*Astarte borealis*

Many-rib cyclocardia	*Cyclocardia crebricostata*
	Mactromeris sp.
Arctic surfclam	*Mactromeris polynyma*
	Tellina sp.
Alaska great-tellin	*Tellina lutea*
	Macoma sp.
Bent-nose macoma	*Macoma nasuta*
	Siliqua sp.
Pacific razor	*Siliqua patula*
Alaska razor	*Siliqua alta*
	Mya sp.
Softshell clam	*Mya arenaria*
Alaska falsejingle (soft oyster)	*Pododesmus macrochisma*
Soft shell unident.	*Anomiidae*
	Ciliatum sp.
Hairy cockle	*Clinocardium ciliatum*
California cockle	*Clinocardium californiense*
	Serripes sp.
Greenland cockle	*Serripes groenlandicus*
Broad cockle	*Serripes laperousii*
	Cyclocardia sp.
	Clinocardium sp.

Coral, Soft coral

	Gersemia sp.
Sea raspberry	*Gersemia rubiformis*
	Gorgonacea sp.
Sea pen (sea whip)	*Pennatulacea*

Snail, snails, welk

	Natica clausa sp.
Aleutian moonsnail	*Cryptonatica aleutica*
Rusty moonsnail	*Cryptonatica russa*
Pale moonsnail	*Euspira pallida*
Great slippersnail	*Crepidula grandis*
Moonsnail eggs unident	*Naticidae eggs*
	Volutopsius sp.
Warped whelk	*Pyrulofusus deformis*
	Beringius sp.
	Beringius kennicottii

	Beringius beringii
	Neptunea sp.
Pribilof whelk	*Neptunea pribiloffensis*
	Neptunea borealis
Lyre whelk	*Neptunea lyrata*
Fat whelk	*Neptunea ventricosa*
	Neptunea heros
Helmet whelk	*Clinopegma magnum*
	Plicifusus kroyeri
	Neptunea sp.
Oregon triton	*Fusitriton oregonensis*
	Tritonia sp.
Rosy tritonia	*Tritonia diomedea*
	Buccinum sp. Angular
whelk	*Buccinum angulosum*
Sinuous whelk	*Buccinum plectrum*
Ladder whelk	*Buccinum scalariforme*
Polar whelk	*Buccinum polare*
Smooth lamellaria	*Velutina velutina*
	Hyas sp.
Snail eggs	*Gastropod eggs*
Snail eggs unident.	*Neptunea sp. eggs*

Barnacles

	Balanus sp.
Giant barnacle	*Balanus evermanni*
Beaked barnacle	*Balanus rostratus*
Barnacle unident.	*Thoracica*

Anemone

	Halipteris sp.
Sea anemone unident.	*Actiniaria*
	Metridium sp.
Clonal plumose anemone	*Metridium senile*
Gigantic anemone	*Metridium farcimen (=Metridium giganteum)*
	Stomphia sp.
	Urticina sp.
Mottled anemone	*Urticina crassicornis*
Chevron-tentacled anemone	*Cribrinopsis fernaldi*

Tentacle-shedding anemone	*Liponema brevicornis*
Stony coral unident.	*Scleractinia*
Star fish, sea star	
	Evasterias sp.
Mottled sea star	*Evasterias troschelii*
Giant sea star	*Evasterias echinosoma*
	Leptasterias groenlandica
Blackspined sea star	*Lethasterias nanimensis*
	Henricia sp.
Blood sea star	*Henricia leviuscula*
Tumid sea star	*Henricia tumida*
	Leptasterias polaris
	Leptasterias katharinae
	Leptasterias arctica
	Leptasterias sp.
	Crossaster sp.
Grooved sea star	*Crossaster borealis*
Rose sea star	*Crossaster papposus*
	Asterias sp.
Purple-orange sea star	*Asterias amurensis*
Brittlestarfish unident.	*Ophiuroidea*
Basketstar	*Gorgonocephalus eucnemis*
Notched brittlestar	*Ophiura sarsi*
Sea urchin	
	Echinacea sp.
Green sea urchin	*Strongylocentrotus droebachiensis*
	Strongylocentrotus sp.
	Strongylocentrotus polyacanthus
Sand dollar	*Echinarachnius parma*
Sponges	
	Stelletta sp.
Stone sponge	*Suberites ficus*
Clay pipe sponge	*Aphrocallistes vastus*
Barrel sponge	*Halichondria panicea*
	Suberites sp.
Sponge	*Porifera*

Jelly fish

	Amphilaphis sp.
Jelly Fish	*Chrysaora melanaster*
Lion's mane	*Cyanea capillata*
Chrysaora jellyfish	*Chrysaora sp.*
Jellyfish unident.	*Scyphozoa*
Comb jelly unident.	*Ctenophora*

Miscellaneous Invertabrate Species

Worm

	Polychaeta
Giant scale worm	*Eunoe nodosa*
Depressed scale worm	*Eunoe depressa*
Striped sea leech	*Notostomobdella cyclostoma*
Echiuroid worm unident.	*Echiura*
Cat worm unident.	*Nephtyidae*
Scale worm unident.	*Polynoidae*
Peanut worm unident.	*Sipuncula*
Tube worm unident.	

Hydroids

	Abietinaria sp.

Bryozoans

Feathery bryozoan	*Eucratea loricata*
Leafy bryozoan	*Flustra serrulata*
	Alcyonidium pedunculatum
Ribbed bryozoan	*Rhamphostomella costata*
Bryozoan unident.	*Bryozoa*

Sea Cucumbers

	Cucumaria sp.
Sea football	*Cucumaria fallax*
Sea cucumber	*Holothuroidea*
	Cucumaria frondosa
Foraminiferan unident.	***Psolus sp.***
	Foraminifera

Ascidians

Orange sea glob	***Aplidium sp.***
Sea pork	*Aplidium californicum*
	Molgula sp.
Sea grape	*Molgula grifithsii*
Sea clod	*Molgula retortiformis*

Table 2: Marine Mammals Species List

Marine mammal species listed have been identified from several sources (Allen 2011, ADFG 2010, BBESI 2001, BB-CRSA 2009).

MARINE MAMMALS **Common Name**	***Scientific Name***
Toothed Whales	***Cetaceans - Ondontocetes***
Beluga whale	*Delphinapterus leucas*
Killer whale	*Orcinus orca*
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
Harbor porpoise	*Phocoena phocoena*
Dall’s porpoise	*Phocoenoides dalli*
Baird’s beaked whale	*Berardius bairdii*
Baleen Whales	***Cetaceans – Balenotropha***
Gray whale	*Eschrichtius robustus*
Humpback whale	*Megaptera novaeangliae*
Fin whale	*Balaenoptera physalus*
Minke whale	*Balaenoptera acutorostrata*
Bowhead whale	*Balaena mysticetus*
Sealion	***Pinnipeds - Otariidae***
Steller sea lion (Eastern)	*Eumetopias jubatus*
Northern fur seal (Eastern)	*Callorhinus ursinus*
Seals	***Pinnipeds - Phocidae***
Harbor seal	*Phoca vitulina*
Spotted seal	*Phoca largha*
Bearded seal	*Erignathus barbatus*
Ringed seal	*Pusa hispida*
Ribbon seal	*Histriophoca fasciata*
	Pinnipeds – Odobenidae
Walrus	*Odobenus rosmarus*
	Mustelidae - Lutrinae
Northern Sea Otter	*Enhydra lutris kenyoni*

AN ASSESSMENT OF POTENTIAL MINING IMPACTS ON SALMON ECOSYSTEMS OF BRISTOL BAY, ALASKA

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Appendix G: Foreseeable Environmental Impact of Potential Road and Pipeline Development on Water Quality and Freshwater Fishery Resources of Bristol Bay, Alaska

Appendix G

Foreseeable Environmental Impact of Potential Road and Pipeline Development on Water Quality and Freshwater Fishery Resources of Bristol Bay, Alaska

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ABSTRACT

While Pacific salmon fishery resources have diminished around the Pacific Rim for more than a century, the Bristol Bay region of Alaska supports a globally unique, robust, productive, and sustainable salmon fishery associated with extremely high quality waters and high integrity freshwater ecosystems. The Bristol Bay watershed has seen a bare minimum of road development to date. However, State of Alaska long range plans envision a future of extensive inter-community transportation routes, including both highways and pipelines. Other developments being considered for the area would also require an infrastructure of roads and pipelines that would traverse previously roadless areas of the Kvichak and Nushagak river drainages. As a plausible example of such potential infrastructure, this report uses the 138-km-long access road and four pipelines likely to be part of Northern Dynasty Minerals' Pebble Mine, should the company elect to pursue development of that prospect. It reviews the known physical and biological effects of road and pipeline development on streams, rivers, lakes, and wetlands. The report identifies two key conditions in the Bristol Bay ecosystem that particularly contribute to its water quality and biological productivity and resilience: 1) a geologic and geomorphic template that provides abundant shallow groundwater resources and strong vertical linkage between surface waters and groundwater, across all stream sizes and wetland types; and 2) the lack of past industrial disturbance, including road development across most of the Bristol Bay watershed. The example Pebble Mine transportation corridor would bisect this landscape with the potential to shape the hydrology, water quality and fish habitat integrity of many of the Kvichak and Nushagak river drainages. Drawing from the literature that conceptualizes how to spatially project risk-impact footprints from road designs and landscape and stream network data, the report maps the spatial extent of potential harm from construction, operation, accidents and accidents response on the Pebble transportation corridor. More than 30 large streams and rivers known to support spawning salmon would intersect with the proposed transportation corridor, potentially affecting between twenty and thirty percent of known spawning populations of sockeye salmon in the Iliamna Lake system. The eastern half of Iliamna Lake supports the highest concentrations of rearing sockeye salmon and would also be very close to the road and pipeline corridor. The corridor would also bisect or closely approach more than 70 streams known to support resident fishes such as Dolly Varden, arctic grayling, and others. The report also assesses potential mitigation measures and identifies practices that could potentially reduce the risk of impact to water quality, freshwater ecosystem function, and Bristol Bay fishery resources should the corridor be developed.

I. INTRODUCTION AND SCOPE OF THIS REPORT

While Pacific salmon fishery resources have diminished around the Pacific Rim to the point that many populations are managed as endangered or threatened species, the Bristol Bay region of Alaska supports a globally unique, robust and productive salmon fishery (Burgner 1991, Schindler et al. 2010). Commercial fishers harvest five Pacific salmon species in Bristol Bay, including a sockeye salmon landing of over 29 million fish in 2010 (ADFG 2010). Bristol Bay's wild rivers support sport fisheries likely exceeding 90,000 angler days and millions of dollars in related expenditures (Duffield et al. 2007).

Hilborn et al. (2003) identified key factors sustaining the productivity and resilience of Bristol Bay, specifically, 1) a highly accountable system of fishery regulation, 2) favorable ocean conditions in recent years, and 3) a stock complex sustained by variable production from an abundance and high diversity of freshwater and estuarine habitats., Salmon production in different Bristol Bay rivers and lakes, in their current, largely natural and undeveloped condition, varies independently over time spans of decades. Despite the local variability, the system sustains a high overall fishery production because at any given time, a collection of extremely high-quality habitats contributes extraordinarily high abundance and production of fishes. These same factors (i.e., diversity and high quality of interconnected habitats) likely confer to Bristol Bay a degree of resilience in the face of future climate and environmental change (Hilborn et al. 2003, Woody and O'Neal 2010, Schindler et al. 2010).

Although some planners have projected extensive highways and industrial development in the Bristol Bay region (BBAP 2005), the Pebble Mine is the most likely large-scale development to be proposed in the near future. Development of the Pebble project would include a major 138-km-long access road, pipeline, and electric utility corridor between the mine site, north of Lake Iliamna, and a deepwater port on Cook Inlet, to the east (Ghaffari et al. 2011) (Figure 1). This corridor would cross many tributaries of the of the Kvichak and Nushagak Rivers, including tributaries of Iliamna lake, as well as bisecting numerous wetlands and groundwater-rich areas that connect to and sustain the water quantity and quality in those fish habitats.

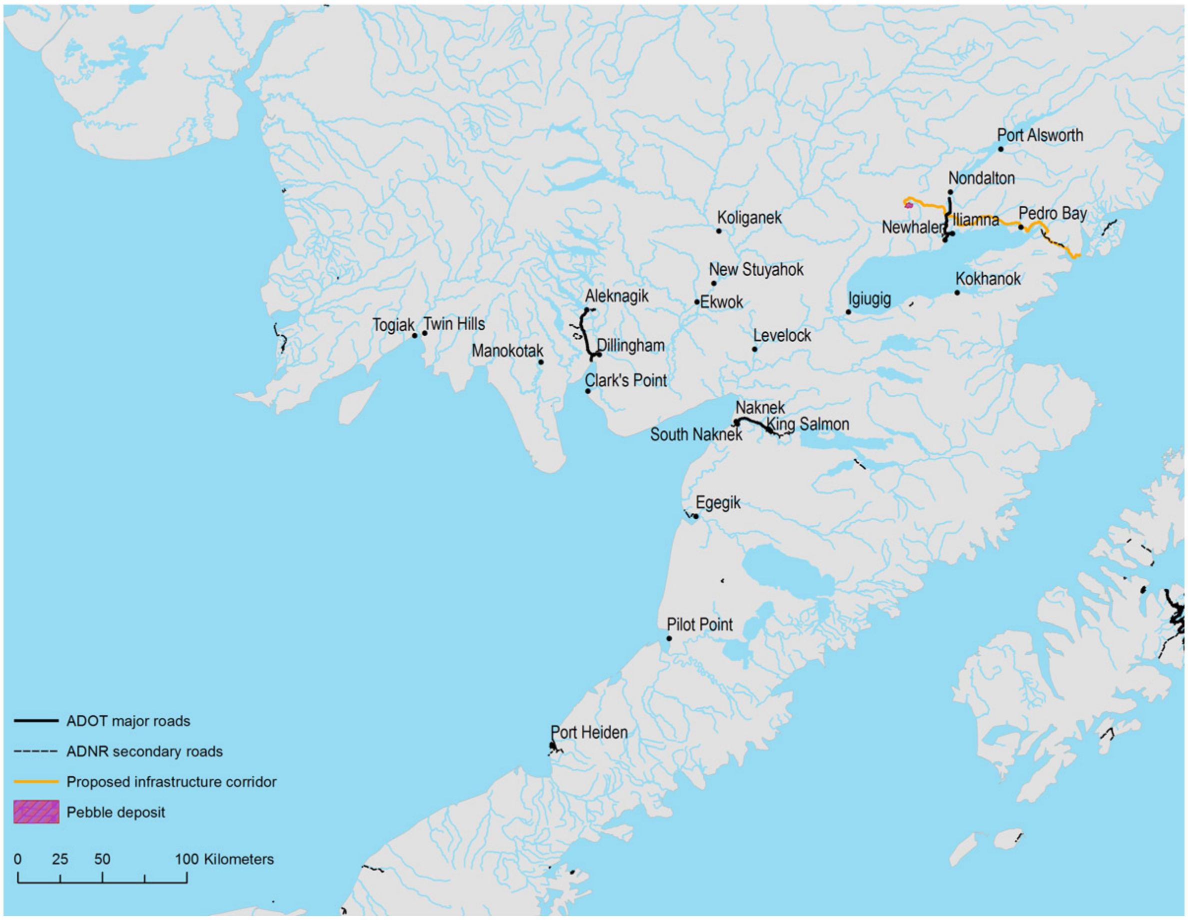

Figure 1. Existing roads in the Bristol Bay region, and the proposed route of the Pebble Mine transportation corridor. Mapped by Rebecca Shaftel (Alaska Natural Heritage Program, Anchorage) based on data from Alaska Department of Transportation and Alaska Department of Natural Resources (Anchorage).

Through its contractor for this report, NatureServe, U.S. Environmental Protection Agency charged the author with providing a review of: 1) relevant literature and expert input on the risks, threats, and stressors to Bristol Bay area water quality and salmon resources associated with the construction, operation, and maintenance of reasonably foreseeable roads in the region; and 2) mitigation practices used to abate such impacts, including both commonly used and available, but uncommonly used practices.

Accordingly, after a brief review of known consequences of road and pipeline development on streams, rivers, and lakes, this report will assess the scope of likely and possible environmental impacts on the water quality and fishery resources of the Bristol Bay region from development of the potential Pebble Mine Transportation Corridor.

II. THE BRISTOL BAY ECOSYSTEM

Bristol Bay is one of the world's few remaining, large virtually roadless near-coastal regions. There are but a few short segments of state highway and road, and no railroads, pipelines, or other major industrial transportation infrastructure. Roadways presently link Iliamna Lake (Pile Bay) to Cook Inlet (tidewater at Williamsport); the Iliamna area (including Iliamna airport) north to a proposed bridge over the Nondalton River and then to the village of Nondalton; and two other short road segments from Dillingham to Aleknagik and Naknek to King (Figure 1). A short road system also connects the village of Pedro Bay with its nearby airstrip. Improvements have been proposed by the state of Alaska for the road between Iliamna and Nondalton, in part to alleviate erosion and sedimentation.

Glacial landforms dominate much of Bristol Bay's surface geology and geomorphology and include extensive glacial outwash glacial till mantles on hillslopes, expansive, interbedded glacial lake deposits, and glacial and periglacial stream deposits (Hamilton 2007). These landforms, and more specifically, the extensive, interconnected surface and near-surface groundwater systems resulting from them, are one of the two factors that principally account for Bristol Bay's high productivity for salmon. (The other key factor is the dearth of industrial and commercial development in the basin.)

Most available information on fish distribution and abundance in the Bristol Bay region focuses on large rivers (in part because they can be surveyed from the air, at least for sockeye salmon). However, a myriad of smaller streams and wetlands also provide high-quality habitat for coho salmon, Dolly Varden, rainbow trout, and arctic grayling, as well as other species including round whitefish, pond smelt, lamprey, slimy sculpin, northern pike, sticklebacks and burbot (Rinella 2011, personal communication, and Shaftel 2011, personal communication). In the most comprehensive published field inventory, Woody and O'Neal (2010) reported detection of one or more of these species from 96 percent of the 108 small waters they sampled in the vicinity of the projected site of Pebble prospect in the Nushagak and Kvichak River drainages. They summarize:

> Small headwater streams are often assumed not to be important salmon producing habitats in Alaska, although collectively they produce millions of salmon and determine water flow and chemistry of larger rivers. As illustrated by this and numerous other studies, headwaters comprise a significant proportion of essential spawning and rearing habitat for salmon and non-salmon species all of which are important to subsistence users in the region.

III. ROADS AND PIPELINES PROPOSED OR FORESEEABLE IN BRISTOL BAY

In evaluating the environmental impact of any road, it is important to recognize that the development of a new road is often only the first step toward industrial or commercial development of the landscape in general, including the proliferation of additional roads (Trombulak and Frissell 2000, Angermeier et al. 2004). Additional large-scale landscape development, facilitated by the initial road, is a reasonably foreseeable impact of road construction in a roadless area. Essentially, finance and construction of the initial road subsidizes future developments that rely on that road to route traffic, particularly when that initial road connects to a possible trade hub, such as a deepwater port. The environmental impact of the ensuing development can dwarf by orders of magnitude the direct, local effects of constructing the initial road segment (Angermeier at al. 2004).

That there is some interest in industrialization of Bristol Bay beyond the Pebble Mine is evident in various State of Alaska sources. The ADNR's Bristol Bay Area Plan from the (BBAP 2005, citing the ADOT's Southwest Alaska Transportation Plan, November 2002), lays out an ambitious long-range vision for future development of a network of roads and highways in the Bristol Bay region. The roads, highways, and related infrastructure envisioned by the BBAP include "regional transportation corridors" that would connect Cook Inlet to the area of the Pebble prospect, as well as Aleknagik (already connected by road to Dillingham), King Salmon, Naknek, Egegik, and Port Heiden, and finally, to Chignik and Perryville, on the southern Alaska Peninsula. The State also foresees other "community transportation projects" that involve extensions, improvements, or new roads within or adjacent to Bristol Bay watershed (Chignik Road Intertie, King Cove-Cold Bay Connection, Newhalen River Bridge, Iliamna-Nondalton Road Intertie, and Naknek-South Naknek Bridge and Intertie). The plans also identify three potential "Trans-Peninsula transportation corridors" (Wide Bay/Ugashik Bay, Kuiulik Bay/Port Heiden, and Balboa Bay/Herendeen Bay,) routes that could serve for roads, oil and gas pipelines or other utilities as needed (BBAP 2005, Figure 2.5).

Several other large ore bodies and at least seven different complexes of mineral claims lie within a roughly concentric 24-km radius around the existing Pebble Prospect, encompassing a vast swath of the Bristol Bay watershed north of Iliamna Lake (Ghaffari et al. 2011, The Nature Conservancy 2010). The area spans the headwaters of the Koktuli, Stuyahok, and Newhalen Rivers, as well as Kaskanak, and both Lower and Upper Talarik Creeks. There are other large mineral leases farther afield within Bristol Bay, including tracts north and west of the Nushagak and Mulchatna Rivers. Although they are at various stages of exploration, these prospects could yield future mine proposals, particularly if road and other transportation improvements completed for Pebble Mine provided a transportation stepping stone to them.

IV. EFFECTS OF ROADS AND PIPELINES ON WATER AND FISH HABITAT

Roads have persistent multifaceted impacts on ecosystems and can strongly affect water quality and fish habitat. Several authors have reviewed the suite and scope of environmental impacts from roads (e.g., Forman and Alexander 1998, Trombulak and Frissell 2000, Gucinski et al. 2001) with particular focus on water quality and fish habitat impacts found in sources such as Furniss et al. (1991), Jones et al. (2000), and Angermeier et al. (2004). The increasing presence of roads in the developed and developing world has been identified as a threat to native freshwater species and water quality alike. Czech et al. (2000), for example, identified roads as a likely contributing factor in the local extinction and endangerment of 94 taxa across the U.S.

Road construction causes mortality and injury of stationary and slow-moving organisms both within and adjacent to the construction footprint and alters the physical conditions in the area, as well (Trombulak and Frissell 2000), often including direct conversion of habitat to non-habitat within and adjacent to the footprint (Forman 2004). Behavior modification depends on species and road size/type. Voluntary modification ranges from use of the road corridor to avoidance; involuntary modification may result when a road completely blocks the movement of organisms, resulting in fragmentation or isolation of populations, often with negative demographic and genetic effects and with potential consequences as grave as local population or species extinction and loss of biodiversity (Forman 2004, Gucinski et al. 2001, Trombulak and Frissell 2000). Truncation of fish migrations due to passage barriers created by roads is one example of involuntary behavioral alterations that compromise survival and productivity. Other behavior modifications include changes in home range, reproductive success, escape response, and/or physiological state (Forman and Alexander 1998, Trombulak and Frissell 2000).

Roads can create long-term, local changes in soil density, temperature, and water content, light, dust, and/or surface water levels, and flow, runoff, erosion, and/or sedimentation patterns, as well as adding heavy metals, deicing salts, organic molecules, ozone, and nutrients to roadside environments (Forman 2004, Gucinski et al. 2001, Trombulak and Frissell 2000, Forman and Deblinger 2000). When delivered to streams, road-derived pollutants directly and indirectly impact water quality. The extension of natural stream networks to integrate eroding road surfaces can cause sustained delivery of fine sediments that alter bed texture and reduce the permeability of streambed gravels (Furniss et al. 1995, Wemple et al. 1996, Jones et al. 2000, Angermier et al. 2004). Increased loading of fine sediments has been linked to adverse impacts on fish though several, often co-occurring biological mechanisms, including decreased fry emergence, decreased juvenile densities, loss of winter carrying capacity, increased predation on fish, and reduced benthic organism populations and algal production (Newcombe and MacDonald 1991, Newcombe and Jensen 1996, Gucinski et al. 2001, Angermier et al. 2004, Suttle et al. 2004, and many others). In steeper terrain, roads greatly increase the frequency of slope failure and debris flow, with the resulting episodic sediment delivery to streams and rivers (Montgomery 1994, Jones et al. 2000, Gucinski et al. 2001). Roads often promote the dispersal of exotic species and pathogens by altering habitats, stressing native species, and providing corridors and vehicle transport for seed/organism dispersal (Forman 2004, Trombulak and Frissell 2000, Gucinski et al. 2001). So long as they remain accessible and passable enough to facilitate human use, roads also lead to increased hunting, fishing, poaching, fish and wildlife harassment, use conflicts, lost soil productivity, fires, landscape modifications, and decreased opportunities for solitude (Forman 2004, Gucinski et al. 2001, Trombulak and Frissell 2000, Angermeier et al. 2004). Although impacts to water and fish are the primary focus of this report, the direct and indirect impacts of roads on other resources and their use should also be recognized.

While the only certainly effective mitigation to avoid the impacts of roads and pipelines is to find alternatives that do not require building and using them, it does not appear geographically or operationally feasible to develop the Pebble mine without a road and pipeline corridor.

Immediate Effects of Construction versus Long-term Impact of Use and Maintenance

Following Angermeier et al. (2004), the effects of roads are distributed across scales of space and time in three discernible quanta. The first is the immediate and site-specific effect from the construction of a new road. Many of these impacts are either transient or are acute only during and shortly after initial construction. An example is the delivery of large pulses of sediment to streams during runoff events after placement of fill or major ground disturbance by heavy equipment. The second quantum is the suite of effects caused by sustained operation, maintenance, and/or mere existence of the roadway. Examples include seasonal runoff of pollutants such as deicing salts into nearby streams, transport of wind-eroded dust from road surfaces to adjacent areas, chronic delivery of sediment from erosion of road surfaces, ditches, and cut slopes, and the alteration or sustained displacement of natural vegetation in the footprint and influence zone of the road. Finally, often the greatest impact of road development is the ancillary development of the landscape, or change in the pattern of human habitation, resource extraction, and land and water use of a region, that the road in some way facilitates. The remainder of this report focuses on the first two quanta, while acknowledging that the third class of impacts is likely the most significant for Bristol Bay.

The hydrologic and biological effects of roads are generally similar in nature for wetlands, streams, rivers, and lakes. Darnell et al. (1976, see especially pp. 129-136) identified basic construction activities typically associated with industrial projects, including roads and pipelines:

1) Clearing and grubbing;
2) Disposition of materials;
3) Excavation;
4) Sub-grade and slope/cut stabilization, including riprap;
5) Placement of fill;
6) Aggregate production;
7) Paving;
8) Equipment staging;
9) Borrow pits;
10) Landfills (disposal sites of excess excavated material).

The authors summarized the categories of possible or likely impact from such projects and activities on adjoining aquatic areas as follows:

1) Loss of natural vegetation;
2) Loss of topsoil;
3) Change of water table elevation;
4) Increased erosion;
5) Leaching of soil minerals from exposed and eroding soil surfaces;
6) Fluctuations in streamflow;
7) Fluctuations in surface water levels;
8) Increased downstream and upstream flooding;
9) Increased sediment load;
10) Increased sedimentation;
11) Increased turbidity;
12) Changes in water temperature;
13) Changes in pH;
14) Changes in chemical composition of soils and waters;
15) Leaching of pollutants from pavement;
16) Introduction of hydrocarbons to soils and waters;
17) Addition of heavy metals;
18) Addition of asbestos fibers (dispersed from industrial or natural sources); and
19) Increased oxygen demand (caused by organic matter export to and accumulation in waterways).

These various alterations interact in complex cause-and-effect chains. Although recognizing that long-term consequences of these alterations are to a significant degree dependent on local circumstances, Darnell et al. (1976) nevertheless identified common, general long-term outcomes that include 1) permanent loss of natural habitat; 2) increased surface runoff and reduced groundwater flow; 3) channelization or structural simplification of streams and hydrologic connectivity; and 4) persistent changes in the chemical composition of water and soil.

Three other categories of impact common to roads have been identified in more recent literature (Trombulak and Frissell 2000, Forman 2004): 1) disruption of movements of animals, including fishes and other freshwater species; 2) aerial transport of pollutants via road dust; and 3) disruption of near-surface groundwater processes, including interception or re-routing of hyporheic flows, and conversion of subsurface slope groundwater to surface flows. Because of their potential importance in the Bristol Bay region, these are further described in the following section.

Connectivity and Barriers to Fish Movement

Because roads alter surface drainage, and their stream crossing structures can either by design or by subsequent alteration by erosion or plugging with debris, roads can form barriers to the movement of freshwater organisms (Roeloffs et al. 1991, Trombulak and Frissell 2000, Gucinski et al. 2001.) Barriers to upstream passage into headwater streams are most common. Pipelines may or may not have similar effects, depending on their crossing design and association with access and maintenance roads.

Small headwater streams are the lifeblood of rivers and lakes; they sustain processes and natural communities that are critically and inextricably linked to water quality, habitat and ecosystem processes that sustain downstream resources (Lowe and Likens 2005). The direct dependence of some fish on headwater streams for habitat is just one example of these linkages. When road crossings block fish passage—as they often do (Harper and Quigley 2000, Gucinski et al. 2001, FSSSWP 2008), the isolated population(s) immediately lose migratory (anadromous or freshwater migrant) species and life history types. Resident species that remain are also at risk of permanent extirpation because barriers can hinder their dispersal and natural recolonization after floods, drought, or other disturbances.

Bryant et al. (2009) found in southeast Alaska that Dolly Varden char moved upstream into very small streams primarily in fall, and coastal cutthroat trout primarily in spring. Both species moved upstream just prior to their spawning season, but during low water intervals, not during high-runoff events. Wigington et al. (2006) developed clear quantitative evidence that free access to spawning and early rearing habitat in small headwater streams is critical for sustaining coho salmon in an Oregon river. Culverts and other road crossing structures not designed, constructed, and maintained to provide free passage of such species can curtail migration, isolate these species from their spawning and nursery habitats, and fragment populations into small demographic isolates that are vulnerable to extinction (Hilderbrand and Kirshner 2000, Young et al. 2004). Drawing inference from natural long-term isolates of coastal cutthroat trout and Dolly Varden in Southeast Alaska, Hastings (2005) found that About 5.5 km length of perennial flow headwater stream habitat supporting a census population size of greater than 2000 adults is required for a high likelihood of long-term population persistence. Beyond diminishing potential survival and reproduction, barriers to movement can truncate life history and genetic diversity of populations, reducing resilience and increasing their vulnerability to environmental variability and change (Hilborn et al. 2003, Bottom et al. 2009).

The loss of some fish species due to road blockages and other barriers can bring cascading ecological effects by altering key biological interactions. For example, the blockage of anadromous salmon from headwater streams could trigger declines in food web productivity caused by loss of marine-derived nutrients that originate from carcasses and gametes of spawning salmon (Bilby et al. 1996, Wipfli and Baxter 2010).

Dust and Its Impact

Previous syntheses of the impacts of roads have not sufficiently addressed the effects of road dust. Dust results from traffic operating on unpaved roads in dry weather, grinding and breaking down road materials into fine particles (Reid and Dunne 1984). The resulting fines either transport aerially in the dry season or are mobilized by water in the wet season. The dust particles may also include trace contaminants including deicing salts, hydrocarbons, and a variety of industrial substances used in construction or maintenance, or that are dispersed intentionally or unintentionally by vehicles on the road (e.g., heavy metals or cyanide from transported mining waste, or asbestos fibers in some mine and treatment projects). Especially after initial suspension by vehicle traffic, aerial transport by wind spreads dust over varying terrain and long distances, meaning that it can reach surface waters that are otherwise buffered from sediment delivery via aqueous overland flow. Walker and Everett (1987) evaluated the impacts of road dust generated in particular from traffic on the Dalton Highway and Prudhoe Bay Spine Road in northern Alaska. Dust deposition altered the albedo of snow cover, causing earlier (and presumably more rapid) snowmelt up to 100 meters from the road margin, as well as increased depth of thaw in roadside soils. The authors also associated dust with loss of lichens, sphagnum and other mosses, and a reduction of plant cover (Walker and Everett 1987). Loss of near-roadway vegetation has important implications for water quality, as that vegetation is a major contributor to filtration of sediment from road runoff. Hence, dust deposition not only contributes to stored sediment that will mobilize to surface waters in wet weather, but can also reduce the capacity of roadside landscapes to filter that sediment.

Near-Surface Groundwater and Hyporheic Flows

The potential Pebble Mine transportation corridor would have a high frequency of crossings of streams, wetlands, and areas of shallow groundwater. These groundwater systems include extensive hyporheic flow networks that connect surface waters through shallow, subsurface flow paths. In the Bristol Bay watershed, they appear to be especially associated with alluvial, glacio-fluvial and glacio-lacustrine deposits, but also locally with slope-mantling till and other locally porous deposits. Existing research sheds relatively little light on the crucial subject of the impacts of road development on shallow groundwater and the connectivity to surface water habitats important to fish. Due to the apparent large extent and hydrologic importance of subsurface-to-surface hydrologic connectivity to streams, lakes and wetlands in Bristol Bay (e.g., Woody and Higman 2011, Woody and O’Neal 2010), and to the recognized importance of groundwater-fed habitats for northern latitude fishes (e.g., Cunjak 1996, Power et al. 1999, Malcom et al. 2004), this review pays particular attention to those linkages and how they can be impacted by roads.

Rudimentary groundwater studies at roads traversing moderate slopes of conifer forest and muskeg in southeast Alaska (Kahklen and Moll 1999) revealed there could be either a bulge or a drawdown in groundwater level near the upslope ditch, while immediately downslope of the road the water table was most often depressed. These effects appeared for distances between 5 and 10 meters on each side of the road prism. The effect of observed water table deformation on the downslope flux of groundwater remains unknown.

The distance to which a road influences subsurface flow paths may be considerably greater in gently sloping alluvial and glaciolacustrine terrain, typically characterized by shallower, porous zones of subsurface hyporheic or channeled subsurface flow that roads can unearth or compact (Jones et al. 2000). It is well-recognized that management of roads in such terrain types can be unpredictable and challenging, in part because it is very difficult to anticipate the extent and nature of disruption to subsurface flow paths, large volumes of water may be involved, and with low gradients, the effects of water table deformation can project hundreds of meters from the road itself (Darnell et al. 1976).

The field observations reported by Hamilton (2007) and Woody and O'Neal (2010) in the Pebble mine area indicate terrain with an abundance of near-surface groundwater and a high incidence of seeps and springs associated with complex glaciolacustrine, alluvial, and slope till deposits. The abundance of mapped wetlands (see main report) further testifies to the pervasiveness of shallow subsurface flow processes and high connectivity between groundwater and surface water systems in the areas traversed by the transportation corridor. The construction and operation of roadways and pipelines can fundamentally alter the intricate connections between shallow aquifers and surface channels and ponds, leading to further impacts on surface water hydrology, water quality, and fish habitat (Darnell et al. 1976, Stanford and Ward 1993, Forman and Alexander 1998, Hancock 2002). In wetlands, for example, hydrologic disruptions from roads, by altering hydrology, mobilizing minerals and stored organic carbon, and exposing soils to new wetting and drying and leaching regimes, can lead to changes in vegetation, nutrient and salt concentrations, and reduced water quality (e.g., Ehrenfeld and Schneider 1991). Hyporheic exchange processes may be further altered by changes in sediment supply, both positive and negative, which alter infiltration, porosity, and exfiltration of subsurface flow paths, as well as affecting mixing of upwelled and surface water (Hancock 2002, Kondolf et al. 2002). Roads can either reduce sediment supply by blocking downslope or downstream sediment transport or increase sediment supply by creating a new source of eroded material (e.g., road fills, cuts, landslides), often exacerbated by stream diversions that result in more erosive flows (Montgomery 1994).

Ground disturbance and catchment alteration by roads and other land use practices generally increases erosion and sediment delivery to streams. In the Bristol Bay region, many streams and rivers connect, directly or indirectly, to lakes. Of particular regard to Pebble project is Lake Iliamna, which supports abundant and diverse sockeye salmon and other species (Schindler et al. 2010). Accelerated sedimentation and accompanying phosphorus deposition in lakes, as well as mobilization of dissolved and particulate carbon and nitrogen result from shoreline and catchment disturbance (Birch et al. 1980, Stendera and Johnson 2006), and these inputs can, in turn, trigger profound changes in lake trophic status and food webs that could result in harmful effects on production of sockeye salmon and other lake-dwelling species (Schindler and Scheurell 2002). Nutrient delivery from road runoff and other road-related hydrologic alterations differs in seasonal timing, quantity, and chemical makeup from nutrients delivered to streams and lakes by anadromous fishes that die after spawning, hence it may have different ecosystem–level effects. For example, road-associated runoff commonly combines inputs of carbon, phosphorus, and nitrogen with suspended sediments, and the physical and light-reducing properties of the sediments can profoundly impact the processing of those nutrients by microbial films, plants, and filter feeders (Newcombe and Jensen 1996, Donohue and Molinos 2009). While the most profound and detectable physical and biological effects occur in littoral zones and deltas, where sediments and nutrients are directly delivered (and where sockeye spawning is often concentrated, [Woody 2007]), suspended sediment and accelerated nutrient delivery can produce lake-wide effects (Schindler and Scheurell 2002, Stendera and Johnson 2006, Donohue and Molinos 2009, Ask et al. 2009). Ultraoligotrophic lakes (nutrient concentrations in both the water column and lake sediments are extremely low) such as Iliamna can be among the most vulnerable to major changes in lake status and function in response to increases in nutrient or sediment inputs (e.g., Ramstack et al. 2004, Bradshaw et al. 2005).

Relationship of Road Density and Roadless Condition to Salmon

Across many studies in North America, higher abundances and more robust populations of native salmonids typically correlate to areas of relatively low road density or large roadless blocks (e.g., Baxter et al. 1999, Trombulak and Frissell 2000, Gucinski et al. 2001). One study from Alberta documented that bull trout occur at substantially reduced abundance when even limited road development (road density of less than one mile per square mile) occurs in the local catchment, compared to their typical abundance in roadless areas (Ripley et al. 2005). In Montana, Hitt et al. (2003) found the incidence of hybridization that threatens the westslope cutthroat trout within its native range increased with increasing catchment road density. However consistent the correlations, the specific causal links between roads and harm to fish are complex and manifold, and seldom laid clear in existing research.

Nevertheless, in light of the already dramatic and widespread influence of roads in North America (Forman 2000), protection of remaining roadless areas has been identified as a potentially crucial and fiscally sound step for effective regional conservation of fish and wildlife (Trombulak and Frissell 2000, Gucinski et al. 2001).

Pipeline Spills

Pipelines have similar environmental effects as roads, with the primary difference being that pipelines constantly or semi-continuously transport potentially toxic or harmful materials that are only intermittently transported on roadways. In contrast to vehicle transport, pipeline transport is often remote from direct oversight by human operators, putting heavy reliance on remote leak detection. As a consequence, accidents with pipelines can lead to dramatically larger spills than roadway accidents. Beyond pipeline design, effective leak detection systems and inspection protocols are crucial for reducing risk of leaks and spills, particularly in a relatively active seismic zone such as the Pebble Mine area. However, in a review of recent pipeline spills in North America, Levy (2009) finds that existing technology and contemporary practice does not provide firm assurance against catastrophic spills.

Pipeline crossings of streams are an obvious source of direct channel disturbance and sediment entry, and as a result they have received considerable study (e.g., Lawrence and Campbell 1980, Lévesque and Dubé 2007, Levy 2009). Pipeline installation can avoid or reduce direct disturbance to channels by building full-span pipeline bridges over waterways (at less expense than road bridges), or by boring underneath the streambed.

In addition to the access road, Ghaffari et al. (2011) describes a transportation corridor (Figure 3) with four pipelines:

1) An 8-inch diameter steel pipeline to transport a slurry of copper-molybdenum concentrate from the mine site to the port site, with one pump station at the mine end of the line and a choke station at the port terminal;
2) A 7-inch diameter steel line returning reclaimed filtrate water (remaining after extraction of the concentrate) to the mine site, fed from a pump station at the port site;
3) A 5-inch diameter steel pipeline for pumping diesel fuel from the port site to the mine site;
4) An 8-inch diameter pipeline for delivering natural gas from the port site to the mine site (specifics of design not yet released).

All four lines would be contained in close proximity, for an unspecific portion of the distance buried about five feet below the ground surface in a common trench, either adjacent to or—in steeper terrain—beneath the road surface. The combined lines would cross streams via either subsurface borings or suspended bridges, apparently with all pipes encased in a secondary containment pipe, although the specific circumstances that would receive secondary containment and what the containment design would be are not available. In the design presented in Ghaffari et al. (2011, p. 336), there would be no secondary encasement of the pipelines away from stream crossings

Available documents do not discuss the composition or potential toxicity of the mineral slurry concentrate. However, it is likely that such a slurry would be toxic to some organisms and that, due to its concentrated, aqueous form, it would readily transport downstream or downslope of a spill site, and deposited materials on terrestrial surfaces could generate leachate that enters groundwater systems. Projected chemical composition of the returned slurry filtrate is also not available, but it is likely that this water would have toxic levels of acidity and/or metals. As for the third line, diesel fuel has known toxicity, with both acute and chronic effects on fish and other organisms (Levy 2009 and elsewhere).

Liquefied natural gas, the product that the fourth line would carry, consists primarily of methane, which dissipates rapidly when released into water or the air, and is considered non-toxic in those circumstances (Levy 2009). Large-scale explosions of natural gas pipelines have occurred as a result of the accumulation of gas from slow leaks. Such an explosion could pose a major risk of damaging or destroying the other pipelines in the

Pebble Mine corridor, disabling electronic leak detection and severing road access necessary for emergency shut-offs or repairs. Containing all four pipelines, the primary access road, and the utility lines in a single narrow corridor, while reducing spatial footprint impacts like erosion and sedimentation, would also bring the consequence, albeit a low-probability one, of compounding the risk and potential scope of environmental impact from a catastrophic event such as a methane explosion.

