Fishery Management Past and Present: Updating the Management of Impacts on ESA-Listed Fish Species Using Genetic Stock Identification Tools In-Season to Validate Pre-Season Fishery Model Predictions

by

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ABSTRACT

Fishery Management Past and Present: Updating the Management of Impacts on ESA-Listed Fish Species Using Genetic Stock Identification Tools In-Season to Validate Pre-Season Fishery Model Predictions

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The Washington Department of Fish and Wildlife, pursuant to North of Falcon agreements made under the Pacific Salmon Treaty, monitors annual impacts on ESA-listed Puget Sound Chinook salmon populations during fisheries held in Washington State waters. A Fishery Regulation Assessment Model, or FRAM, is used by fishery managers to predict and assess harvest-related impacts on ESA-listed Puget Sound Chinook salmon stocks. Yet, beginning in 1998 genetic analysis was used to estimate stock-specific fishery impacts independent of the standard management regime, FRAM. In-season genetic samples from Puget Sound Chinook salmon captured as bycatch were obtained from the sockeye directed purse seine fishery in Marine Areas 7 and 7A, the Chinook directed recreational fishery in Marine Area 7 and the Chinook directed gill net fishery in Marine Areas 7B and 7C. The processing of these samples using genetic stock identification (GSI) techniques allowed fishery managers to report on the actual stocks present and impacted in those fisheries. Since 1998 genetic samples were obtained in 2006 from Marine Areas 7 and 7A purse seine and recreational fisheries and from these fisheries again in 2007, with the addition of gill net samples from Marine Areas 7B and 7C. These in-season samples were processed using GSI and compared to pre-season FRAM stock impact predictions. Results from the 2007 Marine Area 7 and 7A net fishery demonstrate how FRAM pre-season predictions of stock impacts can be very different from how this fishery functions in-season. FRAM predicted over 61% of that fishery's Chinook salmon mortality would be of Puget Sound origin. GSI data indicated a 4% total contribution from Puget Sound Chinook salmon. Additionally, fisheries in Marine Areas 7 and 7A have historically been managed together. These two fishing areas are geographically isolated from each other by the San Juan Islands. The frequency of Chinook salmon observed during commercial fisheries in these two distinct geographical locations from 1997 through 2007 were found to differ significantly through statistical analysis, which may suggest that a different management strategy may be needed to more thoroughly monitor the needs of ESA-listed stocks in these two areas.

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1 Introduction

Puget Sound Chinook salmon were listed under the Endangered Species Act (ESA) as a threatened species on March 24, 1999. Their threatened status was reaffirmed on June 28, 2005. The evolutionarily significant units (ESU) included in this listing encompass all naturally spawned populations of Chinook salmon from rivers and streams flowing into Puget Sound including the Straits of Juan De Fuca from the Elwha River, eastward, including rivers and streams flowing into Hood Canal, South Sound, North Sound and the Strait of Georgia in Washington, as well as twenty-six artificial propagation programs.

Washington State Department of Fish and Wildlife (WDFW) fishery managers currently use a tool called a fishery regulatory assessment model (FRAM) to predict a yearly cap on incidental mortalities of ESA-listed salmon stocks during fisheries targeting other species. Specifically, in this paper, FRAM is used to assess the mortality of ESA-listed Puget Sound Chinook salmon stocks encountered as bycatch during fall commercial sockeye and pink fisheries in WDFW Marine Areas 7 and 7A**.** In 2007 FRAM estimated over 61% mortality on Puget Sound Chinook salmon stocks (Blankenship 2007). However, DNA analysis of fin clip samples of Chinook salmon obtained from vessels during fall sockeye and pink fisheries revealed a 4% confirmed Puget Sound Chinook presence in the fishery. Therefore, I plan to explore in this paper how the sole use of FRAM, which WDFW fishery managers currently use, to estimate Puget

Sound Chinook salmon bycatch mortality in Areas 7 & 7A, is in need of some examination.

Additionally, WDFW Marine Area 7 is located in very near proximity to the San Juan Islands Salmon Preserve (Figure 7) and several Marine Protected Areas. Marine Area 7 is also located at the southern most tip of the San Juan Islands. As adult salmonids of Puget Sound origin return to their natal streams to spawn this area is the last possible open water location for their interception by the United States commercial fishing fleet before reaching fresh water. WDFW Observer data collected during fisheries from 1991 through 2007 suggests that the frequency of Chinook salmon observed in Marine Area 7 during commercial fisheries is lower than in 7A. I would like to argue here in this paper that managing Area 7 & 7A together may not be the best strategy, and demonstrate why not.

Incorporating genetic information into the management of ESA-listed Chinook salmon is highly necessary to offer a more accurate picture of the status of these threatened stocks (OSU 2008). In January of 2006 the Salmon Spawning and Recovery Alliance, Washington Trout, the Native Fish Society and the Clark-Skamania Fly fishers sent a letter of notification to the National Oceanic and Atmospheric Administration (NOAA) asking them to "reinitiate ESA-consultation on the Puget Sound Comprehensive Chinook Management Plan: Harvest Management Component, a Resource Management Plan, or RMP, that was co-developed by the state and tribes for fisheries affecting Puget Sound Chinook salmon (Beardslee 2006). They believed that incidental mortality rates on Chinook salmon from listed and highly threatened ESU's were still too high. The data collected and modeled for mortality on these listed, and considered weak stocks thus far have had great variation. Estimated mortality of listed Chinook salmon stocks either directly, or indirectly has been between 22%-76% annually (Beardslee 2006). If this estimated range of mortality, which is provided to NOAA, does fall within the actual range of mortality experienced by these weak stocks, then certainly these estimates should be cause for alarm. If FRAM has been over predicting mortality on listed Puget Sound Chinook salmon ESUs, then unnecessary lawsuits such as the one mentioned above will continue to happen. Additionally, lawsuits such as these might not be the best way to approach the problem. Conversely, if the mortality estimates provided by the use of FRAM are underestimating the actual impacts on weak and federally listed stocks then it will be very difficult to monitor, as mandated by the ESA, exactly what is happening to stocks listed for protection. Making adjustments to the current FRAM could result in producing more accurate estimates for mortality of ESA-listed Puget Sound Chinook salmon ESUs, and fishery managers would be able to provide those working to recover weak stocks actual information on how well these stocks are rebounding. This paper will use the preferred combination of direct and indirect methods of study, as suggested in Iverson (1996) to examine fishery modeling limitations through a comparison to actual GSI sampling data.

The goal of this paper is to 1) make a compelling argument in favor of a revision of the current standard management regime of the WDFW, the sole use of FRAM modeling pre-season to estimate mortality of ESA-listed Puget Sound

Chinook salmon stocks encountered during commercial fisheries in Marine Areas 7 & 7A, and 2) demonstrate how different the Chinook salmon bycatch frequencies have been consistently over the last ten years between Area 7 & 7A, making the case that these two areas should be managed separately.