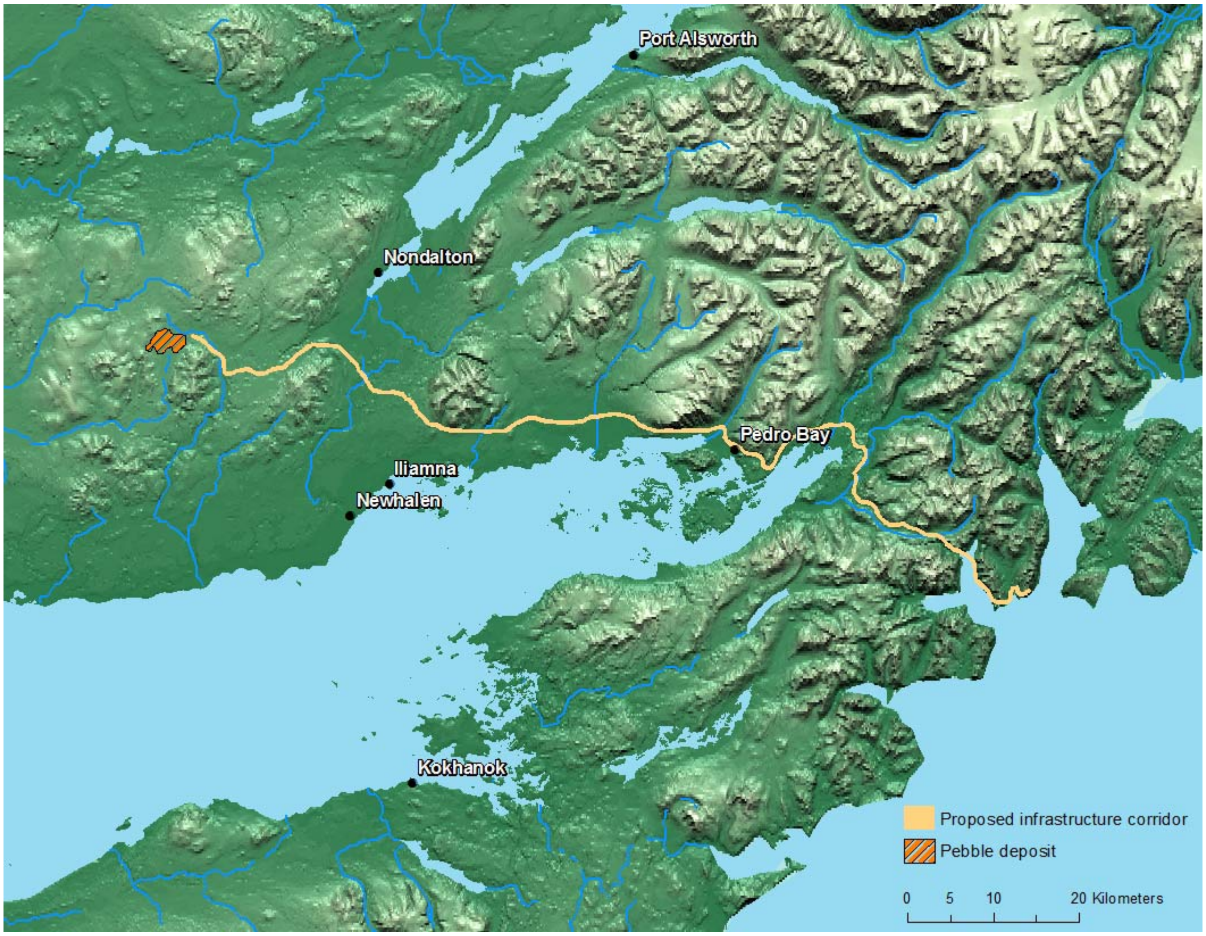

Figure 2. Anticipated location of the road, pipeline, and utility transmission corridor for Pebble Mine (Ghaffari et al. 2011, p. 326). The new road and pipeline corridor would connect the Pebble Mine operations with a new seaport on Cook Inlet. Not shown is an existing north-south connecting tie road from near Nondalton to the Iliamna area (see Figure 1). The Pebble segment from Cook Inlet west to near Lake Iliamna would be reconstructed over an existing lower-standard roadway.

V. IMPACT FOOTPRINT OF THE PROPOSED PEBBLE MINE TRANSPORTATION CORRIDOR ON WATER AND FISH

The Preliminary Assessment of the Pebble Project produced for Northern Dynasty Minerals, Ltd. (Ghaffari et al. 2011) included a map and moderately detailed description of the route of the potential Pebble Mine transportation corridor (see Fig. 2). The following summary relies on that source for road location, while noting the caveat cited in the document that the project ultimately proposed may be different.

According to Ghaffari et al. (2011), the proposed access road and pipelines would provide for the basic infrastructural and transportation needs of the mine and its products and have a fifty-year design life, consistent with the anticipated operating life of the mine. The 86-mile corridor would contain an all-weather road with a two-lane, 30-foot wide gravel driving surface. The road would link with the Iliamna airfield, as well as a new deepwater port on Cook Inlet, from which ships would transport ore elsewhere for processing. Northern Dynasty anticipates that the route would require twenty bridges, ranging from 40 to 600 feet in total span, as well as 1,880 feet of causeway passing over the upper end of Iliamna Bay and five miles of fill embankment along the shorelines of Iliamna and Iniskin Bays.

The route of the transportation corridor stays south of the Lake Clark National Park boundary. About eighty percent of the potential alignment is on private land held by Alaska Native Village Corporations and other corporate landowners, with the rest owned by the State of Alaska (Ghaffari et al. 2011). The route was reportedly selected with regard to transportation and environmental concern in mind, but also with regard to avoiding parcels of private land held by individuals (Ghaffari et al. 2011).

The Preliminary Assessment (Pp. 326-328) characterizes the proposed route as amenable to road and pipeline construction with

> . …terrain favourable for road development. In general, soils are good to excellent; where rock is encountered, it is fairly competent, useable for construction material and amenable to reasonable slope development. The numerous stream crossings appear to have favourable conditions for abutment foundations. There are no significant occurrences of permafrost or areas of extensive wetlands. Where the terrain is challenging, the rock or soil conditions are generally favourable. In intertidal areas, subsurface conditions appear favourable for placement of rock to create the required road embankment

A comparison of the route to National Wetlands Inventory (NWI) data available for the middle portions indicates that while the proposed route might avoid areas of particularly extensive wetlands, nevertheless the route intersects or closely approaches a large number of mapped wetlands (see main report). The route also crosses a great number of mapped (and likely many more unmapped) tributary streams to Iliamna Lake on its 86-mile traverse. The Preliminary Assessment does not identify alternative routes that would avoid or reduce impacts to wetlands, streams or shorelines. Identifying alternative routes to accomplish this would be very difficult given the high density of such hydrologic features.

Summarizing the account of Ghaffari et al. (2011, pp. 327-329), traveling eastward from the Pebble Mine site, north of Iliamna Lake, the proposed transportation corridor passes through diverse terrain and climatic zones. From the mine site, at an elevation of 1,100 feet above mean sea level, the road traverses variably sloping upland terrain over glacial drift before descending to the Newhalen River valley, 11 kilometers north of Iliamna Lake. From there, the route crosses variable terrain of dry, open tundra until approaching Roadhouse Mountain, about 8 kilometers east of the river. The terrain and climatic conditions of this western portion of the route are typical of western interior Alaska, with relatively light precipitation, mild summers and winters with windblown snow. East of Roadhouse Mountain, the route parallels the shoreline of Iliamna Lake apparently at a distance of about five to eight kilometers from the shoreline, spanning a transitional landscape of increasing snowpack and extensive spruce-hardwood forest cover. Roughly 20 kilometers west of Pedro Bay, the route approaches and occupies the shoreline of Iliamna Lake, traversing the steep escarpment of Knutson Mountain, an area vulnerable to avalanches, debris flows, and other high-energy montane processes. After skirting the face of Knutson Mountain above the lakeshore, the route traverses an extensive outwash plain northeast of Iliamna Lake, then ascends rugged terrain to cross Iliamna Pass and wends its way some 32 kilometers through rugged terrain and increasingly warmer and wetter Maritime climatic conditions until descending to the Iniskin Bay port site on Cook Inlet.

This report, together with material referenced on wetlands, provides a quantitative conceptualization of the potential impact footprint of the Pebble Mine transportation corridor on the following known resources:

1) Wetlands (see main report);
2) Anadromous fish-bearing streams (Figures 3a and 3b);
3) Sockeye salmon spawning (Figure 4) and rearing (Figure 5) areas in the Iliamna Lake system; and
4) Resident fish (Dolly Varden, arctic grayling, rainbow trout, three-spine stickleback, nine-spine stickleback, northern pike, and slimy sculpin; Figures 6a, 6b, and 6c).

Figure 3a. Anadromous fish-bearing streams (documented to support at least one species of salmon) crossed by the *eastern half* of the potential Pebble Mine transportation corridor (Chekok Creek east to Y Valley Creek).[1] Map compiled from Alaska Department of Fish and Game catalog sources (ADFG 2012, Johnson and Blanche 2011a, 2011b)[2], supplemented with additional spawner count data (Morstad 2003).

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[1] Median alignment of the corridor was defined by scanning and geo-referencing the Pebble transportation corridor route map from Ghaffari et al. (2011. Figure 1.9.2, p.57).

[2] Field surveys indicate that ADFG Catalog (Johnson and Blanche 2011a, 2011b) under-represents the actual extent of salmon spawning (Woody and O'Neal 2010, and Daniel Rinella, University of Alaska, Anchorage, AK, unpublished data), although these figures do reflect updates based on recent surveys.

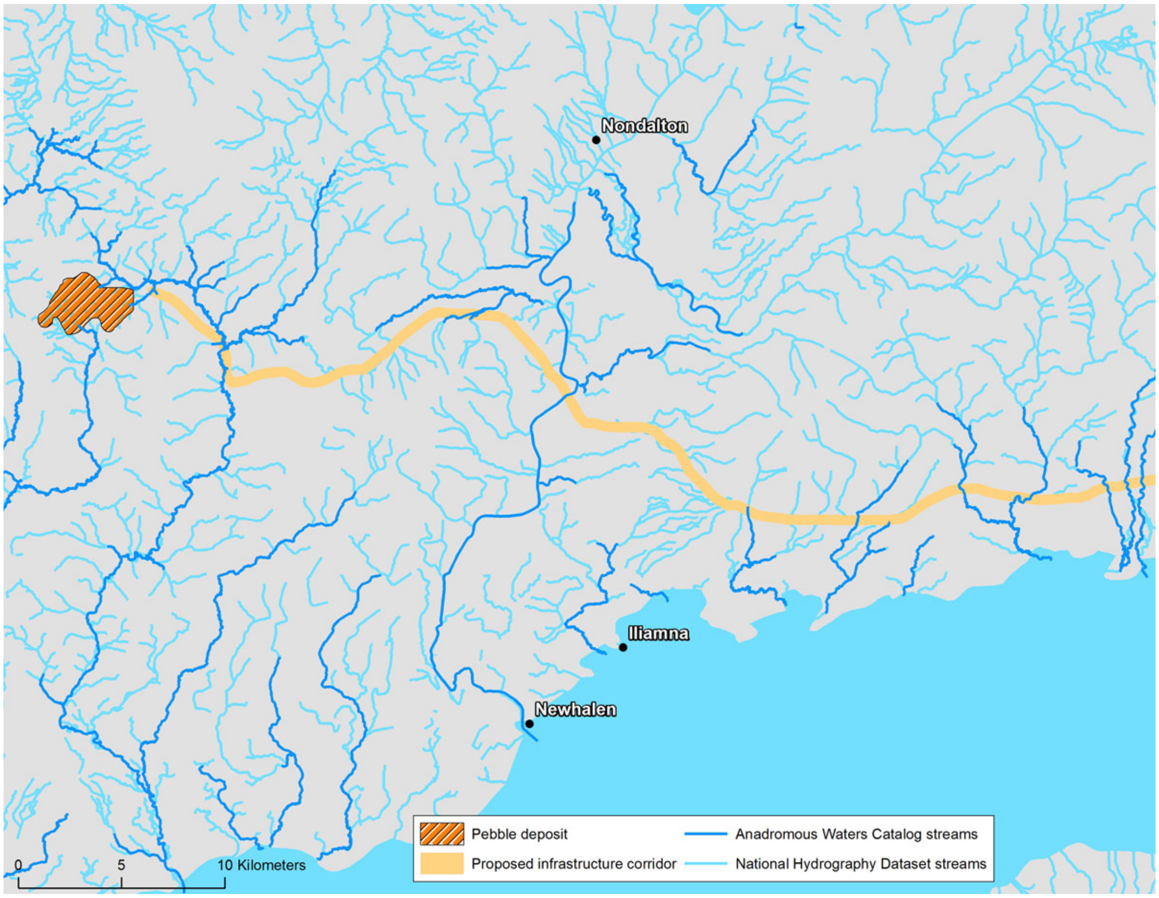

Figure 3b. Anadromous fish-bearing streams (documented to support at least one species of salmon) crossed by the *western half* of the potential Pebble Mine transportation corridor (Upper Talarik Creek east to Canyon Creek).[3] Map compiled from Alaska Department of Fish and Game catalog sources (ADFG 2012, Johnson and Blanche 2011a, 2011b)[4], supplemented with additional spawner count data (Morstad 2003).

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[3] Median alignment of the corridor was defined by scanning and geo-referencing the Pebble transportation corridor route map from Ghaffari et al. (2011. Figure 1.9.2, p.57).

[4] Field surveys indicate that ADFG Catalog (Johnson and Blanche 2011a, 2011b) under-represents the actual extent of salmon spawning (Woody and O'Neal 2010, and Daniel Rinella, University of Alaska, Anchorage, AK, unpublished data), although these figures do reflect updates based on recent surveys.

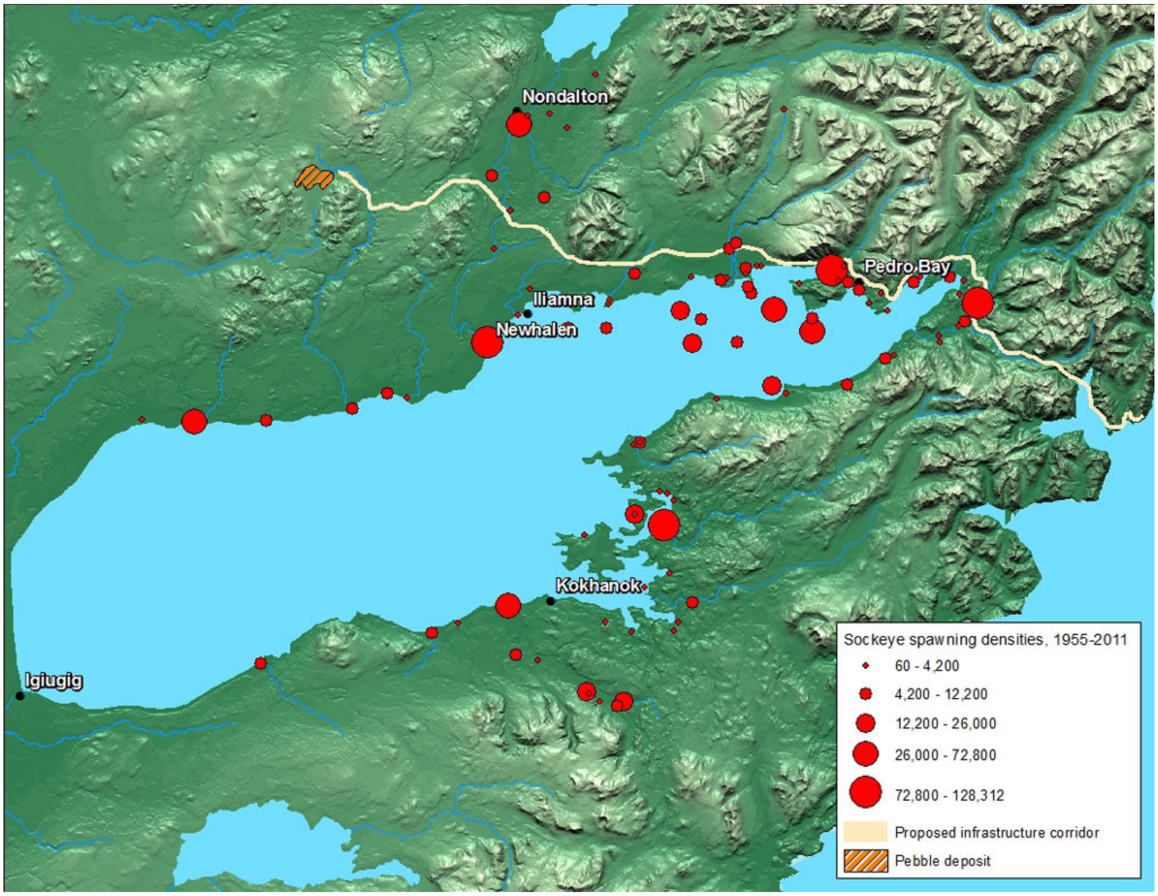

Figure 4. Pattern in abundance of spawning sockeye salmon in Iliamna Lake and tributary streams relative to the potential Pebble Mine transportation corridor. A general concentration of sockeye spawning is apparent in the northeast portion of Iliamna Lake. Spawner density data compiled from Johnson and Blanche (2011a, 2011b, as average counts collected with varying regularity between 1955-2011).[5]

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[5] Morstad (2003) with additional information on sampling locations from Harry Rich (2011, and University of Washington, Seattle, WA, unpublished data)

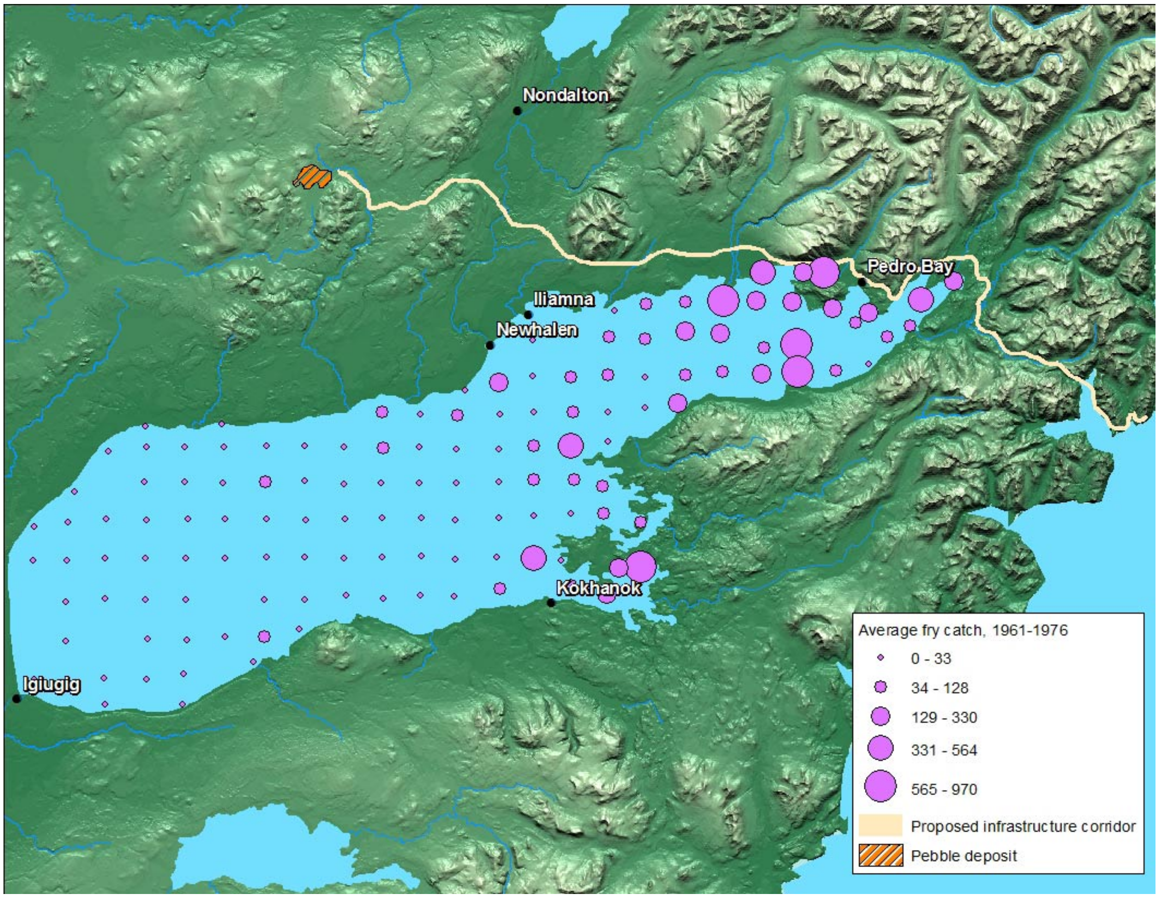

Figure 5. Iliamna Lake juvenile sockeye catches in tow-net sampling, 1961-1976, relative to the potential Pebble Mine transportation corridor. High-density rearing sites are concentrated in the eastern half of the lake, where the transportation corridor comes closest to the lakeshore and intersects with numerous tributaries. Compiled from data provided by Harry Rich (2011, and University of Washington, Seattle, WA, unpublished data).[6]

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[6] Sampling methods for these data are described in Rich (2006).

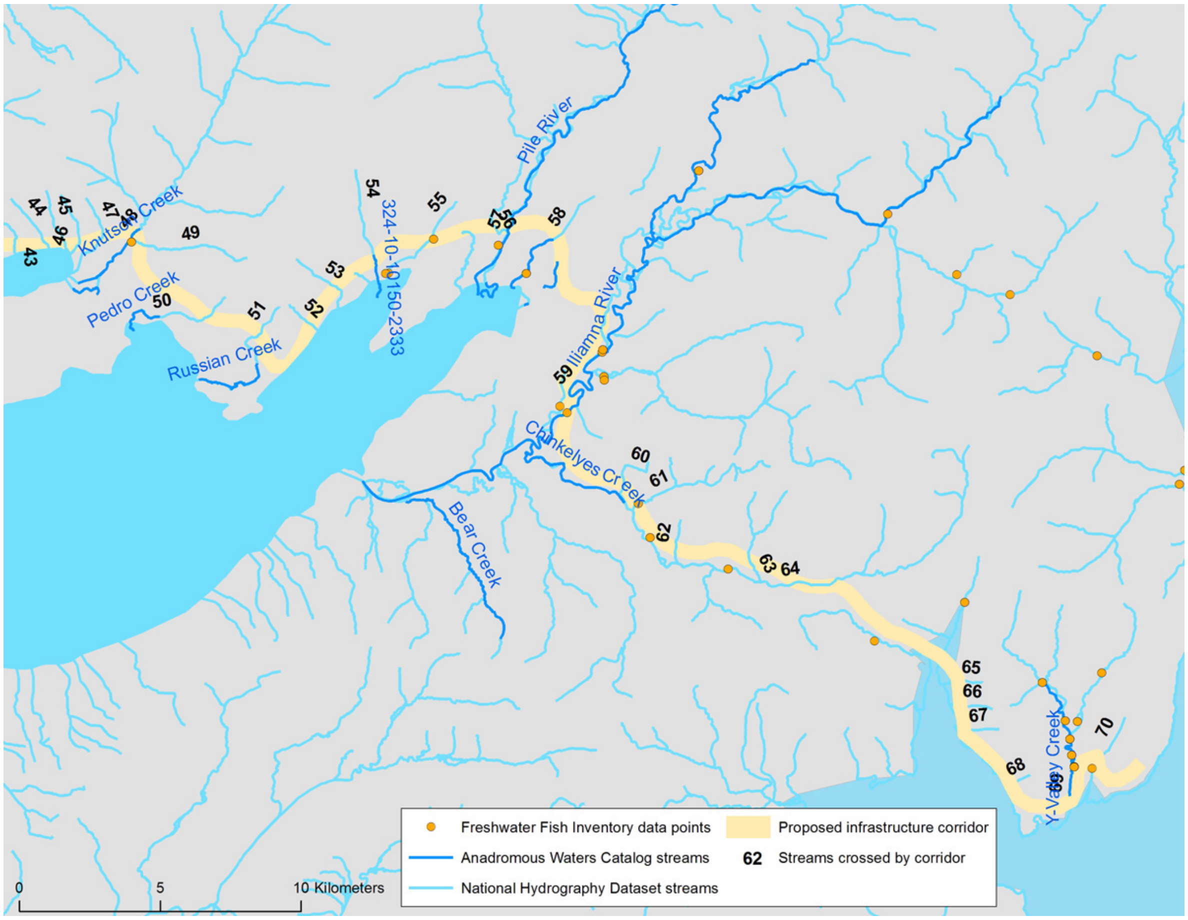

Figure 6a. Resident or nonanadromous fish streams crossed or potentially affected by[7] the *eastern one-third* of the potential Pebble Mine transportation corridor.[8] Compiled from the Alaska Freshwater Fish Inventory (AFFI) Database (ADFG 2012, Johnson and Blanche 2011a and 2011b, additional information provided by Joe Buckwalter, ADFG, Anchorage, AK, Unpublished data). Stream names and fish species known present are summarized in Attachment A.

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[7] Secondary tributaries entering trunk streams downstream of the transportation corridor are indicated because they could be isolated and freshwater migrant life histories harmed by spills affecting the trunk stream.

[8] Median alignment of the corridor was defined by scanning and geo-referencing the Pebble transportation corridor route map from Ghaffari et al. (2011).

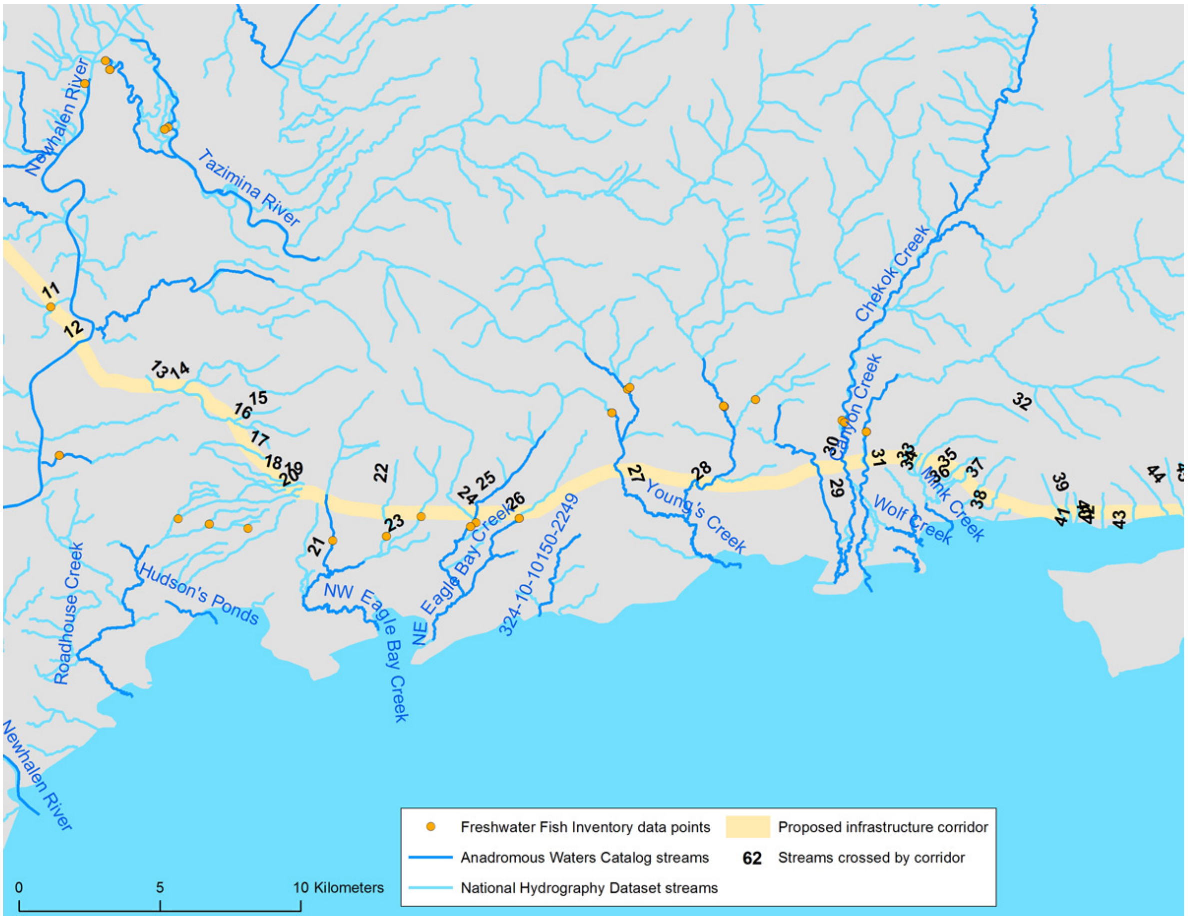

Figure 6b. Resident or non-anadromous fish streams crossed or potentially affected by[9] the *central one-third* of the potential Pebble Mine transportation corridor.[10] Compiled from the Alaska Freshwater Fish Inventory (AFFI) Database (ADFG 2012, Johnson and Blanche 2011a and 2011b, additional information provided by Joe Buckwalter, ADFG, Anchorage, AK, Unpublished data). Stream names and fish species known present are summarized in Attachment A.

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[9] Secondary tributaries entering trunk streams downstream of the transportation corridor are indicated because they could be isolated and freshwater migrant life histories harmed by spills affecting the trunk stream.

[10] Median alignment of the corridor was defined by scanning and geo-referencing the Pebble transportation corridor route map from Ghaffari et al. (2011).

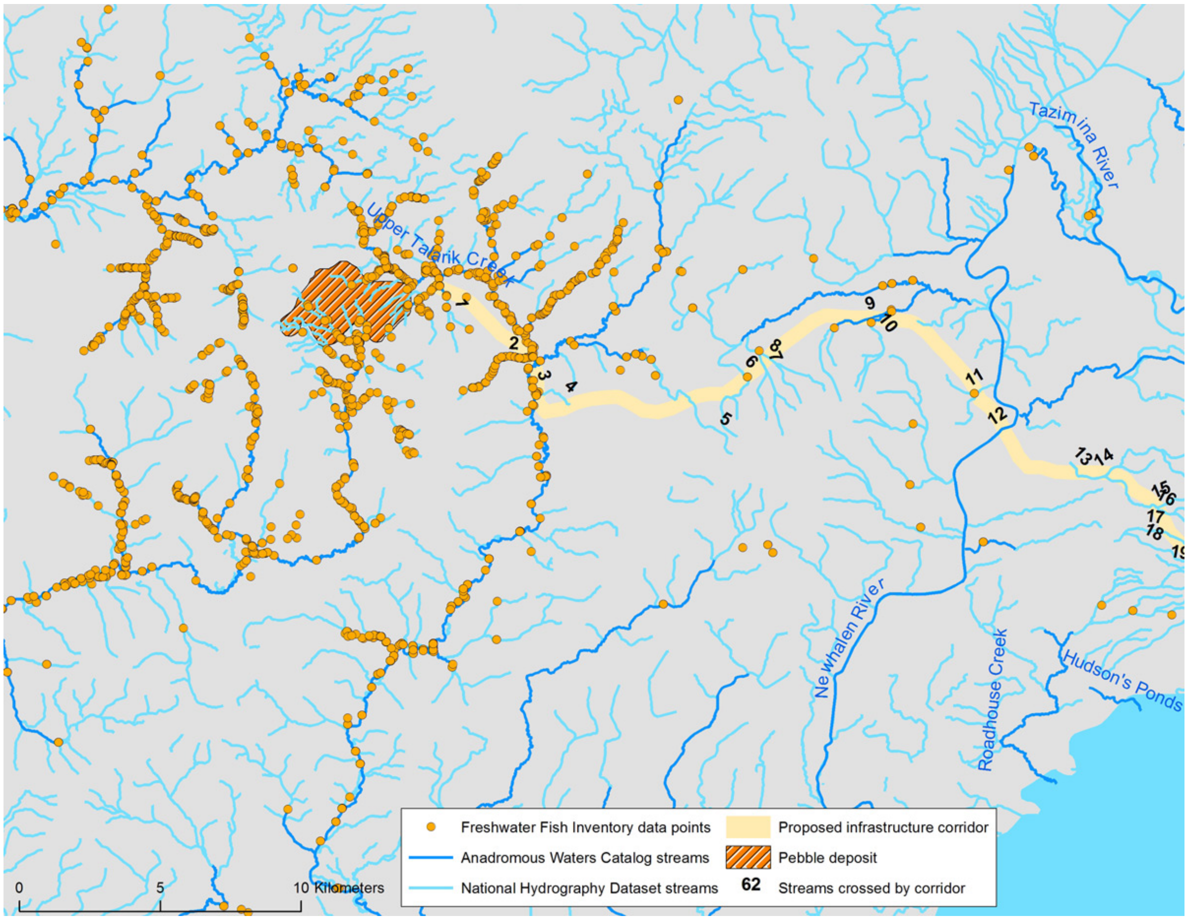

Figure 6c. Resident or non-anadromous streams crossed or potentially affected by[11] the *western one-third* of the potential Pebble Mine transportation corridor.[12] Compiled from the Alaska Freshwater Fish Inventory (AFFI) Database (ADFG 2012, Johnson and Blanche 2011a and 2011b, additional information provided by Joe Buckwalter, ADFG, Anchorage, AK, Unpublished data). Stream names and fish species known present are summarized in Attachment A.

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[11] Secondary tributaries entering trunks downstream of the transportation corridor are indicated because they could be isolated and freshwater migrant life histories harmed by spills affecting the trunk stream.

[12] Median alignment of the corridor was defined by scanning and geo-referencing the Pebble transportation corridor route map from Ghaffari et al. (2011).

Drawing on published conceptualizations that plot the extent of environmental and ecological influences of roads as a spatial footprint (Forman 2000, Forman and Deblinger 2000, Trombulak and Frissell 2000, Jones et al. 2000), Figures 3a through 6c illustrate that the potential Pebble transportation corridor could have widespread regional effect on the aquatic ecosystems that feed Iliamna Lake. Figures 6a, 6b, and 6c identify both upstream and downstream habitat that is susceptible to loss or degradation due to structural failures, spills, sedimentation, or other impacts originating in the transportation corridor. Through hydrological dispersion of sediment or toxicants, the maps illustrate that a large proportion of Iliamna Lake salmon habitat would be vulnerable to indirect impact, or direct impact at a point removed from the origin of a spill, either through potential exposure to pollutants downstream of the transportation corridor or blockage of migration to spawning and nursery habitats upstream.

A significant fraction of Iliamna Lake's sockeye salmon resource would be vulnerable to impacts from the Pebble transportation corridor. Migration and spawning in these streams could be compromised below the corridor crossing by sedimentation or contamination from spills, and habitat upstream from the crossings could be cut off from access by spills or structural failures. To roughly estimate the proportion at risk, we adjusted the stream length potentially affected by the transportation corridor in each system by the average surveyed spawner density for that system (Figure 4). This analysis suggests that about twenty percent of known stream spawning populations of Iliamna system sockeye reproduces in streams and rivers intersected by the Pebble corridor. Moreover, many principal sockeye fluvial spawning areas lie in close proximity to road and pipeline crossing sites. In addition, a major sockeye salmon beach spawning site is located at the mouth of Knutsen Creek (Rich 2006, and unpublished data), a stream that the Pebble transportation corridor would cross, making its delta vulnerable to impacts from upstream. If the Knutsen Creek delta spawning population is included in the tally of potentially affected waters, roughly thirty percent of known Iliamna Lake sockeye spawners could be at risk. A similar analysis from the University of Washington Fisheries Research Institute came to a similar conclusion (Rich 2011, and unpublished data).

Available data show that rearing sockeye salmon are most concentrated in the eastern half of the lake (Figure 5), where the Pebble transportation corridor would intersect with numerous direct tributaries to the lake and for some distance would occupy the lakeshore itself, posing a high risk, if not a certainty of affecting Iliamna Lake habitats.

VI. MITIGATION MEASURES AND THEIR LIKELY EFFICACY

It is commonly recognized that the environmental impact of a major construction project like a road or major pipeline corridor can never be fully mitigated (Trombulak and Frissell 2000). Indeed, inherent to the underlying purpose of road projects (i.e., to alter natural conditions so that vehicle transportation is possible where it was physically impossible before) are changes to landscape structure that not only irretrievably alter ecosystem and biological conditions within the construction footprint, but also interrupt or modify the natural flux of water, sediment, nutrients, and biota across the ecosystem, usually permanently (Darnell et al. 1976, Rhodes et al. 1994, Forman and Alexander 1998, Forman 2000, Forman and Deblinger 2000, Trombulak and Frissell 2000). Moreover, engineering or implementation failures, unanticipated field conditions, and/or unforeseen environmental events inevitably test and compromise the effectiveness of mitigation measures applied in large projects (e.g., Espinosa et al. 1997, Levy 2009). The only sure way to avoid impacts to a freshwater ecosystem from a large road or pipeline project is to refrain from building such a project in that ecosystem (Frissell and Bean 2009).

Unfortunately the scientific and professional literature on the subject of the effectiveness of environmental mitigation measures for water and fish is sparse and poorly synthesized. There are lists of standard practices and there are a scattering of short-term, site-specific studies of efficacy of mitigation measures for roads and pipelines (e.g., assessment of mitigation of the delivery of sediment and its local impact on biota). Some report showing adverse impact, or ineffectiveness of mitigation measures, and others report not detecting adverse effects, which is often taken as circumstantial evidence that mitigation measures were effective. Exceedingly few of these studies extend to medium- or long-term evaluation of mitigation effectiveness, and fewer still have been published in accessible peer-reviewed forums. Therefore, evaluating the effectiveness of proposed mitigation measures remains a process of best professional judgment and logical evaluation of premises, specific environmental context, and likely operational circumstances. The release of the Preliminary Assessment for the Pebble project (Ghaffari et al. 2011) allows some specific analysis of the potential transportation corridor.

A few synthesis documents also provide some guidance (e.g., Rhodes et al. 1994), but the over-arching theme is that implementation of site-specific mitigation measures is fraught with uncertainty and risk and that, overall, mitigation has proven to be ineffective in fully protecting water quality and conserving freshwater fishery resources (Esiponsa et al. 1997).

Mitigation Measures for Pebble Road and Pipelines

In the following section I cite mitigation measures identified in Ghaffari et al. (2011) for the Bristol Bay transportation corridor and briefly assess 1) their likely effectiveness to avoid or prevent harm to Bristol Bay water quality and fishery values, 2) possible adverse side effects of applying the mitigation measure, and 3) alternative mitigation measures that could be more effective, given the project is assumed to proceed.

As far as practicable, minimize areas of disturbances (Ghaffari et al. 2011, p.329). This means restricting the footprint of construction activities and the final footprint of the project to the minimum practical surface area (for example, by stacking the road and pipelines in a single corridor). The effectiveness of this measure depends on the location of disturbance relative to resources at risk. Even a small footprint that involves permanent alteration of soils, vegetation, and hydrology can have significant adverse effects that propagate across the landscape by hydrologic and other vectors. This measure must be practiced in the context of measures to avoid sensitive locations to be effective. Secondly, the effectiveness of this measure depends on how other project parameters, including capital cost, delimit what is "practicable." Limiting the area disturbed can often involve expensive practices such as long-distance hauling of waste material in preference to onsite storage. Finally, it is important to reiterate there are potential risks associated with minimizing the footprint of the transportation corridor by "stacking" the road and pipelines closely together. A pipeline failure or gas explosion could sever the sole available route for ground transportation of equipment and personnel to take emergency remedial measures.

As far as practicable, minimize stream crossings and avoid anadromous streams (Ghaffari et al. 2011, p.329). This mitigation measure can be effective if three conditions are met: 1) the landscape structure supports a route that avoids and is buffered from strong interaction with streams, wetlands, and areas of near-surface groundwater; 2) implementation does not result in a route so long and tortuous that it encumbers additional environmental risk (e.g., to upland vegetation and wildlife), 3) resources are sufficient to ensure that costly but environmentally sounder locations and possibly longer routes are "practicable." Ghaffari et al. (2011, pp. 329-330) lists several other criteria that constrain choice of road location, such as:

1) Avoiding certain "unfavorable" land ownerships;
2) Avoiding potential (albeit unspecified) geologic hazards;
3) Keeping road gradients under 8 percent;
4) Maintaining minimum curvature and design speeds;
5) Facilitating high axle loads for transporting assembled mine equipment;
6) Optimizing crossings of soils suitable to maintaining roadway structure and stability;
7) Optimizing access to sources of construction and surfacing rock;
8) Incorporating minimum 2.5–foot (76 centimeter) ditches (possibly necessary for maintaining subgrade stability in many wet or seasonally wet areas); and
9) Minimizing area of disturbance.

These competing objectives for the roadway, coupled with the large number of streams in the landscape between the Pebble Mine site and Cook Inlet serve to limit the effectiveness of this measure. To be most effective, minimizing stream crossings must take primacy above other objectives of economic or operational convenience in project siting and route location.   However, even then, one potential side effect of basing route selection on minimization of stream crossings in a stream-rich landscape would likely be a route that is tortuous, countervailing the preceding mitigation measure of minimizing area of disturbance. Hence the two most potentially effective mitigation measures can stand in opposition to each other, especially in landscapes of relatively high stream density.

Appropriate Best Management Practices (BMPs) will be utilized for the maintenance of the road during operations and construction. Ghaffari et al. (2011, p. 370). The Preliminary Assessment does not identify the appropriate practices for road maintenance and construction, so it is not possible to specifically address their likely effectiveness at reducing water quality and fisheries impacts. Specifically with regard to maintenance, BMPs should include a strict prohibition on the disposal of material generated from grading and snow removal into surface waters, and should specify grading practices that retain a local road contour necessary to disperse road surface drainage away from streams, rivers, Iliamna Lake and areas that drain to those waterways (Weaver and Hagans 1994, Wemple et al. 1999, Furniss et al. 1991, Moll 1999). Construction specifications should also designate sites for waste rock disposal and temporary materials storage and stipulate that they be in locations with minimum risk of subsequent transport of material to streams, rivers, or Iliamna Lake, whether by water, wind, or mass failure (Weaver and Hagans 1994). These practices pose minimal risk of environmental side effects, though they may increase annual operational costs. However, because these practices are also effective at reducing roadway harm from erosion, over years they may reduce maintenance and repair costs of the roadway.

Road dust abatement measures. Ghaffari et al. (2011, p. 458) mentions dust suppression as a generic need, but the only allusion to specific mitigation regards procurement of a water spreading truck (Ghaffari et al. 2011, p. 313). The Preliminary Assessment mentions developing a dust dispersion model as part of the permitting process for air emissions (Ghaffari et al. 2011, p. 458), but it does not address dust impacts to surface waters. Depending on mineralogy, water application can be effective at reducing dust transport, if application is frequent and of appropriately limited volume (USDA Forest Service 1999). There are, however, offsetting factors: moderate or heavy application of water that exceeds the very low infiltration capacity of the road surface mobilizes dust in fluid runoff instead of aerial deposition. Wherever a road is in close proximity to surface waters, such runoff can deliver suspended sediments, perhaps quite frequently, to locations where, or at seasons when, they are otherwise virtually nonexistent. Loss of fines from the road rock matrix can contribute to breakdown and accelerated erosion of the road surface (USDA Forest Service 1999). On the other hand under-application of water fails to fully abate dust generation.

Dust abatement measures can bring unintended side effects. Even when dust abatement is effective in retaining fines within the road rock matrix during the dry season, these fines are simply mobilized by water and transported to the surrounding landscape in wet season runoff (Reid and Dunne 1984). The fine sediments are not eliminated—merely reallocated. Other dust controls, including chloride salts, clays, lignosulfanate or other organic compounds, and petroleum distillates (Hoover 1981) bring risk of toxic effects when they run off and enter surface waters, though little research is available to assess their environmental risks or safe conditions of application (USDA Forest Service 1999). In the case of chloride salts, one recommendation is to avoid application within 8 meters of surface waters or anywhere groundwater is near the surface (USDA Forest Service 1999). Adverse biological effects are likely to be particularly discernible in naturally low-conductivity waters like those of Bristol Bay, although research is needed to substantiate this speculation. The best practice to minimize dust pollution is to avoid road construction; the next most effective mitigation is surfacing all roadways with high-grade asphalt pavement, with diligent maintenance of the paved road surfaces.

Paving can measurably reduce (though not eliminate) the chronic generation and delivery of both wet-weather surface-erosion and dust (Furniss et al. 1991, Weaver and Hagans 1994). However, asphalt production, deposition, and weathering generates hydrocarbons that may, in some circumstances, be harmful to aquatic life (Spellerberg 1998, Trombulak and Frissell 2000). In addition, off-site transfer of heavy metals and other contaminants from road treatments such as deicing salts could be more rapid and direct from paved road surfaces. Moreover, in the case of the potential Pebble transportation corridor, pavement could complicate excavation needed to access pipelines buried under the road for visual inspection or repairs of leaks.

River and stream crossing structures have been designed to minimize the impact of the project on areas of sensitive habitat (Ghaffari et al. 2011, p. 370). The Preliminary Assessment further specifies that structural elements, including foundation elements, will be designed to comply with a Memorandum of Agreement between ADOT and ADFG regarding the design of culverts for fish passage and habitat protection. Wherever culverts are not "suitable," Ghaffari et al. state the road would incorporate single- or multiple-span bridges, with specifications based on "hydrological considerations, local topography and fish passage requirements." Although criteria for determining crossing structure type are not provided, the Preliminary Assessment identifies thirteen possible multi-span bridge crossings, at "major" rivers, including 600-foot spans both at the Newhalen River and across tidal flats at Iliamna Bay (Ghaffarri et al. 2011, p. 332).

Road crossing designs are much improved over historic practice, but where rivers are wide and river or stream channels shift location frequently, any crossing structure short of fully spanning the channel migration or flood-prone valley width can prove problematic. Because of the nature of design structures and geomorphic setting, crossings of small streams (under about 3 meters in width) pose greater risk of causing barriers to animal migration and movement of sediment and natural debris, whereas crossings of larger streams pose risk of erosion, sedimentation, channel and floodplain alteration, and delivery of pollutants from spills. The importance of small streams in Bristol Bay for Dolly Varden and other fish species (Woody and O'Neal 2010) underscores the need for culverts to provide fish passage and maintain fish habitat, even where salmon are absent. Numerous studies also document that connectivity between small headwater streams (including streams with intermittent or seasonal flow) and downstream habitats is important and, in some cases, critical for productivity and survival of salmonids (e.g., Hilderbrand and Kirshner 2000, Young et al. 2004, Fausch et al. 2002, Hastings 2005, Wigington et al. 2006, Bryant et al. 2009).

In general, culvert crossings of small streams remain problematic, even under contemporary standards and practices as applied by state highway departments and land management agencies. Gibson et al. (2005) surveyed a 210-kilometer segment of the Trans-Labrador highway, newly constructed under prevailing Canadian government and provincial regulations for fish protection, and found that more than half of the culverts posed fish passage problems due to inadequate design or poor installation. Chestnut (2002), in a survey of stream crossings in Kamloops, British Columbia, found that out of 31 culverts assessed, all but one failed to meet Department of Fisheries and Oceans objectives for juvenile fish passage and maintenance of fish habitat. In an audit of two other Provincial Forest Districts in British Columbia, Harper and Quigley (2000) concluded about a third of road culverts blocked fish passage to upstream habitat.

In small streams without significant near-surface groundwater associations, the effectiveness of different stream crossing structures depends on the geomorphic setting, including stream gradient and channel stability, road slope and angle of interception, flashiness of water and sediment flows, potential for ice rafting and plugging, and abundance and size range of wood and other waterborne debris. In small prairie streams, for example, Bouska et al. (2010) found that large box culverts were less disruptive of stream morphology and hydrodynamics than were low water crossings and corrugated metal culverts. Large-width, bottomless arch or "squashed design" culverts that preserve or restore a natural channel bed material train through the length of the culvert are the current standard norm for stream crossings to maintain both physical and biological connectivity (Weaver and Hagans 1994, FSSSWG 2008). In recent years, the US Forest Service has worked to reduce risk of failure and improve passage of fish and other biota at road at road crossings using a new so-called "Stream Simulation" design protocol for culvert crossings of small streams that emphasizes dramatically wider, open-bottom arch stream crossing designs that strive to maintain both geomorphic and biological continuity through the crossing (FSSSWG 2008).   Greater expense of initial design and installation may be compensated by longer life spans (round corrugated steel culverts commonly have a functional life span of 20 years, if properly functioning) and fewer emergency maintenance and repair costs (Weaver and Hagans 1994).

Effective mitigation of adverse roadway impacts to streams must account explicitly not just for the passage of fish and surface waters; in ecosystems like Bristol Bay that are rich in shallow groundwater, roadways must also avoid disrupting or obstructing hyporheic flow paths and shallow aquifers. Short of not building new roads altogether, the most effective practice to avoid alteration of hydrology and hydrologic connectivity is to locate the route well away from streams, wetlands, springs, seeps, areas of near-surface groundwater, pond and lake shorelines, and alluvial fans and glacio-alluvial valley trains where frequently shifting stream courses are present. Due to the number and density of streams, zones of near-surface groundwater, and associated wetlands in the area of the potential transportation corridor (Hamilton 2007), complete avoidance of "sensitive habitat" would be exceedingly difficult. If avoidance of these sensitive hydrologic features is impossible, the next best mitigation is bridge the roadway across them, completely spanning the area of both surface water and near-surface groundwater, thereby reducing direct physical intersection of the roadway and water features. At streams, crossings should occur only where channels are stable, not migrating and not branching. Where long suspensions are necessary to bridge multiple or coextensive hydrologic features, special engineering is required to manage stormwater drainage that accrues on the extensive suspended roadway and route and disperse this discharge to areas well away from surface waters.

Where spanning extensive areas of shallow groundwater is impracticable (e.g., due to expense), the next most effective mitigation would be to "lift" the road surface over them by use of porous fills. Porous fills (commonly large, angular open-framework rock capped by a surface of mixed material) can provide a stable road prism and support heavy vehicle loads, while passing overland or sheet flow with limited concentration and maximum dispersion of water, thereby reducing erosive forces and impacts to local hydrology (Moll 1999). Nevertheless, porous fills do partly obstruct surface drainage, blocking the movement of sediment, debris, and aquatic organisms and despite some filtering capacity, they do not fully control delivery of sediment and other pollutants from the road surface into surface waters. Under heavy tire loads, porous fill road beds may, over time, subside into subsurface soils and alluvial deposits, allowing native fines to enter and clog the porous matrix, eventually making it a barrier to subsurface flow.

Burial in a common trench. (Ghaffari et al. 2011, p. 336). Burial aids in insulation of the pipeline. It also can reduce pipeline impact on wildlife movements, and in steep, mountainous terrain, it can partially protect pipelines from damage and potential spills caused by surface processes like avalanches, landslides and debris flows (Levy 2010). Equally important, clustering of pipelines reduces the direct spatial footprint of disturbance to habitat by concentrating construction and maintenance activity. The smaller footprint, in turn, minimizes the area destabilized by excavation and backfill, thus reducing impacts to water quality from construction site runoff. The downsides of pipeline burial are that: 1) it prevents visual inspection of the lines for leakage and visual monitoring of spilled materials; 2) it typically does not incorporate secondary containment measures for spills and leaks; and 3) it can disrupt subsurface hydrology by severing, damming, or capturing buried flow paths. Visual inspection is a vital backup to electronic leak detection systems and may be the only sure way to detect some chronic, slow leaks. Finally, buried pipelines are still vulnerable to stress and rupture from subsurface processes, such as earthflows, slumps, and seismic shocks.

Secondary containment of buried lines, using an impermeable lining for the trench, could help limit the discharge of material in the event of leaks or spills, but would have the opposing effect of causing greater distortion of natural subsurface flow paths. By acting as a subsurface dam, a lined trench could not only disrupt natural hydrology patterns, but by obstructing subsurface water flow, belowground containment structures could complicate the management of drainage that is necessary to maintain the road surface and the trench itself. From the standpoint of the protection of water quality and fish resources, ideal mitigation measures could include: 1) keeping the pipelines above ground and visible (except where landslide and avalanche risks are moderate to high); 2) incorporating some means of secondary containment for spills and leaks; 3) installing manual shutoff valves at either side of all surface water crossings and all locations vulnerable to damaging landslides or avalanches; and 4) implementing robust plans for both very frequent or full-time visual inspection for leaks, and rapid response for containment, shutdown, repair, and disposal of contaminated material when leaks do occur. Note that these measures may have adverse side effects; for example, elevated pipelines may be more disruptive of wildlife movements, such as caribou migrations.

There is another drawback of clustering that the above mitigation measures would not resolve. With common proximity of the lines, there might be some risk that natural gas leakage and subsequent explosion could both damage the other lines and hinder rapid response to repair damage and contain spills (due to damage to the road). This risk bears close examination by appropriate experts.

Boring pipelines under stream (Ghaffari et al. 2011, p.337). Horizontal boring of a pipeline under stream crossings can reduce much of the channel disruption, erosion and sedimentation associated with trenching and exposed line surface crossings. However, the method suffers from the same drawbacks identified above under *Burial in a common trench*. In particular, leakage of the lines under the stream course could result in undetected contamination of hyporheic, thence surface waters. To reduce impacts to fish and water quality, the most effective mitigation measure likely would include suspending pipelines (along with road crossings) on full-span bridges that minimize disturbance to surface water, as well as containing the pipelines in a secondary pipe designed for and operated under a plan that includes frequent visual inspection and robust spill response procedures. Burial—with secondary containment—could be appropriate for unavoidable crossings of areas with unstable slopes prone to landslides and avalanches. Note that these measures may have adverse side effects; for example, elevated pipelines may be more disruptive of wildlife movements.

Secondary containment pipe ("encased in a protective layer") for overhead stream crossings on bridges (Ghaffari et al. 2011, p. 337). Secondary containment is a particularly important measure for isolating and managing leaks or spills wherever the pipeline is directly above surface water. Ideally, some form of secondary containment should extend to other locations where leaks or spills could reach and contaminate surface or subsurface waters. There also should be specific procedures and requirements for response and materials handling in the event of leaks or spills into the containment system, to prevent secondary pollution from leaching or spill of contaminated materials. Advance designation and preparation of an array of well-distributed storage pads for contaminated soils at dry, stable sites far removed from surface waters or shallow groundwater would be among the needs to implement this measure effectively. These precautionary structural measures are likely to be costly.

Manual isolation valves on either side of major river crossings (Ghaffari et al. 2011, p. 376). The Preliminary Assessment does not define "major" river crossings, but they would presumably include multi-span crossings such as that of the Newhalen River. The effectiveness of manual closure correlates directly to the effectiveness of leak detection and rapid response. Coupled with full-time, fully redundant electronic and visual leak detection systems and valve locations as suggested above, manual valves could considerably improve the odds of successful stream protection from leaks and spills. Again, the surveillance and logistical measures needed to support a rapid response to accidents can be costly.

Electronic Leak Detection Systems (Ghaffari et al. 2011, p. 376). The Preliminary Assessment discusses implementing an electronic leak detection system for the pipelines, using pressure transmitters located along the length of the lines. It also specifies a SCADA (Supervisory Control and Data Acquisition) system for monitoring and control of the pumping stations, with fiber optic communications between the concentrator and the port site tying the detection systems together. The most effective approach to leak detection includes redundant systems for each separate pipeline. However, the proposed approach appears to tie leak detection for all four systems to a single fiber optic line. Coupled with the close proximity of the four pipelines, a single communications line increases the chance that leak detection could be disrupted by the same event that triggered a leak (e.g., a seismic dislocation, lake seiche wave, or large landslide). As suggested above, providing for rigorous visual inspection would further increase the effectiveness of electronic leak detection and reduce the risk of undetected spills.

Likely Effectiveness of Mitigation Measures

Special circumstances prevail in Bristol Bay and specifically in the area proposed for the Pebble Mine road and pipeline corridor that render the effectiveness of standard or even "state of the art" mitigation measures highly uncertain. These include:

1) Subarctic extreme temperatures and frozen soil conditions could complicate planning for remediation, with outcomes uncertain as a result of variable conditions and spill material characteristics.
2) Subarctic climatic conditions limit the lushness and rapidity of vegetation growth or re-growth following ground disturbance, reducing the effectiveness of vegetated areas as sediment and nutrient filtration buffers.
3) Widespread and extensive areas of near-surface groundwater and seasonally or permanently saturated soils limit potential for absorption or trapping of road runoff, and increase likelihood of its delivery to surface waters.
4) Likelihood of ice flows and drives during thaws that can make water crossing structures problematic locations for jams and plugging.

5) Seismically active geology; even a small increment of ground deformation can easily disturb engineered structures and alter patterns of surface and subsurface drainage in ways that render engineered mitigations inoperative or harmful.
6) Remote locations that are not frequented by human users, hence mitigation failures and accidents may not be detected until substantial harm to waters has occurred.

While many possible mitigation measures can be identified and listed in a plan, they cannot all be ideally applied in every instance. Mitigation measures are commonly mutually limiting or offsetting in field application, as is common knowledge to practicing engineers. As a salient example for the potential Pebble Mine corridor, choosing a road location that minimizes crossings of streams, wetlands, and areas of shallow groundwater in a landscape that is rich in those hydrologic features can result in a tortuous alignment, or one that is substantially lengthened, and might involve substantially more vertical curvature to accommodate upland terrain. A tortuous alignment greatly increases the total ground area disturbed, and increased road curvature in either horizontal and vertical dimensions may increase risk of traffic accidents and consequent spills. Moreover in this case it would increase the length and structural complexity of the road-parallel pipelines. Avoidance of sensitive features therefore elevates other environmental risks. This underscores the fact that there is no “free lunch” when it comes to mitigating the environmental impacts of a new road in a previously roadless landscape.

VII. CONCLUSIONS

- Bristol Bay’s robust and resilient salmon fishery is in part associated with the watershed’s extremely high quality waters and high integrity freshwater ecosystems, minimally impacted by roads and industrial development.

- A second major contributor to the Bristol Bay watershed’s productivity for salmon is its abundant and extensive near-surface groundwater and strong vertical linkage between surface waters and groundwaters, across a wide range of stream sizes and landscape conditions.

- Any environmental analysis and planning of a road project such as the Pebble Mine road must consider the significance of initial road development as an economic and social stepping stone to future roads and developments.

- Roads, in particular can foster the incremental decline of salmon and other native fishes by their own direct environmental impact, but equally important is that roads facilitate a variety of human activities that bring their own suite of impacts including increased access to primitive lands, increasing legal and illegal hunting and fishing, use of off-highway vehicles, increased mineral prospecting, and others.

- For the Pebble road corridor, each stream or wetland crossing has the potential for impacts to not just salmon populations in the stream itself, but also downstream in Iliamna Lake, which is in close proximity.

- The Pebble transportation corridor poses risks of direct and acute impacts to salmonids, including possible loss of populations due to blocking of migration pathways from spills or from stream crossing dysfunctions. Like any such development, it will certainly cause chronic, pervasive "press disturbances" (Yount and Niemi 1990) all along its length and for its entire existence, contributing to deterioration of quality of spawning habitats, reduced habitat diversity, disrupted groundwater hydrology, alteration of roadside vegetation, and related impacts that stem from construction, operation and maintenance.

- Many environmental mitigation measures identified for the Pebble Project suffer from being mutually exclusive or offsetting, from being potentially superseded or limited by engineering, operational, maintenance, or fiscal concerns, or are likely to be ineffective given the hydrogeomorphology, subarctic climate and hydrogeologic conditions, seismicity, and pristine condition and inherent sensitivity of the environment in Bristol Bay watershed.

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Attachment A

Resident fish streams potentially affected, crossed or closely approached by the potential Pebble Mine transportation corridor.

Compiled from the Alaska Freshwater Fish Inventory (AFFI) Database (ADFG 2012, Johnson and Blanche 2011a and 2011b, additional information provided by Joe Buckwalter, ADFG, Anchorage, AK, Unpublished data).

Stream names from the Alaska Freshwater Fish Inventory Database.

“Yes (spp?)” entry in the Anadromous Fish column means the AFFI database classifies the stream as “Anadromous,” but anadromous species present are not identified.

Stream No. (west to east)	Stream Name (if known)	NHD Reach Code	Stream Order (Map)	Resident Fish	Anadromous Fish
1		19030206007351	1	Dolly Varden, rainbow trout, slimy sculpin	Coho
2		19030206007354	1	Dolly Varden, slimy sculpin	Coho
3	Upper Talarik Cr.	19030206007015	4	Arctic grayling, Dolly Varden, ninespine stickleback, rainbow trout, slimy sculpin, threespine stickleback	Chinook, chum, coho, sockeye
4		19030206007159	1	[none reported]	Coho
5		19030206007175	1	Dolly Varden, ninespine stickleback, rainbow trout, slimy sculpin, threespine stickleback	
6		19030205007587	2	Ninespine stickleback, slimy sculpin	
7		19030205007593	2	Dolly Varden	

Stream No. (west to east)	Stream Name (if known)	NHD Reach Code	Stream Order (Map)	Resident Fish	Anadromous Fish
8		19030205007598	2	Dolly Varden	
9		19030205007606	2	Slimy sculpin	Yes (spp.?)
10		19030205007602	2	Slimy sculpin	Yes (spp.?)
11		19030205007615	2	Arctic grayling, longnose sucker	
12	Newhalen River	19030205000002	5+	Arctic grayling, jumpback whitefish, longnose sucker, rainbow trout, round whitefish, sculpin	Arctic char, chinook, coho, sockeye
13		19030205013069	3	[no data]	
14		19030205013055	2	[no data]	
15		19030205013057	1	[no data]	
16		19030205013041	2	[no data]	
17		19030205010623	1	[no data]	
18		19030205010628	1	[no data]	
19		19030205010629	1	[no data]	
20	Roadhouse Cr	19030206006712	1	Slimy sculpin	
21	NW Eagle Bay Cr	19030206006678	2	Dolly Varden	Arctic char, sockeye
22		19030206006677	1	Ninespine stickleback, slimy sculpin	
23		19030206006644	2	Dolly Varden	

Stream No. (west to east)	Stream Name (if known)	NHD Reach Code	Stream Order (Map)	Resident Fish	Anadromous Fish
24		19030206006671	2	Dolly Varden, ninespine stickleback	
25		19030206006663	2	Dolly Varden, ninespine stickleback	Arctic char, sockeye
26	NE Eagle Bay Cr	19030206006654	1	Ninespine stickleback, Rainbow trout, slimy sculpin	Sockeye
27	Young's Cr, mainstem	19030206006598	3	Dolly Varden, ninespine stickleback, rainbow trout, slimy sculpin	Arctic char, coho, sockeye
28	Young's Cr, east branch	19030206006553	3	Dolly Varden, rainbow trout, slimy sculpin	Arctic char, coho, sockeye
29	Chekok Cr, west branch	19030206006533	2	[no data]	Arctic char, coho, sockeye
30	Chekok Cr, mainstem	19030206032854	3	Rainbow trout, slimy sculpin	Arctic char, sockeye
31	Canyon Cr	19030206006359	3	Dolly Varden, slimy sculpin	Arctic char, sockeye
32		19030206006336	1	[no data]	
33		19030206006337	1	[no data]	
34		19030206006236	1	[no data]	

Stream No. (west to east)	Stream Name (if known)	NHD Reach Code	Stream Order (Map)	Resident Fish	Anadromous Fish
35		19030206006331	1	[no data]	
36		19030206006329	1	[no data]	
37		19030206006327	1	[no data]	
38		19030206006325	1	[no data]	
39		19030206006322	1	[no data]	
40		19030206006320	1	[no data]	
41		19030206006321	1	[no data]	
42		19030206006318	1	[no data]	
43		19030206006317	1	[no data]	
44		19030206006316	1	[no data]	
45		19030206006315	1	[no data]	
46		19030206006314	1	[no data]	
47		19030206006251	1	[no data]	
48	Knutson Cr	19030206006255	4	Dolly Varden, slimy sculpin	Arctic char, sockeye
49		19030206006280	1	Dolly Varden, slimy sculpin	
50	Pedro Cr	19030206006239	1	[no data]	
51	Russian Cr	19030206006248	1	[no data]	
52		19030206006231	1	[no data]	
53		19030206006230	1	[no data]	
54		19030206006228	1	[no data]	
55		19030206006227	1	Dolly Varden, slimy sculpin	
56		19030206006222	1	[no data]	
57	Pile River	19030206000474	3	Slimy sculpin, threespine stickleback	Arctic char, sockeye

Stream No. (west to east)	Stream Name (if known)	NHD Reach Code	Stream Order (Map)	Resident Fish	Anadromous Fish
58	(Long L. outlet)	19030206010632	1	Threespine stickleback, rainbow trout, slimy sculpin	Yes (spp?)
58a		19030206010632_2	1	[no data]	Yes (spp?)
59	Iliamna R	19030206000032	4	Dolly Varden, slimy sculpin	Chinook, chum, coho, pink, sockeye, Dolly Varden
60		19030206005773	1	[no data]	
61		19030206005761	2	Dolly Varden, slimy sculpin	
62		19030206005759	1	[no data]	
63		19030206005754	2	[no data]	
64	Chinkelyes Cr	19030206005737	2 (at crossing)	Slimy sculpin	
65		19020602004863	1	[no data]	
66		19020602004864	1	[no data]	
67		19020602004865	1	[no data]	
68		19020602004866	1	[no data]	
69	Y-Valley Cr	19020602004967	1	Dolly Varden	Arctic char, chinook, chum, coho, pink, sockeye
70		19020602004882		No fish recorded or observed	

AN ASSESSMENT OF POTENTIAL MINING IMPACTS ON SALMON ECOSYSTEMS OF BRISTOL BAY, ALASKA

VOLUME 3—APPENDICES E-J

Appendix H: Geologic and Environmental Characteristics of Porphyry Copper Deposits with Emphasis on Potential Future Development in the Bristol Bay Watershed, Alaska

Geologic and Environmental Characteristics of Porphyry Copper Deposits with Emphasis on Potential Future Development in the Bristol Bay Watershed, Alaska

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U.S. Department of the Interior
U.S. Geological Survey

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Geologic and Environmental Characteristics of Porphyry Copper Deposits with Emphasis on Potential Future Development in the Bristol Bay Watershed, Alaska

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Introduction

This report is prepared in cooperation with the Bristol Bay Watershed Assessment being conducted by the U.S. Environmental Protection Agency. The goal of the assessment is to help understand how future large-scale development in this watershed may affect water quality and the salmon fishery. Mining has been identified as a potential source of future large scale development in the region, especially because of the advanced stage of activity at the Pebble prospect. The goal of this report is to summarize the geologic and environmental characteristics of porphyry copper deposits in general, largely on the basis of literature review. Data reported in the Pebble Project Environmental Baseline Document, released by the Pebble Limited Partnership in 2011, are used to enhance the relevance of this report to the Bristol Bay watershed.

The geologic characteristics of mineral deposits are paramount to determining their geochemical signatures in the environment. The geologic characteristics of mineral deposits are reflected in the mineralogy of the mineralization and alteration assemblages; geochemical associations of elements, including the commodities being sought; the grade and tonnage of the deposit; the likely mining and ore-processing methods used; the environmental attributes of the deposit, such as acid-generating and acid-neutralizing potentials of geologic materials; and the susceptibility of the surrounding ecosystem to various stressors related to the deposit and its mining, among other features (Seal and Hammarstrom, 2003). Within the Bristol Bay watershed, or more specifically the Nushagak and Kvichak watersheds, the geologic setting is permissive for the occurrence of several mineral deposit types that are amenable for large-scale development. Of these deposit types, porphyry copper deposits (e.g., Pebble) and intrusion-related gold deposits (e.g., Shotgun) are the most important on the basis of the current maturity of exploration activities by the mining industry. The Pebble deposit sits astride the drainage divide between the Nushagak and Kvichak watersheds, whereas the Humble, Big Chunk, and Shotgun deposits are within the Nushagak watershed. The Humble and Big Chunk prospects are geophysical anomalies that exhibit some characteristics similar to those found at Pebble. Humble was drilled previously in 1958 and 1959 as an iron prospect on the basis of an airborne magnetic anomaly. Humble is approximately 85 miles (137 km) west of

Pebble; Big Chunk is approximately 30 miles (48 km) north-northwest of Pebble; and Shotgun is approximately 110 miles (177 km) northwest of Pebble. The H and D Block prospects, west of Pebble, represent additional porphyry copper exploration targets in the watershed.

Geologic Characteristics of Porphyry Copper Deposits

Geologic Setting of the Bristol Bay Watershed

The Nushagak and Kvichak watersheds are characterized by a complex geologic history. The history, going back at least 100 million years, has been dominated by northward movement and subduction of the oceanic crust beneath the Alaskan continental landmass, which continues today. The northward subduction of oceanic crust led to the accretion of island land masses to the Alaskan mainland. The divide between the Nushagak and Kvichak watersheds is near the geologic boundary between the Peninsular Terrane to the southeast and the Kahiltna Terrane to the northwest (Decker and others, 1994; Nokleberg and others, 1994). The Peninsular Terrane consists of Permian limestone, Triassic limestone, chert, and volcanic rocks, Jurassic volcanic and plutonic rocks, and Jurassic to Cretaceous clastic sedimentary rocks.

The Pebble porphyry copper deposit and the Humble and Big Chunk prospects are located within the southern Kahiltna Terrane (Fig. 1). The southern Kahiltna Terrane consists of a deformed sequence of Triassic to Jurassic basalt, andesite, tuff, chert, and minor limestone of the Chilikadrotna Greenstone, which is overlain by the Jurassic to Cretaceous Koksetna River sequence comprising turbiditic sandstones, siltstone, and shales (Wallace and others, 1989). The area was intruded by Cretaceous to Tertiary plutons, which include those associated with the Pebble deposit. The area also was partially covered by Tertiary to Quaternary volcanic rocks and varying thicknesses of glacial deposits (Detterman and Reed, 1980; Bouley and others, 1995).

The underlying geology can exert a significant influence on water chemistry, and therefore the possible toxicity of trace elements to aquatic organisms. The presence or absence of carbonate minerals and pyrite is the most significant influences on water chemistry in terms of pH, hardness, and alkalinity. Carbonate minerals such as calcite – the main constituent of limestone – can raise the pH and increase water hardness and alkalinity. Limestone, dolomite, and siltstone with abundant calcareous concretions are the most common hosts of carbonate minerals and are most abundant in Kvichak watershed in the vicinity of Lake Clark (Detterman and Reed, 1980; Bouley and others, 1995). Pyrite, a potential source of acid, can be a minor constituent of turbiditic sediments such those found in the Koksetna River sequence, northeast of Pebble. Hydrothermal activity associated with the formation of mineral deposits, discussed below, also can introduce significant amounts of both pyrite and carbonate minerals.

Mineral Resource Potential of the Nushagak and Kvichak Watersheds

The geologic setting of the Nushagak and Kvichak watersheds has characteristics that indicate that the region is favorable for several different mineral-deposit types (Schmidt and others, 2007). These deposit types include porphyry copper deposits, copper and iron skarn deposits, intrusion-related gold deposits, tin greisen deposits, epithermal gold-silver vein deposits, hot spring mercury deposits, placer gold deposits, and sand and gravel deposits (Table 1). Of these deposit types, porphyry copper deposits and intrusion-related gold deposits are represented by current prospects within the area that could prompt large-scale development. Copper skarn deposits hold less potential, in the absence of infrastructure from other mine development in the region, because of their typical smaller size (John and others, 2010). Significant exploration activity associated with porphyry copper

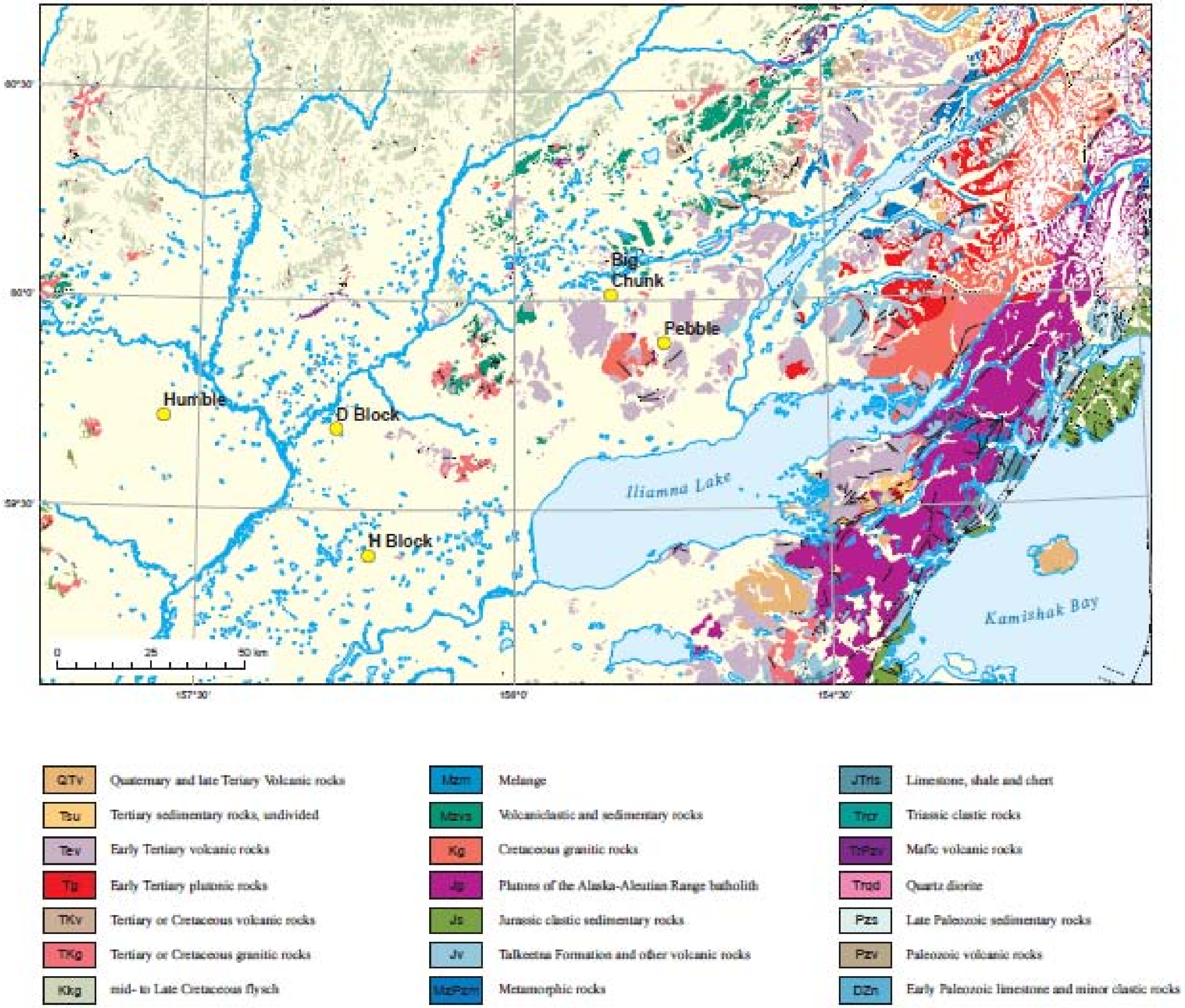

Figure 1. Generalized geologic map of the central part of the Bristol Bay watershed showing the general locations of the Pebble, Humble, and Big Chunk prospects. Adapted from Wilson and others (2006). Map was made by Keith Labay (USGS).

deposits is currently being done at the Pebble prospect, and to a lesser extent the Humble and Big Chunk prospects. Several other porphyry copper prospects are immediately adjacent to Pebble, including the H Block and D Block prospects. Although the Humble (also known as Kemuk Mountain) prospect is currently being promoted as a porphyry copper target (http://www.millrockresources.com/projects/humble/), the initial exploration (1957 – 1959) identified significant iron and titanium resources in a mafic intrusive complex (ALS Chemex, 2008). Notable exploration also is being done in the watershed at several gold properties including Shotgun, Kisa, and Bonanza Hills.

The Pebble deposit is the most advanced among the mining prospects in the Bristol Bay watershed in terms of exploration and progress towards the submission of mine permit applications. Therefore, the potential for large-scale mining development within the watershed in the near future is greatest for porphyry copper deposits. Accordingly, the remainder of the report will focus exclusively on this deposit type – porphyry copper deposits.

Table 1. Deposit types with significant resource potential for large-scale mining in the Nushagak and Kvichak watersheds.

Deposit type	Commodities	Examples	References
Porphyry copper	Cu, Mo, Au, Ag	Pebble, Big Chunk, Kijik River	Schmidt and others (2007); Bouley and others (1995)
Intrusion-related gold	Au, Ag	Shotgun/Winchester, Kisa, Bonanza Hills	Schmidt and others (2007); Rombach and Newberry (2001)
Copper(-iron-gold) skarn	Cu, Au, Fe	Kasna Creek, Lake Clark Cu, Iliamna Fe, Lake Clark	Schmidt and others (2007), Newberry and others (1997)

General Characteristics of Porphyry Copper Deposits

Geologic Features:

The geologic characteristics of porphyry copper deposits recently have been reviewed by John and others (2010), Sinclair (2007), and Seedorff and others (2005). Therefore, only salient features are summarized here. Porphyry copper deposits are found around the world, most commonly in areas with active or ancient volcanism (Fig. 2). The economic viability of porphyry copper deposits is dictated by the economy of scale – they typically are low grade (average 0.44 % copper in 2008), large tonnage (typically hundreds of millions to billions of metric tonnes of ore) deposits that are exploited by bulk mining techniques (John and others, 2010). Because of their large size, their mine lives typically span decades.

Primary (hypogene) ore minerals found in porphyry copper deposits are structurally controlled and genetically associated with felsic to intermediate composition, porphyritic intrusions that typically were emplaced at shallow levels in the crust. Mineralization commonly occurs both within the associated intrusions and in the surrounding wall rocks. The primary minerals fill veins, veinlets, stockworks and breccias. Pyrite (FeS_2) is generally the most abundant sulfide mineral. The main copper-sulfide ore minerals are chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4). A number of other minor copper sulfide minerals are commonly found; most notable from an environmental perspective is the arsenic-bearing mineral enargite (Cu_3AsS_4). Molybdenite (MoS_2) is the main molybdenum mineral. Gold in porphyry copper deposits can be associated in appreciable amounts with bornite, chalcopyrite, and pyrite; the gold may occur as a trace element within these sulfide minerals or as micrometer-scale grains of native gold (Kesler and others, 2002).

Hydrothermal mineralization produces hydrothermal alteration haloes that are much larger than the actual ore deposit. The classic alteration zonation includes a potassium feldspar-biotite rich core, surrounded by a muscovite/illite sericitic (phyllic) alteration zone, which is surrounded by a clay-rich argillic alteration zone and finally by a chlorite-epidote rich propylitic zone (Fig. 3; Lowell and Gilbert, 1970). The ore zones generally coincide with the potassic and sericitic alteration zones. From an environmental perspective, the importance of these alteration types is that the sericitic and argillic alteration tends to destroy the acid-neutralizing potential of the rock, while enhancing the acid-generating potential through the addition of pyrite. In contrast, the outer portion of the propylitic zone tends to have enhanced acid-neutralizing potential due to the introduction of trace amounts of carbonate minerals.

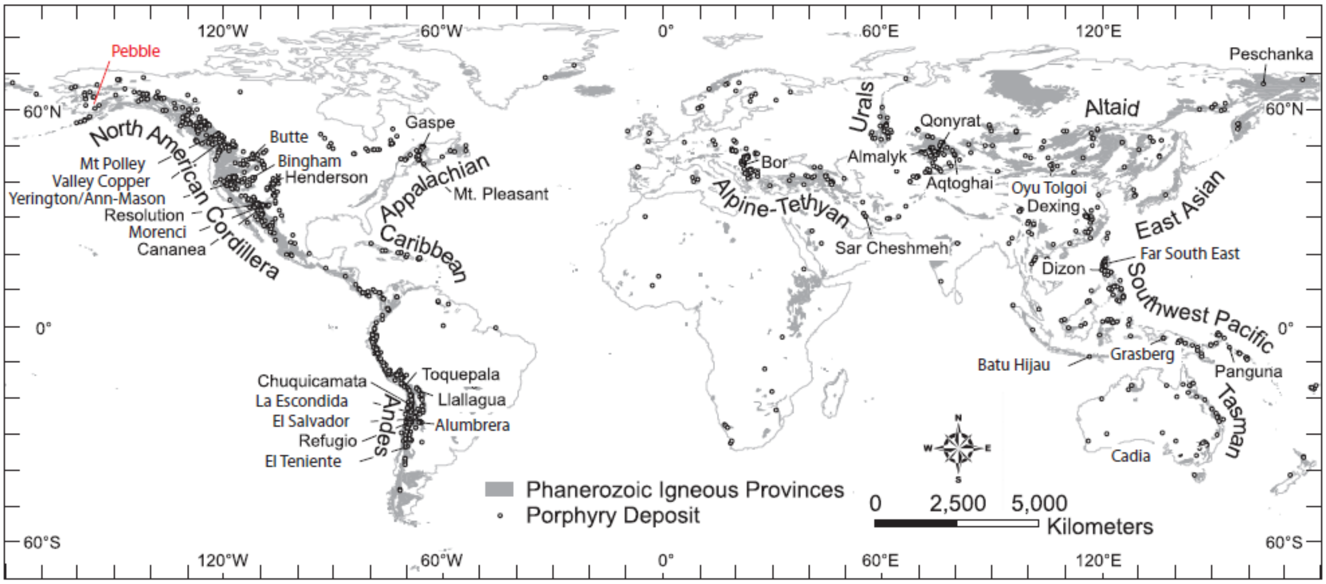

Figure 2. Map showing location of Phanerozoic porphyry deposits with representative deposits labeled. Modified from Seedorff and others (2005) and John and others (2010).

Supergene (weathering) processes, which occur long after the initial hydrothermal mineralizing events, can lead to zones of supergene enrichment near the tops of these deposits (John and others, 2010). The supergene enrichment zones can be either oxide- or sulfide-dominated depending on the prevailing oxidation state at the site of formation, the depth of the water table, and climate. Mined material from the oxide enrichment zone is amenable to a heap-leaching method of ore processing known as “solvent-extraction – electrowinning” (SX-EW; Jergensen, 1999). However, supergene ores are likely to be minor in Alaska due to recent glaciation.

Porphyry copper deposits can be divided into three subtypes on the basis of Au (g/t)/Mo (%) ratios: porphyry Cu, porphyry Cu-Mo, and porphyry Cu-Au deposits, where Cu-Au deposits have Au/Mo ratios greater than or equal to 30, Cu-Mo deposits have Au/Mo ratios less than or equal to 3, and Cu deposits are all other deposits not within these bounds (Sinclair, 2007; Singer and others, 2008). On the basis of these criteria, the Pebble deposit would be classified as a porphyry Cu deposit.