1.1 The Endangered Species Act

> "Nothing is more priceless and more worthy of preservation than the rich array of animal life with which our country has been blessed."
>
> — *President Nixon*, upon signing the Endangered Species Act

The Endangered Species Act of 1973 (ESA) was signed on December 28, 1973, and provides for the conservation of species which are endangered, or threatened throughout all or a significant portion of their range, and the conservation of the ecosystems on which they depend. The ESA replaced the Endangered Species Conservation Act of 1969; it has been amended several times. A species is defined as "endangered" if it is in danger of extinction throughout all or a significant portion of its range. A species is defined as "threatened" if it is likely to become an endangered species within the foreseeable future.

There are approximately 1,880 species listed under the ESA. Of these species, approximately 1,310 are found in part or entirely in the United States and its waters. NOAA's National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) share responsibility for implementing the ESA. The USFWS manages land and freshwater species, and NMFS manages marine and "anadromous" species. Currently NMFS has jurisdiction over approximately 60 listed species (NOAA 2008).

1.2 The History of Puget Sound Chinook Salmon ESA Listings

Scientists estimate nearly 1,383 genetically-isolated Pacific salmon populations once spawned from California to southern British Columbia. However, due to dam building and other alterations of lakes and rivers, 406 or 29% of the salmon populations have become extinct in the last 240 years (Osborn 2008).

Table 1

Common Name	**Scientific Name**	**Extinct**	**Surviving**
Steelhead	*Oncorhynchus mykiss*	131	436
Chinook	*Oncorhynchus tshawytscha*	159	237
Sockeye	*Oncorhynchus nerka*	34	38
Coho	*Oncorhynchus kisutch*	50	135
Chum	*Oncorhynchus keta*	23	89
Pink	*Oncorhynchus gorbuscha*	9	42

Table 1. Number of populations of each Pacific salmon species that are extinct or still surviving in California, Nevada, Oregon, Washington, Idaho and southern British Columbia. (Osborn 2008).

As previously mentioned, Puget Sound Chinook salmon were listed as a threatened species on March 24, 1999; their threatened status was reaffirmed on June 28, 2005. An evolutionarily significant unit, or ESU, of Pacific salmon is considered to be a "distinct population segment" and thus a "species" under the Endangered Species Act. The threatened Puget Sound ESU includes all naturally spawned populations of Chinook salmon from rivers and streams flowing into Puget Sound including the Straits of Juan De Fuca from the Elwha River, eastward, including rivers and streams flowing into Hood Canal, South Sound, North Sound and the Strait of Georgia in Washington, as well as twenty-six artificial propagation programs which encompass: the Kendal Creek Hatchery, Marblemount Hatchery (fall, spring yearlings, spring sub-yearlings, and summer run), Harvey Creek Hatchery, Whitehorse Springs Pond, Wallace River Hatchery (yearlings and sub-yearlings), Tulalip Bay, Issaquah Hatchery, Soos Creek Hatchery, Icy Creek Hatchery, Keta Creek Hatchery, White River Hatchery, White Acclimation Pond, Hupp Springs Hatchery, Voights Creek Hatchery, Diru Creek, Clear Creek, Kalama Creek, George Adams Hatchery, Rick's Pond Hatchery, Hamma Hamma Hatchery, Dungeness/Hurd Creek Hatchery, and the Elwha Channel Hatchery Chinook hatchery programs (NOAA 2008).

Over the past several decades, wild populations of salmon throughout the West Coast have declined to dangerously low levels. In 1991 NMFS began a series of comprehensive status reviews of salmon populations throughout Washington, Oregon, Idaho, and California. Ten of the seventeen West Coast Chinook salmon ESUs, including the Puget sound Chinook ESU, have been listed as endangered or threatened under the ESA (Table 2). The locations of watersheds from which the ESA-listed Chinook salmon ESUs originate are such that 53%, or roughly 30 miles, of riparian habitat immediately inland from the Puget Sound and surrounding the natal freshwater rivers and streams is owned privately (Figure 1). Privately owned land is the most difficult to regulate and monitor for habitat and fish population health and species recovery (NOAA 2008).

Table 2

Endangered Species Act Status of West Coast Salmon & Steelhead

(Updated Feb. 26, 2008)

Species[1]			*Endangered Species Act Listing Status*[2]	*ESA Listing Actions Under Review*
Sockeye Salmon (*Oncorhynchus nerka*)	1	Snake River	*Endangered*	
	2	Ozette Lake	*Threatened*	
	3	Baker River	*Not Warranted*	
	4	Okanogan River	*Not Warranted*	
	5	Lake Wenatchee	*Not Warranted*	
	6	Quinalt Lake	*Not Warranted*	
	7	Lake Pleasant	*Not Warranted*	
Chinook Salmon (*O. tshawytscha*)	8	Sacramento River Winter-run	*Endangered*	
	9	Upper Columbia River Spring-run	*Endangered*	
	10	Snake River Spring/Summer-run	*Threatened*	
	11	Snake River Fall-run	*Threatened*	
	12	Puget Sound	*Threatened*	
	13	Lower Columbia River	*Threatened*	
	14	Upper Willamette River	*Threatened*	
	15	Central Valley Spring-run	*Threatened*	
	16	California Coastal	*Threatened*	
	17	Central Valley Fall and Late Fall-run	*Species of Concern*	
	18	Upper Klamath-Trinity Rivers	*Not Warranted*	
	19	Oregon Coast	*Not Warranted*	
	20	Washington Coast	*Not Warranted*	
	21	Middle Columbia River spring-run	*Not Warranted*	
	22	Upper Columbia River summer/fall-run	*Not Warranted*	
	23	Southern Oregon and Northern California Coast	*Not Warranted*	
	24	Deschutes River summer/fall-run	*Not Warranted*	
Coho Salmon (*O. kisutch*)	25	Central California Coast	*Endangered*	
	26	Southern Oregon/Northern California	*Threatened*	
	27	Lower Columbia River	*Threatened*	• Critical habitat
	28	Oregon Coast[2]	*Threatened*	
	29	Southwest Washington	*Undetermined*	
	30	Puget Sound/Strait of Georgia	*Species of Concern*	
	31	Olympic Peninsula	*Not Warranted*	
Chum Salmon (*O. keta*)	32	Hood Canal Summer-run	*Threatened*	
	33	Columbia River	*Threatened*	
	34	Puget Sound/Strait of Georgia	*Not Warranted*	
	35	Pacific Coast	*Not Warranted*	
Steelhead (*O. mykiss*)	36	Southern California	*Endangered*	
	37	Upper Columbia River	*Endangered*	
	38	Central California Coast	*Threatened*	
	39	South Central California Coast	*Threatened*	
	40	Snake River Basin	*Threatened*	
	41	Lower Columbia River	*Threatened*	
	42	California Central Valley	*Threatened*	
	43	Upper Willamette River	*Threatened*	
	44	Middle Columbia River	*Threatened*	
	45	Northern California	*Threatened*	
	46	Oregon Coast	*Species of Concern*	
	47	Southwest Washington	*Not Warranted*	
	48	Olympic Peninsula	*Not Warranted*	
	49	Puget Sound	*Threatened*	• Critical habitat • Protective Regulations
	50	Klamath Mountains Province	*Not Warranted*	
Pink Salmon (*O. gorbuscha*)	51	Even-year	*Not Warranted*	
	52	Odd-year	*Not Warranted*	

Table 2. http://www.nwr.noaa.gov/ESA-Salmon-Listings/upload/snapshot0208.pdf

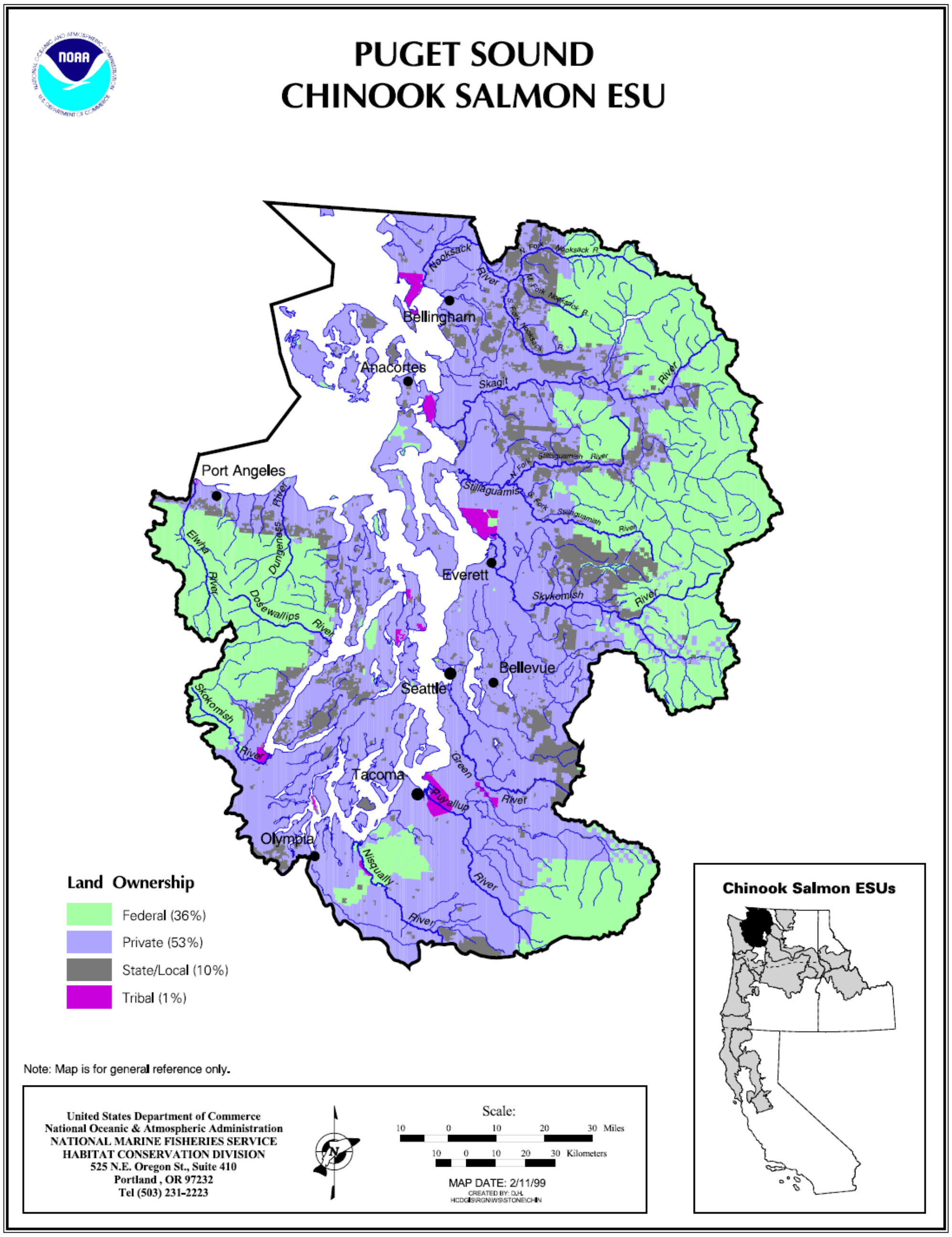

Figure 1. NOAA WEBSITE- http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon Populations/Maps/upload/chinpug.pdf.

1.3 The National Oceanic and Atmosphere Administration and National Marine Fisheries Service

> The National Oceanic and Atmospheric Administration's (NOAA) MISSION STATEMENT: *Stewardship of living marine resources through science-based conservation and management and the promotion of healthy ecosystems (NOAA 2008).*

NOAA's National Marine Fisheries Service (NMFS) is the federal agency that is responsible for the stewardship of our nations living marine resources and their habitat. The NMFS is responsible for the management, conservation and protection of living marine resources within the United States' Exclusive Economic Zone (EEZ), which is defined as water three to 200 mile offshore. Using the tools provided through the Magnuson-Stevens Act (See Section 1.4), NMFS assesses and predicts the status of fish stocks, ensures compliance with fisheries regulations and works to reduce wasteful fishing practices. Under the Marine Mammal Protection Act (MMPA), first established in 1972, and the ESA, the NMFS aims to recover protected marine species without impeding economic and recreational opportunities. Through the use of regional offices and staff the NMFS is able to work directly with communities on fishery management issues (NOAA 2008). The NMFS also plays an advisory role in managing living marine resources located in coastal areas that are under state jurisdiction. It provides scientific and policy leadership in the international arena, and implements international conservation and management measures as necessary.

1.4 The Magnuson-Stevens Act of 1976

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) is the primary law governing marine fisheries management in United States federal waters. The Act was first enacted in 1976 and amended in 1996 (NOAA 2008). The Magnuson-Stevens Act (MSA) aided in the development of the domestic fishing industry by phasing out foreign fishing within the EEZ. In order to manage the fisheries, and promote conservation, the MSA created eight regional fishery management councils. Under Section 302 of the Magnuson-Stevens Act (SEC. 302. REGIONAL FISHERY MANAGEMENT COUNCILS 16 U.S.C. 1852 97-453, 101-627,104-297) the following councils apply specifically to Pacific salmonid populations:

> **The Pacific Council** --The Pacific Fishery Management Council shall consist of the States of California, Oregon, Washington, and Idaho and shall have authority over the fisheries in the Pacific Ocean seaward of such States.
>
> **The North Pacific Council** --The North Pacific Fishery Management Council shall consist of the States of Alaska, Washington, and Oregon and shall have authority over the fisheries in the Arctic Ocean, Bering Sea, and Pacific Ocean seaward of Alaska.

> **The Western Pacific Council** --The Western Pacific Fishery Management Council shall consist of the States of Hawaii, American Samoa, Guam, and the Northern Mariana Islands and shall have authority over the fisheries in the Pacific Ocean seaward of such States and of the Commonwealths, territories, and possessions of the United States in the Pacific Ocean area.