Economic Characteristics:

Porphyry copper deposits are important sources of copper, molybdenum, gold, and silver; they also can supply significant amounts of byproduct rhenium, tellurium, and platinum-group metals. Porphyry copper deposits supply over 60 percent of the copper for global copper production and together with porphyry molybdenum deposits, account for over 95 percent of the molybdenum production (Sinclair, 2007; John and others, 2010). In 2010, the United States consumed 1,730,000 tonnes of copper, of which 30 percent was imported, chiefly from Chile, Canada, and Peru. In the same year, the United States consumed 48,000 tonnes of molybdenum, and was a net exporter. In 2010, the United States consumed 380 tonnes of gold of which 33 percent was imported, primarily from Canada, Mexico, Peru, and Chile. These commodities serve myriad uses (U.S. Geological Survey, 2011). Copper is used primarily in building construction (wiring and pipes; 49 %), electric and electronic products (20 %), vehicles (12 %), consumer products (10 %), and industrial machinery and equipment (9 %). Molybdenum is primarily used as a steel alloy (75 %). Gold is used mainly for jewelry (69 %), and electrical and electronic products (9 %). Silver is used for a variety of applications including industrial and medical uses, electronics, coins and silverware, and photography (albeit a declining application). Rhenium is principally used as an alloy in turbine engines (70 %) and for petroleum refining (20 %). Tellurium is primarily used as an alloy with steel, iron, and lead, but increasingly is being used in photovoltaic cells. Platinum-groups metals (platinum, palladium, rhodium, ruthenium, iridium, and osmium) principally are used in vehicle catalytic converters, as catalysts for chemical manufacturing, in electronics and in emerging applications to fuel cells.

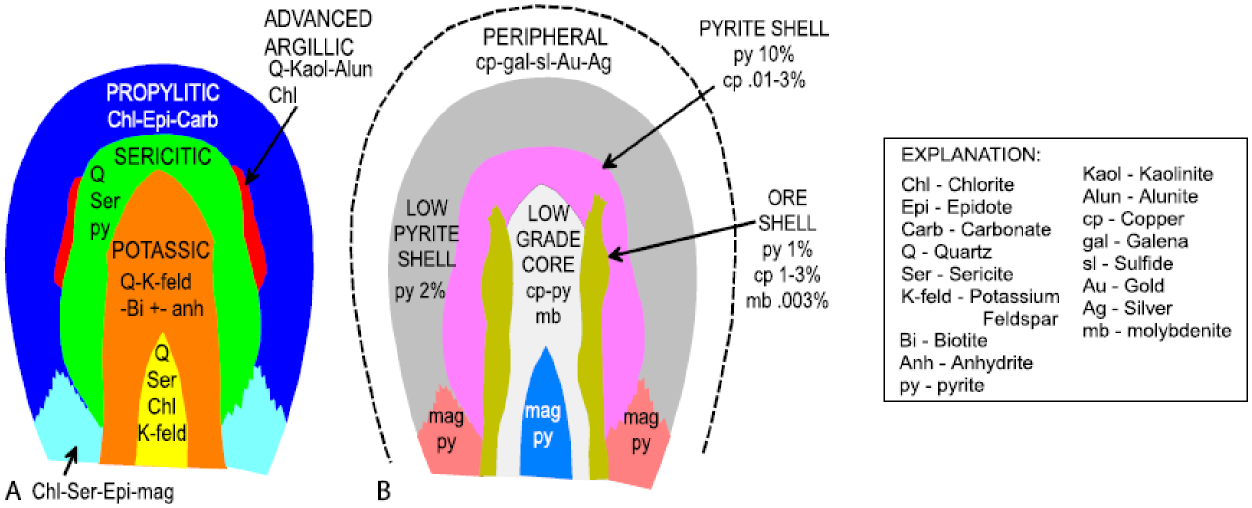

Figure 3. Idealized cross section through a porphyry copper deposit showing the relationship of the ore zone to various alteration types. A. Distribution of alteration types; B. Distribution of ore mineral assemblages. The causative intrusion corresponds to the potassic alteration zone. From John and others (2010) and modified from Lowell and Guilbert (1970).

The grade and tonnage of porphyry copper deposits vary widely (Singer and others, 2008). Summary statistics compiled for 256 porphyry copper deposits are presented in Table 2 and Figure 4. For total tonnage of ore, Pebble is in the upper 5th percentile, lower 50th percentile for copper grade, upper 10th percentile for molybdenum grade, and upper 10th percentile for gold grade. The amount of metal contained in the Pebble deposit corresponds to a 21-year supply of copper for the United States, a 53-year supply of molybdenum, and a 9-year supply of gold, based on 2010 consumption statistics (Table 3). From the perspective of future discoveries in the watershed, it is therefore highly unlikely that new deposits will approach the size of Pebble, but instead will be considerably smaller.

Geology of Bristol Bay Porphyry Copper Deposits:

Several porphyry copper prospects within the Bristol Bay watershed are being explored, and include Pebble, Humble, and Big Chunk. The Pebble deposit is the only one with a significant published description of its geology (Bouley and others, 1995; Kelley and others, 2010). The deposit is controlled by the Pebble Limited Partnership – a joint venture between Northern Dynasty Minerals, Ltd., and Anglo American. The Pebble deposit may be viewed as consisting of two contiguous ore bodies: Pebble West and Pebble East, with the buried Pebble East having the higher ore grades. Pebble West was discovered in 1989 at the surface, and delineation drilling in 2005 resulted in discovery of Pebble East beneath a 300 to 600 m thick cover of Tertiary volcanic rocks. The deposit has been explored extensively with more than 1,150 drill holes that total greater than 949,000 feet (289,250 m) (Northern Dynasty Minerals, 2011).

Table 2. Global grade and tonnage summary statistics for porphyry copper deposits (n = 256; Model 17, Singer and others, 2008) compared to the Pebble deposit.

Parameter	10th Percentile	50th Percentile	90th Percentile	Pebble[1]
Tonnage (Mt)	1,400	250	30	10,777
Cu grade (%)	0.73	0.44	0.26	0.34
Mo grade (%)	0.023	0.004	0.0	0.023
Ag grade (g/t)	3.0	0.0	0.0	unknown
Au grade (g/t)	0.20	0.0	0.0	0.31

Sources: [1]PLP (0.3 % Cu cut-off grade), includes measured, indicated, and inferred resources (*http://www.pebblepartnership.com/*)

Table 3. Annual consumption of copper, molybdenum and gold compared to the Pebble deposit.

Commodity	US Annual Consumption (2010)[1]	Pebble Resource[2]	Years of 2010 Consumption
Copper (tonnes)	1,730,000	36,636,364	21
Molybdenum (tonnes)	48,000	2,531,818	53
Gold (tonnes)	380	3,337	9

Sources: [1]U.S. Geological Survey (2011); [2]PLP (0.3 % Cu cut-off grade), includes measured, indicated, and inferred resources (*http://www.pebblepartnership.com/*)

The oldest rocks in the vicinity of the deposit are Jurassic to Cretaceous (ca. 150 Ma) clastic sedimentary rocks (i.e., mudstone, siltstone, and sandstone), which were intruded by dominantly granitic plutons from 100 to 90 Ma; granodiorite stocks and sills, spatially and genetically related to the Cu-Au-Mo mineralization, were intruded about 90 Ma (Kelley and others, 2010). Intrusion of these granodiorite bodies resulted in hydrothermal activity that produced the mineralization and associated alteration of the intrusions and surrounding rocks. The Pebble West deposit extends from the surface to a depth of about 500 m and encompasses roughly 6 square kilometers on the surface. Pebble East is covered by a wedge of post-mineralization Tertiary volcanic rocks that exceeds 600 m in thickness towards the east. The eastern end of the deposit is truncated by a high-angle fault that offsets the deposit 600 to 900 m down to the east (Kelley and others, 2010). Early copper mineralization was dominated by pyrite, chalcopyrite, and gold, which was overprinted by pyrite, bornite, digenite, covellite, and minor enargite, followed by quartz-molybdenite veinlets (Bouley and others, 1995; Kelley and others, 2010).

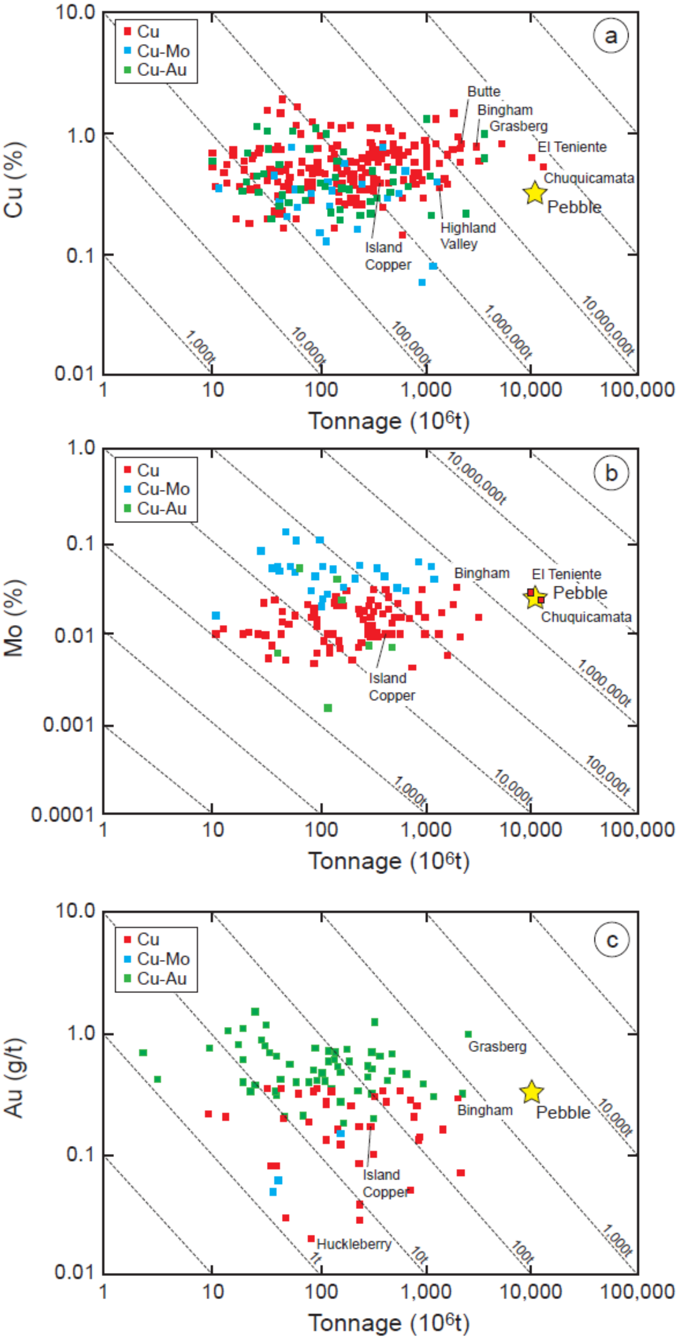

Figure 4. Grade-tonnage characteristics of the Pebble deposit compared to other porphyry-type deposits. A. Copper; B. Molybdenum; C. Gold. The Pebble deposit is shown as the yellow star. Selected, noteworthy deposits are labeled. Pebble is classified as a porphyry Cu deposit (red squares). The dashed diagonal lines represent the total contained metal. Modified from Sinclair (2007).

Geologic information on the Humble prospect (also known as Kemuk) is limited to the details found on the Millrock Resources, Inc. website (*http://www.millrockresources.com/projects/humble/*). The prospect is covered by glacio-fluvial gravels and sands 30 to greater than 140 m thick. The site was identified on the basis of the presence of an airborne geophysical (magnetic) anomaly and the presence of igneous rocks similar to those found at Pebble. The Humble Oil Company drilled the property in 1958 and 1959 as an iron prospect. No mention is made of Cu-Au-Mo mineralization from the 1950s drilling, and there are no recent data available. Information on the Big Chunk Super project is limited to details on the Liberty Star Uranium and Metals Corporation website (*http://www.libertystaruranium.com/www/projects/big-chunk-super-project*). Current exploration efforts are focused on six to seven airborne electromagnetic geophysical anomalies from data collected in 2009 that are consistent with porphyry-style mineralization. Although exploratory drilling is mentioned on the web site, no results are discussed.

Mining and Beneficiation Considerations:

Mining and ore-processing methods can vary based on whether or not parts of the ore are weathered, and on the commodities being extracted. Due to their large size and low grades, porphyry copper deposits are mined by bulk mining methods such as open-pit mining for deposits near the surface, and block caving for deposits at depth. Because the copper ore grades are generally less than 2 percent, greater than 98 percent of the material mined ends up as waste. The beneficiation of the ore is distinctly different between hypogene (primary) sulfide ores and supergene (secondary) oxide ores. Mining begins with the removal of waste rock, which may or may not be acid-generating. Country rocks that host the mineralization are commonly acid-generating due to the presence of hydrothermal pyrite formed during the mineralizing event. These rocks may be classified as subeconomic ore and may be stockpiled separately from barren waste rock. The processing of subeconomic ore commonly is prompted by either an increase in metal prices making the material economically viable, or if a high-grade zone is encountered during mining, the subeconomic ore may be mixed with high-grade ore to ensure that an optimal grade of material is being fed to the mill. In either case, subeconomic ore generally is handled in a similar fashion to that of waste rock during mine operations because of its acid-generating potential.

The primary (hypogene) sulfide ore is crushed to sand or silt size prior to ore-concentrate separation using the froth flotation method (Fuerstenau and others, 2007). For porphyry copper deposits, such as Pebble, separate concentrates for copper and molybdenum generally are produced. The gold in porphyry copper deposits can be partitioned variably among the copper-sulfide minerals (chalcopyrite, bornite, chalcocite, digenite, and covellite), pyrite, and free gold (Kesler and others, 2002). Gold associated with the copper minerals remains with the copper concentrate and is recovered at an off-site smelter. Gold associated with pyrite will end up in the tailings, unless a separate pyrite concentrate is produced. Pyrite concentrates can be produced during froth flotation for the recovery of gold or to more effectively manage the high acid-generating potential of this material. Gold commonly is recovered by cyanidation, but gold recovery from sulfide-rich material is poor (Marsden and House, 2006). To improve gold recovery, pyritic material typically is oxidized by various means including high-temperature (pyrometallurgical) roasting; low-temperature, pressurized autoclaving; or bio-oxidation using bacteria. Following oxidation, the material then is leached with cyanide, usually in a vat to recover gold (Marsden and House, 2006). The resulting spent iron oxides generally are disposed with the tailings. Autoclaving is probably the most likely option in southwest Alaska because cyanide can be managed effectively in a vat-leaching operation. High-temperature roasting is energy intensive and presents additional challenges with respect to stack emissions. Bioleaching may be more difficult because of the cold climate and slow biotic oxidation rates at lower temperatures.

Tellurium generally is recovered from the copper anode slimes at the refinery (John and others, 2010). Rhenium is recovered as a byproduct of the roasting of the molybdenum concentrate at the refinery (U.S. Geological Survey, 2011). The platinum-group metals generally are associated with copper concentrates (Tarkian and Stribrny, 1999) and thus, would not be recovered on site at Pebble. Therefore, the recovery of tellurium and platinum-group metals from Pebble or other porphyry copper deposits in the watershed would likely be an activity conducted off-site when ore concentrates are further processed.

Supergene (secondary) oxide ores commonly are beneficiated using a heap-leach method known as solvent extraction-electrowinning (SX-EW). This process involves placing coarsely crushed ore on a lined pad and applying sulfuric acid to leach copper from the ore. The pregnant leach solution is collected and the copper is removed from the leachate electrolytically (Jergensen, 1999). The supergene enrichment zone at Pebble is poorly developed and dominated by the secondary copper sulfide minerals covellite (CuS), digenite ($Cu_{1-x}S$), and chalcocite (Cu_2S), in part due to recent glaciation (Bouley and others, 1995). Therefore, processing of oxide ore is unlikely at Pebble or geologically similar deposits within the watershed.

Environmental Characteristics of Porphyry Copper Deposits

Overview

Porphyry copper deposits can pose geochemical risks to aquatic and terrestrial ecosystems, and to human health. The risks can range from nil to significant and depend upon a variety of factors. Factors that influence the environmental characteristics of mineral deposits range from geologic setting (both local and regional), hydrologic setting, climatic settings, and mining methods, to ore beneficiation methods. The sources of the risk can be considered in the broad categories of acid-generating potential, trace element associations, mining and ore beneficiation methods, and waste disposal practices. The significance of these sources of risk will vary from deposit to deposit, but some generalizations can be made for porphyry copper deposits as a whole.

Acid-Generating Potential

Acid generation can be considered a “master variable” for aqueous risks. Metals and other cations are more soluble at low pH than at neutral or high pH. Therefore, the acid-generating or acid-neutralizing potentials of the waste rock, tailings, and mine walls are of prime importance in identifying the potential environmental risks associated with mining and ore beneficiation.

The acid-generating or acid-neutralizing character of a rock or mine waste material is evaluated in terms of an “acid-base account”. Acid-base accounting uses static tests to assess maximum acid-generating potential. Static tests are based on a single analysis of waste material and therefore are independent of rates of reactions. In contrast to static tests, kinetic tests expose mine waste samples for weeks, months, or years. Most proposed mining projects take a staged approach to evaluating acid-generating potential starting with acid-base accounting data to screen numerous samples, which are followed by the more laborious kinetic testing process on fewer, carefully selected samples.

The acid-generating potential of rocks and mine waste samples can be evaluated using a variety of techniques (Price, 2009; INAP, 2011). In North America, one of the most common techniques investigates the difference or ratio of the acid-generating and acid-neutralizing potential of the sample. Theoretically, a sample with an acid-neutralizing potential (NP) equal to its acid-generating potential (AP) is “net neutral”, meaning that its acid-neutralizing potential (NP) should theoretically cancel (or neutralize) its acid-generating potential (AP). Numerically, this is expressed as a “net neutralizing potential” (NNP) of zero, where

$$NNP = NP - AP$$

Values for AP, NP, and NNP are typically expressed in the units of kilograms of calcium carbonate per tonne of waste material (kg $CaCO_3$/t), such that the amount of calcium carbonate amendment that would be needed to achieve "net neutrality" is readily apparent. The AP values are generally based on an analysis of the sulfide-sulfur content of the sample, and the NP values are based on either an analysis of the carbonate content of the sample or by leaching of the sample followed by a wet chemical titration of the resulting leachate. NNP values that are greater than zero have theoretical acid-neutralizing potential present in excess of acid-generating potential and those below zero have theoretical acid-generating potential present in excess of acid-neutralizing potential. Alternatively, the acid-base account of a sample also can be expressed in terms of its neutralizing potential ratio (NPR), which is simply the ratio of its NP to its AP:

$$NPR = NP/AP$$

Thus, a sample with a NPR equal to one is net neutral, greater than one has theoretical acid-neutralizing potential exceeding acid-generating potential, and less than one has theoretical acid-generating potential exceeding acid-neutralizing potential. Current industry standards generally divide rocks and mine waste samples into three distinct categories based on the NPR values: potentially acidic drainage generating (PAG) for NPR less than 1; uncertain (possibly) acidic drainage generating for NPR between 1 and 2; and non-potentially acidic drainage generating (non-PAG) greater than 2 (INAP, 2011). Note that the requirement that non-PAG material have a NPR value greater than 2 represents twice the amount of alkalinity needed for net neutrality under equilibrium conditions. In practice, kinetic considerations are important, which is why a NPR greater than 2 is desirable. However, no universal consensus exists on the NPR value required to ensure no acid generation; recommended values range from 1 to 4 (White and others, 1999). The NPR is typically used as a screening tool and mine-waste management decisions will be based on more extensive characterization using additional techniques (Price, 2009).

The rocks associated with porphyry copper deposits, in general, tend to straddle the boundary between having net acid-generating potential and not having net acid-generating potential. This aspect is illustrated well by the study of Borden (2003) on the Bingham Canyon porphyry copper deposit in Utah (Figures 5 and 6), which shares many similar geologic features with the Pebble deposit. The AP values for porphyry copper deposits approximately reflect the distribution of pyrite. The distribution of acid-generating and non-acid-generating material in plan view at the Bingham mine matches well with the idealized cross section of porphyry copper deposits shown in Figure 3B. The pyrite-poor, low-grade core corresponds to the central part of the Bingham Canyon deposit where NNP values are greater than 0. The progression out to the ore shell and pyrite shell with their increasing abundance of pyrite in these areas is reflected in the progressively more negative NNP values.

During mining of porphyry copper deposits, a variety of materials with differing NNP values may be encountered. The low NNP, largely barren pyrite shell likely represents waste rock that may need to be removed to access the ore (Fig. 3B). The boundary between the ore shell and the pyrite shell is cryptic and typically is defined operationally on the basis of a cut-off copper grade. Therefore, some of the "waste" material with significant, subeconomic copper grades could be stockpiled for potential future beneficiation. The intrusions that produce porphyry copper deposits can intrude any rock type. Therefore, the NNP values of the country rock of undiscovered deposits cannot be predicted reliably. Likewise, geologic events following ore formation could juxtapose a variety of rock types against an ore deposit, which can have a range of NNP values. In the case of Pebble, subsequent volcanic activity after mineralization covered the eastern part of the deposit with material that has limited acid-generating potential (Kelley and others, 2010; Pebble Partnership, 2011).

The mining method will influence the amount of waste rock removed. Open pit mining can require the removal of large volumes of potentially acid-generating material. A waste-to-ore ratio of 2:1, meaning that two tonnes of waste are removed for each tonne of ore mined, is not uncommon for porphyry copper deposits (Porter and Bleiwas, 2003). Underground block caving of ore requires that a shaft or decline be sunk to facilitate mining. The amount of waste rock removed for block caving is much less than that removed in a typical open pit operation. In the specific case of Pebble, the volcanic rocks overlaying Pebble East have limited amounts of pyrite and are generally classified as non-PAG material, which would not require special handling to mitigate acidic drainage (Pebble Partnership, 2011). In fact, this material could be used for a variety of construction projects on site (e.g., road fill, tailings dam construction). In contrast, the Pre-Tertiary rocks at Pebble are generally classified as PAG, with some samples having uncertain potential for generating acid and fewer with no potential for generating acid (non-PAG). During mining, some of this rock will be waste rock removed to access the ore, and some of it will be ore that will be processed to extract mineral concentrates.

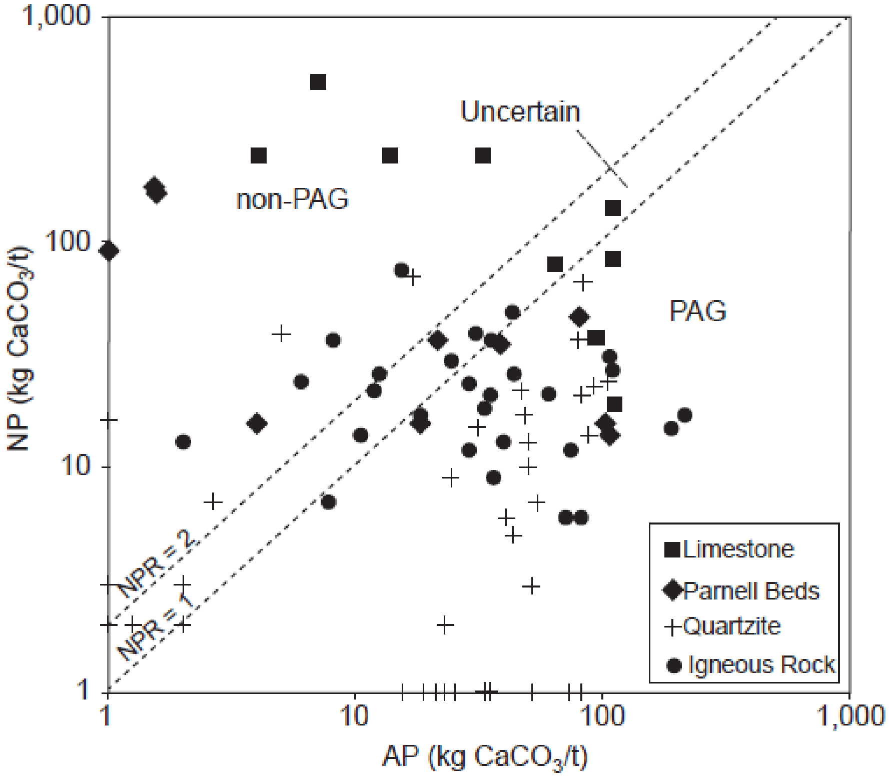

Figure 5. Plot of neutralizing potential (NP) and acid-generating potential (AP) for mineralized rock types at the Bingham Canyon porphyry copper deposit, Utah. Modified from Borden (2003).

The most profound influence that beneficiation of ore can have on mine tailings derived from froth flotation centers on the fate of pyrite (Fuerstenau and others, 2007). At many porphyry copper mines, the pyrite is discharged with the waste tailings, thereby contributing to the acid-generating potential of the tailings. However, the option exists to produce a pyrite concentrate to manage more effectively the acid-generation risks associated with tailings, to extract gold associated with the pyrite, or both. The production of a pyrite concentrate will decrease the acid-generating potential of the tailings.

Waste Rock

Waste rock associated with porphyry copper deposits reflects the geologic history of the deposit. Because porphyry copper deposits are associated with igneous rocks intruded into shallow levels of the Earth's crust, the geochemical properties of the country rocks can vary widely, particularly in terms of their acid-base accounting properties and their trace element compositions. The hydrothermal activity that forms the ore deposits introduces sulfur, which commonly forms sulfide minerals such as pyrite, and a variety of trace elements. Introduced sulfur may also occur as the sulfate minerals anhydrite ($CaSO_4$), or barite ($BaSO_4$), which are environmentally benign with respect to acid-generating potential. In fact, for acid-base accounting, the portion of sulfur that occurs as sulfate should be subtracted from the total amount of sulfur present to accurately estimate acid-generating potential (Price, 2009). The hydrothermal alteration haloes around these deposits are significantly more extensive than the ores themselves (Fig. 3) and commonly represent waste rock with significant associated environmental risks. Rocks that form after the mineralization event, and not affected by supergene processes, are devoid of these hydrothermal overprints of sulfur and trace elements.

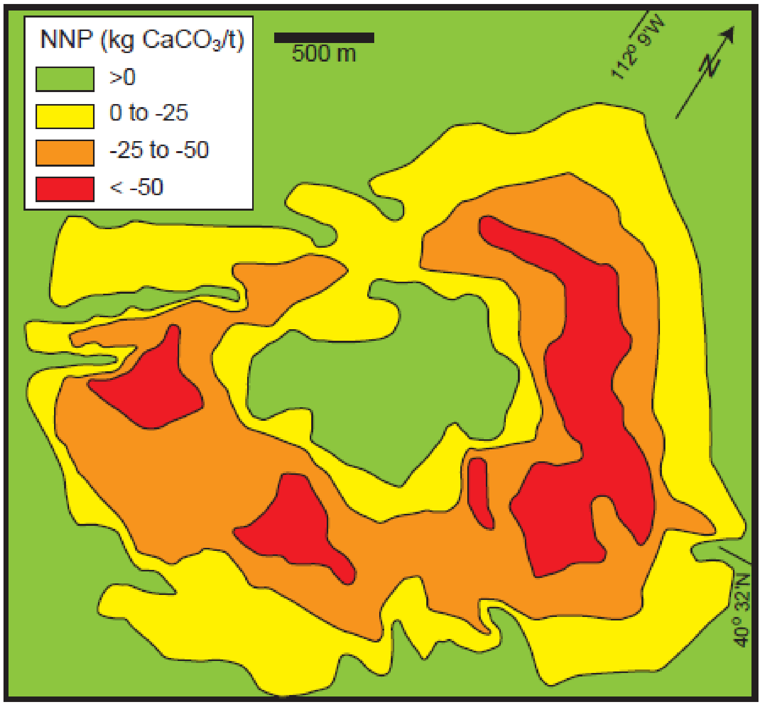

Figure 6. Plan view of the distribution of net neutralizinig potential (NNP) values at the Bingham Canyon porphyry copper deposit, Utah. NNP values above zero are “net alkaline”; those below zero are “net acid”. Modified from Borden (2003).

An early step in mining is to remove the waste rock to access the ore. For open pit mines, waste to ore (stripping) ratios commonly can exceed 2:1 (Porter and Bleiwas, 2003). As discussed in the previous section, the acid-generating potential of the waste rock can span the range from potentially acid-drainage generating (PAG) to non-PAG. The ability of leachate generated from waste rock to mobilize metals and oxyanions will vary, depending in part, on the pH of the resulting solution, which largely is a function of the pyrite content of the waste rock.

The primary environmental concerns associated with waste rock are due to the oxidation of waste-rock material, which may result in contamination of either groundwater or surface water. The oxidation of sulfide minerals such as pyrite produces sulfuric acid, which then can dissolve metals and related elements from associated sulfide, silicate, and carbonate minerals. The magnitude of this risk will depend upon waste management practices and whether or not drainage is treated.

The geochemical characteristics of waste-rock dump drainage have been investigated by several studies. Day and Rees (2006) conducted a study of dump seepage associated with several operating or recently closed porphyry copper and porphyry molybdenum mines in British Columbia, many of which are located in the Fraser River watershed. Porphyry copper mines included in their study were Gibraltar, Huckleberry, Island Copper, and Mount Polley; the data from Huckleberry were from laboratory column tests only. These deposits fell into two groups: those that produced low pH drainage and those that did not. The pH of waste-dump drainage from Gibraltar and Huckleberry ranged from neutral down to approximately 2, whereas drainage from Island Copper only reached a low of approximately 4.5. In contrast, the pH of waste-rock drainage at Mount Polley ranged between 7 and 8.5. The concentrations of sulfate and metals were negatively correlated with pH. The maximum concentrations of sulfate (<30,000 mg/L), Al (< 1,000 mg/L), Mn (< 100 mg/L), and Cu (< 1,000 mg/L) were all highest from Gibraltar; the highest concentrations of Zn (< 100 mg/L) were found in the Huckleberry column tests (Day and Rees, 2006). For comparison, Lister and others (1993) found that 41 percent of the NPR values for waste rock at Island Copper were below 1, 23 percent were between 1 and 3, and 36 percent were above 3, which is consistent with the range of pH values, from 4.5 to 8, observed by Day and Rees (2003). Khorasanipour and others (2011) found similar geochemical trends, but in a more arid environment, for drainage associated with waste-rock dumps at the Sarcheshmeh mine in southeastern Iran. The pH ranged between 3.1 and 6.3, specific conductance between 0.72 and 2.25 mS/cm, sulfate between 365 and 1,590 mg/L, Al between < 0.05 and 60 mg/L, Mn between 14.6 and 95.8 mg/L, Cu between 2.15 and 70 mg/L, and Zn between 2.4 and 27.4 mg/L.

In the vicinity of the proposed Pebble mine, the best insights into the potential behavior of waste rock come from the humidity-cell tests being conducted by the Pebble Limited Partnership and its contractors (Pebble Partnership, 2011). Management of waste rock during mine operation typically involves placing waste rock in subaerial piles on site. This configuration is similar to the conditions of humidity-cell tests where samples are exposed to a weathering protocol under unsaturated conditions (Price, 2009). Standard procedures for humidity-cell tests require that rock be crushed to less than 6 mm, placed in cylinders, cycled through moist and dry air for six days, and leached on the seventh day, all at room temperature. This requirement produces a material that has significantly more surface area than waste rock produced during mining, which makes the test material more reactive than the actual material. As such, this approach does not incorporate the temperature and precipitation variations encountered on site, or the heterogeneous grain size of typical waste rock. “Barrel” kinetic tests were conducted also, where rather than weathering samples in the laboratory, larger volumes of material were placed in barrels in the field and the samples were exposed to site conditions. The goal of barrel testing is to scale-up laboratory results to conditions that are more representative of the site in terms of amount and seasonality of precipitation and temperature variations. The barrel test results are only discussed on a limited basis in this report. However, despite these caveats, the humidity-cell results presented by the Pebble Partnership (2011) provide relevant information.

Pebble Partnership (2011) has divided material at the site into several different groups, for both Pebble West and Pebble East: Pre-Tertiary sedimentary and volcano-sedimentary units, Pre-Tertiary plutonic units, and Tertiary volcanic units. In general, results from the Pre-Tertiary rocks from Pebble West and Pebble East were not significantly different. The Pre-Tertiary rocks were present at the time of mineralization and therefore have the potential to be significantly mineralized. The Tertiary volcanic rocks were deposited after mineralization, and therefore should have limited concentrations of sulfide minerals to serve as a sources of acidity and dissolved metals.

The results of the Pebble Partnership (2011) humidity-cell tests are summarized in Table 4. Table 4 presents the mean composition of leachate from these a number of individual tests divided into three groups: Tertiary rocks, hydrothermally altered Pre-Tertiary rocks (undifferentiated) from Pebble West, and hydrothermally altered Pre-Tertiary rocks (undifferentiated) from Pebble East. The results from the variety of Pre-Tertiary rock types were grouped together here with the assumption that individual waste-rock types would not be selectively removed during mining. Individual humidity-cell tests can show a range of leachate concentrations that vary over the course of the experiment. In general, the concentrations of dissolved constituents are most erratic and highest during the initial flush covering the first few one-week cycles in humidity-cell tests; several weeks after the start of the experiments, the concentrations of dissolved constituents tend to stabilize. The average release rates used in Table 4 obscure this variability, although its magnitude can be assessed by the standard deviations presented with means in Table 4. The concentration of constituents in the leachate was calculated from the average release rate data presented by the Pebble Partnership using the formula:

Concentration (mg/L) = [Release (mg/kg/week) x Mass of Sample (kg)]/Leachate Recovered (L),

where the average release rate, the mass of the solid sample, and amount of leachate recovered are provided in the Pebble Partnership (2011) report. The results from Pebble include a number of parameters (Pebble Partnership, 2011): pH, conductivity, acidity, alkalinity, total dissolved solids, hardness, F, Cl, SO_4, Al, Sb, As, Ba, Be, Bi, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, K, Se, SiO_2, Ag, Na, Tl, Sn, V, and Zn. The present discussion focuses on pH, sulfate, Cu, Mo, As, and Zn. The pH of a solution is a master variable that controls the solubility of most elements. Sulfate is a proxy for pyrite oxidation, which produces the acid in acid-mine drainage. Copper is a cationic species, and the most likely inorganic ecologic stressor expected at the site, especially for aquatic organisms. Zinc commonly occurs in base-metal hydrothermal systems, but typically not in economic concentrations in porphyry copper deposits. Arsenic and molybdenum are oxyanion species, which behave differently from cations; arsenic is a potentially significant stressor, especially with respect to drinking water contamination, whereas molybdenum is an important ore constituent with less potential to be an environmental stressor.

The Pre-Tertiary rocks show a range of responses in the humidity-cell tests as reflected by the significant standard deviations associated with their mean leachate concentrations (Table 4). The leachates from the Pre-Tertiary rocks are characterized by neutral to acidic pH values. As expected from the role of pyrite oxidation in acid generation, the samples that generated the lowest pH values had the higher sulfate concentrations and lower alkalinity values. For example, the mean pH for humidity-cell leachates for Pebble East was 4.8 ± 1.9 compared to 6.6 ± 1.7 for Pebble West, presumably reflecting the higher grade and pyrite content of Pebble East. The pH of the samples correlated negatively with the alkalinity of the leachates. Copper concentrations generally correlate with sulfate concentrations and low pH, as would be expected from the higher solubility of metals with acidic pH conditions. The mean concentrations of copper in humidity-cell leachates from both Pebble West and Pebble East were high compared to other metals and exceeded 1 mg/L. The mean zinc concentration reached 0.5 mg/L. In contrast, the highest mean molybdenum concentration was less than 0.005 mg/L and the highest mean arsenic concentration was 0.008 mg/L. The high standard deviations associated with all parameters in the leachate chemistry from Pre-Tertiary waste-rock types underscore the challenges associated with predicting waste-rock seepage chemistry with a high level of confidence. At an operating mine, the drainage from waste-rock piles will be a mixture of direct leachates from the waste rock and local ambient surface water and precipitation. The relative proportion of these sources will depend upon local climatic conditions, the natural topography, alterations to the natural topography made during mine construction, and engineering controls put in place during mine construction to manage surface water. The range of potential compositions of seepage is shown in Figure 7, which shows average dissolved copper and hardness values for various waters. The leachate values associated with the Pebble East Zone humidity-cell tests (PEZ HCT), the Pebble West Zone humidity-cell tests (PWZ HCT), the Pebble West Zone Barrel test (PWZ Barrel), and the Tertiary Waster Rock humidity-cell tests are all averages of mean release rates from individual experiments. The mean values for the North Fork of the Koktuli River are merely meant to

Table 4. Summary of geochemical results from mean humidity-cell tests on waste-rock samples conducted by the Pebble Partnership (2011).

Parameter	Units	Tertiary Waste Rock		Pebble West Pre-Tertiary Waste Rock		Pebble East Pre-Tertiary Waste Rock	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Pebble Partnership (2011) Source		Table 11-31 (calc); Appendix 11C (pH)	Table 11-31 (calc); Appendix 11C (pH)	Table 11-21 (calc); Appendix 11C (pH)	Table 11-21 (calc); Appendix 11C (pH)	Table 11-21 (calc); Appendix 11C (pH)	Table 11-21 (calc); Appendix 11C (pH)
pH	S.U.	7.2	1.3	6.6	1.7	4.8	1.9
Alkalinity	mg/L $CaCO_3$	65.9	51.0	18.5	16.4	9.9	14.1
Hardness	mg/L $CaCO_3$	74.0	88.1	59.2	51.9	21.9	23.1
Cl	mg/L	0.53	0.11	0.52	0.01	0.91	0.91
F	mg/L	0.06	0.09	0.12	0.12	0.11	0.16
SO_4	mg/L	28.0	83.8	60.8	68.4	51.9	52.0
Ag	mg/L	0.000011	0.000003	0.000027	0.000044	0.000019	0.000013
Al	mg/L	0.08	0.21	0.32	0.85	0.38	0.58
As	mg/L	0.0027	0.0042	0.0015	0.0018	0.0080	0.0189
B	mg/L	0.0177	0.0122	0.0159	0.0085	0.0125	0.0052
Ba	mg/L	0.0572	0.0824	0.0136	0.0087	0.0045	0.0056
Be	mg/L	0.0003	0.0005	0.0003	0.0003	0.0006	0.0006
Bi	mg/L	0.0005	0.0002	0.0007	0.0004	0.0006	0.0003
Ca	mg/L	21.3	31.6	12.7	8.9	6.3	5.3
Cd	mg/L	0.0002	0.0006	0.0004	0.0007	0.0032	0.0083
Co	mg/L	0.0039	0.0157	0.0070	0.0146	0.0097	0.0120
Cr	mg/L	0.0006	0.0002	0.0007	0.0004	0.0016	0.0023
Cu	mg/L	0.0032	0.0061	1.5989	3.2469	1.4162	2.1609
Fe	mg/L	0.140	0.484	1.671	6.042	10.195	16.051
Hg	mg/L	0.000010	0.000001	0.000011	0.000002	0.000010	0.000001
K	mg/L	1.85	2.24	1.41	0.72	0.96	0.69
Mg	mg/L	5.06	7.49	6.69	8.68	1.50	3.40
Mn	mg/L	0.1015	0.3990	0.7289	1.5653	0.3386	1.0745
Mo	mg/L	0.0063	0.0138	0.0018	0.0018	0.0043	0.0070
Na	mg/L	7.21	12.46	2.05	0.03	2.07	0.06
Ni	mg/L	0.0044	0.0165	0.0068	0.0143	0.0105	0.0168
Pb	mg/L	0.0001	0.0002	0.0002	0.0003	0.0004	0.0004
Sb	mg/L	0.0021	0.0019	0.0031	0.0018	0.0008	0.0018
Se	mg/L	0.0019	0.0020	0.0038	0.0057	0.0032	0.0024
Sn	mg/L	0.0013	0.0015	0.0001	0.0001	0.0019	0.0022
Tl	mg/L	0.00007	0.00003	0.00041	0.00098	0.00009	0.00010
V	mg/L	0.0018	0.0022	0.0007	0.0004	0.0024	0.0056
Zn	mg/L	0.0159	0.0500	0.0556	0.1080	0.4786	1.3618

represent generic, uncontaminated surface water in the vicinity of the Pebble deposit. The triangular field shown in Figure 7 defined by the composition of the North Fork of the Koktuli River, the average humidity-cell results from samples of the Pebble East Zone, and the barrel test results from the Pebble West Zone represent the likely range of potential surface-water compositions downstream of Pre-Tertiary (i.e., mineralized) waste-rock piles in the vicinity of the Pebble deposit (mine). Likewise, the dashed line connecting the average composition of the North Fork of the Koktuli River and the average humidity-cell results for Tertiary waste rock represents the likely range of potential surface-water compositions downstream of Tertiary (i.e., unmineralized) waste-rock piles in the vicinity of the Pebble deposit (mine). The location of the hypothetical compositions either within the triangular field for those waters associated with the Pre-Tertiary waste-rock piles or along the join associated with Tertiary waste-rock piles will depend on the water balance of the contributing drainages and will be influenced by the mine plan.