The 1996 amendments to the MSA focused on rebuilding over-fished fisheries, protecting essential fish habitat and reducing bycatch. Congress added new habitat conservation provisions to that act in recognition of the importance of fish habitat to productivity and sustainability of U.S. marine fisheries. The re-named Magnuson-Stevens Act mandated identification of essential fish habitat (EFH) for managed species. The act also requires measures to conserve and enhance the habitat needed by fish to carry out their life cycles. Congress defined EFH as "*those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity*." An additional EFH guideline used to interpret the provided EFH definition, and which applies specifically to the ESA-listing of Puget Sound Chinook salmon is:

> -*necessary* means the habitat required to support a sustainable fishery and the managed -species' contribution to a healthy ecosystem (NOAA-NMFS 2008).

1.5 The History of the Drafting of the Pacific Salmon Treaty

The original document that addressed the need to fairly allocate transboundary salmonid resources between the United States and Canada was the Fraser River Convention, which was ratified in 1937 (Shepard et al., 2005). Around the 1960's, and toward the end of the Convention period, when negotiations were well underway for the subsequent 1985 Pacific Salmon Treaty, a sudden shift in ocean conditions contributed to a marked increase in the average Johnstone Strait diversion rate (Miller 2002). By the late1970's the Canadian fishing fleet was taking full advantage of this newly discovered phenomenon now known as the "Northern diversion rate". This phenomenon is observed through a change in expected migratory patterns of the returning adult salmonids on their journey back to natal spawning grounds through the Straits in the San Juan Islands and around West Vancouver Island (Section 2.3 and Figure 2). Once discovered, the Canadian purse seine fleet began to target returning salmon outside the original 1937 Convention Waters in the Georgia Strait, especially during higher "northern diversion rate" years, in order to increase their catches and thus their bargaining power at the international treaty table (Brown 2005; Miller 2002; Shepard et al., 2005).

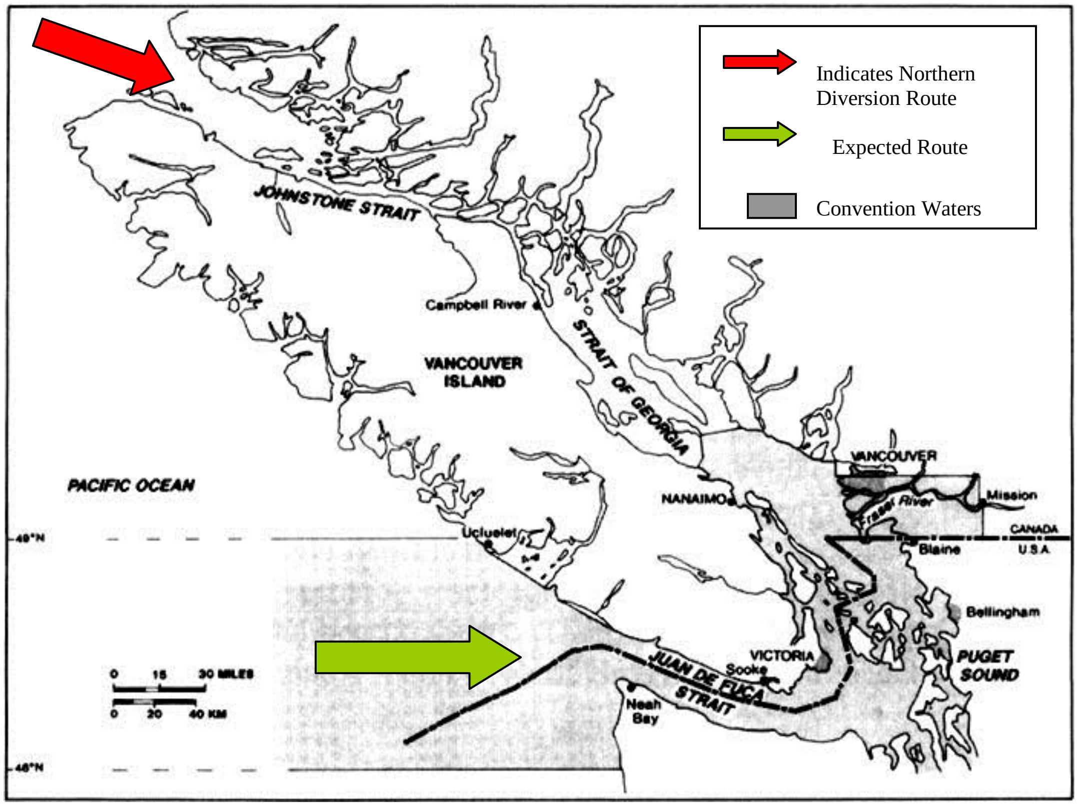

Figure 2. Convention Waters Fishing Area for 1937 Convention. Source: North American Pacific Salmon: A Case of Fragile Cooperation. Kathleen A. Miller. 2002.

Between the years of 1953-1976 the diversion rate averaged 16.4 percent. From 1977 through 1985, the diversion rate average increased to 46 percent (Miller 2002). This increase in interception opportunities shift surely strengthened Canada's hand in the negotiations which eventually lead to the 1985 Treaty. The Canadian fishermen took advantage of unusually high diversion rates in 1978, 1980, 1981, and 1983 which resulted in a substantial increase in their overall share of the salmon harvest (Figure 3).

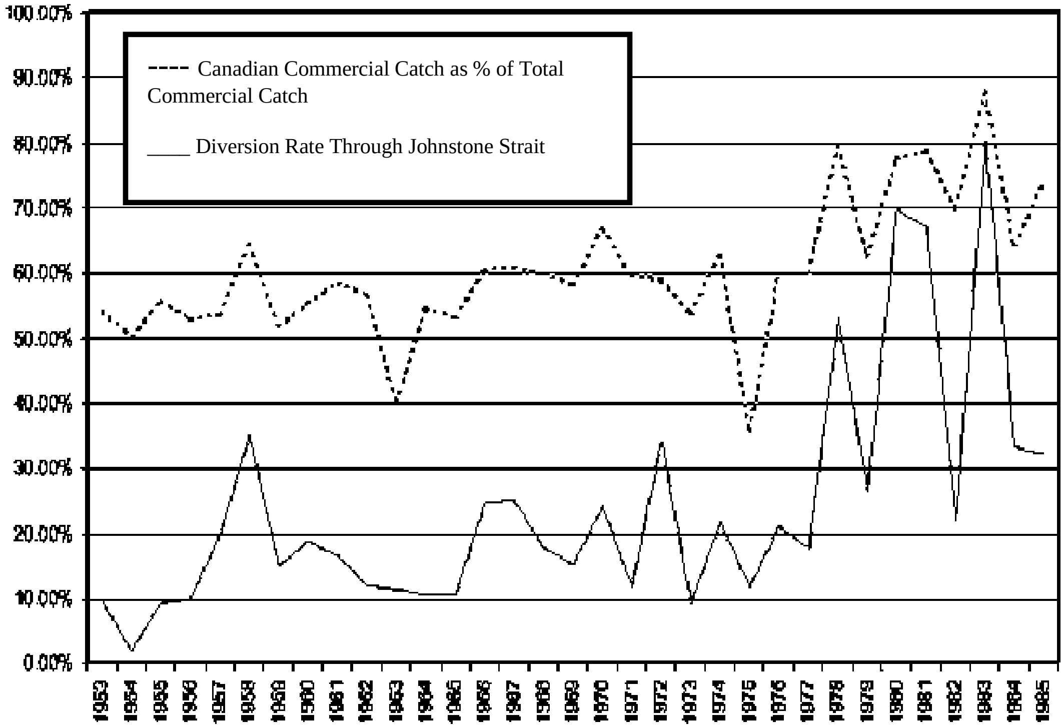

Figure 3. Percentages of Commercial Salmon Catches from Canadian waters versus the Diversion Rate into United States Waters. Source: North American Pacific Salmon: A Case of Fragile Cooperation. Kathleen A. Miller. 2002.

Due to the life cycle migration patterns of west coast salmonids (Figure 4) fishermen from the state of Alaska and the country of Canada, both situated north of Washington and in colder more nutrient rich waters, were perfectly placed to intercept great numbers of homeward bound West Coast salmonids during spawning season (Pearcy 1992; Miller 2002; Quinn 2005; Dominquez 2007). Thus, Alaska was apprehensive about signing any rights away during the negotiations of the Pacific Salmon Treaty with Canada.

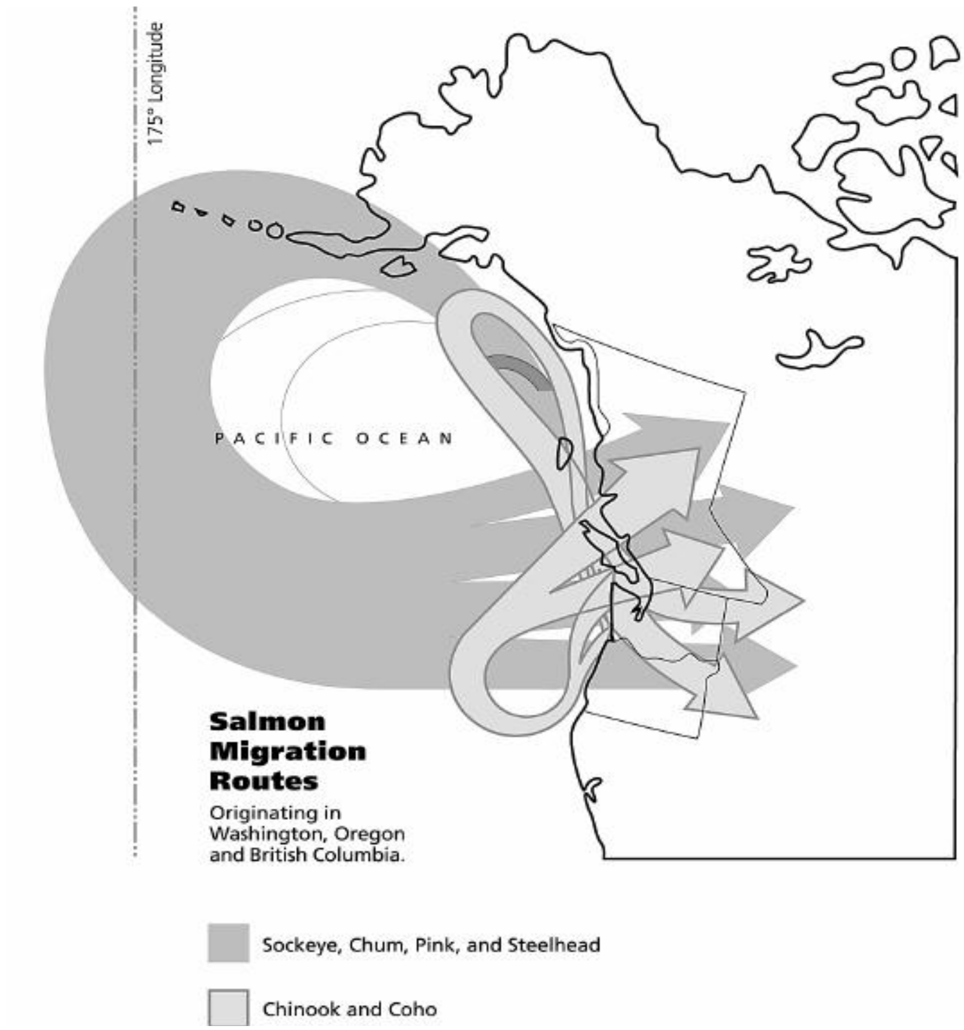

Figure 4. Salmon Migration Routes of Pacific Salmon. Source: Salmon Ecology Key Slides - Prof. Larry Dominguez. The Evergreen State College 2007.

By 1984 the state of Washington alone had been spending $87 million a year on salmon management and hatchery production. $800 million had been invested in fish passage and hatchery production to mitigate the damage to Columbia River stocks due to the construction of several hydroelectric facilities, and $750 million in restoration due to the 1980 Northwest Power Act, a Congressional mandate (Blumm 1994). At this point the state began to believe their hard work was not "paying off" as they had foreseen. They were not seeing a "return on these investments", which they predicted would quickly be observed through increased Columbia River salmonid populations. The 1984 Secretary of Energy, Donald P. Hodel wrote to the Secretary of State George Shultz:

> "Much of this substantial investment…is severely jeopardized by continued uncontrolled harvest of Columbia River Chinook runs by Canadian and Alaskan fishermen. It is imperative that if this investment is to achieve corresponding regional benefits, the United States and Canada must soon reach accord on an interception treaty. Continued decline of the Columbia's salmon runs may only lead to further regional hardship…"

Eventually a treaty was signed in 1985 that represented a new era of cooperation between the two countries. This new Pacific Salmon Treaty (PST) would forever require an annual re-evaluation of stocks and regulations for each country. In July of 1999 the two countries signed a revised Pacific Salmon Agreement which was developed through cooperation by the U.S. and Canadian federal governments, tribes, state governments, and sport and commercial fishing groups.

It is simply not possible to successfully monitor and recover declining transboundary populations of marine organisms if both sides of the international border have unique management strategies; therefore a treaty, such as the PST, was the best possible solution for both sides to such a complicated issue. Russel Barsh, an Ecologist with the Center for the Study of Coast Salish Environments, has been studying the life history of the salmonid populations which originate near the Canadian-United States border for many years. More recently his research has included an examination of the habitat use and behaviors of juvenile salmonid outmigrants throughout the San Juan Islands. Results from his studies thus far show that juvenile outmigrants from both Canadian origin stocks and United States origin stocks are completely intermixed throughout the islands. “As far as juveniles are concerned, they all congregate and feed in the islands in mixed groups from both sides of the international border before heading out to the open ocean. It is therefore presumably safe to assume that adults returning to natal spawning grounds would also stop in the islands, commingling and feeding before continuing inland and entering the senescence life history phase. ” (Barsh 2008). This research highlights the largely still unknown life history characteristics of returning Pacific salmonids, as fishermen and fishery managers have speculated for years about what adult salmon did upon reaching this ecosystem. The widely accepted belief was that they quickly and independently migrated through the islands from open water in segregated runs, as data collected through the use of WDFW test fisheries had previously suggested.