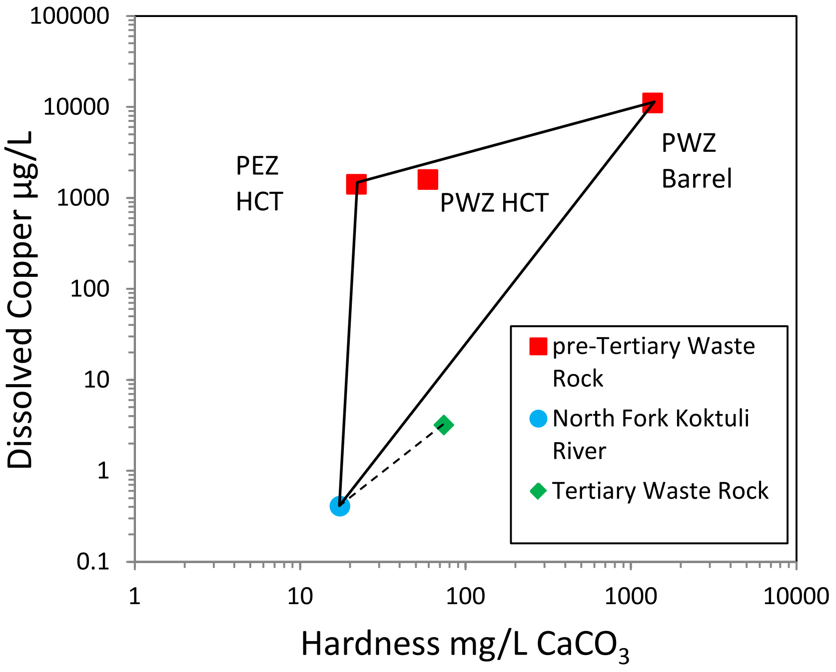

Figure 7. Dissolved copper concentrations and water hardness values for various potential end-member waters around the Pebble site in the Bristol Bay watershed associated with waste-rock piles. The humidity-cell test concentrations are from Table 4. The barrel-test results and the mean concentration for the North Fork of the Koktuli River are from Pebble Partnership (2011). The triangle represents the range of potential compositions that could be expected for seepage from Pebble West and Pebble East waste rock piles and the dashed line represents the range of potential compositions that could be expected from piles of Tertiary waste rock (see text). Abbreviations: PWZ, Pebble West Zone; PEZ, Pebble East Zone; HCT, Humidity-Cell Test.

The average humidity-cell test results for the Tertiary volcanic rocks yielded more coherent results than did the Pre-Tertiary rocks discussed above. Invariably, the humidity-cell test results show no ability to generate acid with all pH values ranging between 7 and 9 with a mean pH 7.2 ± 1.3. Sulfate concentrations generally range between 1 and 100 mg/L with a mean concentration of 28.0 mg/L, but the lack of correlation with pH suggests that the resulting sulfate may be derived from benign sulfate minerals rather than acid-generating iron sulfide minerals. Copper concentrations were low and generally correlated with sulfate concentrations.

Tailings

Mill tailings are the waste products from froth flotation, a process used to produce concentrates of economic minerals. The specific minerals separated greatly influence the character of the waste material. For porphyry copper deposits, it is typical to separate the copper-sulfide minerals [chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4)] as a copper concentrate, and the molybdenum-sulfide mineral, molybdenite (MoS_2) as a molybdenum concentrate (Fuerstenau and others, 2007). Gold commonly is associated with the copper sulfide minerals or pyrite. The gold associated with the copper concentrate will be recovered during smelting, typically conducted off-site. Gold associated with pyrite will require additional processing commonly on-site, as described above, to recover the gold. Thus, pyrite, the main source of acid-mine drainage, can be disposed with the tailings or it can be separated as a concentrate to either recover gold or to more effectively manage acid-generation risks. Therefore, the acid-generating potential and mobility of trace metals will be affected by whether or not pyrite is separated from tailings prior to disposal.

A greater number of environmental concerns are associated with tailings due to their finer grain size compared to waste rock. Like waste rock, tailings can weather and the associated leachate can contaminate surface water and groundwater (Stollenwerk, 1994; Brown and others, 1998; Khorasanipour and others, 2011). Furthermore, because of the sand to silt size grains, tailings are prone to be transported by waters, especially in the case of tailings dam failure, and wind. Thus, they present additional potential risks to aquatic organisms through sediment contamination.

A compilation of geochemical analyses of “pristine”, unoxidized tailings from porphyry copper deposits is presented in Table 5. These data include analyses of tailings from the Aitik mine, Sweden (R. Seal, unpublished data), the El Teniente mine, Chile (Smuda and others, 2008; Dold and Fontboté, 2001), the Andina mine, Chile (Dold and Fontboté, 2001), the El Salvador mine, Chile (Dold and Fontboté, 2001), and the Sarcheshmeh mine, Iran (Khorasanipour and others, 2011). It is important to note that none of these tailings had a pyrite concentrate removed.

A summary of the geochemistry of tailings derived from metallurgical testing of drill core from the Pebble deposit is summarized in Table 6 from the PLP Environmental Baseline Document (Pebble Partnership, 2011). That report presents data from three sample sets, 2004, 2005, and 2008, which were used in the humidity-cell tests described below. The 2004 and 2005 samples were from Pebble West. The 2008 samples were from Pebble West and Pebble East. The analyses for all sets included acid-base accounting analyses. The analyses for the 2004 and 2005 samples focused on a more restricted group of analytes, limited mostly to elements for which regulatory guidance exists (Ag, As, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, Tl, and Zn). The analyses for the 2008 samples included a larger group of analytes (Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn, and Zr. The table includes average values, the standard deviation for the average, and the low and high values. For the entire dataset, paste pH values are near neutral, ranging from 6.6 to 8.9. The NP/AP ratio ranges from 0.1 to 9.0, corresponding to probably acidic drainage generating values (PAG) to not probably acidic drainage generating (non-PAG), with the average being 2.7 (non-PAG). None of the tailing samples presented in Table 5 had pyrite separated; all of their NNP values are negative, indicating a net acidic character, unlike the Pebble tailings, which had pyrite removed. Otherwise, the overall chemistry of the tailing samples in Tables 5 and 6 compares favorably in terms of the range of values. It is worth noting that the 2005 LT C2 Combined Pre-Cleaner Tailings sample (Table 11-46 of the Pebble Project Environmental Baseline Document) has a copper concentration (2,050 mg/kg) that is 68 percent of the 0.3 percent cut-off grade, a molybdenum concentration (188 mg/kg) that 80 percent of the published resource molybdenum grade, and one of the lowest NNP values (-30 $kgCaCO_3/t$). Further metallurgical testing presumably will seek to improve copper and molybdenum recovery, which also will improve the separation of sulfide minerals and increase NNP of the resulting tailings.

Table 5. Geochemical composition of porphyry copper tailing samples from the literature and unpublished USGS studies.

Mine	Unit	Aitik	El Teniente	El Teniente	Cauquenes-Teniente	Piquenes-Andina	El Salvador	Sarcheshmeh
Country		Sweden	Chile	Chile	Chile	Chile	Chile	Iran
Sample No.		Aitik 1	Channel average	Sediment average	T1 average	A2 average	E2 average	S6/S7 average
Source		1	2	2	3	3	3	4
Al_2O_3	%	15.65						
CaO	%	3.425						
Fe_2O_3	%	10.3						
K_2O	%	4.775						
MgO	%	2.185						
MnO	%	0.32						
Na_2O	%	2.36						
P_2O_5	%	0.64						
SiO_2	%	54.4						
TiO_2	%	0.74						
As	mg/kg	3.50	33.0	36.0	92.9	62.0	136.3	18.5
Ba	mg/kg	930.5	382	384	470.3	721.3	418.3	
Be	mg/kg	1.55						
Bi	mg/kg	1.505						
Cd	mg/kg	<0.01						
Co	mg/kg	61.45						27.6
Cr	mg/kg	20	67	64	29.4	14.4	8.5	53
Cu	mg/kg	478	1035	921	3037	2515.2	5091.2	1205
Mn	mg/kg	2165	358	376	334.5	592.3	67.3	700.5
Mo	mg/kg	11.75	89	101	108.5	53	234.6	96.7
Ni	mg/kg	14.15	23	23				40
Pb	mg/kg	9.85			20	36.9	22.5	46.0
Sb	mg/kg	2.77						
U	mg/kg	4.45						
V	mg/kg	155.5	243	230	208.9	125.5	139.9	
Zn	mg/kg	74	62	58	92.94	208.98	42.9	210
S	%	2.64	3.62	3.43				
Carbonate C	%	0.01						
Total C	%	0.01						
LOI	%	3.55						
NNP	kg $CaCO_3$/t	-74.3			-18.2	-28.3	-101.6	

Sources: 1. This study; 2. Smuda and others (2008); 3. Dold and Fonboté (2001); 4. Khorasanipour and others (2011)

Additional insights into aquatic concerns associated with tailings can be found in case studies from mines. The geochemical characteristics of tailings seepage have been investigated by several studies. Smuda and others (2008) investigated the geochemical environment associated with tailings at the El Teniente porphyry copper deposit, Chile. They found a range of values for various water-quality parameters associated with the tailings pond. These parameters included pH (7.2-10.2), sulfate (1556-5574 mg/L), Fe (1.44-8.59 mg/L), Al (below detection - 0.886 mg/L), Mn (0.001-20.1 mg/L), Ni (0.008-0.393 mg/L), Cu (0.003-0.250 mg/L), Zn (0.007-130 mg/L), Mo (0.033-13.2 mg/L), and As (below detection–0.345 mg/L). Khorasanipour and others (2011) studied the geochemical environment associated with tailings at the Sarcheshmeh mine, Iran. They too found a range of values for water-quality parameters such as pH (3.6-7.9),sulfate (1348-4479 mg/L), Fe (<0.01-19.3 mg/L), Al (<0.5-154 mg/L), Mn (5.6-73.7 mg/L), Ni (0.088-1.74 mg/L), Cu (< 0.002-149.9 mg/L), Zn (0.094-20.3 mg/L), Mo (0.027-2.9 mg/L), and As (< 0.005-0.04 mg/L).

Table 6. Geochemical composition of test tailings samples from the Pebble deposit from the Pebble Project Environmental Baseline Document. Summary statistics include all samples presented in Tables 11-46 and 11-47 in Pebble Partnership (2011).

Parameter	Units	Average	Standard Deviation	Low	High
Ag	mg/kg	0.7	0.5	0.23	2.17
As	mg/kg	25.2	31.6	4.2	169
Ba	mg/kg	30.0	10.6	20	50
Be	mg/kg	0.3	0.1	0.18	0.64
Bi	mg/kg	0.6	0.5	0.2	1.98
Cd	mg/kg	0.1	0.1	0.03	0.4
Co	mg/kg	8.1	10.2	2.2	45.9
Cr	mg/kg	149.9	177.3	6	748
Cu	mg/kg	682.9	414.0	142	2050
Hg	mg/kg	0.1	0.1	< 0.01	0.56
Mn	mg/kg	359.9	201.4	84	880
Mo	mg/kg	51.9	35.1	10.5	188
Ni	mg/kg	67.7	111.6	6.3	452
Pb	mg/kg	15.0	16.6	3.3	88.4
Sb	mg/kg	1.0	1.0	0.2	5.41
Se	mg/kg	1.8	2.0	0.4	8.8
Tl	mg/kg	0.3	0.2	0.07	1.2
U	mg/kg	0.4	0.2	0.17	0.87
V	mg/kg	87.3	36.0	36	149
Zn	mg/kg	87.4	66.3	29	267
Paste pH	Standard Unit	8.2	0.4	6.6	8.9
Total S	%	0.5	0.9	0.09	4.19
Sulfate	%	0.0	0.0	-0.01	0.2
Sulfide	%	0.5	0.9	0.05	4.12
AP	kg $CaCO_3$/t	14.2	27.8	1.56	128.8
TIC	%	0.3	0.2	0.05	0.75
TIC	kg $CaCO_3$/t	22.6	15.5	4.5	62.5
NP (Modified)	kg $CaCO_3$/t	13.5	6.9	4.6	25.9
NP/AP	ratio	2.7	1.9	0.1	9
NNP	kg $CaCO_3$/t	-0.5	27.2	-110.2	22.4

Morin and Hutt (2001) compared predictions for tailing leachate chemistry with actual drainage chemistry at the Bell mine in British Columbia on the basis of samples collected seven years after closure. The predictions indicated that drainage from the tailing piles would start at near neutral pH conditions, but would turn acidic over the course of several decades. Their post-closure sampling results indicated that acid generation is roughly 100 times less than predicted. The authors attributed this discrepancy to basing prediction on an insufficient number of humidity-cell tests and incorrect assumptions about the rate of sulfide oxidation. Weibel and others (2011) found similar results in studies of a porphyry copper mine in Chile.

As with the waste rock at Pebble, the best insights into the potential behavior of mill tailings come from the humidity-cell tests being conducted by the Pebble Limited Partnership and its contractors (Pebble Partnership, 2011). The Pebble Partnership initiated two sets of humidity-cell tests on tailings derived from preliminary metallurgical testing: one set in 2005 and one set in 2008 (Pebble Partnership, 2011). Humidity-cell tests represent one of the best predictors of long-term weathering of tailings in an aerobic environment (Price, 2009). The test conditions are most representative of unsaturated tailings exposed at the surface of a pile. The geochemical environment found at depth in the saturated zone is typically quite different (Blowes and others, 2003). The 2005 tailings samples originated from a relatively simple set of metallurgical methods, whereas the 2008 samples originated from a greater variety of metallurgical processing methods. The humidity-cell tests for the tailings samples were conducted using standard procedures, as described above for the waste-rock samples (Price, 2009). However, the grain size of the tailings is well below the 6 mm maximum size of waste-rock samples, which means that the tailings should be more reactive than the waste-rock samples in humidity-cell tests. The results included the same set of parameters as with the waste-rock testing. As for the waste-rock samples, the following discussion focuses on pH, sulfate, copper, zinc, molybdenum, and arsenic.

The mean humidity-cell results were similar for both the 2005 and 2008 sets of tailings (Pebble Partnership, 2011). Both sets had pH values ranging between 7 and 8.5 in experiments lasting up to five years for the 2005 samples and for more than one year for the 2008 samples (Table 7). As with the waste-rock samples, individual humidity-cell tests for tailings can show a range of leachate concentrations that vary over the course of the experiment. In general, the concentrations of dissolved constituents are most erratic and highest in the initial flush covering the first few one-week cycles in humidity-cell tests; several weeks after the start of the experiments, the concentrations of dissolved constituents tends to stabilize. The average release rates used in Table 7 obscure this variability, although its magnitude can be assessed by the standard deviations present with means in Table 7. Sulfate concentrations for both sets (2005 and 2008) generally are below 40 mg/L after the initial flush of soluble sulfate salts. The mean sulfate release concentration was 17.4 ± 8.0 mg/L. The mean copper (5.3 ± 2.2 µg/L), and zinc (3.2 ± 1.7 µg/L) concentrations were less than those from the waste-rock samples, whereas the molybdenum (33.5 ± 23.7 µg/L), and arsenic (5.5 ± 8.4 µg/L) concentrations were higher (Table 4).

The chemical composition of the pond on top of the tailing impoundment is difficult to estimate, but bounds can be placed on its composition. During mine operation, the water should represent a mixture of the supernatant solution from the mill that is pumped with the tailings slurry to the impoundment, solutes derived from aerobic leaching of the tailings material, which can be limited by the average humidity-cell results from tailings, and ambient surface water and precipitation, which can be approximated generically by the mean composition of the North Fork of the Koktuli River. The range of potential compositions is shown in Figure 8 by the triangle, which limits the range from these three sources in terms of dissolved copper concentration and water hardness. The supernatant solution has the highest copper concentration and water hardness of the three end members. The variability of its composition in the samples from metallurgical testing is reflect by the standard deviations shown in Table 7. The location of the hypothetical compositions either within the triangular field for those waters associated with the Pre-Tertiary waste-rock piles will depend on the water balance of water-management practices during and after mining.

Table 7. Summary of geochemical results from mean humidity-cell tests on tailing samples and the supernatant solution from metallurgical testing conducted by the Pebble Partnership (2011)

Parameter	Units	Tailings Humidity Cell		Supernatant	
		Average	Standard Deviation	Average	Standard Deviation
Pebble Partnership (2011) Source		Table 11-49 (calc); Appendix 11L (pH)	Table 11-49 (calc); Appendix 11L (pH)	Table 11-48	Table 11-48
pH	S.U.	7.8	0.2	7.9	0.3
Alkalinity	mg/L $CaCO_3$	59.7	15.5	74.8	20.4
Hardness	mg/L $CaCO_3$	66.8	13.6	322.8	254.8
Cl	mg/L	0.52	0.08	nr	nr
F	mg/L	0.451	0.440	nr	nr
SO_4	mg/L	17.4	8.0	318.7	372.1
Thiosalts (S_2O_3)	mg/L	nr	nr	44.1	156.1
Ag	mg/L	0.00001	0.00000	0.00002	0.00025
Al	mg/L	0.02	0.03	0.07	0.08
As	mg/L	0.0055	0.0084	0.0172	0.0212
B	mg/L	0.0107	0.0010	nr	nr
Ba	mg/L	0.0092	0.0050	nr	nr
Be	mg/L	0.0002	0.0000	nr	nr
Bi	mg/L	0.0005	0.0000	nr	nr
Ca	mg/L	22.6	3.9	116.0	101.2
Cd	mg/L	0.00001	0.00000	-0.00008	0.00018
Co	mg/L	0.0002	0.0002	-0.0001	0.0004
Cr	mg/L	0.0005	0.0000	-0.0010	0.0012
Cu	mg/L	0.0053	0.0022	0.0078	0.0049
Fe	mg/L	0.03	0.00	0.02	0.32
Hg	mg/L	0.000010	0.000000	-0.000037	0.000103
K	mg/L	4.02	1.69	25.95	8.16
Mg	mg/L	2.55	2.07	8.00	5.53
Mn	mg/L	0.0441	0.0224	0.0719	0.0631
Mo	mg/L	0.0335	0.0237	0.0697	0.0560
Na	mg/L	2.10	0.26	43.78	132.40
Ni	mg/L	0.0005	0.0001	-0.0008	0.0018
Pb	mg/L	0.00006	0.00001	0.00023	0.00062
Sb	mg/L	0.0018	0.0017	0.0060	0.0058
Se	mg/L	0.0015	0.0006	0.0076	0.0062
Sn	mg/L	0.0029	0.0040	nr	nr
Tl	mg/L	0.00005	0.00000	0.00002	0.00022
V	mg/L	0.0008	0.0008	nr	nr
Zn	mg/L	0.0032	0.0017	0.0043	0.0080

nr: not reported

The composition of water potentially seeping from the base of tailing piles is more problematic to estimate. At depth in the saturated zone in tailing piles, dissolved oxygen is rapidly removed by reaction with trace amounts of sulfide minerals, which limits the ability to generate acid during further interaction with tailings material. In these acid-limited environments, silicate minerals such as feldspars and trace amounts of carbonate minerals can effectively neutralize acid and restrict the ability of groundwater to dissolve additional metals and other trace elements (Blowes and others, 2003). Under these conditions, the chemical composition of seepage from a tailings pile should fall along the join between the average humidity-cell test composition and ambient surface water and groundwater (Figure 8).

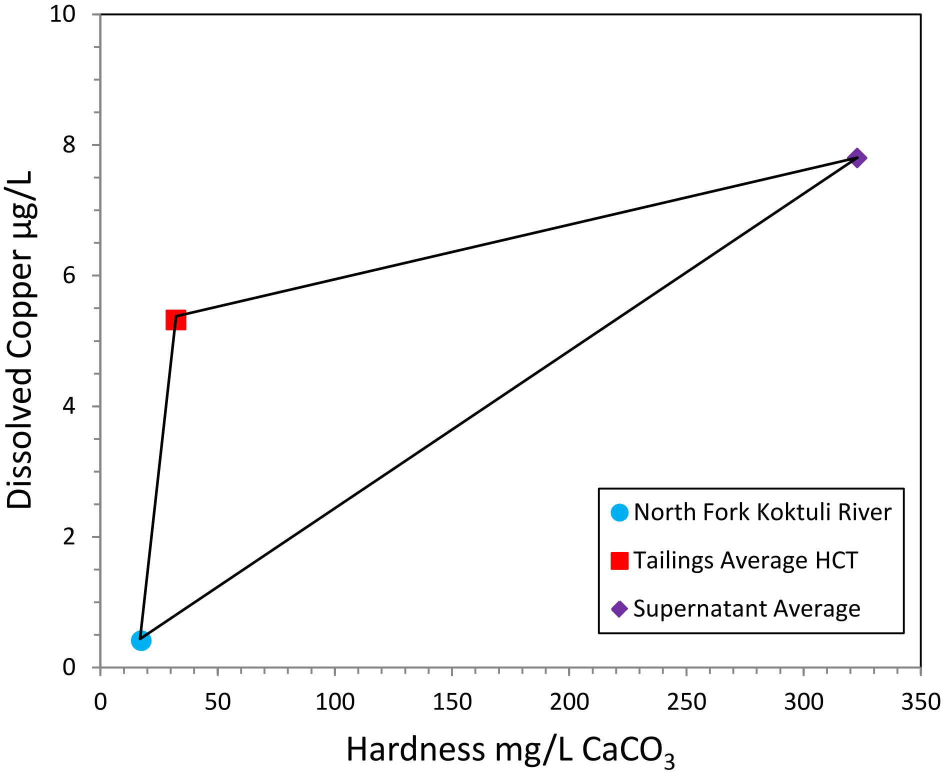

Figure 8. Dissolved copper concentrations and water hardness values for various potential end-member waters around the Pebble site in the Bristol Bay watershed associated with a tailings impoundment. The humidity-cell test concentrations are from Table 7. The mean concentrations for the North Fork of the Koktuli River are from Pebble Partnership (2011). The triangle represents the range of potential compositions that could be expected for a tailing pond during mine operation; after closure, once ore processing has ceased, the join between the North Fork and the Tailings Average HCT compositions may be more representative of the range of potential compositions (see text). Abbreviations: HCT, Humidity-Cell Test.

Copper Concentrate

Limited data are available on the geochemistry of copper concentrates from porphyry copper deposits. The geochemical analysis by USGS laboratories of a single sample of a copper concentrate from the Aitik porphyry copper deposit is presented in Table 8. X-ray diffraction analysis indicates that the sample is dominated by chalcopyrite with trace amounts of pyrite, quartz, and possibly molybdenite. The ideal composition of chalcopyrite is 34.6 weight percent Cu, 30.4 weight percent Fe, and 34.9 weight percent S. For the analysis presented in Table 8, the Cu concentration is above the upper detection limit. However, the analyzed concentration of S (33.4 wt. %) indicates that the sample is greater than 95 percent chalcopyrite, whereas that of Fe (25.8 wt. %) indicates approximately 85 percent chalcopyrite. The most notable trace elements in this concentrate are Zn (2190 mg/kg), presumably reflecting the presence of minor sphalerite, Mo (1100 mg/kg), presumably reflecting the presence of molybdenite, and Mn (346 mg/kg), likely hosted by sphalerite or traces of the Fe-carbonate mineral siderite.

Table 8. Geochemical analysis of the copper concentrate (Aitik 2) from the Aitik porphyry copper mine, Sweden

Element	Units	Concentration
Al	%	0.98
Ca	%	0.32
Fe	%	25.8
K	%	0.49
Mg	%	0.11
Na	%	0.19
Ti	%	0.05
Ag	mg/kg	>10
As	mg/kg	12
Ba	mg/kg	59
Bi	mg/kg	44.9
Cd	mg/kg	2.4
Co	mg/kg	53.9
Cu	mg/kg	>10000
Ga	mg/kg	0.88
In	mg/kg	2.35
Mn	mg/kg	345
Mo	mg/kg	1100
Ni	mg/kg	72.1
Pb	mg/kg	64.9
Sb	mg/kg	43.4
Te	mg/kg	4.1
Th	mg/kg	1.5
Tl	mg/kg	0.2
U	mg/kg	2.2
V	mg/kg	23
Zn	mg/kg	2190
S	%	33.4

The solution chemistry associated with the transport of concentrate as a slurry in a pipeline can be assessed by conducting leaching experiments on the Aitik copper concentrate sample described above, which is mineralogically similar to copper concentrates from most porphyry copper mines. In flotation circuits, chalcopyrite is not especially sensitive to pH, but pH may be adjusted to alkaline values to separate molybdenite or pyrite (Fuerstenau and others, 2007).

The leachability of elements from copper concentrate was evaluated using the *Synthetic Precipitation Leaching Procedure* (USEPA Method 1312), and a modification of this protocol. The standard procedure reacts a sample in a 20:1 (solution: sample) ratio with a weak acidic solution (pH 5), made of a mixture of sulfuric and nitric acids, under continuous agitation for 18 hours, after which the solution is sampled. Additional leaching experiments were conducted in which the copper concentrate sample was leached following the same procedure except that the starting leaching solution was either distilled water + NaOH solutions (pH 6, 7, 8, 9), or distilled water + Na_2CO_3 solutions (pH 7, 9) adjusted to various starting pH values. The purpose of these experiments was to evaluate the range of starting pH values that may be associated with a copper-concentrate slurry discharged from a mill to a pipeline.

The results of the leaching experiments on the copper concentrate are presented in Table 9. Results from a copper tailings sample from Aitik are also presented in Table 9. One of the most striking features of these experiments using the copper concentrate is that regardless of the starting pH (pH = 5 to 9), the final pH after 18 hours for all experiments ended up between 4.1 and 4.2. Equally striking was the fact that dissolved copper concentrations in the leachate ranged between 15,300 and 16,800 µg/L, dissolved iron concentrations ranged between 5,480 and 10,200 µg/L, and dissolved sulfate ranged between 183.7 and 208.8 mg/L.

Summary

The Pebble deposit in the Bristol Bay watershed, southwestern Alaska, shares many geologic attributes with typical porphyry copper deposits throughout the world. These features include: (1) its spatial association with coeval granitic intrusions; (2) its large tonnage of ore and its low grade, although the size of Pebble places it in the upper 5 percent of porphyry copper deposits globally; (3) the association of copper, molybdenum, and gold; (4) the style of mineralization as veinlets, stockworks, and disseminations with igneous and sedimentary host rocks; and (5) its zoned ore-mineral and alteration assemblages. From an environmental perspective, the acid-generating potential of Pebble is similar to that found at other porphyry copper deposits: waste rock and tailings span the range from potentially acidic drainage generating to non-potentially acidic drainage generating due to the low contents of pyrite and other sulfide minerals as potential sources of acid, and the presence of silicate minerals such as feldspars and trace amounts of carbonate minerals to neutralize acid. Humidity-cell tests by Pebble Partnership (2011) indicate that drainage associated with Pre-Tertiary waste rocks is likely to have higher concentrations of solutes and lower pH than drainage associated with mine tailings. Solutions associated with a copper concentrate slurry are likely to be weakly acidic and have high concentrations of dissolved copper and zinc.

Table 9. Geochemical analyses of dissolved constituents (< 0.45 µm) in leachates from tailings and copper concentrate from the Aitik Mine, Sweden, using USEPA Method 1312 and a modified leaching method.

Field No.	Units	Tailings	Copper Concentrate						
Base (Acid)		WSP*	WSP*	NaOH	NaOH	NaOH	NaOH	Na_2CO_3	Na_2CO_3
Starting pH	S.U.	5	5	6	7	8	9	7	9
Final pH	S.U.	7.3	4.2	4.2	4.2	4.2	4.1	4.2	4.2
Spec. Cond.	µS/cm	133	349	362	350	345	372	340	340
DO	mg/L	10							
T	°C	22.6							
Alkalinity	mg/L $CaCO_3$	9.3	0	0	0	0	0	0	0
Ag	µg/L	<1	<10	<10	<10	<10	<10	<10	<10
Al	µg/L	158	1,910	1,820	1,790	1,770	1,850	1,950	1,870
As	µg/L	<1	<10	<10	<10	<10	<10	<10	<10
Ba	µg/L	50.5	38.6	39.2	40	40.7	38.5	37.9	36.2
Ca	mg/L	16	30	28.9	29	28.5	28.7	28.2	28.3
Cd	µg/L	<0.02	6.3	6	5.9	5.9	6	6.3	6
Co	µg/L	0.43	157	151	152	151	151	154	152
Cr	µg/L	<1	<1	<1	<1	<1	<1	<1	<1
Cu	µg/L	0.8	16,500	16,300	15,400	15,300	16,800	16,300	15,600
Fe	µg/L	<50	7,940	9,190	7,440	7,070	10,200	5,560	5,480
K	mg/L	2.15	3.4	3.7	3.4	3.4	3.8	3	3.1
Mg	mg/L	0.38	5.5	5.2	5.3	5.3	5.2	5.5	5.4
Mn	µg/L	20	931	887	891	880	883	918	899
Mo	ug/L	< 2	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Na	mg/L	4.67	0.41	0.52	0.84	0.89	1	0.87	1.5
Ni	µg/L	<0.4	634	607	613	609	607	620	612
Pb	µg/L	<0.05	6.16	6.93	6.15	6.08	7.92	5.36	5.55
Sb	µg/L	0.47	17.4	13.4	16.6	16.2	14.7	16.8	16.6
Se	µg/L	< 1	<10	<10	<10	<10	<10	<10	<10
SiO_2	mg/L	1.8	<2	<2	<2	<2	<2	<2	<2
U	µg/L	< 0.1	33.7	33.8	31.2	31.9	34	34.8	33
Zn	µg/L	0.6	2,040	1,920	1,950	1,940	1,940	2,040	1,980
Cl	mg/L	0.8	2.6	2.6	2.8	2.6	2.6	2.6	2.5
F	mg/L	0.2	1.4	1.5	1.5	1.5	1.5	1.6	1.5
NO_3	mg/L	0.7	0.4	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
SO_4	mg/L	43.6	192.6	200.8	191.4	185.1	208.8	183.7	184.5

*WSP: Mixture of H_2SO_4 and HNO_3 with pH = 5.0 in accordance with EPA Method 1312.

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AN ASSESSMENT OF POTENTIAL MINING IMPACTS ON SALMON ECOSYSTEMS OF BRISTOL BAY, ALASKA

VOLUME 3—APPENDICES E-J

Appendix I: Conventional Water Quality Mitigation Practices for Mine Design, Construction, Operation, and Closure

Appendix I

Conventional Water Quality Mitigation Practices for Mine Design, Construction, Operation, and Closure

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Mitigation includes the steps needed to avoid, minimize, or compensate for any potential adverse impacts on the environment from a given activity (Hough and Robertson, 2009). Hardrock metal mining is an activity that provides metals for numerous purposes, but it has the potential to have adverse effects on nearby aquatic environments. Many mitigation measures developed to avoid or minimize impacts to water quality and aquatic ecosystems have become current industry practice and several of these are presented in this document for selected waste streams associated with mining, along with discussions of accidents and failures associated with storage of waste rock and tailings. Compensatory mitigation, which may be required under Section 404 of the Clean Water Act (CWA) when there are unavoidable impacts anticipated to lead to the loss of wetland, stream, or other aquatic resource, is not included in this Appendix.

The most important aspects of mitigation for any mining site are proper planning, design, construction, operation, management, and closure of waste and water containment and treatment facilities, and monitoring and maintenance over all mine-life phases, including following closure. A failure in any aspect of mitigation may result in environmental and/or human health impacts. Planning for design and construction must consider site-specific factors such as climate, topography, hydrology, geology, seismicity, and waste material specific factors such as geochemistry, mineralogy, particle size, and presence of process chemicals. These factors should be based upon accurate characterization and conservative estimates of future conditions to minimize potential for failure over time. In addition, the planning and design should incorporate considerations for the land's use following closure of mining operations.

1. WASTE ROCK

Overburden is unconsolidated surface material that would be removed to expose the ore/waste rock zone and often comprises alluvium, colluvium, glacial tills, or other soils; overburden may be stockpiled separately for later use in reclamation. Waste rock includes rock that is removed above the ore and rock that is removed along with the ore, but cannot be mined economically at the time of mining (sub-economic ore). The particle size distribution of waste rock may vary from sand-sized fines to large boulders, with the quantity in a given particle size class dependent upon the site geology and the specifics of the method(s) in which it was extracted (e.g., blasting strength). The sources of potential environmental influence to surface water from waste rock piles include sediment loading due to erosion and deposition of fugitive dusts, and contaminant loading due to leaching of acidity and inorganic contaminants, such as metals and metalloids, contained in the waste rock. Precipitation and surface water run-on can lead to weathering and erosion of materials into runoff (dissolved and particulate) transported to surface water. Percolation and infiltration that lead to leaching and transport of ions through seepage of the leachate to groundwater may occur also, as may seepage through sloped pervious material to a surface water body. Additional routes of environmental exposure include movement of material mass (e.g., through rockslides due to physical instability) into a water body and wind erosion carrying finer particles (dust) through the air.

Waste rock, and other mining materials may be classified as potentially acid-generating (PAG) or non-acid generating (NAG, also called non-PAG); this distinction is determined through geochemical characterization, acid-base accounting (ABA) static tests, and kinetic leachate testing [e.g., see (American Society for Testing and Materials (ASTM) 2000, Hornberger and Brady 1998, Lapakko 2002)]. ABA tests are rapid methods to determine the acid-generation potential (AP) and neutralization potential (NP) of a rock or mining waste material, independent of reaction rates (i.e., in contrast to kinetic tests). These potentials are then compared to one another by either their differences (net neutralization potential, NNP) or their ratios (neutralization potential ratio, NPR).

Although methods used for ABA have limitations, it is common industry practice to consider materials that have an NPR of 1 or less as potentially acid generating (PAG) (e.g., Brodie et al., 1991; Price, 2009; Price and Errington, 1998) and materials with a ratio greater than 3 (Brodie et al., 1991) or 4 (Price and Errington, 1998) as having no acid generation potential (non-PAG or NAG). Materials having ratios between 1 and 4 require further testing via kinetic tests and geochemical assessment for classification (Brodie et al., 1991; Price, 2009; Price and Errington, 1998). This further testing and assessment are necessary because if neutralizing minerals react before acid generating minerals, the neutralizing effect may not be realized and acid might be generated in the future. Additionally, some toxic elements (e.g., selenium and arsenic) may be released from mining materials under neutral or higher pH conditions, which would be observed during kinetic leaching tests conducted at variable pH values.

Waste rock is susceptible to acid generation and leaching of ions due to the open pore network allowing for easy advection of air (Mining Minerals and Sustainable Development (MMSD) 2002) to oxidize minerals, which subsequently are dissolved in water that encounters the rocks.

1.1 CONVENTIONAL PRACTICES

There are numerous mitigation measures available for waste rock piles. The selection of mitigation measures are site-specific and depend on the sizes and amounts of the material to be placed in the pile, the methods employed during mining, the mineralogy of the material, the site’s specific hydrology, climate, seismicity, and topography, and plans for future land-use.

1.1.1 Operational Phase

Non-reactive (i.e., NAG) waste rock might be used in creation of mining roadways or transported off-site for use in roadways or another purpose requiring rockfill, with unused waste rock stored in piles. Waste rock piles generally are disposed in locations close to the mine site to reduce handling costs and are placed in locations that provide physical stability. Waste rock and overburden piles typically are not placed on lined foundations because of the cost and stability risk (Mining Minerals and Sustainable Development (MMSD) 2002), but rather are constructed on natural terrain; although the decision for lined or unlined piles is site-specific. Prior to placement of a waste rock pile, the topsoil is removed and stockpiled for later use in reclamation. The angle of repose (where the outer slope is just stable under static loading conditions) is typically 37-40° (Mining Minerals and Sustainable Development (MMSD) 2002), but will depend on site-specific and material-specific factors. Piles constructed in lifts or by using benches typically have lower slope angles and concurrent increased stability (U.S. Environmental Protection Agency (U.S.EPA) 1995b, Mining Minerals and Sustainable Development (MMSD) 2002).

When waste rock contains materials that have the potential to generate acid or release metals, metalloids, or other ions of concern that would have environmental or human health impacts, management of the materials must include practices to minimize potential for any environmental impacts. Mitigation/management measures used during the operational phase can include a variety of methods either used independently or in combination; these include diversion systems to route water away from the pile, use of liners underneath the waste rock pile, selective handling / segregation, blending and layering, minimization of infiltration potential, leachate collection systems and seepage drains and routing systems to divert leachate to treatment facilities, addition of bactericides to slow oxidation of PAG, encapsulation, and/or adding low permeability materials to slow infiltration rates (Boak and Beale 2008, Mining Minerals and Sustainable Development (MMSD) 2002, U.S. Environmental Protection Agency (U.S.EPA) 1995b, U.S. Environmental Protection Agency (Region 10) 2003a, U.S. Environmental Protection Agency (Region 10) 2003b, Perry et al. 1998). Additionally, the amount of waste rock exposed to the environment can be reduced by disposing the rock into depleted pits or underground mine tunnels, or through reclamation activities conducted concurrent with active mining (called progressive reclamation).

Selective handling involves placement of materials combined with management strategies to avoid or minimize release of acidic drainage. Physical separation of PAG and NAG materials will not prevent acid-rock drainage formation, but may be necessary to control the amount and location of potential drainage and to manage the PAG material. PAG material can be kept completely saturated to minimize air exposure (e.g., placed into the open pit post active mining), disposed in a separate lined or unlined engineered containment system, or blended with NAG material and stored in an aboveground pile, coupled with minimizing exposure to water.

Blending involves mixing waste rock types of varying acid-producing potential (AP) and neutralization potential (NP) to create a mixture that has acceptable quality (i.e., no net acid-generation potential). The viability of blending as a mitigation measure depends on the materials available and the mine plan, the stoichiometric balance between acid generating and neutralizing materials, geochemical properties, reactivity of waste rock types, flow pathways created within the waste rock pile, and extent of mixing and blending. If a site does not have sufficient neutralizing material with which to blend the PAG material, limestone or other neutralizing rock might be used, if available from another location on-site, or trucked into the site. The geochemical characteristics of the materials being blended and mixed must be well-characterized in order to attain a resultant mix that has no net acid production potential.

PAG materials may be kept isolated from direct exposure to precipitation and oxygen transfer by layering NAG materials on top of them in the waste pile. This would involve layering of PAG with a mix of PAG-NAG material, with a top layer of NAG only material, or another combination.

Encapsulation of a waste rock pile with an impermeable layer serves to limit infiltration and oxygen transfer. Progressive reclamation with multiple impermeable layers within a waste rock pile can minimize infiltration, seepage, and oxygen transfer. Compaction is used also, if it can be done safely (physically). Once a pile is covered, overburden or other non-reactive material can be placed on top and the site vegetated to provide stability against erosion and to meet regulatory requirements for restoration.

Some microorganisms are able to facilitate rapid oxidation of PAG sulfidic minerals; thus, a bactericide could be added to eliminate their presence and slow the oxidation rate. Such an amendment must be mixed thoroughly into the PAG material as the pile is constructed to ensure effectiveness.

Sub-economic ore removed during the active mining phase might be segregated from the primary waste rock pile to be mined if/when it becomes economically feasible. These piles may be mined with their resultant waste disposed into a tailings impoundment or placed directly in the completed pit, if mined at closure.

Building an under-drain system to collect seepage/leachate water potentially containing leached ions/acidity allows this water to be directed toward collection systems for either use in processing or treatment and discharge to a surface water body. Diversion structures collect and direct runoff and seepage to treatment and/or settling ponds. Groundwater monitoring wells are used downstream of these structures to evaluate their performance.

1.1.2 Closure and Post-Closure

During the closure phase of mining, a dry cover (or encapsulation) can be placed over the waste rock pile to isolate it from water and oxygen, or the pile can placed into the completed open pit to be kept below the water line (subaqueous disposal if PAG material), with choices dependent upon site specifics (O'Kane and Wels 2003). Additionally, in some settings, it is beneficial to fill the pit with waste rock and other waste material and then construct a dry cover over the filled pit area. When stored above ground, the stockpiled overburden may be used to cover the pile and then it is vegetated to provide stability against erosion. Blight and Fourie (Blight and Fourie 2003) recommend that outer slopes reclaimed with vegetation not exceed 15 degrees. Post-closure monitoring, maintenance, and inspection are conducted indefinitely when a pile requires long-term collection and treatment of leachate through use of the drainage collection and monitoring structures in place during the operational phase of mining. A number of different types of covers could be used, with each having their benefits and limitations. Factors affecting the long-term performance of covers include physical stability, volume change, vegetation, soil evolution, and ecological stability (Wilson, Williams and Rykaart 2003).

1.2 ACCIDENTS AND FAILURES

If waste rock piles are designed properly with appropriate mitigation measures, monitored and maintained, release of contaminants is possible, but unlikely; however, accidents and failures causing contaminants to be transported may still occur. Seven major factors affecting the physical stability of a waste rock pile against failure are: 1) configuration; 2) foundation conditions; 3) waste material properties; 4) method of construction; 5) dumping rate; 6) piezometric and climatic conditions; and 7) seismic and blasting activities ((Piteau Associates Engineering Ltd. 1991), as referenced in (U.S. Environmental Protection Agency (U.S.EPA) 1995b). An additional factor to consider is monitoring and maintenance for early detection of conditions that indicate inadequate stability. Although it depends on a number of site-specific factors, data indicate that most waste dump failures occur on foundations with slopes in excess of 20 degrees (U.S. Environmental Protection Agency (U.S.EPA) 1995b).

Physical failures of waste rock piles may occur through slope failures. These result from changes in the effective stresses of the rock material, variations in material properties (including particle size and gravity sorting), or changes in the rock pile's geometry (Pastor et al. 2002, Tesarik and McKibbin 1999). Changes in effective stress can result from earthquakes, human actions, changes in underlying soil properties, or through changing pore pressures resulting from rainfall, snowmelt, or changes in drainage conditions. Properties of the rock will change over time due to weathering and from the influence of acid dissolution, if any nearby PAG materials are oxidized and dissolved. Changes in a waste rock pile's geometry can result from erosion or from actions such as excavation, construction, or rebuilding/reshaping of the pile.