Since the signing of the 1985 PST, in order to help fulfill conservation goals and ensure that each country has the right to reap the benefits created from its own fisheries enhancement efforts, the PST has been implemented by an eight-member bilateral Pacific Salmon Commission (PSC). The PSC includes representatives of federal, state and tribal governments from both countries. The PSC does not regulate salmon fisheries. However, it does provide regulatory advice and recommendations in a forum which fosters the ability for the two countries to reach a mutual agreement about transboundary resource issues such as salmonid harvest opportunities.

According to the 1999 Annex to the Pacific Salmon Treaty, the U.S. share of the Total Allowable Catch (TAC) of sockeye salmon in Marine Areas 7/7A is 16.5%, with the non-treaty share of the U.S. TAC being 32.3%. These U.S. and non-treaty share proportions will remain in effect through 2010 (WDFW 2008). However, since a new threat to the health of sockeye populations from the Fraser River was discovered in 2001, the abilities of both countries to fully harvest their PST derived sockeye harvest shares has been impacted by conservation concerns for "late run" sockeye. This stock group has been entering the Fraser River in August, four to six weeks earlier than they normally do, in September, and suffering a nearly 95% combined migration and pre-spawning mortality rate (Cook 2004). These fish have begun to head directly into freshwater instead of remaining in the Strait of Georgia for several weeks as was customary, and milling around before heading to spawning grounds. What has been identified by UBC biologists at this time as the cause of the significantly increased mortality rate is a rapid increase in kidney parasite infections, which impairs these fishes ability to regulate the vital physiological adjustments necessary when transitioning from salt to fresh water (Cook 2004). The higher water temperature allows the parasite, *Parvicapsula*, to proliferate at a much faster rate than previously observed, and result in pre-spawning mortality. Because the "late run" sockeye timing overlaps with abundant summer sockeye runs present in WDFW Marine Areas 7 and 7A fisheries, limiting harvest seasons to reduce impacts on these late run sockeye, which now have dramatically reduced populations, requires additional new regulations on the number of harvestable summer runs of sockeye.

1.6 The Washington Department of Fish and Wildlife

The Washington Department of Fish and Wildlife (WDFW), previously known as the Washington Department of Fisheries, is the state agency responsible under legislative mandate to *manage all marine and freshwater species and to "preserve, protect and perpetuate" fish populations and at the same time to "enhance and improve recreational and commercial fishing in this state"* (WDFW 2008). The WDFW, known in 1977 as the Washington Department of Fisheries, initiated a comprehensive and long-range research effort to address the specific needs of managing Washington's naturally-produced salmon runs. This became known as the Wild Salmon Production Evaluation unit (WSPE). It was created to measure production, survival, and fisheries contribution of wild origin salmon stocks. Since its creation, WSPE has continued to measure survival at three long-term monitoring stations located around the state. The WSPE monitors wild salmon populations in Puget Sound, the Washington coast and lower Columbia River. Regional biologists and the Hatchery/Wild Interactions Unit monitor the freshwater production of wild origin salmon populations at additional sites statewide (WDFW 2008). WDFW defines a fish stock as:

> -*A <u>stock</u> is a group of fish of the same species that spawn in the same location at the same time with little interbreeding with other groups.*

-Basic unit of assessment for productivity, extinction probability, and recovery plan.

The goal of the WDFW's Wild Salmonid Policy is: *to protect, restore, and enhance the productivity, production, and diversity of wild salmonids and their ecosystems to sustain ceremonial, subsistence, commercial, and recreational fisheries, non-consumptive fish benefits, and other related cultural and ecological values* (WDFW 2008).

Under the framework of the Wild Salmon Policy, there are components that must be monitored for the program to be considered a success. Fish Populations, Escapement, Genetics, Harvest Management, and Hatcheries must be monitored and measured against the standards set by the Wild Salmon Policy. Specifically, for the purposes of this paper the Harvest Management Policy Statement reads: *The fisheries will be managed to meet the spawning escapement policy as well as genetic conservation and ecological interaction policies.* The Harvest Management performance standards that must be met are as follows:

-Harvest management will be responsive to annual fluctuations in abundance of salmonids, and will be designed to meet any requirements for sharing of harvest opportunity.

-The allowable incidental harvest impact on populations shall be addressed in existing preseason and in-season planning processes...

-Where a population is not meeting its desired spawner abundance level, the State, in managing the non-treaty harvest, may give priority to non-treaty fisheries that can minimize their impacts on weak stocks and increase their

> *harvest on healthy stocks by: (1) using gears that can selectively capture and release stocks with minimal mortality, or (2) avoid impacts by eliminating encounters with weak populations (proven time/area closures, gear types). This must be done consistent with meeting treaty and non-treaty allocations and in accordance with agreed mass marking policies* (NOAA-NMFS 2008).

Currently the WDFW also is responsible for drafting Harvest Management Plans which outline objectives to guide the Washington co-managers in planning annual harvest regimes, as they affect ESA-listed Puget Sound Chinook salmon. The current Plan under review by NOAA Fisheries for approval applies to management years 2004 - 2009. These objectives include total U.S. exploitation rate ceilings, and spawning escapement goals. This Plan describes the technical derivation of these objectives, and how these guidelines are applied to annual harvest planning. The Plan guides the implementation of fisheries in Washington, and it considers the total harvest impacts of all fisheries, including those in Alaska and British Columbia, to assure that conservation objectives for ESA-listed Puget Sound Chinook salmon ESUs are achieved. The accounting of total fishery-related mortality includes incidental harvest rates such as mortality rates for fish encountered as "bycatch" in fisheries which are directed at other salmon species, and for non-landed Chinook salmon mortality, or mortalities that result from hook-and-release fisheries. The fundamental intent of the Plan is to enable harvest of strong, productive stocks of Chinook salmon and other salmon species and to minimize harvest of "weak" or critically depressed Chinook salmon stocks. As mentioned, the Puget Sound ESU currently includes many "weak" populations. A “weak” population is defined as an ESU which is not meeting escapement goals as currently set. Providing adequate conservation of weaker stocks necessitates foregoing some harvestable surplus of healthy stocks. Some of the WDFW policies that specifically apply to commercial and recreational harvest management are as follows:

-*The Department will support harvest strategies that promote optimum long-term sustainable harvest levels.*

-*The Department will support monitoring programs which gather biological, discard, and bycatch data from each of the fisheries.*

-*The Department will take a precautionary approach in the management of species where the supporting biological information is incomplete and/or the total fishery-related mortalities are unknown.*

-*The Department will support consideration of the use of risk-averse management tools to protect the resources in the face of management uncertainty.*

-*The Department will support management measures which conserve, restore, and enhance the quality of essential fish habitats upon which Council-managed fisheries resources depend* (WDFW 2008).

1.7 The Department of Fisheries and Oceans, Canada

The Department of Fisheries and Oceans, Canada (DFO) is responsible for managing sockeye, pink, chum, coho and Chinook salmon within their territorial waters and EEZ. They uphold PST obligations with the United States and the

British Columbian tribes through participation in the PSC. They do so through the use of some of the same tools U.S. fishery managers use, such as test fisheries (Section 2.1). Commercial fisheries in Canada are also managed under the ITQ system (Section 2.1). The DFO uses salmon management advisory boards to oversee operational issues associated with salmon fisheries, such as pre-season planning and appropriate enforcement. The advisory board is also compelled to follow conservation guidelines and other policy directives, and the scientific advice provided by the Pacific Scientific Advice Review Committee, stock assessment reports, and other policy documents to guide their planning.

DFO uses ongoing fisheries reform initiatives and new commitments such as their complimentary Wild Salmon Policy and the implementation of mark-selective fisheries to also attempt to recover weak salmon populations which originate in Canadian waters. Additionally, new fishery management tools such as Genetic Stock Identification (GSI) is actively being used in Canada to manage coho salmon fisheries off the west coast of Vancouver Island (OSU 2008).

2 Fishery Management Tools

The extent of intermingling of stocks of marine fish is often complicated. For example, in the North Pacific Ocean, where there is no obvious physical barrier to widespread migration and intermingling of salmon, *Oncorhynchus* sp., stocks intermingle over broad oceanic areas (Pearcy 1992; Iverson 1996; Quinn 2005; Barsh 2008). Rational fisheries management requires knowledge of the extent to which exploited populations comprise a discrete, and self-sustaining stock (Iverson 1996).

2.1 Population Assessment Methods

Studies which use either indirect or direct sampling techniques, or a combination of both, are generally performed by fisheries biologists to determine how large a population unit, or subpopulation is that they are attempting to manage. One direct method is tagging individual fish to determine the exact extent of movement of individuals, or groups of fish. Fish are marked at a specific location and at a particular time with specialized tags, such as coded wire tags, which bear identifying information and are surgically implanted into the snouts of young hatchery fish (WDFW 2008). Tagged fish are recaptured at a later date and the coded wire tag (or other tag) is recovered, identified, and recorded. This tool is used to suggest the extent of movement of these fishes (Marshall 1998; Hall 2001; Quinn 2005). Coded wire tag data has been used since 1986 to gather distribution and migration data about both hatchery and wild populations under the assumption that hatchery fish behavior is identical to wild fish behavior. Recent studies have begun to attempt to test the validity of this assumption (Barnett-Johnson et al., 2007; OSU 2008).

Indirect methods include counts of body parts, body proportions, physiological attributes, parasite fauna used as natural markings, and genetics (Iverson 1996; Dominquez 2007). These indirect measurements may also include spawning surveys to count the number of redds, fish nests constructed, or the counting of carcasses on a spawning ground to calculate the number of reproductively successful adults of a population.

WDFW also uses a tool called a "test fishery" to predict the size of a returning run of salmon. (The term "run" is synonymous with the term stock for this discussion). This requires fishery biologists to operate fishing vessels to simulate fishing methods employed by fishermen at various locations to predict the time a salmon stock will "peak", and to gather the age and sex ratio present in the stock. These data are gathered by using net gear and counting and sexing all fish captured each fishing day, per set, for a period of several weeks. During this process the number of fish caught will increase until it reaches a "peak", or maximum number, and this will indicate the majority of the fish for that run have then passed through that fishing area for the season. This information is used to forecast what is called "run timing", helping to predict where the fish will be located as they continue to migrate from test fishing grounds to natal spawning grounds. This knowledge can help fishery managers both examine the size and strength of a run, the potential reproductive health indicated by the sex ratio, and the average age of sexual maturity for a run. It also allows managers to change fishing regulations if information from test fisheries being conducted indicates that the number of fish actually returning differs substantially from pre-season estimates (WDFW 2008).

2.2 Population Forecasting

The annual process of setting Washington State fishing seasons begins each year with a pre-season forecast of the abundance of various individual fish stocks. These forecasts are based on estimates of the number of juvenile wild salmon produced in a river system and counted as outmigrating juveniles, surveys of adult fish which have returned to spawn, counts of fish returning to hatcheries to spawn, and samples from fisheries in "terminal" areas, or the waters near the home streams where fish are returning to spawn. When compiled, these numbers give WDFW fishery managers an estimate of the size and strength of the upcoming season's fish populations. This pre-season forecast estimate is then added to a base of information on the historic run-size strength and predicted fishery impacts for the various fish populations. The primary tool used to develop this base of information for Chinook salmon has been coded wire tags (WDFW 2008).

2.3 Predicting the Northern Diversion Rate

Occasionally salmon will return in higher abundance to spawning grounds located in Washington and British Columbia through the Strait of Georgia, rather than the historically customary route through the Strait of Juan de Fuca. The cause of this change in migratory behavior is still largely unknown. Many scientists speculate that it is temperature related (Groot and Quinn 1987; Miller 2002; Folkes 2007). To measure and test this hypothesis, the Department of Fisheries and Oceans (DFO) in Canada has set up temperature monitoring stations along the coast of the Strait of Georgia to examine the relationship between an increase in sea surface temperature and an increase in the "northern diversion rate" of Fraser River sockeye salmon (Folkes 2007). Data collected thus far seems to indicate that in years where the sea surface temperature is warmer than average, the sockeye returning to the Fraser River will choose to return through Johnstone Strait and the Strait of Georgia, rather than through the Strait of Juan de Fuca (Figure 5).