Waste rock piles typically have heterogeneous particle size distribution and varied permeability throughout the depth and breadth of the pile. In a field test using tracers, Eriksson et al. (Eriksson, Gupta and Destouni 1997), found that 55-70% of the total water followed preferential flow pathways. The authors also found that chemical tracers behaved differently in weathered waste rock piles versus newer piles. Results from Eriksson et al. (Eriksson et al. 1997), support the need for understanding longer-term behavior of the materials and their distribution within a waste rock pile through leaching tests, modeling, and field measurements. Blending waste rock with limestone is a standard practice to minimize the production of acidic leachate; however, the mixing method used during construction of the pile construction may influence the method's success. For example, Miller et al. (Miller et al. 2006), reported blending during waste rock pile construction to have only limited success when using haul trucks, due to insufficient blending of the limestone with the finer size fraction of waste rock, but that better mixing was achieved using a conveyer and stacker. Morin and Hutt (Morin and Hutt 2004), as presented in Price (Price 2009), found that variability in acidity from seeps of a single waste rock dump ranged from zero to approximately 90 g $CaCO_3$/L (standard unit for acidity, where 50 grams of $CaCO_3$ neutralizes 1 mol H^+) in one year, which further supports the need for homogenous blending of neutralizing materials and complete characterization of waste rock materials.

Isolation covers have the highest probability of success against geochemical failure (i.e., leaching of acidic and/or contaminant-laden water), with their purpose being to limit infiltration and oxygen transfer. In a study of a waste rock pile at a mine site in Papau Province, Indonesia, however, Andrina et al. (Andrina et al. 2006), found aspects of a waste rock pile, including the type of waste rock, particle size distribution, and dumping methods, each influenced variations in oxygen and temperature profiles. At that site, they found that an impermeable surface cover had only a limited effect on oxygen concentrations within the profile of the waste rock pile and concluded that advection of airflow through the coarse rock / rubble zone at the foundation of the dump was the primary pathway for oxygen transport.

Monitoring and maintenance activities must continue beyond construction of a waste rock pile. Although the pile may have been constructed based on sound slope stability studies, and have appropriate covers and means to divert water, the properties of the pile may change over time and breaches to covers may occur. Additionally, freeze/thaw cycling in colder climates may cause cracks, channeling, and exposure of surfaces below the cover (Sartz et al. 2011) and should be considered when designing piles and mitigation measures in these climates. Such cycling could result in accelerated weathering and leaching of materials (Dawson and Morin 1996, SRK Consulting 2009). With careful monitoring and early remedy of observed defects, some catastrophic consequences can be avoided.

2. TAILINGS

Tailings are a solid-liquid slurry material comprising fine-grained waste particles remaining after ore processing (e.g., milling, flotation, separation, leaching) and typically in the silt size-fraction ranging from 0.001 to 0.6 mm, along with water and residual chemicals (Mining Minerals and Sustainable Development (MMSD) 2002, U.S. Environmental Protection Agency (U.S.EPA) 1994). Similar to waste rock, tailings materials may be potentially acid-generating (PAG) or non-acid generating (NAG) and testing is conducted to assess their characteristics. The majority of ore mined and processed ends up as tailings. Tailings slurries have a solids content from 15 to 55 percent weight (U.S. EPA 1994). The liquid portion of tailings comprises water and chemicals used in processing of the ore (e.g., sodium ethyl xanthate, methyl isobutyl ketone, hydroxy oxime, acids, alcohols). Cyanide and metals may be present if the process includes cyanidation or pyrite suppression, with disposal of waste solution and tailings in the tailings impoundment. Logsdon et al (Logsdon, Hagelstein and Mudder 1999) present concentrations of cyanide and various metals that might be expected (if present in the ore) in solutions following gold extraction: total cyanide (50-2000 mg/l), arsenic (0-115 mg/l), copper (0.1-300 mg/l), iron (0.1-100 mg/l), lead (0-0.1 mg/l), molybdenum (0-4.7 mg/l), nickel (0.3-35 mg/l) and zinc (13-740 mg/l).

The sources of potential environmental impacts to water from tailings storage facilities (TSF) are sediment loading and leaching of acidity and inorganic contaminants, such as metals and metalloids, and other chemicals used that may be present in the processing waste tailings. The main environmental influences originate from seepage of contaminants into groundwater, leakage through containment walls, and exposure of waterfowl (if a tailings pond is present) to chemical contaminants. Additional routes of environmental exposure include movement of material mass from structural failure of a tailings impoundment (e.g., through breach of embankments) into a water body, and wind erosion carrying finer particles through the air during construction.

2.1 CONVENTIONAL PRACTICES

The selection and design of a tailings disposal site is site specific and depend on factors such as climate, topography, geology, hydrology, seismicity, economics, and environmental and human safety (e.g., see (Commonwealth of Australia 2007, U.S. Environmental Protection Agency (Region 10) 2003a, U.S. Environmental Protection Agency (Region 10) 2003b). The most basic requirements of any tailings storage facility (TSF), also called a tailings disposal facility, are that it is safe, stable, and economical, and that it presents negligible public health and safety risks and acceptably low social and environmental impacts during operation and post-closure. Effective construction must be based on a correct geotechnical assessment.

2.1.1 Operational Phase

Disposal options for tailings include 1) land-based placement into an impoundment; 2) disposal into underground workings or open pits; and 3) underwater (sub-aqueous) disposal into an existing water body or a constructed water body. The most common method of disposal is into a tailings slurry impoundment. Tailings impoundments are constructed as water-holding structures. This generally is accomplished by constructing a tailings dam in a valley. As tailings are placed behind the dam, a basin is formed. The solid portion of the tailings settles and the liquid portion creates a tailings pond. Construction of a tailings impoundment is done in lifts over the life of the mine. Tailings deposited against the embankment in creation of beaches leads to water draining away from the embankment, which reduces seepage and increases dam stability. Water levels in the tailings pond are controlled through removal of excess water for use in the mining process or for treatment and discharge to the local surface water; this minimizes water storage to enhance stability.

Special care must be taken during operations and post-closure to isolate acid-producing/metal leaching tailings from oxidation. A common method is for disposal of such tailings underwater (either into an existing water body or into a tailings pond). Sub-aqueous disposal is common in Canada and is considered a BMP for long-term isolation of tailings from oxidation; loss of any existing water body through this method must be replaced (O'Kane and Wels 2003). Sub-aqueous disposal has the potential for problems with physical stability, seepage, and water quality; however, if properly designed, constructed, and maintained, this type of storage provides good long-term isolation post-closure. At least a 30-cm barrier of stagnant water should overly the tailings (wave action would re-suspend particles closer to the surface if not stagnant); in Canada, a minimum recommended depth is 100-cm (SRK Consulting 2005). Sub-aqueous disposal is not applicable in all environments (e.g., arid regions), and disposal into an existing water body is not supported at all in Australia (Witt et al. 2004).

Tailings impoundments can be constructed using upstream, downstream, and centerline methods. The upstream method involves construction of walls on top of consolidated and desiccated tailings in an upstream direction, using waste rock or tailings for construction material; the downstream method involves construction with waste rock or borrow materials in a downstream direction; and the centerline method involves construction of the walls above a fixed crest alignment, using waste rock, borrow materials, or tailings (Commonwealth of Australia 2007). According to the International Commission on Large Dams (ICOLD), from a seismic standpoint, tailings dams built by the upstream method are less stable than dams built by either the downstream or the centerline method (International Commission on Large Dams (ICOLD) 2001). The state of Idaho considers upstream construction unsuitable for impoundments intended to be very high and/or to contain large volumes of water or solids (http://www.idl.idaho.gov/Bureau/Minerals/bmp_manual1992/p16-ch4.pdf). The downstream method is considered more stable from a seismic standpoint, but it also is the most expensive option; centerline construction is a hybrid of upstream and downstream construction types and has risks and costs lying between them (Chambers and Higman 2011, Martin et al. 2002).

When tailings impoundments are constructed in earthquake-prone locations, a critical design criterion is magnitude of earthquake that could be expected to occur. The most conservative design would consider the maximum credible earthquake (MCE), which would be the largest quake that could occur reasonably at any location at the mine site, based on seismological and geological evidence and interpretation (Chambers and Higman 2011).

Dewatering (thickening) of tailings prior to disposal enables more process water to be directly recycled back to mineral processing plant to reduce losses and operational demand, while reducing the amount of water stored in the TSF. Reduction of water quantity will reduce risks of overtopping, seepage, and evaporative losses of water that could be used in the mining process (rather than fresh water). Depositional beach angles also are steeper, which aids in containment.

Paste tailings technology requires thickening (water content ~ 20%) the tailings and placing them onto a lined disposal site. Dry stack tailings require filtering the tailings and placing the tailings onto a lined pad. Tailings thickened to a paste and filtered tailings can be 'stacked' for long-term storage. This method is relatively new, but has the advantages of reduced potential for liquefaction during an earthquake and tailings release from a breach in containment would be localized instead of flowing long distances (Witt et al. 2004). Filtered (e.g., moisture content ~ < 20%) and stacked tailings require a smaller footprint for storage, are easier to reclaim both at closure and by progressive reclamation, and have lower potential for structural failure and environmental impacts (Martin et al. 2002). Additionally, in cold climates, dry stacking prevents pipes from freezing, prevents frosting problems associated with conventional impoundments, and assists in retention and recycling of process water during cold weather operations (Access Consulting Group 2007). Disadvantages include that dry stacking is not appropriate for acid-generating tailings and pumping to the storage facility is difficult due to high viscosity and resistance to flow (filtered tailings for stacking are transported to storage via truck). There also is potential for generation of dusts (Witt et al. 2004). Thickened and paste tailings disposal is becoming more widespread; past limitations were high costs and lack of suitable thickener technology (Commonwealth of Australia 2007). This type of storage has less application at larger operations where tailings ponds may serve a dual role of process and excess water storage as well as tailings storage. Dry stacked tailings disposal is most applicable in arid regions or in cold regions where water handling is difficult (Martin et al. 2002).

Mitigation measures for a TSF may include any combination of a liner, under-drains, and decant systems when there is expectation of seepage or the presence of groundwater, and prevention of the formation of low permeability lenses or layers on tailings beaches that could cause future seepage or stability concerns (Commonwealth of Australia 2007). Liners can include a high-density polyethylene (HDPE) or other type of geosynthetic material, a clay cover over an area of high hydraulic conductivity, or a combination. A properly constructed clay liner could be expected to have a saturated hydraulic conductivity of 10^{-8} m/s and a geomembrane to have a hydraulic conductivity of ~ 10^{-10} m/s; however, the lifetime of a geomembrane may vary widely, depending on a number of factors, including composition and site temperature. For example, Koerner et al. (2011) presents that a nonexposed HDPE liner could have a predicted lifetime ("as measured by its halflife") of 69 years at 40 °C to 446 years at 20 °C. Where geomembranes are used, a drainage layer atop the membrane is commonly included to reduce the water pressure on the liner and minimize leakage. Liners may cover the entire impoundment area, or only the pervious bedrock or porous soils. Full liners beneath TSFs are not always used; however, there is a growing requirement to use liners to minimize risks of groundwater contamination, with new mines in Australia being required to justify why one wouldn't be required (Commonwealth of Australia 2007). Under-drains serve a dual purpose of reducing water saturation of the tailings sediments to improve geotechnical strength and safety of the facility as well as for directing drainage toward a storage area for subsequent treatment. If seepage from the TSF is expected (or if observed during monitoring), mitigation or remedial measures include interception trenches and/or seepage recovery wells to be installed around the perimeter and downstream to capture the water for redirection to a treatment facility. A spillway diversion commonly is constructed to provide a catchment for precipitation runoff.

The flotation process used to produce metal sulfide concentrates from porphyry deposits results in two tailings waste streams: one from the rougher circuit (to remove gangue material comprising silicates and oxides) and one from the cleaner circuit (pyrite-rich). It is possible to use a technique called "selective flotation" to separate most of the pyrite into the cleaner circuit tailings (PAG) with the rougher tailings comprising mostly NAG. Traditionally, these tailings streams were combined, but they could be separated selectively, with the PAG being discharged deeper into the TSF and the NAG discharged and used as a cover for the PAG. Success is dependent upon the ore and the efficiency of a clean separation (Martin et al. 2002).

In leaching of gold ore, mitigation practices include not locating leaching operations in or near a water body, detoxification of materials prior to disposal or closure, and ensuring that the solution can be contained in the presence of increased flows, up to the maximum reasonable storm event (U.S. Environmental Protection Agency (U.S.EPA) 1995a). When tank leached, the tailings and spent solution are stored in the TSF. The conventional method for recovery of gold from ore typically involves tank leaching with dilute (100-500 ppm) sodium cyanide (Logsdon et al. 1999). Following leaching, either zinc metal or activated carbon is added to the solution to recover the gold. The residual solution either is treated in a water treatment plant or stored with the process tailings in the TSF pond. When stored in the TSF pond, the cyanide concentrations should be such that there would be no adverse effects to wildlife, such as birds landing on the pond. Although rates could depend on the climate and other site specifics, cyanide concentrations are known to decrease through natural attenuation, including volatilization and subsequent interactions with UV, biological oxidation, and precipitation (Logsdon et al. 1999).

Monitoring groundwater quality for contaminant transport includes piezometers for groundwater mounding assessment. Regular inspections/monitoring for TSF stability include evaluation of seepage discharges through the dams, foundations, abutments, and liners; phreatic surface in ponds and dams; pore pressures; horizontal and vertical movement; and the status of leak detection systems, secondary containment, auto flow measurement and fault alarms, condition of pump and pipelines. Azam and Li (Azam and Li 2010) point out the importance of monitoring pore water pressures and embankment deformation based on correlation with several types of failure, and provides a basis to rectify the situation before failure ensues.

2.1.2 Closure and Post-Closure

Closure requires the TSF to have either a continuous water cover or an engineered cover to prevent oxidation of tailings. Sufficient capital is required to finance inspections, maintenance, and repairs in post-closure for as long as the tailings exist.

Closure of a TSF includes containment/encapsulation, minimization of seepage, stabilization with a surface cover to prevent erosion and infiltration, diversions and collection of precipitation, and design of final landform to minimize post-closure maintenance (the final landform desired should be considered during the planning phase). There are a number of cover types and depths that can be chosen; the choice is site specific and depends on climate, type and volume of tailings, size and geometry of the TSF, available cover material, and the end-use for the property (e.g., (O'Kane and Wels 2003, Wilson et al. 2003). A conventional cover is typically a low hydraulic conductivity layer of clay (and/or a geosynthetic membrane) overlain with protective soil layers and generally 1.2 to 1.5 meters thick (O'Kane and Wels 2003). The soil layers minimize deterioration due to desiccation, frost action, erosion, animal burrowing, and infiltration of plant roots [(Caldwell and Reith 1993) as reported in (O'Kane and Wels 2003)]. Covers are not used for submerged tailings, and placing covers on tailings that have not been dewatered can cause future stability problems (http://www.idl.idaho.gov/Bureau/Minerals/bmp_manual1992/p16-ch4.pdf).

Diversions and spillway structures are constructed to minimize potential erosion of the cover from surface water. Traditionally, water in TSF ponds has been drained as completely as possible prior to closure to reduce potential for overtopping and erosion of the embankments; raising water levels in large dams could cause considerable long-term risk. However, water covers might be used when feasible to maintain a submerged condition, such as in regions where the hydrology is well-understood and the terrain is flat, such as has been used and encouraged in Canada (Martin et al. 2002).

Regardless of the type of reclamation used for closure, the reclaimed facility must be monitored and maintained to ensure stability over time. Post-closure monitoring for contaminant transport is the same as during the operational phase, with piezometers for assessment of ground water mounding and monitoring wells for groundwater quality. The reclaimed facility should be monitored for any deformations, structural changes, or weaknesses, and the surfaces should be inspected for intrusion by animals, humans, or vegetation, any of which could compromise long-term stability.

2.2 ACCIDENTS AND FAILURES

The main causes of physical failures of tailings storage facilities are related to 1) a lack of control on the water balance; 2) lack of control on construction; and 3) a general lack of understanding of the features that control safe operating conditions (International Commission on Large Dams (ICOLD) 2001). Additionally, the upstream method for dam construction was found to be more prone to failure as compared to those constructed via the downstream method most likely due to embankment material generally having a low relative density and high water saturation (U.S. EPA, 1994).

In order of prevalence, failure mechanisms observed for TSFs are slope instability, earthquakes, overtopping, inadequate foundations, seepage, and structural problems (Blight and Fourie 2003, Commonwealth of Australia 2007). Failure during operation could occur from any of the following: 1) rupture of delivery pipeline or decant water return pipeline; 2) rainfall induced erosion or piping of outer tailings face; 3) geotechnical failure or excessive deformation of containment dyke; 4) overfilling of the tailings storage facility leading to overtopping by water; 5) seepage through containment dyke; and/or 6) seepage into the foundation. In addition to the above (aside from deliver and return pipelines), failures post-closure could result from failure of the spillway (if present), or failure of the cover through internal or external forces, including weathering of materials, erosion, extreme weather events, or intrusion by vegetation or wildlife (Commonwealth of Australia 2007, Witt et al. 2004).

Earthquakes can cause liquefaction, which is a process in which a soil mass loses shear resistance through increased water pressure. Liquefaction in the absence of an earthquake is called static liquefaction. Static liquefaction can result from slope instability or another mechanism. As reported in Davies (Davies 2001), upstream constructed dams are “more susceptible to liquefaction flow events and are solely responsible for all major static liquefaction events”; the author also states that earthquakes are of little concern for non-upstream dams. Liquefaction of a large volume of tailings causes them to flow out of a breach as a viscous liquid which is capable of moving long distances before coming to rest. For example, 3 million cubic meters of tailings escaped at Bafokeng, South Africa, and travelled 42 km before the remaining 2 million cubic meters was stopped by flowing into a water retention dam (Blight and Fourie 2003). Conventional TSF materials can have very low shear strength and are susceptible to liquefaction. Therefore, earthquake-induced liquefaction is a key design consideration to minimize risks of failure resulting from an earthquake event (Martin et al. 2002). Earthquake risks also are reduced when tailings have a higher density or are dry tailings.

Overtopping is caused by excessive water inflow, such as through precipitation or rapid snowmelt, and is cited as being the primary failure mode for almost half of all reported incidents occurring at inactive dams (Davies 2001). Overtopping can result in erosion and breaching of the embankment to release tailings and contaminated water downstream. Internal erosion by water (called piping) is a slow process and related to seepage/infiltration causing internal water pressures to exceed the critical hydraulic gradient and result in a pathway through which particles are carried. Guidelines exist for TSF design to minimize this risk; however, Jantzer and Knutsson (Jantzer and Knutsson 2010) believe that, at least in Sweden, critical gradient guidelines are insufficient to yield long-term stability. Unstable materials experience particle migration at much lower hydraulic gradients than do more stable or compacted materials.

Structural failure could result in the release of large amounts of tailings solids and water; for example, a failure at Church Rock, New Mexico released 357,000 cubic meters of tailings water and ~990 tons of solids into an adjacent stream in 1979 (Witt et al. 2004). Closed facilities are more prone to failures caused by external erosion, primarily because of a lack of frequent monitoring, which occurs more easily when the site is occupied daily during active mining. Diversion ditches help prevent erosion by redirecting surface flow away from the TSF. Usually, failures result from a combination of factors, with climate, tailings properties, and geometry influencing which of these processes is likely to be the most prominent cause. Seepage-related failures are the main failure mode for tailings dams constructed using downstream or centerline methods (Davies 2001). Increases in seepage rates or turbidity can be key indicators of a developing failure situation (Alaska Department of Natural Resources (AK DNR) 2005). Thus, adequate planning, suitable design, and monitoring and control of operation and post closure may prevent deteriorative actions.

The failure rate of tailings dams depends directly on the engineering methods used in design and the monitoring and inspection programs in the other mine-life stages. According to Witt et al. (Witt et al. 2004), with an assumption of 3500 worldwide tailings dams and failure rates of 2-5 dams per year, the annual probability of a TSF failure is between 1 in 700 to 1 in 1750, in contrast to < 1 in 10,000 apparent for conventional water dams. Using data obtained from the World Information Service of Energy (WISE, www.wise-uranium.org/mdaf.html) for the 10 years prior to March 22, 2011, Chambers and Higman (Chambers and Higman 2011) report that the worldwide failure rate of tailings dams has remained at 1 failure every 8 months (i.e. two failures every 3 years). Azam and Li (Azam and Li 2010), using databases from the United Nations Environmental Protection (UNEP), the International Commission on Large Dams (ICOLD), the World Information Service of Energy (WISE), the United States Commission on Large Dams (USCOLD), and the United States Environmental Protection Agency (U.S. EPA), found that causes of observed failures occurring in the years of 2000-2009, regardless of country (e.g., North American, South American, European, Asian, African, and Australian), were unusual weather, management, seepage, instability, and defect, in order of decreasing percentage contribution. Weather causes were observed to have increased by 15% from pre-2000 failures and management issues by 20%. Azam and Li (Azam and Li 2010) report that failures in all but Europe and Asia have decreased since 2000; this is attributed to improved engineering practices, with none from 2000-2009 being due to subsidence of the foundation or to overtopping. Additionally, seismic liquefaction was not a causal mechanism in failures between 2000 and 2009, but accounted for 14% of failures prior to 2000. Data presented indicate that failures peaked to about 50 per decade in the 1960's through the 1980's and has dropped to about 20 per decade over the last 20 years, with the frequency of failure occurrences shifting to developing countries. The authors also estimate that, on average, one fifth of the stored tailings are released resulting from tailings dam failure. Dalpatram (Dalpatram 2011) presented a slide at a recent Workshop on Dam Break Analysis that indicated volumes released range from 20-40% of the stored tailings.

Reports of failures generally discuss physical failures causing a large release of tailings and/or water, but failure in design, construction, monitoring, and/or maintenance of the entire TSF system could result in slow release of contaminants into surface water or groundwater. Additionally, releases could result from compromise to the cover over PAG material or from inaccurate prediction of acid-generation potential for storage of PAG versus NAG tailings.

3. PIT

Following open-pit mining, a wide and deep hole remains that typically is filled in (or fills naturally) with water to form a pit lake. The source of environmental influence from pits and resultant lakes includes their size and the potential for acid-rock drainage (ARD) from dissolution of sulfidic minerals exposed on pit walls. Contaminated water may seep into groundwater, overflow into surface water, or adversely affect waterfowl landing in the formed pit lake. Additionally, the steep pit slopes generally remain after closure and continue to pose a risk to wildlife from falling into the pit and not being able to get out. Mitigation methods chosen will depend on site-specific considerations, as well as the future use envisioned for the pit (McCullough 2011).

3.1 CONVENTIONAL PRACTICES

3.1.1 Operational Phase

During the operational phase, pit walls are monitored closely for signs of weakness that might lead to a failure. Suggested means for reducing operational hazards from a slope failure in a pit include "1) safe geotechnical designs; 2) secondary supports or rock fall catchment systems; 3) monitoring devices for adequate advance warning of impending failures; and 4) proper and sufficient scaling of loose/dangerous material from highwalls" (Girard 2001). Typically, water is pumped or drained out of the pit to allow safe access as well as to expose material being mined.

3.1.2 Closure and Post-Closure

At closure, pits may be used as a repository for waste rock, followed by sealing of the area against air and water exposure, such as by an isolation cover, to minimize the potential for generation of acidity. Partial backfilling and regrading of upper levels with subsequent vegetation and/or creation of wetlands provides for passive water treatment. Most commonly, pits naturally fill with water over time, from groundwater, surface water, and precipitation inflows. Filling may be accelerated by pumping water from the TSF or other storage ponds both to minimize exposure of any PAG rock wall materials and PAG waste rock and/or tailings disposed into the pit at closure to oxygen, and to balance high pore water pressures to help prevent slope failures. Once the desired water level is achieved to retain the pit lake as a sink, water can be directed away from entering the pit through diversions that were used during the operational phase, or pit water can be pumped and treated prior to discharge to a surface water body.

Because the pit walls contain mineralized rock that has been exposed during the mining period, and during the period over which the pit lake forms, pit lake water can become acidic and/or contain metals and metalloids from natural geochemical processes. If acidity is anticipated from pit walls, mitigation measures to control for acid generation (e.g., sealing the rock against oxidation) and/or for ensuring that any such acidic or metal/metalloid-laden water would not migrate to surface or groundwater must be considered.

Water quality modeling can assist in identifying if a pit lake will become acidic and/or accumulate metals and metalloids. The three basic processes of importance and considered in modeling include the chemical loading by water sources flowing into the pit; loading from the rock walls, benches, and fractures behind the walls, and the geochemistry of the water during the time it has been in the pit (Morin and Hutt, 2001). Factors important in these processes include the time of exposure of a surface to both oxygen and water, and the surface area of reactive materials exposed. During mining, oxidized pit wall surfaces are washed with precipitation and that water is pumped out of the pit, but not all surfaces are reached by precipitation (e.g., fractures behind walls) and may have years of accumulation of oxidized minerals that will release acid and/or metals/metalloids into the pit lake once exposed to water. Although not the only issue, one inherent difficulty in prediction is that it is difficult to measure or estimate percentages of surface areas that are flushed regularly, intermittently, or never during the operational phase of mining for use in modeling anticipated pit water chemistry (Morin, 1994). Nonetheless, modeling is useful in planning for closure and post-closure of the pit.

If production of acidity and contaminant ions are anticipated, and exposed surfaces cannot be covered or sealed against oxidation, chemicals may be added to the pit lake to neutralize acidity and precipitate metals. Organic material and microorganisms may be added and conditions optimized for sulfate-reducing bacteria (SRB) to allow for formation of insoluble metal sulfides in the anaerobic regions of the lake. If pit water becomes contaminated, treatment of any water leaving the pit would be necessary to meet applicable water quality standards prior to any discharge.

Barriers, such as fences, berms, or other structures, are constructed to mitigate unauthorized access by humans and access by wildlife and should be monitored and maintained regularly for stability.

4. UNDERGROUND MINE WORKINGS

The sources of potential environmental influences from underground mining are similar to those for open pit mining, i.e., waste rock piles, tailings, dust, and wastewater. An additional source of potential impact to both groundwater and surface water is from acid rock drainage from tunnels and adits created during mining. Depending on many factors, including the depth of the underground mine to the surface and the strength of the overburden rock, mine workings have the potential to subside and may create a depression in the landscape and alterations in surface and ground water flows.

4.1 CONVENTIONAL PRACTICES

The mitigation measures to prevent potential significant environmental impacts from wastes originating from underground mining are similar to those for open pit mining. In addition, waste rock and or tailings may be disposed in mined out tunnels, which may assist in minimizing impacts from subsidence. Additionally, void-filling grout may be used to mitigate subsidence. In regions where there is potential for ground water interaction with mine workings, cracks may be sealed with grouting or other material. Additionally, groundwater flow paths may be intercepted (such as by grouting of faults and sheer zones, or by a grout curtain) and thus redirected to avoid the mined out area, minimizing contact of the water with potentially acid-generating rock surfaces (e.g., (Wireman and Stover 2011)). In some cases, the mine workings are flooded, which, if done prior to oxidation occurring on PAG surfaces and kept anaerobic, will minimize the formation of acidic drainage.

5.0 DUST

Mining activities can generate dust during multiple stages in the operational phase, including those generated during construction of roads, trucking of materials, and heavy equipment exhaust. Fugitive dusts are diffuse and generated through wind erosion of large areas, including waste rock piles, tailings, the pit, and other disturbed areas. Other dusts originate at locations where processes are occurring, such as blasting, crushing, grinding, and milling. Dusts containing metals from mining activity pose human health concerns through inhalation. The particles are carried by the wind and may cause environmental concerns through sedimentation in water bodies and/or by being transported further downstream.

5.1 CONVENTIONAL PRACTICES

Mitigation of dust from processing points within mining operations can include collection by dry collectors, wet scrubbers, enclosures at the source, and/or wetting of surfaces (Commonwealth of Australia 1998). A cover on a truck bed can minimize dusts originating from materials being hauled. Wetting of surfaces is most useful for active blasting, haul roads, and material movement and placement activities, and may involve the use of water or water mixed with a chemical dust suppressant. Typically, dust from waste rock piles is controlled by wetting during the operational phase. During closure, waste rock piles are covered and vegetated; this can be done as piles are completed during the operational phase to minimize potential for dust production. Although wet slurry tailings do not pose a dust issue, dust from large dry beaches of tailings facilities is a concern, and wetting or using special products to stabilize the surfaces is used for temporary wind erosion and dust control. Tailings beaches are covered with gravel (or other material) and may be vegetated during closure.

6. STORM AND WASTEWATER

Storm and wastewater have the potential to contain suspended sediment and particulate and dissolved contaminants that could contaminant water bodies if they were to leave the site untreated. The main environmental influences originate from seepage of contaminants into groundwater, leakage through barriers (e.g., tailings embankment), and flooding or washout into nearby surface water bodies.

6.1 CONVENTIONAL PRACTICES

Mitigation of stormwater begins with designing components using an accurate site water balance to assure adequate storage and treatment capacity. Conventionally, runoff and seepage are diverted through ditches and diversion channels to a treatment pond, or to a settling pond if the water source is solely from precipitation. Water from settling ponds can be decanted and discharged (if it meets required water quality criteria), or used in the mining process if of sufficient quality. Spillway diversions commonly are constructed around waste rock and tailings facilities to provide catchments for precipitation runoff. Excess water in tailings ponds is controlled through removal and treatment for use in the mining processes or discharge to the surface water. Traditionally, water in TSF ponds is drained as completely as possible prior to closure to minimize potential for overtopping due to precipitation. For TSF ponds containing sub-aqueously disposed PAG tailings, sufficient water would remain in the pond post-closure to ensure they remain isolated from oxygen.

Stormwater from undisturbed areas may require treatment only for sediment, which is accomplished through simple settling in a sedimentation pond. Stormwater from disturbed areas and mining wastewater is treated via either active or passive methods prior to being used in the mining process or released into a water body. Active treatment of wastewater generally involves a chemical addition (e.g., lime, alum, iron oxides) to precipitate and/or adsorb metals and metalloids followed by dewatering of the precipitated solid and disposal; and/or a physical process (e.g., reverse osmosis, filtration, microfiltration). Operating mines generally have high volumes of water needing treatment prior to discharge to a surface water body and thus rely on active treatment methods. Active treatments also include microbial methods, such as the use of contained bioreactors, but these generally require lower flows and are options for post-closure or co-treatment during operations. Passive treatments are those that capitalize on natural processes and do not require constant reagent addition for operation. Wetlands are an example of a commonly used passive treatment system for water contaminants, as are anaerobic biochemical reactors (also called sulfate-reducing bioreactors). Passive treatment options are most commonly used post-closure, although they can be used during the operational phase for other purposes. For example, a biochemical reactor could be used to treat contaminants present in brine from reverse osmosis treatment. Passive treatment technologies generally require large land areas and low flows to allow sufficient time for biological processes to convert them to non-toxic forms. Additional passive and active treatment options for potential use post-closure can be found in U.S. EPA (2006).

7. CHEMICALS

Chemicals used at mining sites have the potential to enter into the environment through accidental spills during transport, storage, and/or use, or from excess usage in processes to recover metals being mined (e.g., during flotation/frothing, cyanidation, or smelting).

7.1 CONVENTIONAL PRACTICES

Conventional practices include having a chemical hygiene plan and training of all personnel in the proper handling of chemicals, including how to deal with cleanup of spills, provision of spill kits and personal protective equipment, and availability of MSDS for consultation (e.g., see (Logsdon et al. 1999)). Secondary containment (dikes or collection basins) must be used and incompatible chemicals must be isolated from one another during storage and use. Storage containers are commonly equipped with indicators and instrumentation to monitor levels in tanks to ensure that a spill does not occur, or that any spill/leak is captures quickly when it begins.

8. PIPELINES

A slurry-concentrate pipeline break or spill has potential to affect aquatic life adversely, if into a nearby stream. Additionally, placement of pipelines results in land disturbance and can cause soil/sediment to enter streams through runoff.

8.1 CONVENTIONAL PRACTICES

Pipelines that might be necessary for mining operations include those for transport of slurry, return water, and fuel for the mining site. Standard practices for construction, operation, and monitoring of slurry pipelines are available from the American Society of Mechanical Engineers (American Society of Mechanical Engineers (ASME) 2003).

Mitigation measures for pipelines include using the proper pipe material, protection against leaks, breaks, and corrosion, containment drains or sumps along the corridor, and secondary containment of the pipeline where crossing a river or transportation route. Protection includes increased wall thickness, corrosion inhibitors, and internal linings or coatings. Joints, welds, valves, etc. are designed to accommodate expected stress, as based on flows desired for the pipeline. Pipelines may be equipped with monitoring systems to detect flow, temperature, or pressure changes, along with alarms and automatic shutoffs. Pipelines are stress-tested for leaks and weaknesses prior to being placed into operation; and they require routine inspections over the course of their use. Mitigation of construction impacts, such as soil erosion and turbid storm water runoff caused by pipe installation (e.g., excavation and boring), can include silt fences, ditches, or other temporary diversions. Pipelines that are constructed near water bodies require containment and may or may not be placed above ground on bridge structures.

9. NON-MINING MATERIAL AND DOMESTIC WASTE

Mining operations produce a number of wastes in addition to waste mineral materials. Additionally, there is domestic waste produced from persons employed. These wastes have the potential to attract wildlife (food wastes), or to contaminate water bodies (e.g., sewage waste) and thus must be managed.

9.1 NON-MINING MATERIAL AND DOMESTIC WASTE

At remote mining sites, non-hazardous wastes generally are managed on site. Non-hazardous solid wastes typically would be disposed in engineered solid waste landfills that meet regulatory requirements. For some types of wastes, and in some locations, incineration may be an acceptable alternative. Recycling of segregated wastes such as paper and plastic may be preferable, but high transportation costs could make this option economically unattractive.

Sanitary waste often is treated via a decentralized system (e.g., septic tank) or in a packaged sewage treatment plant, with the effluent discharged after verification that it meets the permitted discharge standards. Sewage sludge may be land-farmed, hauled to a licensed treatment facility, or land filled on site depending on local requirements.

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AN ASSESSMENT OF POTENTIAL MINING IMPACTS ON SALMON ECOSYSTEMS OF BRISTOL BAY, ALASKA

VOLUME 3—APPENDICES E-J

Appendix J: Compensatory Mitigation and Large-Scale Hardrock Mining in the Bristol Bay Watershed

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Appendix J

Compensatory Mitigation and Large-Scale Hardrock Mining in the Bristol Bay Watershed

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Table of Contents

This appendix provides an overview of Clean Water Act Section 404 compensatory mitigation requirements for unavoidable impacts to aquatic resources, and discusses an array of measures that various entities have proposed as having the potential to compensate for the unavoidable impacts to wetlands, streams, and fish identified in the Bristol Bay Assessment. Please note that any formal determinations regarding compensatory mitigation can only take place in the context of a regulatory action. The Bristol Bay Assessment is not a regulatory action, and thus a complete evaluation of compensatory mitigation is outside the scope of the assessment.

1. Overview of Clean Water Act Section 404 Compensatory Mitigation Requirements

The overall objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the nation's waters. To help achieve that objective, Section 404 of the Clean Water Act establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Section 404 requires a permit before dredged or fill material may be discharged into waters of the United States, unless the activity is exempt from Section 404 regulation (e.g. certain farming and forestry activities).

The U.S. Environmental Protection Agency (EPA) and the Department of the Army, operating through the Army Corps of Engineers (ACOE), share responsibilities for implementing the Section 404 program. Section 404(a) authorizes the ACOE to issue permits for the discharge of dredged or fill material into waters of the U.S. at specified disposal sites. Section 404(b) directs the ACOE to apply environmental criteria developed by EPA in making its permit decisions (these criteria are binding regulations known as the "Section 404(b)(1) Guidelines" (40 CFR Part 230)). Under EPA's Section 404(b)(1) Guidelines, no discharge of dredged or fill material may be permitted by the ACOE if: (1) a practicable alternative exists that is less damaging to the aquatic environment so long as that alternative does not have other significant adverse environmental consequences or (2) the nation's waters would be significantly degraded. Under the Guidelines, a project must incorporate all appropriate and practicable measures to first avoid impacts to wetlands, streams, and other aquatic resources and then minimize unavoidable impacts; after avoidance and minimization measures have been applied, the project must include appropriate and practicable compensatory mitigation for the remaining unavoidable impacts.

Compensatory mitigation refers to the restoration, establishment, enhancement, and/or preservation of wetlands, streams, or other aquatic resources conducted specifically for the purpose of offsetting authorized impacts to these resources (Hough and Robertson 2009). Compensatory mitigation regulations jointly promulgated by EPA and the ACOE (40 CFR §§ 230.91 - 230.98 and 33 CFR §§ 332.1 - 332.8) state that "the fundamental objective of compensatory mitigation is to offset environmental losses resulting from unavoidable impacts to waters of the United States authorized by [Clean Water Act Section 404 permits issued by the ACOE]" (40 CFR Part 230.93(a)(1)). Compensatory mitigation enters the analysis only after a proposed project has incorporated all appropriate and practicable means to avoid and minimize adverse impacts to aquatic resources (40 CFR Part 230.91(c)).

Section 404 permitting requirements for compensatory mitigation are based on what is "practicable and capable of compensating for the aquatic resource functions that will be lost as a result of the permitted activity" (40 CFR Part 230.93(a)(1)). In determining what type of compensatory mitigation will be "environmentally preferable," the ACOE "must assess the likelihood for ecological success and sustainability, the location of the compensation site relative to the impact site and their significance within the watershed, and the costs of the compensatory mitigation project"(40 CFR Part 230.93(a)(1)). Furthermore, compensatory mitigation requirements must be commensurate with the amount and type of impact associated with a particular Section 404 permit (40 CFR Part 230.93(a)(1)). The regulations recognize that there may be instances when the ACOE cannot issue a permit "because of the lack of appropriate and practicable compensatory mitigation options" (40 CFR Part 230.91(c)(3)).

1.1 Compensatory Mitigation Methods

Compensatory mitigation can occur through four methods: aquatic resource **restoration**, **establishment**, **enhancement**, or in certain circumstances, **preservation** (40 CFR Part 230.93(a)(2)).

- Restoration is the reestablishment or rehabilitation of a wetland, stream, or other aquatic resource with the goal of returning natural or historic functions and characteristics to a former or degraded aquatic resource. When it is an option, restoration is generally the preferred method, due in part to its higher likelihood of success as measured by gain in aquatic resource function, area, or both.
- Establishment, or creation, is the development of a wetland or other aquatic resource where one did not exist previously, with success measured as a net gain in both area and function of the aquatic resource.
- Enhancement includes activities conducted within existing aquatic resources that heighten, intensify, or improve one or more aquatic resource functions, without increasing the area of the aquatic resource. Examples include improved floodwater retention or wildlife habitat.
- Preservation is the permanent protection of aquatic resources and/or upland buffers or riparian areas through legal and physical mechanisms, such as conservation easements and title transfers. Because preservation does not replace lost aquatic resource area or functions, regulations limit its use to situations in which the resources to be preserved provide important functions for and contribute significantly to the ecological sustainability of the watershed,

and those resources are under threat of destruction or adverse modification (40 CFR Part 230.93(h)).

1.2 Compensatory Mitigation Mechanisms

There are three general mechanisms for achieving the four methods of compensatory mitigation (listed in order of preference as established in 40 CFR 230.93(b)): **mitigation banks**, **in-lieu fee programs**, and **permittee-responsible mitigation**.

- A mitigation bank is a site with restored, established, enhanced, or preserved aquatic resources, riparian areas and/or upland buffers that the ACOE has approved for use to compensate for losses from future permitted activities. The bank approval process establishes the number of available compensation credits, which permittees may purchase upon ACOE approval that the bank represents appropriate compensation. The bank sponsor is responsible for the success of these mitigation sites.
- For in-lieu fee mitigation, a permittee provides funds to an in-lieu fee program sponsor who conducts compensatory mitigation projects according to the compensation planning framework approved by ACOE. Typically specific compensatory mitigation projects are started only after pooling funds from multiple permittees. The in-lieu fee program sponsor is responsible for the success of these mitigation sites.
- In permittee-responsible mitigation, the permittee undertakes and bears full responsibility for the implementation and success of the mitigation. Mitigation may occur either at the site where the regulated activity caused the loss of aquatic resources (on-site) or at a different location (off-site), preferably within the same watershed.

Although it is the permit applicant's responsibility to propose an appropriate compensatory mitigation option, mitigation banks and in-lieu fee programs are the federal government's preferred forms of compensatory mitigation as they "usually involve consolidating compensatory mitigation projects where ecologically appropriate, consolidating resources, providing financial planning and scientific expertise (which often is not practical for permittee-responsible compensatory mitigation projects), reducing temporal losses of functions, and reducing uncertainty over project success" (40 CFR 230.93(a)(1); *see also* 40 CFR 230.93(b)).

1.3 Location, Type, and Amount of Compensation

Regulations regarding compensatory mitigation require the use of a watershed approach to "establish compensatory mitigation requirements in [Department of the Army] permits to the extent appropriate and practicable" (40 CFR 230.93(c)(1)). Under these regulations, the watershed approach to compensatory mitigation site selection and planning is an analytical process for making compensatory mitigation decisions that support the sustainability or improvement of aquatic resources in a watershed. It involves consideration of watershed needs and how locations and types of compensatory mitigation projects address those needs (40 CFR 230.92). The regulations specifically state that compensatory mitigation generally should occur within the same watershed as the impact site and in a location where it is most likely to successfully replace lost functions and services (40 CFR 230.93(b)(1)). The goal of this watershed approach is to "maintain and improve the quality and quantity of aquatic resources within watersheds through strategic selection of compensatory mitigation sites" (40 CFR 230.93(c)(1)).

The regulations emphasize using existing watershed plans to inform compensatory mitigation decisions, when such plans are determined to be appropriate for use in this context (40 CFR 230.93(c)(1)). Watershed plans that could support compensatory mitigation decision-making are typically:

> "…developed by federal, tribal, state, and/or local government agencies or appropriate non-governmental organizations, in consultation with relevant stakeholders, for the specific goal of aquatic resource restoration, establishment, enhancement and preservation. A watershed plan addresses aquatic resource conditions in the watershed, multiple stakeholder interests, and land uses. Watershed plans may also identify priority sites for aquatic resource restoration and protection" (40 CFR 230.92).

Where appropriate plans do not exist, the regulations describe the types of considerations and information that should be used to support a watershed approach to compensation decision-making. Central to the watershed approach is consideration of how the types and locations of potential compensatory mitigation projects would sustain aquatic resource functions in the watershed. To achieve that goal, the regulations emphasize that mitigation projects should, where practicable, replace the suite of functions typically provided by the affected aquatic resource, rather than focus on specific individual functions (40 CFR 230.93(c)(2)). For this purpose, "watershed" means an "area that drains to a common waterway, such as a stream, lake, estuary, wetland, or ultimately the ocean" (40 CFR 230.92). Although there is flexibility in defining geographic scale, the watershed "should not be larger than is appropriate to ensure that the aquatic resources provided through compensation activities will effectively compensate for adverse environmental impacts resulting from [permitted] activities" (40 CFR 230.93(c)(4)).

With regard to type, in-kind mitigation (i.e., involving resources similar to those being impacted) is generally preferable to out-of-kind mitigation, because it is most likely to compensate for functions lost at the impact site (40 CFR 230.93(e)(1)). Furthermore, the regulations recognize that, for difficult-to-replace resources such as bogs, fens, springs, and streams, in-kind "rehabilitation, enhancement, or preservation" should be the compensation of choice, given the greater likelihood of success of those types of mitigation (40 CFR 230.93(e)(3)).

The amount of compensatory mitigation required must be, to the extent practicable, "sufficient to replace lost aquatic resource functions" (40 CFR 230.93(f)(1)), as determined through the use of a functional or condition assessment. If an applicable assessment methodology is not available, the regulations require a minimum one-to-one acreage or linear foot compensation ratio (40 CFR 230.93(f)(1)). Certain circumstances require higher ratios, even in the absence of an assessment methodology (e.g., use of preservation, lower likelihood of success, differences in functionality between the impact site and compensation project, difficulty of restoring lost functions, and the distance between the impact and compensation sites) (40 CFR 230.93(f)(2)).

1.4 Compensatory Mitigation Guidance for Alaska

In addition to the federal regulations regarding compensatory mitigation, the agencies have also developed compensatory mitigation guidance applicable specifically to Alaska. In their 1994 Alaska Wetlands Initiative Summary Report, EPA and the Department of the Army concluded that it was not necessary to provide "broad exemptions" from mitigation sequencing in Alaska, given the "inherent flexibility provided by" the regulations and associated guidance. The agencies also recognized that "it may not always be practicable to provide compensatory mitigation through wetlands restoration or creation in areas where there is a high proportion of land which is wetlands. In cases where potential compensatory mitigation sites are not available due to the abundance of wetlands in a region and lack of enhancement or restoration sites, compensatory mitigation is not required under the [Section 404(b)(1)] Guidelines" (EPA et al., 1994). In promulgating the compensatory mitigation regulations in 2008, EPA and the ACOE specifically referenced the 1994 policy and reiterated the flexibility and discretion available to decision-makers (e.g., 40 CFR 230.91(a)(1), 40 CFR 230.93(a)(1)).

Although opportunities for wetland restoration and creation continue to be rather limited in Alaska, a number of other wetland compensatory mitigation options (e.g., mitigation banks, in-lieu fee programs) have become available since 1994. Moreover, it is important to note that the 1994 policy applies only to compensatory mitigation for impacts to wetlands and does not address compensatory mitigation for impacts to Alaska streams. Furthermore, subsequent guidance issued by the ACOE Alaska District in 2009 clarifies that fill placed in streams or in wetlands adjacent to anadromous fish streams in Alaska will require compensatory mitigation (ACOE 2009). A 2011 supplement to the Alaska District's 2009 guidance further recommends that projects in "difficult to replace" wetlands, fish-bearing waters, or wetlands within 500 feet of such waters will also likely require compensatory mitigation, as will "large scale projects with significant aquatic resource impacts," such as "mining development" (ACOE 2011).

The ACOE's 2009 Alaska guidance also provides sample compensatory mitigation ratios based on the type of mitigation and the ecological value of the impacted resource (high, moderate, or low). These guidelines include streams in the high quality category, indicating compensation ratios of 2:1 for restoration and/or enhancement and 3:1 for preservation (ACOE 2009).

2. Compensatory Mitigation Considerations for the Bristol Bay Assessment

2.1 Important Ecological Functions and Services Provided by Affected Streams and Wetlands

Bristol Bay's stream and wetland resources support a world-class commercial and sport fishery for Pacific salmon and other important fish. They have also supported a salmon-based culture and subsistence-based lifestyle for Alaska Natives in the watershed for at least 4,000 years. Bristol Bay's streams and wetlands support production of 35 species of fish including all five species of Pacific salmon found in North America: sockeye (*Oncorhynchus nerka*), coho (*O. kisutch*), Chinook or king (*O. tshawytscha*), chum (*O. keta*), and pink (*O. gorbuscha*). Because no hatchery fish are raised or released in the watershed, Bristol Bay's salmon populations are entirely wild. These fish are anadromous, hatching and rearing in freshwater systems, migrating to the sea to grow to adult size, and returning to freshwater systems to spawn and die.

In the Bristol Bay region, hydrologically-diverse riverine and wetland landscapes provide a variety of salmon spawning and rearing habitats. Environmental conditions can be very different among habitats in close proximity, with ponds, lakes and streams expressing very different flow, temperature, and physical habitat characteristics at very fine spatial scales (see Chapter 7 of the assessment for additional discussion). Recent research has highlighted the potential for local adaptations and fine-scale population structuring in Bristol Bay and neighboring watersheds associated with this environmental template (Quinn et al. 2001, Olsen et al. 2003, Ramstad et al. 2010, Quinn et al. 2012). For example, sockeye salmon that use spring-fed ponds and streams located approximately 1 km apart exhibit differences in traits such as spawn timing, spawn site fidelity, and productivity consistent with discrete populations (Quinn et al. 2012). Bristol Bay's streams and wetlands support a diverse array of salmon populations that are unique to specific drainages within the Bay and this population diversity is key to the stability of the overall Bristol Bay salmon fishery (i.e., the portfolio effect) (Schindler et al. 2010).

As discussed in detail in the Bristol Bay Assessment (see Chapter 7), streams and wetlands that would be lost as a result of the mine footprints described in the assessment's scenarios provide important ecological functions. These headwater streams provide spawning habitat for coho and sockeye salmon and likely spawning habitat for anadromous and resident forms of Dolly Varden. Headwater streams and associated wetlands also provide rearing habitat for chum salmon, sockeye salmon, Chinook salmon, coho salmon, Dolly Varden, rainbow trout, Arctic grayling, slimy sculpin, northern pike, and ninespine stickleback (Johnson and Blanche 2012, ADFG 2012a). Headwater streams and associated wetlands are often exploited by fish for spawning and rearing because they can provide refuge from predators and competitors that are more abundant downstream (Quinn 2005). Off-channel wetlands with their unique low-velocity, depositional environments and variable thermal conditions provide additional options for juvenile salmon feeding and rearing. For example, ephemeral swamps provided important thermal and hydraulic refuge for coho salmon in a coastal British Columbia stream (Brown and Hartman 1988). Off-channel ponds provided highly productive foraging environments and enhanced overwinter growth of coho salmon in an interior British Columbia stream (Swales and Levings 1989).

It has long been recognized that in addition to providing habitat for stream fishes, headwater streams and wetlands serve an important role in the stream network by contributing nutrients, water, organic material, algae, bacteria and macroinvertebrates downstream, to higher order streams in the watershed (Vannote et al. 1980, Meyer et al. 2007). But only recently have specific subsidies from headwater systems been extensively quantified (Wipfli and Baxter 2010). The contributions of headwaters to downstream systems results from their high density in the dendritic stream network. Headwater streams also have high rates of instream nutrient processing and storage, thereby determining downstream water chemistry due to relatively large organic matter inputs, high retention capacity, high primary productively, bacteria-induced decomposition, and extensive hyporheic zone interactions (Richardson et al. 2005, Alexander et al. 2007, Meyer et al. 2007). Because of their crucial influence on downstream water flow, chemistry, and biota, impacts to headwaters reverberate throughout entire watersheds downstream (Freeman et al. 2007, Meyer et al. 2007).

The majority of streams directly in the footprint of the mine scenarios are classified as small headwater streams (less than 0.15 m^3/s mean annual streamflow) (see assessment Table 7-6). Because of their narrow width, headwater streams receive proportionally larger inputs of organic material than do larger stream channels (Vannote et al. 1980). This material is either used in the headwater environment (Tank et al. 2010) or transported downstream as a subsidy to larger streams in the network (Wipfli et al. 2007). Consumers in headwater stream food webs, such as invertebrates, juvenile salmon, and other fishes rely heavily on the terrestrial inputs that enter the stream (Doucett et al. 1996, Eberle and Stanford 2010, Dekar et al. 2012). Headwater streams also encompass the upper limits of anadromous fish distribution, and may receive none, or lower quantities of marine-derived nutrients (MDN) from spawning salmon relative to downstream portions of the river network, making terrestrial nutrient sources relatively more important (Wipfli and Baxter 2010).

Both invertebrates and detritus are exported from headwaters to downstream reaches and provide an important energy subsidy for juvenile salmonids (Wipfli and Gregovich 2002, Meyer et al. 2007). Headwater wetlands and associated wetland vegetation can also be important sources of dissolved and particulate organic matter, and macroinvertebrate diversity (King et al. 2012), contributing to the chemical, physical, and biological condition of downstream waters (Shaftel et al. 2011a, Shaftel et al. 2011b, Dekar et al. 2012, Walker et al. 2012). Thus, losses of headwater streams and wetlands due to the mine scenario footprints would not only eliminate important fish habitat but also reduce inputs of organic material, nutrients, water, primary producers, bacteria, and macroinvertebrates to reaches downstream of the mine scenario footprints.

2.2 Identifying the Appropriate Watershed Scale for Compensatory Mitigation

As previously noted, the regulations regarding compensatory mitigation specifically state that compensatory mitigation generally should occur within the same watershed as the impact site and in a location where it is most likely to successfully replace lost functions and services (40 CFR 230.93(b)(1)).

For the mine scenarios evaluated in the Bristol Bay Assessment, the lost functions and services occur in the watersheds that drain to the North Fork Koktuli (NFK) and South Fork Koktuli (SFK) Rivers and Upper Talarik Creek (UTC) (see Figure 1). Accordingly, the most appropriate geographic scale at which to compensate for any unavoidable impacts resulting from such a project would be within these same watersheds, as this location would offer the greatest likelihood that compensation measures would replace the "suite of functions typically provided by the affected aquatic resource" (40 CFR 230.93(c)(2), Yocom and Bernard 2013). An important consideration is that salmon populations in these watersheds may possess unique adaptations to local environmental conditions, as suggested by recent research in the region (Quinn et al. 2001, Olsen et al. 2003, Ramstad et al. 2010, Quinn et al. 2012). Accordingly, maintenance of local biocomplexity (i.e., salmon genetic, behavioral, and phenotypic variation) and the environmental template upon which biocomplexity develops will be important for sustaining resilience of these populations (Hilborn et al. 2003, Schindler et al. 2010). Thus, the most appropriate spatial scale and context for compensation would be within the local watersheds where impacts to salmon populations occur.

If there are no practicable or appropriate opportunities to provide compensation in these watersheds, it may be appropriate to explore options in adjoining watersheds. However, defining the watershed scale too broadly would likely fail to ensure that wetland, stream, and associated fish losses under the mine scenarios would be effectively offset, because compensation in a different watershed(s) would not address impacts to the portfolio effect from losses in the impacted watersheds. Similarly, compensation in different watersheds would not address impacts to the subsistence fishery where users depend on a specific temporal and spatial distribution of fish to ensure nutritional needs and cultural values are maintained (see Bristol Bay Assessment Chapter 12).

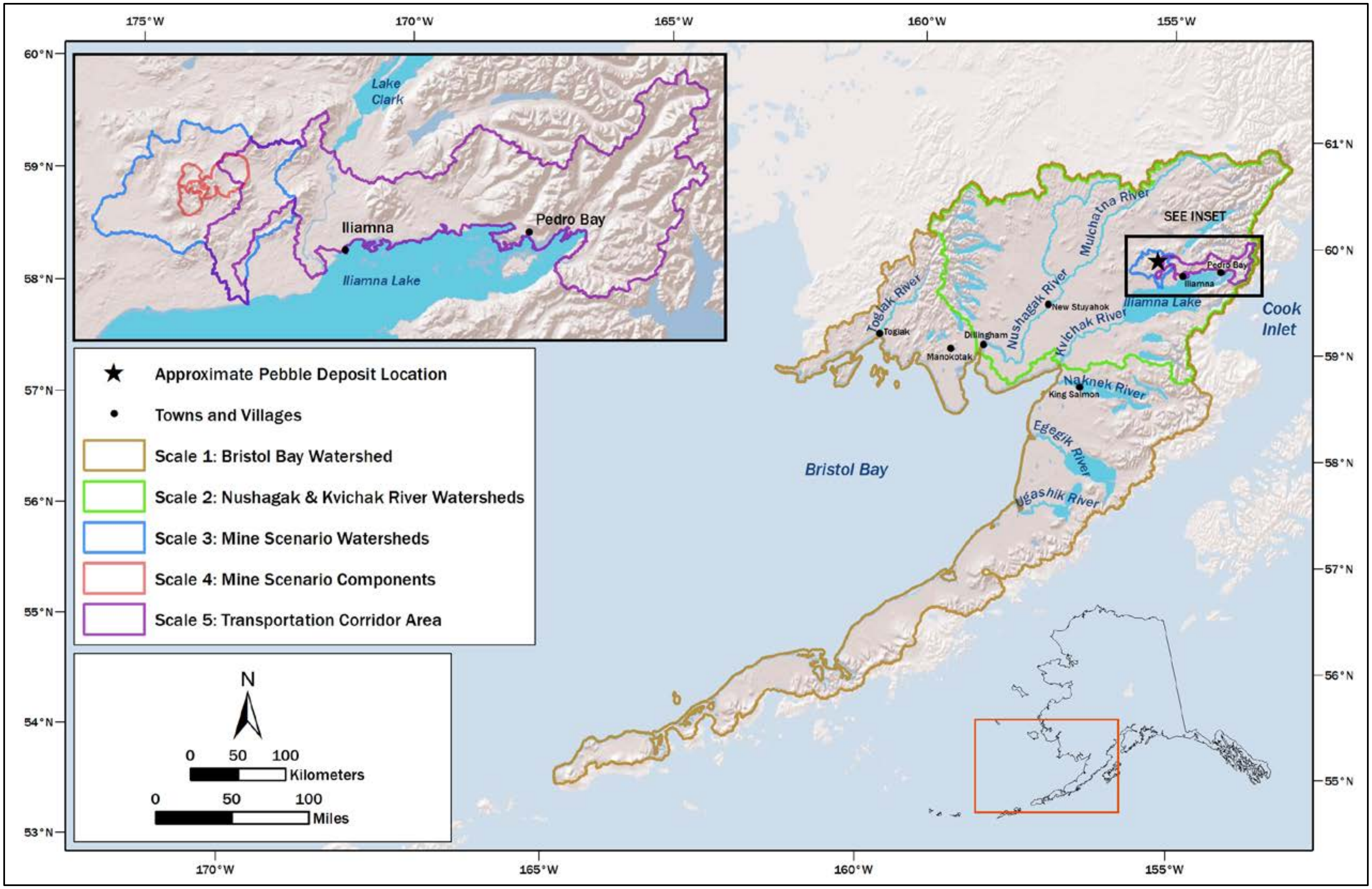

Figure 1. The boundaries of the Bristol Bay watershed (brown), the Nushagak and Kvichak River watersheds (green) and the North Fork Koktuli, South Fork Koktuli, and Upper Talarik Creek watersheds (blue).

3. Potential Compensatory Mitigation Measures in Bristol Bay

As discussed in Chapter 7 of the Bristol Bay Assessment, impact avoidance and minimization measures do not eliminate all of the footprint impacts associated with the mining scenarios. Reasons impact avoidance and minimization measures fail to eliminate these kinds of impacts include: the large extent and wide distribution of wetlands and streams in the watersheds, the fact that substantial infrastructure would need to be built to support porphyry copper mining in this largely undeveloped area and the fact that ore body location constrains siting options. The mine scenarios evaluated in the assessment identify that the mine footprints alone would result in the unavoidable loss (i.e., filling, blocking or otherwise eliminating) of hundreds to thousands of acres of high-functioning wetlands and tens of miles of salmon-supporting streams (see Figure 2).

The public and peer review comments on the draft Bristol Bay Assessment identified an array of compensation measures that some commenters believed could potentially offset these impacts to wetlands, streams, and fish. The following discussion considers the likely efficacy of the complete array of compensation measures proposed by commenters at offsetting potential adverse effects, organized in the order that the regulations prescribe for considering compensation mechanisms:

1) Mitigation bank credits;
2) In-lieu fee program credits; and
3) Variations of permittee-responsible mitigation.

3.1 Mitigation Bank Credits

There are currently no approved mitigation banks with service areas[1] that cover the impact site for the mine scenarios; thus, no mitigation bank credits are available. Should one or more bank sponsors pursue the establishment of mitigation bank sites to address the impacts associated with the mine scenarios, they would likely encounter the same challenges described below (Section 3.3).

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[1] The service area is the watershed, ecoregion, physiographic province, and/or other geographic area within which the mitigation bank or in-lieu fee program is authorized to provide compensatory mitigation (40 CFR 230.98(d)(6)(ii)(A)).

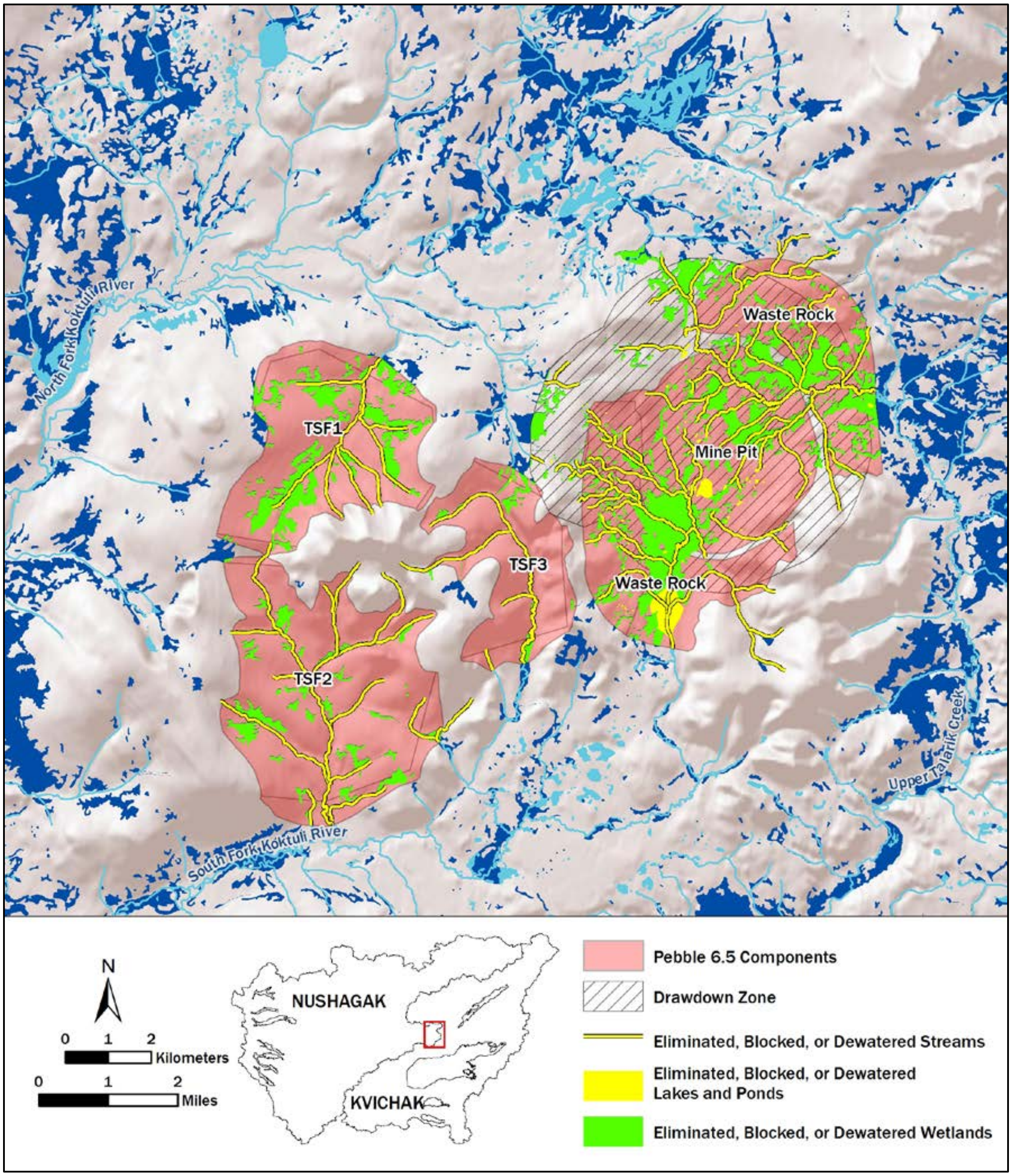

Figure 2. Streams, wetlands and other waters lost (eliminated, blocked, or dewatered) in the Pebble 6.5 scenario evaluated in the Bristol Bay Assessment.

3.2 In-Lieu Fee Program Credits

There is currently one in-lieu fee program approved to operate in the Bristol Bay watershed, which has been administered by The Conservation Fund (TCF) since 1994. The TCF program operates statewide, and the Bristol Bay watershed falls within one of its service areas. According to TCF, its compensation projects consist almost entirely of wetland preservation. To date, TCF has completed four wetland preservation projects in the Bristol Bay watershed, financed in part with in-lieu fee funds. Although the majority of in-lieu fees collected by the TCF program have been for relatively small impacts to aquatic resources, TCF has accepted in-lieu fees to compensate for a few projects with over 50 acres of impacts statewide. To date, the largest impact represented in the TCF program is the loss of 267 acres of wetlands associated with the development of the Point Thomson natural gas production/processing facilities on Alaska's Beaufort Sea coast. It is not clear if this program could effectively provide the magnitude of compensation necessary to address the loss of hundreds to thousands of acres of high functioning wetlands and tens of miles of salmon-supporting streams associated with the mine scenarios. In addition, it is likely that any in-lieu fee sponsor seeking to address the impacts associated with the mine scenarios would encounter the same challenges described below (Section 3.3).

3.3 Permittee-Responsible Compensatory Mitigation

Currently, there is no watershed plan for the NFK, SFK, or UTC, or other components of the Nushagak or Kvichak River drainages that could serve as a guide to permittee-responsible compensatory mitigation. In the absence of such a plan, the regulations call for the use of a watershed approach that considers information on watershed conditions and needs, including potential sites and priorities for restoration and preservation (40 CFR 230.93(c)). When a watershed approach is not practicable, the next option is to consider on-site (i.e., on the same site as the impacts or on adjoining land) and in-kind compensatory mitigation for project impacts, taking into account both practicability and compatibility with the proposed project (40 CFR 230.93(b)(5)). When such measures would be impracticable, incompatible, or inadequate, the last resort would be off-site and/or out-of-kind mitigation opportunities (40 CFR 230.93(b)(6)).

3.3.1 Opportunities within the NFK, SFK, and UTC Watersheds

In the context of the mine scenarios, the primary challenge to both a watershed approach and on-site compensatory mitigation is the absence of existing degraded resources within the NFK, SFK and UTC watersheds. Specifically, these three watersheds are largely unaltered by human activities; thus, opportunities for restoration or enhancement are very limited, and, as discussed below, likelihood of success appears to be very low.

Here we discuss specific suggestions for potential compensation measures within the NFK, SFK and UTC watersheds that were provided in the public and peer review comments on the Bristol Bay Assessment.

3.3.1.1 Increase Habitat Connectivity

Connectivity among aquatic habitats within stream networks is an important attribute influencing the ability of mobile aquatic taxa to utilize the diversity and extent of habitats within those networks. Within riverine floodplain systems, a complex array of habitats can develop that express varying degrees of surface and sub-surface water connectivity to main channels (Stanford and Ward 1993). In the study area, off-channel floodplain habitats can include side channels (both inlet and outlet connections to main channel), various types of single-connection habitats including alcoves and percolation channels, and pools and ponds with no surface connection to the main channel during certain flow conditions (PLP 2011 Appendix 15.1D). Beaver can be very important modifiers and creators of habitat in these off-channel systems (Pollock et al. 2003, Rosell et al. 2005). As a result of their morphology and variable hydrology, the degree of surface-water connectivity and the ability of fish to move among floodplain habitats changes with surface water levels. Connectivity for fish movement at larger spatial scales within watersheds is influenced by barriers to longitudinal movements and migrations. Examples include dams and waterfalls.

Efforts to manage or enhance connectivity within aquatic systems have primarily focused on watersheds altered by human activities, where land uses and water utilization have lead to aquatic habitat fragmentation. Specific activities to increase habitat connectivity within human-dominated stream-wetland systems may include: 1) improving access around real or perceived barriers to migration (including dams constructed by humans or beaver); 2) removing or retrofitting of road culverts; and 3) excavating and engineering of channels to connect isolated wetlands and ponds to main channels. Within watersheds minimally impacted by human activity, efforts may include creation of passage around barrier waterfalls to expand the availability of habitat for species like Pacific salmon. Human-created dams do not offer any opportunities for habitat improvement or expansion in the Nushagak or Kvichak River watersheds because they are absent, so they are not discussed further. Since road stream crossing retrofits presently offer no opportunities for habitat improvement or expansion within the NFK, SFK, and UTC watersheds, but exist elsewhere in the larger Nushagak and Kvichak River watersheds, they are discussed in Section 3.3.2.3. Here, we focus on beaver dam removal and engineered connections to variably-connected floodplain habitats, and habitats upstream of barrier waterfalls. For each of these measures, the potential applicability, suitability, and effectiveness as mitigation tools within the study area watersheds are addressed.

3.3.1.1.1 Remove Beaver Dams

Two commenters suggested the removal of beaver dams as a potential compensation measure. Presumably, the rationale for this recommendation is that beaver dams can block fish passage, limiting fish access to otherwise suitable habitat, thus, the removal of beaver dams could increase the amount of available fish habitat. This rationale is based upon early research that led to the common fish management practice of removing beaver dams to protect certain fish populations like trout (Sayler 1934, Reid 1952, *in* Pollock et al. 2004). However, more recent research has documented numerous benefits of beaver ponds to fish populations and habitat (Murphy et al. 1989, Pollock et al. 2003). For example, Bustard and Narver (1975) found that a series of beaver ponds on Vancouver Island had a survival rate for overwintering juvenile coho salmon that was twice as high as the 35% estimated for the entire stream. Pollock et al. (2004) estimated a 61% reduction in summer habitat capacity relative to historical levels, for coho salmon in one Washington watershed, largely due to loss of beaver ponds.

Kemp et al. (2012) recently published a definitive review of the effects of beaver in stream systems, indicating that they have a positive impact on sockeye, coho, and Chinook salmon as well as Dolly Varden, rainbow trout, and steelhead. Using meta-analysis and weight-of-evidence methodology, the review showed that most (71.4%) negative effects cited, such as low dissolved oxygen and impediment to fish movement, lack supportive data and are speculative in nature, whereas the majority (51.1%) of positive impacts cited are quantitative in nature and well-supported by data (Kemp et al. 2012). In addition to increased invertebrate (i.e., food) production and habitat heterogeneity, the study cited the importance of beaver ponds as rearing habitat due to the increased cover and protection that higher levels of woody material and overall structural diversity provide. Other studies have identified beaver ponds as excellent salmon rearing habitat because they have high macrophyte cover, low flow velocity, and increased temperatures, and they trap organic materials and nutrients (Nickelson et al. 1992, Collen and Gibson 2001, Lang et al. 2006). DeVries et al (2012) describe a stream restoration approach that attempts to mimic and facilitate beaver dam creation and the numerous positive benefits for stream habitat and riparian enhancement. Studies in Oregon have shown that salmon abundance is positively related to pool size, especially during low flow conditions (Reeves et al. 2011), and beaver ponds provide particularly large pools. During winter, beaver ponds typically retain liquid water below the frozen surface, providing refugia for species that overwinter in streams and off-channel habitats (Nickelson et al. 1992, Cunjak 1996).

Beaver dams generally do not constitute significant barriers to salmonid migration even though their semi-permeability may temporarily limit fish movement during periods of low stream flow (Rupp 1954, Gard 1961, Bryant 1984, Pollock et al. 2003). Even when beaver dams impede fish movements, the effects are typically temporary, with higher flows from storm events ultimately overtopping them or blowing them out (Leidholt-Bruner et al. 1992, Kemp et al. 2012). Even the temporary effect may be limited, when seasonal rainfall is at least average (Snodgrass and Meffe 1998, Kemp et al. 2012). Adding to the body of evidence, Pacific salmon and other migratory fish species commonly occur above beaver dams, including above beaver dams in the study area (PLP 2011; Appendix 15.1D). One study in southeast Alaska documented coho salmon upstream of all surveyed beaver dams, including one that was two meters high; in fact, the survey recorded highest coho densities in streams with beaver (Bryant 1984). Other surveys have documented both adult and juvenile sockeye salmon, steelhead, cutthroat, and char upstream of beaver dams (Bryant 1984, Swales et al. 1988, Murphy et al. 1989, Pollock et al. 2003).

Beavers preferentially colonize headwater streams, such as those found near the Pebble deposit, because of their shallow depths and narrow widths (Collen and Gibson 2001, Pollock et al. 2003). An October 2005 aerial survey of active beaver dams in the mine scenarios area mapped a total of 113 active beaver colonies (PLP 2011). The Pebble Limited Partnership's (PLP) Environmental Baseline Document (EBD) highlights the significant role that beaver ponds are currently providing for Pacific salmon in this area when it states:

> "[W]hile beaver ponds were relatively scarce in the mainstem UT [UTC], the off-channel habitat study revealed a preponderance of beaver ponds in the off-channel habitats. As in the SFK watershed, beaver ponds accounted for more than 90 percent of the off-channel habitat surveyed. Beaver ponds in the UT provided habitat for adult spawning and juvenile overwintering for Pacific salmon. The water temperature in beaver ponds in the UT was slightly warmer than in other habitat types and thus, beaver ponds may represent a more productive habitat as compared to other mainstem channel habitat types" (PLP 2011).

The current body of literature describing the effects of beaver dams on salmonid species reports more positive associations between beaver dam activity and salmonids than negative associations (Kemp et al. 2012). Hence, removal of beaver dams as a means of compensatory mitigation could lead to a net negative impact on salmonid abundance, growth, and productivity. Moreover, since the mine scenario would eliminate or block several streams with active beaver colonies in the headwaters of the SFK and UTC, the benefits provided by those habitats would be part of the suite of functions that compensatory mitigation should aim to offset.

3.3.1.1.2 Connect Off-channel Habitats and Habitat Above Impassible Waterfalls

Off-channel habitats can provide important low-velocity rearing habitats for juvenile salmon and other native fishes. Floodplain-complex habitats including beaver ponds, side channels, oxbow channels, and alcoves can contribute significantly to juvenile salmonid rearing capacity (e.g., Beechie et al. 1994). Such habitats are a common feature of unmodified alluvial river corridors. These habitats may express varying degrees of surface-water connectivity to main channels that in unmodified rivers is dependent upon streamflow stage and natural channel dynamics. Off-channel habitats may become isolated from the main channel during certain streamflow conditions due to channel migration or avulsion, and in highly dynamic channels, connectivity may change frequently during bed-mobilizing events (Stanford and Ward 1993). This shifting mosaic of depositional and erosional habitats within the floodplain creates a diverse hydraulic and geomorphic setting, contributing to biocomplexity (Amoros and Bornette 2002). In river systems modified by human activity, isolation or elimination of off-channel habitats has had severe impacts on salmon productivity (e.g., Beechie et al. 1994), and re-connection and re-creation of off-channel habitats are now common tools for increasing juvenile salmonid habitat capacity in those systems (Morley et al. 2005, Roni et al. 2006).

Waterfalls or high-gradient stream reaches can prevent mobile fish species from accessing upstream habitats, due to velocity barriers or drops that exceed passage capabilities of fish (Reiser et al. 2006). Waters upstream of barriers may be devoid of all fish life, or may contain resident fish species including genetically-distinct populations (e.g., Whiteley et al. 2010). Engineered passageways for fish around waterfalls have been used to create access to upstream lakes or stream systems for fish such as salmon. However, the response of resident fish species to barrier removal and the colonization success of species from downstream habitats may be difficult to predict (Kiffney et al. 2009). Salmon population responses to a fishway in southeast Alaska depended on the species, and the ecological effects of fish passage on the upstream lake system and watershed are not fully understood (Bryant et al. 1999). Burger et al. (2000) provide a well-documented history of colonization of sockeye salmon in Frazer Lake, Alaska above a historically-impassible waterfall following passage installation and planting of salmon eggs, fry, and adults above the barrier. Their study documents how differing donor populations, each with different life-history characteristics, contributed differently toward the establishment of populations in the newly accessible habitats (Burger et al. 2000). This study highlights the importance of genetics and life history adaptations of source populations to colonization success.

Creating connectivity between parts of the river network that are naturally disconnected can have adverse ecological effects, including impacts to resident vertebrate and invertebrate communities, as well as disruptions to ecosystem processes. Introduction of fish to fish-less areas can lead to altered predator-prey interactions, food web changes, changes in algal production, nutrient cycling and meta-population dynamics of other vertebrate species (see Section 3.3.2.5). For example, previous studies on the introduction of trout species to montane, wilderness lakes have shown that introducing fish to fish-less lakes can have substantial impacts to nutrient cycles (Knapp et al. 2001). The risk of disruption to the functions of naturally fish-less aquatic ecosystems should be fully evaluated before these approaches are used for the sole purpose of creating new fish habitat area.

Rosenfeld and co-authors (Rosenfeld et al. 2008, Rosenfeld et al. 2009) conducted a variety of experiments and monitoring activities within a re-connected river meander in coastal British Columbia to explore the relationship of salmon productivity to habitat features. Their work highlights the importance of habitat configuration. In their study, spacing of pools (foraging habitats for fish) and riffles (source areas for invertebrate prey) was an important factor influencing growth rates of juvenile coho salmon. Given the high diversity of channel conditions within floodplain habitats in the project area (PLP 2011), it is likely that fish responses to increased connectivity would be highly variable.

Rosenfeld et al. (2008) point out the importance of considering the full suite of factors that influence habitat capacity and productivity when designing restoration or enhancement projects. For instance, 'optimising' habitat structure for one species may adversely impact species with differing habitat preferences, as demonstrated by Morley et al. (2005) who found differential responses of juvenile steelhead and juvenile coho salmon to conditions in constructed and natural off-channel habitats. Predator-prey relationships also need to be considered. Increased connectivity of off-channel habitats has been proposed as a strategy for enhancing northern pike production in northern Canada (Cott, 2004). How increased connectivity in the project area would influence trophic relationships among northern pike and salmon, trout and char is unknown, although introduced northern pike in other areas of Alaska have the potential to reduce local abundances of salmonids via predation (Sepulveda et al. 2013). Bryant et al. (1999) in their study of the effects of improved passage at a waterfall concluded that the effects on food webs, trophic relationships, and genetics among resident and newly-colonizing species were largely unknown. Rosenfeld and co-authors (2009) emphasize the high degree of uncertainty associated with channel design for enhanced fish productivity, stating:

> "…despite the enormous quantity of research on stream rearing salmonids and their habitat associations, stream ecologists still lack a definitive understanding of the relationship between channel structure, prey production and habitat capacity for drift-feeding fishes" (Rosenfeld et al. 2009, page 581).

Several commenters proposed that enhanced or increased connectivity of off-channel habitats or habitats above waterfalls could provide fish access to habitat currently underutilized or inaccessible. This comment presumes that currently disconnected habitats would provide suitable mitigation sites. Based on the above, there are multiple criteria that would have to be met, and numerous assumptions that would have to be validated in order for these sites to qualify as valid mitigation sites. For such measures to succeed, the following conditions would need to be considered:

a. Are currently inaccessible habitats suitable for salmon and other target fish species?

b. Does improved access to habitat address a currently limiting factor or condition?

c. Can the habitat be effectively connected in a way that enhances productivity?

d. Will enhanced connectivity be sustainable over the long term (e.g., be maintained despite sediment dynamics or channel adjustments)?

e. If enhanced connectivity is not self-sustainable, can a feasible monitoring and maintenance plan ensure continued connectivity and effectiveness?

f. What is the risk that changes to the hydrology, chemistry, temperature and morphology of the habitat complex associated with the construction of hydrologic connectivity will fundamentally alter the habitat suitability of the site such that it is no longer addressing a habitat need?

g. Would predators/competitors present within the existing disconnected habitat overwhelm the benefit to target species?

h. Are fish populations present in isolated habitats (e.g., above impassible waterfalls) genetically distinct or otherwise of special value, and potentially lost if connections to downstream fish populations are enabled?

i. How would potential adverse ecosystem changes in fish-less isolated habitats (e.g., above impassible waterfalls) due to fish introductions be evaluated and addressed?

Given the above considerations and examples of the challenges of connectivity management, use of fishways at waterfalls and engineered connections to off-channel habitats have many unanswered questions for the project area streams and wetlands. Such approaches would be effectively an “adaptive management experiment” (Rosenfeld et al. 2008); requiring careful monitoring and evaluation of alterations within an experimental context.

3.3.1.2 Increase Habitat Quality

Addition of large structural elements such as wood and boulders to streams has been a common stream habitat rehabilitation approach in locations where stream habitats have been extensively simplified by mining, logging and associated timber transportation, or other disturbances (Roni et al. 2008). The goals of large structure additions are typically to create increased hydraulic and structural complexity and improve local-scale habitat conditions for fish in streams that are otherwise lacking in rearing or spawning microhabitats. Properly engineered structural additions to channels can increase hydraulic diversity, habitat complexity, and retention of substrates and organic materials in channels, but benefits for aquatic life have been difficult to quantify (see review by Palmer et al. 2010). The paucity of demonstrated beneficial biotic responses to stream structural enhancements is at odds with perceptions by managers whose evaluations tend to be overtly positive – but usually based on qualitative opinion rather than scientific observation (Jähnig et al. 2011). In addition, improperly sited or engineered structural additions can fail to achieve desired effects or have adverse, unanticipated consequences (e.g., via structural failure or scour and fill of sensitive non-target habitats (Frissell and Nawa 1992)), highlighting the need for appropriate design.

Commenters proposed that quality of stream habitats in the project area could be enhanced by increasing habitat complexity through the addition of boulders or large wood to existing off-channel habitats. Off-channel habitats can provide important low-velocity rearing habitats for juvenile salmon and other native fishes. Floodplain-complex habitats including beaver ponds, side channels, oxbow channels, and alcoves provide hydraulic diversity that can be important for fish in variable flows (Amoros and Bornette 2002, Rosenfeld et al. 2008). Beaver are a major player in the creation and maintenance of these habitats in the study area (PLP 2011, Appendix 15.1D), as has been noted elsewhere (Pollock et al. 2003, Rosell et al. 2005). Off-channel habitats also provide important foraging environments, and can be thermally-diverse, offering opportunities for thermoregulation or enhanced bioenergetic efficiency (Giannico and Hinch 2003). Off-channel habitats are relatively frequent and locally-abundant in area streams and rivers, particularly in lower-gradient, unconstrained valley settings and at tributary confluences (e.g., PLP 2011 Figure 15.1-15, cover photo of this assessment). PLP's EBD, Appendix 15.1D (PLP 2011) contains an assessment of the natural fluvial processes creating and maintaining off-channel habitats, and their quality and quantity and function in the study area, including mechanisms of connectivity to the mainstem channels. This background information provides very useful information for evaluating the potential effectiveness of off-channel habitat modification.

Commenters proposed that off-channel habitats could also be improved by engineered modifications to the depth, shoreline development ratio, and configuration of off-channel habitats to create better overwintering habitat for juvenile salmon. The degree to which existing habitats could be enhanced to improve survival of juvenile salmon as proposed by commenters will be dependent upon several considerations, including an evaluation of factors known to influence the utilization, survival, and growth within these habitats. These considerations are discussed below.

Off-channel habitats surveyed by PLP and other investigators reveal that patterns of occupancy and density are high but variable among off-channel habitats (PLP 2011, Appendix 15.1D). Some of the highest densities observed were within off-channel habitats such as side channels and alcoves, but even some 'isolated' pools held fish (PLP 2011, Appendix 15.1D). This variability could reflect variation in suitability, access, or other characteristics of individual off-channel habitats. Juvenile salmonids require a diverse suite of resources to meet habitat requirements – cover and visual isolation provided by habitat complexity is one such resource, but other critical resources include food, space, and suitable temperatures and water chemistry (Quinn 2005). Habitat configuration within constructed side-channel habitats can also strongly influence density, size and growth of juvenile salmonids (Rosenfeld and Raeburn 2009). Giannico and Hinch (2003) in experimental treatments in side channels in British Columbia, found that wood additions were beneficial to coho salmon growth and survival in surface-water fed side channels, but not in groundwater-fed channels. They attributed this effect to differences in foraging strategy and bioenergetics of the juvenile coho salmon overwintering in the channels. Additions of wood had no effect, or even possibly a detrimental effect, on coho salmon survival in groundwater-fed side channels. These findings highlight the importance of understanding the ecology, bioenergetics, and behavior of the species and life histories present within habitats that may be quite diverse with regard to hydrology and geomorphology.

It is not clear from current data that adding complexity would address any limiting factor within existing off-channel habitats, or that additions of boulders and wood would enhance salmonid abundance or survival. Placement of structures (e.g., boulders, large wood) within stream channels should also be guided by careful consideration of potential adverse consequences, including unanticipated shifts in hydraulic conditions that lead to bank erosion or loss of other desirable habitat features. Sustainability of off-channel habitat modifications is also in question. As stated in the EBD, off-channel habitats are a product of a dynamic floodplain environment and "..are continually being created and destroyed" (PLP 2011; Appendix 15.1D; page 2). Maintenance of engineered structures or altered morphologies of such habitats over the long term would be a challenging task. Observations from the EBD suggest that beaver are already providing desired complexity; to quote, "..habitat mapping from this off-channel study shows that the beaver ponds contain extensive and diverse habitats and dominate the active valley floor." And, "…these off-channel habitats provide a critical habitat component of freshwater rearing of coho salmon, and to a lesser extent, other anadromous and resident species." (PLP 2011, Appendix 15.1D page 14).

3.3.1.3 Increase Habitat Quantity

The creation of spawning channels and off-channel habitats has been proposed as a means to compensate for lost salmon spawning and rearing areas. The intent of a constructed spawning channel is to simulate a natural salmon stream by regulating flow, gravel size, and spawner density (Hilborn 1992). Off-channel habitats may be enlarged or modified to alter habitat conditions and capacities for rearing juvenile salmonids. Examples include the many spawning channels (Bonnell 1991) and off-channel habitats (Cooperman 2006) enhanced or created in British Columbia and off-channel ponds rehabilitated by the City of Seattle (Hall and Wissmar 2004).

Off-channel spawning and rearing habitats can be advantageous to salmon populations by providing diverse hydraulic and habitat characteristics. Redds constructed in these habitats may be less susceptible to scour compared to main channel habitats due to flow stability provided by their hyporheic or groundwater sources (Hall and Wissmar 2004). Moderated thermal regimes can provide benefits for growth and survival for overwintering juveniles (Giannico and Hinch 2003). Morley et al. (2005) compared 11 constructed off-channel habitats to naturally-occurring paired reference side channels and found that both natural and constructed off-channel habitats supported high densities of juvenile salmonids in both winter and summer. Although numerous studies have documented short-term or localized benefits of constructed off-channel habitats, ascertaining population-level effects is much more difficult. Any additional fry produced by spawning channels (if successful) would require additional suitable habitat for juvenile rearing and subsequent life stages in order to have a net positive effect on populations. Hilborn (1992) indicates that success, measured by increased production of adult fish from such channels, is unpredictable and generally unmonitored. A notable exception is the study by Sheng et al. (1990), which documented 2- to 8-fold increases in recruitment of coho spawner production from groundwater-fed off-channel habitats. Sheng et al. (1990) stated that effectiveness would be greatest in systems which currently lack adequate overwinter refuges. As with any rehabilitation strategy, population responses will be dependent upon whether factors actually limiting production are addressed. As stated elsewhere in this assessment, additional research and monitoring is required to quantify factors currently limiting production within project area watersheds.

Replacing destroyed salmon habitats with new constructed channels is not a simple task. Factors for consideration in designing and implementing off-channel habitat development are outlined in Lister and Finnigan (1997), and include evaluation of species and life stages present, current habitat conditions, and factors limiting capacity or productivity (Roni et al. 2008). Research indicates that channels fed by hyporheic flow or groundwater may be most effective for creating suitable spawning and rearing habitats (Lister and Finnigan 1997). Near-stream excavation and compaction associated with channel construction can alter groundwater flowpaths, so designing projects to protect current function and groundwater connectivity is very important.

Numerous researchers have emphasized that replacing lost habitats is not merely a process of providing habitat structure (Lake et al. 2007). Effective replacement of function also requires establishment of appropriate food web structure and productivity to support the food supply for fish – in essence, an entire ecosystem, including all full suite of organisms such as bacteria, algae, and invertebrates – needs to be in place in order for a constructed channel to begin to perform some of the same functions of a destroyed stream (Palmer et al. 2010). Quigley and Harper (2006b), in a review of stream rehabilitation projects, concluded “the ability to replicate ecosystem function is clearly limited.”

There is some history of using constructed spawning channels to mitigate for the impacts of various development projects on fish, based on the premise that they would provide additional spawning habitat and produce more fry, which would presumably result in more adult fish returning (Hilborn 1992). Off-channel rearing habitats have also been used to create additional overwintering habitats in Pacific Northwest rivers (Roni et al. 2006), and spawning channels have also been shown to provide suitable overwintering habitats for juvenile coho salmon (Sheng et al. 1990). However, there are very few studies regarding the efficacy of such channels at enhancing adult salmon recruitment in the published literature. Constructed spawning channels, particularly those dependent upon surface flow, may also require annual maintenance and cleaning (Hilborn 1992), and salmon using them can be prone to disease outbreaks (Mulcahy et al. 1982). The need for frequent maintenance would be contrary to the regulations' intent that compensatory mitigation projects be self-sustaining (40 CFR 230.97(b)). Off-channel habitats to mainstems are also extremely difficult to engineer in a way that can self-sustain in the face of a dynamic fluvial environment. Alluvial channels frequently shift (Amoros and Bornette 2002), and beaver are highly effective ecosystem engineers whose activities are constantly re-arranging floodplain channels and creating new dams (Pollock et al. 2003) - including within engineered channels and culverts (Cooperman 2006).

In light of their uncertain track record, it does not appear that constructed spawning channels and engineered connections of off-channel habitats would provide reliable and sustainable fish habitat in the Bristol Bay region.

3.3.1.4 Manage Water Quantity

Two commenters suggested a variety of techniques to manipulate water quantities within the NFK, SFK and UTC watersheds to improve fish productivity. Possible techniques for accomplishing this include: flow management, flow augmentation, and flow pump-back.

3.3.1.4.1 Direct Excess On-site Water

Commenters suggested that fish habitat productivity could be improved through careful water management at the mine scenario site, including the storage and strategic delivery of excess water to streams and aquifers to maintain or enhance flow and/or thermal regimes in the receiving streams. Delivering such flows via groundwater (i.e., by using wastewater treatment plant (WWTP) discharges to "recharge and surcharge groundwater aquifers") was identified as a preferred approach; commenters argued doing so would both render the measure less prone to operational anomalies at the WWTP and better mimic current natural flow patterns, thereby attenuating potential adverse effects related to discharge volume and temperature. Ideally, flow, temperature, and habitat modeling would inform the design and operation of flow management to optimize species and habitat benefits by, for example providing water at specific times to locations where low flow currently limits fish productivity.

Manipulation of surface flows at another mine in Alaska—Red Dog, in the northwest part of the state—has resulted in an increase in fish (Arctic grayling and Dolly Varden) use of the downstream creek (Scannell 2005, Ott 2004). The circumstances at Red Dog, however, differ from those in the NFK, SFK, and UTC area. As described in Scannell (2005), the near complete absence of fish in Red Dog Creek prior to implementation of the water management techniques was the direct result of water quality, not quantity, as the stream periodically experienced toxic levels of metals that occurred naturally as it flowed through and downslope of the exposed ore body. Furthermore, the Red Dog water management system primarily involves point-to-point diversion or transfer of surface, rather than groundwater, both around the ore body and from tributaries upstream of the mine. We have been unable to locate any documentation of successful attempts to manage flow volume or temperature from mine sites (or other industrial developments), via groundwater, for the benefit of fish and/or fish habitat.

Given that most streams in the area support multiple salmonid species and life stages, with differing habitat needs at different times, designing and managing a water delivery system to overcome limiting factors for one or more species without adversely impacting others would be a significant challenge. Given the complexity of the surface-groundwater connectivity in the area, ensuring that discharges to groundwater actually reached the target habitat at the intended time would, perhaps, be the most difficult task. Quigley and Harper (2006b), in a review of stream rehabilitation projects, concluded “the ability to replicate ecosystem function is clearly limited.”

This challenge could potentially be easier to overcome where habitat limitations occurred only as a result of mine development, assuming pre-project modeling and verification accurately identified groundwater flow paths to those areas. It is important to note, however, that even if such actions appeared to be feasible, they likely would be required to avoid or minimize the adverse impacts of flow reduction due to mine development, rather than to compensate for unavoidable habitat losses.

If it were an overall enhancement to pre-existing habitat, using WWTP discharges to groundwater to address natural limitation factors could be a form of compensatory mitigation. For example, PLP (2011) points out that productivity may be limited by the existence of “losing” reaches along the SFK mainstem and intermittent or ephemeral tributaries to both the SFK and NFK. Altering the natural flow regimes at such sites, however, could have unintended consequences on the local ecosystem and species assemblages (Poff et al. 1997). Moreover, “enhancing” these habitats through a WWTP-sourced groundwater flow delivery system would be even more challenging than managing flow to avoid or minimize impacts to already productive habitat, because it would require “improving” the natural flow delivery system that currently results in the periodic drying/low flows. We have not located any documented successful application of this technique, making it a highly experimental approach to enhancing fish productivity, particularly in a natural stream system. Highly experimental and unpredictable activities are generally discouraged as compensatory mitigation (40 CFR 230.93(a)(1); *see also* 73 FR 19633). The regulations also strongly discourage compensatory mitigation projects that require the long-term use of active engineering features (40 CFR 230.97(b)).

3.3.1.4.2 Augment Flows

Another means suggested for maintaining or increasing habitat productivity downstream of the mine site is to increase flow volume into certain streams by creating new sources of surface flow and/or groundwater recharge, specifically, from impoundments and/or ice fields. We are unaware of any documented successful efforts to create impoundments or ice fields for the benefit of salmonids. As described in the previous section, actions to maintain or reestablish pre-mine flow in streams likely would be required as avoidance or minimization measures, and would not constitute compensatory mitigation for unavoidable impacts.

Only if it were an overall enhancement to existing habitat would creating impoundments and/or ice fields have the potential for offsetting unavoidable adverse impacts. Thus, the objective would be to target stream reaches where flow-habitat modeling indicated opportunities for enhancement.

PLP’s EBD notes that a portion of the SFK mainstem, as well as some Koktuli River tributaries, exhibit either intermittent or ephemeral flow that appears to be a limiting factor for salmonid productivity (PLP 2011). However, two of the tributaries are in the uppermost reaches of the SFK and would be eliminated by the mine scenarios.

Although there are potential locations for impoundments to manage flow in the stream reaches identified as having ”sub-optimal” flow, logistical and environmental issues decrease the likely efficacy and sustainability of such an approach. Manipulating streamflows in particular watersheds would require diverting water from other basins or capturing water during peak flows for subsequent release at other times, with the concomitant engineering, construction, and maintenance challenges. Doing so would create additional adverse impacts from the construction of infrastructure and would be subject to modeling and perpetual management sufficient to ensure that water withdrawals from the “donor” watershed or from other times of the year would not adversely impact fish habitat and populations in its downstream waters. These concerns are in addition to those commonly associated with impoundments, such as alteration of flow, thermal, and sediment transport regimes.

Creating ice fields to increase the total volume of water available to a stream would also require water diversion, with the same challenges and concerns related to building and maintaining system infrastructure and reducing water volumes in the source watershed.

Using ice fields to change the timing of water availability would encounter issues related to managing the melt to produce stream flow at the intended time (i.e., late summer or late winter low-flow periods). Moreover, since aquatic organisms supported by a particular water body typically have evolved specific life history, behavioral, and morphological traits consistent with the characteristics of that water body's natural flow regime, local populations are inherently vulnerable to flow modification (Lytle and Poff 2004). Any use of ice fields would face the potentially substantial challenges of the effects of climate change on ice production and preservation. Besides requiring active management in perpetuity, ice field creation for flow augmentation would be decidedly experimental, with high uncertainty regarding the likelihood of success. Flow augmentation techniques would also be inconsistent with the regulation's provision that "[c]ompensatory mitigation projects shall be designed, to the maximum extent practicable, to be self-sustaining once performance standards have been achieved. This includes minimization of active engineering features…" (40 CFR 230.97(b)).

3.3.1.4.3 Pump Water Upstream

Another option suggested for making flow in some stream reaches more persistent is to pump groundwater or surface water from a down-gradient site upstream to either a direct release point or a recharge area. This technique has been used for fish habitat restoration at sites in the continental U.S. (e.g., the Umatilla River, OR (Bronson and Duke 2005), the Lower Owens River, CA (LADWP 2013), and Muddy Creek, CO (AECOM et al. 2010 and GrandRiver Consulting 2008)), although we are unaware of any documentation addressing its efficacy in increasing salmonid productivity. As with flow management and augmentation, using this technique to offset flow reductions from mine operations would not be compensatory mitigation, limiting its potential use as such to reaches that already have sub-optimal flow. One such stream is NFK 1.190.10, a tributary that enters NFK 1.190 downstream of the tailings storage facility location. Flow modeling, however, indicates that mine development would diminish flow in that stream even further (see Figures 7-15 through 7-17 of the assessment).

For the periodically intermittent or ephemeral reaches identified in the EBD, potential source sites presumably would be in or along the lower reaches of the NFK or SFK, downstream of the mine, waste rock, and tailings storage facilities. Flow modeling indicates that the NFK would experience a decrease in flow under the Pebble 6.5 scenario (see Figure 7-17 of the assessment), increasing the possibility that withdrawing additional water from the system to pump back upstream either would not be possible or would have adverse downstream impacts. Extensive modeling would be necessary to assess downstream effects in either watershed.

Even with sufficient downstream water, this technique would require substantial disturbance associated with the construction of tens of kilometers of water pipeline, power infrastructure, and access, along with maintenance of those facilities in perpetuity. It would also entail active management to ensure that releases occur at appropriate times, to increase the persistence of flow in target streams without otherwise adversely impacting their hydrographs or habitat. Such management would be another aspect of the approach that would be perpetual. In total, this technique would involve a great deal of uncertainty with regard to both efficacy and sustainability, making it a questionable mechanism for providing compensatory mitigation. This technique would also be inconsistent with the regulation's provision that "[c]ompensatory mitigation projects shall be designed, to the maximum extent practicable, to be self-sustaining once performance standards have been achieved. This includes minimization of active engineering features (e.g., pumps) and appropriate siting to ensure that natural hydrology and landscape context will support long-term sustainability" (40 CFR 230.97(b)).

3.3.1.5 Manipulate Water Quality

Two commenters suggested that alteration of stream water chemistry would improve fish production in the NFK, SFK and UTC. They suggest increasing two groups of water chemistry parameters: basic parameters such as alkalinity, hardness, and total dissolved solids, and nutrients such as nitrogen (N) and phosphorous (P). This argument suggests that low concentrations of basic parameters and/or nutrients limit the production of algae, which limits aquatic macroinvertebrate production and habitat complexity. This in turn can reduce overall fish production, reduce individual fish growth rates, or result in fish movements away from low production areas.

3.3.1.5.1 Increase Levels of Alkalinity, Hardness, and Total Dissolved Solids

Commenters propose that altering stream water chemistry to increase levels of alkalinity, hardness, and total dissolved solids would improve the buffering capacity, primary productivity, secondary productivity, and reduce the potential toxicity of metals at waters downstream of these altered locations. Commenters suggest two mechanisms to achieve these improvements: 1) the addition of limestone in some form at "appropriate" locations or 2) the discharge of higher alkalinity water into fish-producing streams through a water management program. Commenters argue that current levels of alkalinity, hardness, and total dissolved solids in the NFK, SFK and UTC are suboptimal for fish production and could be manipulated to improve fish production. However, the majority of the literature relating to alkalinity and limestone management, including every published study cited by commenters, evaluates these approaches in streams and lakes in northern Europe, eastern U.S., or eastern Canada whose fisheries have been heavily impacted by acid mine drainage, acid deposition or other mechanisms of acidification and even in these degraded water bodies, alkalinity/limestone treatment results were variable (Gunn and Keller 1984, Hasselrot and Hultberg 1984, Rosseland and Skogheim 1984, Zurbuch 1984, Gagen et al. 1989, Lacroix 1992, Clayton et al. 1998, McClurg et al. 2007). It is not clear from any of the published studies cited by commenters what effect the addition of limestome or higher alkalinity water would have on the kinds of unaltered stream systems and fishery resources found in the Bristol Bay region of Alaska.

Alkalinity has two potential roles. First, it is a measure of the ability of water to neutralize acids. If the intent is to neutralize acid rock drainage from the potential mine, that use constitutes impact minimization or remediation, not compensation. Second, alkalinity is primarily due to carbonate and bicarbonate, which is the source of carbon used by aquatic algae so increasing alkalinity is potentially fertilization. However, given that the streams at the site are relatively shallow and rapidly flowing, it is very unlikely that they are carbon limited. Therefore, it is unlikely that increasing alkalinity would increase algal production unless it is neutralizing acids from a mine.

Similar considerations apply to increasing hardness. Aqueous hardness is due to calcium and magnesium, which reduce the toxicity of divalent metals such as copper by competing for uptake sites. Increasing hardness would be a potential means of remediating the effects of high metal levels drainage from mine waste leachate into streams. Alternatively, calcium and magnesium are nutrient elements and hypothetically could be limiting production. However, the commenters produce no evidence that such limitations are occurring, and it is less credible than the potential N and P limitations discussed in the next section.

Manipulating water chemistry could have a deleterious effect on salmon populations. A key characteristic of Pacific salmon is their homing migrations from oceanic feeding grounds, through diverse habitats, to their natal river to spawn. Homing is generally precise and has resulted in reproductively isolated spawning populations with specialized adaptations for their natal habitat. (Wisby and Hasler 1954, Hasler and Scholz 1983, Quinn and Dittman 1992, Dittman et al. 1995, Dittman and Quinn 1996). Olfactory systems of salmon are acutely sensitive to changes in water chemistry (McIntyre et al. 2012). Physiological and behavioral experiments demonstrate that calcium is an important odorant enabling salmon to recognize individual waters and that sockeye salmon olfactory systems are acutely sensitive to calcium ions (Bodznik 1978). This would suggest that manipulating stream chemistry through the addition of limestone or higher alkalinity water could impede salmon from recognizing and homing to their natal streams. Some commenters who raised concerns about manipulating stream chemistry through these approaches point out that homing failure could reduce productivity if salmon die without spawning or stray to non-natal habitats to which they are poorly adapted and experience higher mortality.

We are not aware of any published studies describing projects where the chemistry of unaltered/un-degraded salmon streams in Alaska or elsewhere has been manipulated through the addition of limestone or higher alkalinity water to achieve improvements in buffering capacity against natural acidity, increase primary or secondary productivity, or reduce toxicity to naturally occurring metals. Rather, the scientific literature suggests that such chemical alterations could result in deleterious effects on salmon in unaltered/un-degraded stream systems. Manipulating stream chemistry in the NFK, SFK and UTC through the addition of limestone or higher alkalinity water would be a challenging and difficult experiment with an unknown outcome.

3.3.1.5.2 Increase Levels of Nitrogen and/or Phosphorus

The same two commenters suggest altering stream water chemistry to increase levels of N and P where they are individually or co-limiting. They provide four categories of considerations for determining how to increase stream or lake nutrients:

1) The spatial and temporal distribution of the limiting nutrients,
2) The timing and duration of nutrient application(s),
3) The desired concentrations of each nutrient and the ratio between N and P for each application location, and
4) The need for detailed pre-project information including the biological species composition of the waterbody and a low level nutrient analysis.

The commenters make a few general recommendations about how to consider these factors when developing mitigation in the NFK, SFK and UTC. They suggest that the spatial distribution could focus on existing or newly created side channels, sloughs, beaver ponds, alcoves, or, if necessary, the main channels at 10 km intervals. They suggest several possible temporal distribution options; of adding the nutrients only during the growing season, potentially earlier, or all winter in open water locations where biological production continues year round. They further indicate that the key considerations are access cost and maintenance requirements. The commenters note several types of nutrient delivery methods: liquid fertilizer, slow-release fertilizer, and nutrient analogs (which are essentially slow-release pellets of processed fish).

As support for their conclusion that lake and stream fertilization represent "demonstrably successful mitigation techniques" for the NFK, SFK and UTC, the commenters cite a number of papers summarizing experiments and case studies, as well as references to several management programs in the U.S., Canada, and northern Europe. These studies have examined the use of increased levels of N and P, or fish carcasses, to improve ecosystem productivity and/or fish production.

The two commenters argue that current levels of N and P in the NFK, SFK and UTC are suboptimal for fish production stating that benefits of fertilizing oligotrophic waters to stimulate fish production have been demonstrated in many venues. Although numerous studies show an effect at one or more trophic levels in response to fertilization, these studies are insufficient for drawing conclusions regarding the long-term effectiveness of nutrient application to streams in the NFK, SFK and UTC watersheds because they lack scientific controls or have not been replicated, do not account for potential confounding factors, were conducted in very different ecosystems, and/or only evaluated short-term effects. These differences are pointed out in the following paragraphs.

Commenters provided examples of experiments and studies aimed at increasing primary productivity and theoretically salmon productivity. These studies assume that nutrients are the limiting factor preventing increased salmon productivity, but that is not necessarily the case. Paleolimnetic studies in Alaska indicate nutrient inputs are not always tied to higher primary productivity or salmon productivity (Chen et al 2011). Wipfli and Baxter (2010) found that most fish consume food from external or very distant sources, including from marine systems borne by adult salmon, from fishless headwaters that transport prey to downstream fish, and from riparian vegetation and associated habitats. An increase in food via nutrients may not overcome other limiting factors such as habitat availability or interspecies competition.

Most studies on stream and lake fertilization to increase productivity are short-term in duration and conducted in ecosystems with important differences from Bristol Bay (e.g. Perrin et al. 1987, Raastad et al. 1993, Wipfli et al. 1998, Slaney et al. 2003). For example, studies conducted at the Keogh and Salmon Rivers (Ward et al. 2003, Slaney et al. 2003) examined the effect of nutrient supplement in the form of salmon carcasses and inorganic N and P, respectively, in two coastal river systems for a period of three years. A spike in productivity has been seen in a number of these studies, but long term studies call into question whether the trend will be sustained over longer periods as is described in the following two long-term studies.

Results from the longest running study on stream fertilization raise concerns about using fertilization other than as an interim restorative measure. Slavik et al (2004) found that persistent increased levels of N and P can result in dramatic ecosystem shifts. This long term ecological research on the North Slope of Alaska examined the effect of P input into P-limited streams, finding an increase in production for some species at all trophic levels over the first few years. However, starting at seven or eight years, nutrient enrichment caused a dramatic rise in moss (photos A and B) that changed ecosystem structure. Despite higher insect biomass in the fertilized area during this period, the growth of fish was no longer significantly greater than in the reference area (Slavik et al. 2004). The resulting decrease in fish productivity was thought to result from the effects of moss on preferred insect prey. Following cessation of nutrient enrichment, it took eight years of recovery to approach reference levels, after storms had scoured most remnant moss in the recovering reach. These results demonstrate that even at low concentrations, sustained nutrient enrichment can have “dramatic and persistent consequences” (Benstead et al. 2007).

Photos showing the difference in bottom coverage between the diatom state (Photo A, left) and the fertilized moss state (Photo B, right). Used with permission (Slavik et al.).

In another study, long-term nutrient enrichment produced an unanticipated trophic decoupling whereby enrichment continued to stimulate primary consumer production without a similar increase in predator fish. The majority of the increased ecosystem productivity was confined to lower trophic levels because the long-term enrichment primarily stimulated primary consumers that were relatively resistant to predation. Based on these results, the authors concluded that "even in ecosystems where energy flow is predicted to be relatively efficient, nutrient enrichment may still increase the production of non-target taxa (e.g. predator or grazer resistant prey), decrease the production of higher trophic levels, or lead to unintended consequences that may compromise the productivity of freshwater ecosystems" (Davis et al. 2010 p 124).

These unanticipated results raise important questions about the potential consequences of long-term nutrient supplementations. They also underscore the unpredictability of nutrient additions on the food web, and the greater likelihood of unintended consequences as the effects ripple through complex interactions between species. These implications are especially relevant considerations for potential long-term mitigation that would be necessary in the NFK, SFK and UTC. If long-term nutrient addition were to cause an ecosystem shift at lower trophic levels in the NFK, SFK and UTC, effects on higher trophic levels including the productivity of salmon and other target fish species are unknown.

Studies examining the relationship between salmon carcasses and productivity at various trophic levels are another active area of investigation. Some research provides evidence that carcasses are superior to inorganic nutrient amendments for sustaining and restoring stream productivity, including fish production, potentially because inorganic nutrients lack biochemicals and macromolecules that are utilized directly by consumers (Wipfli et al. 2010, Martin et al. 2010, Heintz et al. 2010). Others have found the effects of carcasses can be transient, localized, and variable with no increase in fish growth (Cram et al. 2011). Few studies have documented the long-term impacts of carcass addition, and there are many remaining gaps in understanding the efficacy of this method of potentially improving salmon productivity. In addition, a number of authors express concern about the potential for the spread of toxins and pathogens when carcasses are used as the supplemental nutrient source (Compton et al. 2006).

Setting aside questions of scientific efficacy and applicability, there are numerous practical challenges inherent in nutrient addition as a potential mitigation method. Conducting a long-term management protocol in remote waterways subject to extreme weather changes necessarily requires careful monitoring of water chemistry and precise application of nutrients, which calls into question the sustainability of altering stream water chemistry to improve the fish production.

Authors of many of these studies state that the application of their results are relevant and appropriate for salmonid restoration in streams or lakes with depressed numbers (Larkin and Slaney 2011). The authors do not describe their results as informing methods to manipulate existing unaltered wild systems to further augment salmon production. Although the commenters draw heavily from Ashley and Stockner (2003), the authors of that study actually state:

> "The goal of stream and lake enrichment is to rebuild salmonid escapement to historical levels via temporary supplementations of limiting nutrients using organic and/or inorganic formulations. Stream and lake enrichment should not be used as a 'techno-fix' to perpetuate the existing mismanagement of salmonids when there is any possibility of re-establishing self-sustaining wild populations through harvest reductions and restoration of salmonid habitat. Therefore, fertilization should be viewed as an interim restorative measure that is most effective if all components of ecosystem recovery and key external factors (e.g. overfishing) are cooperatively achieved and coordinated. This paper reviews some of the technical and more applied aspects of stream, river, and lake enrichment as currently practiced in British Columbia and elsewhere. As a caveat, the discussion assumes that salmonid stock status of candidate lakes and streams has been quantified and classified as significantly depressed and that additional limiting factors (e.g. habitat/water quality and quantity) have been addressed and/or incorporated into an integrated basin or lake restoration plan." (Ashley and Stockner 2003 p. 246)

There are still many gaps in understanding the role of nutrients in fish productivity, so there is a great deal we do not know about whether nutrient addition can be a successful method to increase fish productivity. At this time there are no scientific studies showing how an increase in nutrients resulting in increase salmon productivity can be reliably achieved on a long-term basis in the NFK, SFK and UTC watersheds or the larger Bristol Bay ecosystem without risk to the region's existing robust populations. Just as for the addition of non-nutrients such as limestone, manipulating stream chemistry in this largely unaltered ecosystem through the addition of N and P would be a challenging and difficult experiment with many negative outcomes possible.

3.3.1.6 Preserve Aquatic Resources

As described above, preservation as compensatory mitigation for the mine scenarios would require a site that is very large, performs similarly important aquatic functions, and is under threat of destruction or adverse modification. No commenters identified specific potential preservation sites, either within these watersheds or elsewhere in Bristol Bay. One challenge in identifying appropriate preservation sites is the high percentage of state and federal land ownership in the area. Public lands can provide mitigation, but only if the mitigating measure—in this case, preservation—is "over and above [that] provided by public programs already planned or in place" (40 CFR 230.93(a)(3)). Further, the aquatic functions of any preservation site downstream from the proposed mine scenarios would be subject to degradation from the direct, secondary, and cumulative effects of the mine itself. These factors could limit most properties of adequate area and similar aquatic function from serving as acceptable mitigation sites. Moreover, there is no precedent for such a preservation-dominated compensation approach in the context of this type and magnitude of ecological loss.

3.3.2 Other Opportunities within the Nushagak and Kvichak River Watersheds

As noted above, if practicable or appropriate opportunities to provide compensation within the NFK, SFK or UTC watersheds are non-existent or limited, it may be appropriate to explore options in adjoining watersheds. For example, there are a few scattered degraded sites in more distant portions of the Nushagak and Kvichak River watersheds that could potentially benefit from restoration or enhancement.

Here we discuss specific suggestions for other potential compensation measures within the Nushagak and Kvichak River watersheds that were provided in the public and peer review comments on the Bristol Bay Assessment.

3.3.2.1 Remediate Old Mine Sites

The U.S. Geologic Survey (USGS) identifies four small mine sites within the Nushagak and Kvichak River watersheds: Red Top (in the Wood River drainage), Bonanza Creek (a Mulchatna River tributary), Synneva or Scynneva Creek (a Bonanza Creek tributary), and Portage Creek (in the Lake Clark drainage) (USGS 2008, 2012). These sites could provide opportunities for performing ecological restoration or enhancement. However, due to their relatively small size and distant location, it is unlikely that these sites could provide sufficient restored or enhanced acreage or ecological function to offset what would be lost under the assessment mine scenarios. Further, some mitigation measures have already occurred at these mines; for example, there have been some remediation activities at Red Top mine, although traces of mercury and diesel-range organics remain in soils (BLM 2000). Resolution of liability and contamination issues at these old mines would be necessary before they could serve as compensatory mitigation sites for other projects.

3.3.2.2 Remove Roads

Another potential type of restoration within the Nushagak and Kvichak River watersheds is the removal of existing or abandoned roads. As described in detail in Appendix G of the assessment, roads have persistent, multifaceted impacts on ecosystems and can strongly affect water quality and fish habitat. Common long-term impacts from roads include: 1) permanent loss of natural habitat; 2) increased surface runoff and reduced groundwater flow; 3) channelization or structural simplification of streams and hydrologic connectivity; 4) persistent changes in the chemical composition of water and soil 5) disruption of movements of animals, including fishes and other freshwater species; 6) aerial transport of pollutants via road dust; and 7) disruption of near-surface groundwater processes, including interception or re-routing of hyporheic flows, and conversion of subsurface slope groundwater to surface flows (Darnell et al. 1976, Trombulak and Frissell 2000, Forman 2004). Road removal, thus, could facilitate not only the reestablishment of former wetlands and stream channels, but also the enhancement of nearby aquatic resources currently degraded by the road(s).

Commenters did not offer specific suggestions for potential road removal sites. As Appendix G of the assessment highlights, the Nushagak and Kvichak River watersheds are almost entirely roadless areas (see Figure 1 of Appendix G). Further, it is unlikely that local communities would support removal of any segments of the few existing roads in the watersheds. Thus, it would appear there are very few, if any, viable opportunities to provide environmental benefits through road removal.

3.3.2.3 Retrofit Road Stream Crossings

Another potential type of enhancement within the Nushagak and Kvichak River watersheds is to retrofit existing road stream crossings to improve fish passage through these man-made features. Stream crossings can adversely impact spawning, rearing (Sheer and Steel 2006, Davis and Davis 2011), and refuge habitats (Price et al. 2010), as well as reduce genetic diversity (Wofford et al. 2005, Neville et al. 2009). These changes can in turn reduce long-term sustainability of salmon populations (Hilborn et al. 2003, Schindler et al. 2010). Blockage or inhibition of fish passage is a well-documented problem commonly associated with declines in salmon and other fish populations in many regions of the U.S. (Nehlsen et al. 1991, Bates et al. 2003), including Alaska (ADFG 2012b).

Removing and replacing crossings that serve as barriers to fishes could improve fish passage and re-open currently inaccessible habitat. However, as noted in Section 3.3.2.2, the Nushagak and Kvichak River watersheds are almost entirely roadless areas, and thus offer few, if any, viable opportunities to provide the extent of environmental benefits necessary to offset the magnitude of impacts associated with the mine scenarios and associated development. Further, prior to concluding that any effort to retrofit existing stream crossings would be appropriate compensatory mitigation, it would first be necessary to determine that no other party has responsibility for the maintenance of fish passage at those stream crossings (e.g., through the terms or conditions of a Section 404 permit that authorized the crossing).

3.3.2.4 Construct Hatcheries

One commenter referenced the potential use of hatcheries as a compensation measure. Such a proposal could be very problematic, particularly in the context of Bristol Bay, where the current salmon population is entirely wild. There are several concerns over the introduction of hatchery-produced salmon to the Bristol Bay watershed, best expressed by the National Oceanic and Atmospheric Administration's Northwest Fisheries Science Center:

> "Over the past several decades, wild salmon populations have declined dramatically, despite, and perhaps sometimes because of, the contribution of hatcheries. Many salmon stocks in Washington and Oregon are now listed as either threatened or endangered under the U.S. Endangered Species Act. With this decline has come an increased focus on the preservation of indigenous wild salmon stocks.
>
> Hatcheries have the potential to assist in the conservation of wild stocks, but they also pose some risks. At this time, scientists still have many questions about the extent to which hatchery programs enhance or threaten the survival of wild populations. Additional research and investigation is needed." (NOAA 2012)

Many of the potential risks associated with fish hatcheries concern reductions in fitness, growth, health, and productivity that result from decreases in genetic diversity when hatchery-reared stocks hybridize with wild salmon populations. Hatchery-raised salmon have lower genetic diversity than wild salmon (Christie et al. 2011, Yu et al. 2012). Consequently, when hatchery-raised salmon hybridize with wild salmon, the result can be a more genetically homogenous population, leading to decreases in genetic fitness (Waples 1991). In some cases, wild populations can become genetically swamped by hatchery stocks. Zhivitovsky et al. (2012) found evidence of such swamping in a wild chum salmon population in Kurilskiy Bay, Russia during a two-year period of high rates of escaped hatchery fish. This genetic homogenization is of concern because hatchery-raised fish stocks are considered less genetically "fit" and therefore could increase the risk of collapse of salmon fisheries. This concern is supported by Araki et al. (2008), a review of 14 studies which suggests that nonlocal hatchery stocks reproduce very poorly in the wild. The authors of this review also found that wild stocks reproduce better than both hatchery stocks and wild, local fish spawned and reared in hatcheries.

Hatchery fish can also compete directly for food and resources with wild salmon populations in both freshwater and marine environments (Rand et al. 2012a). Ruggerone et al. (2012) examined the effect that Asian hatchery chum salmon have had on wild chum salmon in Norton Sound, Alaska since the early 1980s. They found that an increase in adult hatchery chum salmon abundance from 10 million to 80 million adult fish led to a 72% reduction in the abundance of the wild chum salmon population. They also found smaller adult length-at-age, delayed age-at-maturation, and reduced productivity were all associated with greater production of Asian hatchery chum since 1965 (Ruggerone et al. 2012). In addition to this competition for resources, hatchery-raised subyearling salmon can also prey upon wild subyearling salmon, which tend to be smaller in size (Naman and Sharpe 2012).

Despite extensive efforts to restore federally listed Pacific Northwest salmon populations, they remain imperiled, and hatchery fish stocks may be a contributing stressor (Kostow 2009). Given the exceptional productivity of the wild Bristol Bay salmon population, hatcheries would appear to pose greater ecological risks than benefits to this unique and valuable wild salmon population.

3.3.2.5 Stock Fish

Since many of the fish used in fish stocking originate in hatcheries, fish stocking raises many of the same concerns as hatcheries and thus would also be a problematic form of compensatory mitigation for the Bristol Bay region. Although stocking has been a common practice in other regions, even in previously fishless habitats (e.g., Red Dog Mine, Alaska), a large body of literature describes widespread adverse impacts of such management decisions. Fish stocking throughout western North America and worldwide has impacted other fish (Knapp et al. 2001, Townsend 2003), nutrient cycling (Schindler et al. 2001, Eby et al. 2006, Johnson et al. 2010), primary production (Townsend 2003, Cucherousset and Olden 2011), aquatic macroinvertebrates (Dunham et al. 2004, Pope et al. 2009 Cucherousset and Olden 2011), amphibians (Pilliod and Peterson 2001, Finlay and Vredenberg 2007), and terrestrial species (Epanchin et al. 2010). Although fish stocking has provided limited benefits in certain circumstances, it would appear from the growing body of literature that the ecological costs of fish stocking far outweigh any potential benefits.

3.4 Other Suggested Compensation Measures

Comments also included suggestions that compensatory mitigation for impacts to fish and other aquatic resources could take the form of making payments to organizations that support salmon sustainability or investing in various public education, outreach, or research activities designed to promote salmon sustainability. Although these kinds of initiatives can provide benefits in other contexts, compensatory mitigation for impacts authorized under Section 404 of the Clean Water Act can only be provided through purchasing credits from an approved mitigation bank or in-lieu fee program or conducting permittee-responsible compensatory mitigation projects (40 CFR 230.92). One commenter also suggested reducing commercial fishery harvests to compensate for fish losses due to large-scale mining; however, such a measure would also be inconsistent with the definition of compensatory mitigation (40 CFR 230.92).

4. Effectiveness of Compensation Measures at Offsetting Impacts to Salmonids

In North America, 73% of fish extinctions are linked to habitat alterations (Miller et al. 1989). Although extensive efforts have been undertaken to create or improve salmon habitat and prevent losses to fisheries, the current status of U.S. salmon is a sobering testament to the billions spent on mitigation efforts given that all U.S. Atlantic salmon populations are endangered (NOAA 2013), 40% of Pacific salmon in the Lower 48 are extirpated from historic habitats (NRC 1996), and one third of remaining populations are threatened or endangered with extinction (Nehlsen et al. 1991, Slaney et al. 1996, Gustafson et al. 2007). Approximately one third of sockeye salmon population diversity is considered endangered or extinct (Rand et al. 2012b), and Bristol Bay sockeye salmon likely represent the most abundant diverse sockeye salmon populations left in the U.S.

Since 1990, a billion dollars has been spent annually in the U.S. on stream and watershed restoration (Bernhardt et al. 2005) and more than 60% of the projects completed during this period were associated with salmon and trout habitat restoration efforts in the Pacific Northwest and California (Katz et al. 2007). Despite the proliferation of projects and the significant funds being expended on these efforts, debate continues over the effectiveness of various fish habitat restoration techniques and the cumulative impact of multiple, poorly coordinated restoration actions at a watershed or regional scale (Reeves et al. 1991, Chapman 1996, Roni et al. 2002, Kondolf et al. 2008). Further, independent evaluations of the effectiveness of fish habitat compensation projects are rare (Harper and Quigley 2005b, Quigley and Harper 2006a, Quigley and Harper 2006b), and consequently the long-term success rates and efficacy of such projects are not well known (DFO 1997, Lister and Bengeyfield 1998, Lange et al. 2001, Quigley and Harper 2006a). A recent study by Roni et al. (2010) clearly questions the efficacy of mitigation to specifically offset salmon losses.

The most comprehensive investigation, to date, of the efficacy of fish habitat mitigation measures was conducted by the Department of Fisheries and Oceans, Environment Canada (Harper and Quigley 2005a, Harper and Quigley 2005b, Quigley and Harper 2006a, Quigley and Harper 2006b). Quigley and Harper (2006a) showed that 67% of compensation projects resulted in net losses to fish habitat and only 2% resulted in no net loss, whereas only 31% achieved a net gain in habitat area. Quigley and Harper (2006a) concluded that habitat compensation in Canada was, at best, only slowing the rate of fish habitat loss. Quigley and Harper (2006b) showed that 63% of projects resulted in net losses to aquatic habitat productivity and only 25% achieved no net loss, whereas only 12% provided net gains in aquatic habitat productivity. Quigley and Harper (2006b) concluded "the ability to replicate ecosystem function is clearly limited."

Quigley and Harper (2006b) highlight the need for improvements in compensation science as well as institutional approaches such as better project planning, monitoring, and maintenance. However, they also recognize that, based on decades of experience in wetland replacement projects, simply achieving compliance with all regulatory requirements does not ensure that ecological functions are replaced (NRC 2001, Sudol and Ambrose 2002, Ambrose and Lee 2006, Kihslinger 2008). Although there are clearly opportunities to improve the performance of fish habitat compensation projects, Quigley and Harper (2006b) caution:

> "it is important to acknowledge that it is simply not possible to compensate for some habitats. Therefore, the option to compensate for HADDs [*harmful alteration, disruption or destruction to fish habitat*] may not be viable for some development proposals demanding careful exploration of alternative options including redesign, relocation, or rejection."

5. Conclusions

There are significant challenges regarding the potential efficacy, applicability and sustainability of compensation measures proposed by commenters for use in the Bristol Bay region, raising questions as to whether sufficient compensation measures exist that could address impacts of the type and magnitude described in the Bristol Bay Assessment. The mine scenarios evaluated in the assessment show that the mine footprint alone would result in the loss (i.e., filling, blocking or otherwise eliminating) of hundreds to thousands of acres of high-functioning wetlands and tens of miles of salmon-supporting streams. In addition to these direct losses, these mine scenarios would also result in extensive adverse secondary and cumulative impacts to wetlands, streams, and fish that would have to be addressed. Such extensive habitat losses and degradation could also result in the loss of unique salmon populations, eroding the genetic diversity essential to the stability of the overall Bristol Bay salmon fishery.

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