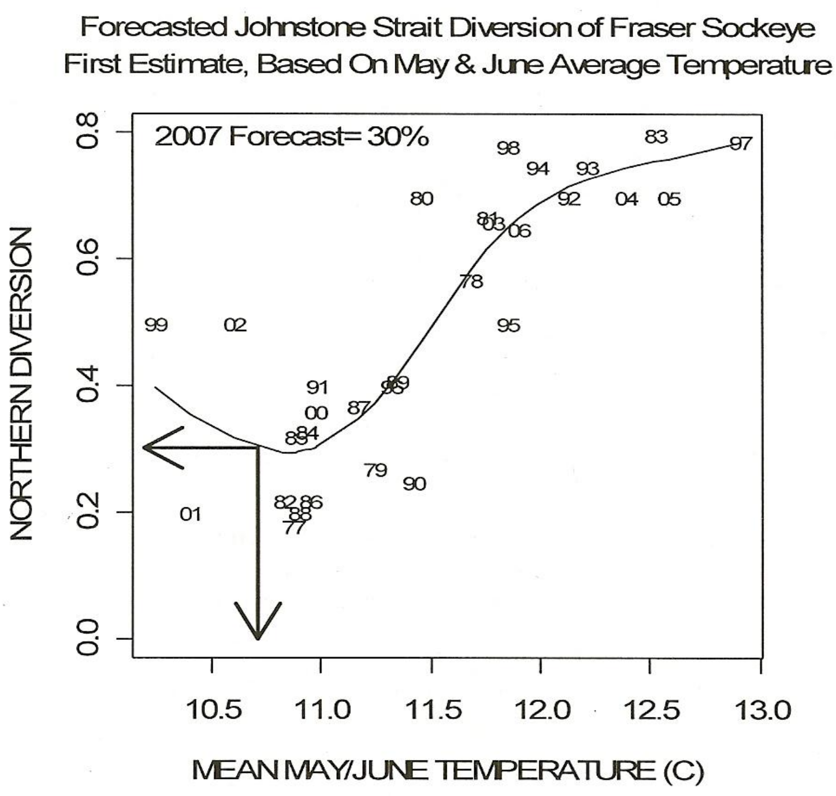

Figure 5. 2007 Northern diversion rate forecast. The relationship between Kains Island SST and estimated proportion of the Fraser sockeye run that diverts through Johnstone Strait (1977-2006). The relationship was fit using a General Additive Model (GAM) with binomial error and a logic link function. Data labels represent year (i.e. 83- 1983). (Folkes 2007).

This predicted information is generated by DFO and provided to WDFW fishery managers in the months prior to the pre-season forecasting, in order to help WDFW predict the size of the salmon runs returning to U.S. waters. This information is also helpful when fishery managers make pre-season calculations about potential impacts to ESA-listed bycatch species as a function of the total days a fishery is open for net fishing in these areas.

2.4 Setting Yearly Harvest Exploitation Rate, Rules and Regulations

The WDFW participates each year in setting the non-treaty commercial and recreational fishing regulations. Harvest rules are built on a foundation of historical scientific surveys, computer model predictions and joint deliberations involving representatives of treaty tribes, several states, the federal government and the public. Using data collected annually from thousands of stream and harvest surveys and inputting these data into the computer modeling program FRAM, the WDFW works each year with tribal co-managers, other governments and the public to set fishing seasons. The goal is to protect weak wild fish populations while providing harvest opportunities on healthy wild and hatchery origin stocks. Setting successful harvest regulations requires fishery managers to pay acute attention to overarching conservation goals, which were designed to ensure that enough fish survive annual harvest in order to spawn and perpetuate the long-term viability of each run. These goals are set based on what is believed to be the best available scientific information available on the number of fish a given stream is capable of supporting, and the number of "recruits," or new fish that can be produced by each pair of spawning adults.

Admittedly, managing salmon fisheries in the state of Washington is one of the most complex natural resource challenges in the country. This is due to the life history characteristics of Pacific salmonids, behavior patterns and geographical factors. As previously mentioned Pacific salmon are highly migratory, passing from freshwater streams and major rivers, out to the Puget Sound, up along the coast of British Columbia and as far north as Alaska before returning to natal streams to spawn. This means that salmonid survival rates depend biologically on habitat conditions over thousands of miles of fresh and saltwater. It also means that politics which dictate harvest rates in Alaska and Canada can affect the number of salmon that return to Washington waters (Shepard et al., 2007). Taking into account the fact that Washington State fishing activities involve several species that migrate over thousands of miles and across international boundaries, the WDFW participates in three separate harvest management panels:

-The **Pacific Salmon Commission** (PSC), which consists of representatives of Alaska, Washington, Oregon and Canada, the treaty Indian tribes of Washington and the Columbia River and the federal government.

-The **Pacific Fisheries Management Council** (PFMC) which includes the principal fisheries officials from the states of California, Oregon, Washington and Alaska, the regional director of the National Marine

Fisheries Service and eight private citizens appointed by the U.S. Secretary of Commerce from lists submitted by each state governor, jointly manages coastal fisheries, including salmon and ground fish from three to 200 miles off shore. The season setting process occurs in a series of public meetings.

-The **North-of-Falcon** (NOF) public planning forum in which federal, state and tribal fish managers meet in tandem with PFMC deliberations on ocean seasons, to set recreational and commercial salmon fisheries for waters within three miles of the coast of Washington and northern Oregon, as well as Puget Sound. The North of Falcon season setting process occurs in a series of public meetings each spring, attended by federal, state, tribal and commercial fishing industry representatives and concerned citizens.

Fishing season options are developed each year in the late winter and early spring. After fishing seasons are set each April, the WDFW and tribes continue to monitor in-season activity and stock impacts as they are occurring "on-the-water". This is performed using the sampling techniques (discussed in Section 2.1 and 2.6) such as Test Fisheries and genetic stock identification tools. Fishery managers must make frequent in-season re-assessments about which regulations should be adjusted, and how, according to the "real-time" data collected and analyzed during fishery operations.

The objective for annual, pre-season fishery planning is to develop a fishing regime that will assure that exploitation rates that do not exceed the objectives established for each WDFW management unit. As the Puget Sound

ESU has many stocks listed for ESA protection, annual target rates that emerge from WDFW pre-season planning aim to fall well below their respective ceiling rates. While these ESA-listed stocks are rebuilding, annual harvest objectives will intentionally be conservative, even for relatively strong and productive populations (WDFW 2008). These harvest thresholds are intentionally set above the level at which a population may become demographically unstable, or subject to further loss of genetic integrity. If abundance (i.e., escapement) is forecast to fall to or below this threshold, harvest impacts will be further constrained, by what fishery managers call Critical Exploitation Rate Ceilings, so that escapement will exceed the low abundance threshold.

Quantification of recent stock productivity (i.e., recruitment and survival) is subject to uncertainty and bias through the sampling methods employed and discussed in Section 2.1. The implementation of harvest regimes is also subject to management error. WDFW fishery managers specifically consider these sources of uncertainty and error, and must make in-season adjustments to manage the consequent risk that harvest rates will exceed appropriate levels. The productivity of each stock is re-assessed annually, and harvest objectives are modified as necessary, to reflect current population status (WDFW 2008).

Washington State and Canada currently participate in the Total Allowable Catch (TAC) quota system for limiting take during fisheries. The TAC system applies to all fisheries held within each countries' EEZ. Those opposed to this quota system state that if the fishery is simply closed once the TAC is reached, this causes fishermen to "race against each other" to harvest a larger share of the

TAC than their competitors in the fishery (Runolfsson 1997). Such behavior, which has fishermen fishing to a maximum sustainable yield (MSY) level each year in a fishery over time has been documented to drive healthy populations to extinction over relatively short periods of time (Cook 2006; Iverson 1996). Thus, continuous adjustment of a fisheries' TAC is necessary because of the inherent biological variability in fisheries, and their ecological interrelationships. The ability of fishery managers to set TAC at a sustainable level should continue to improve over time as they employ research methods to understand how ecosystem populations and interactions vary annually, and through the use of diligent and long-term monitoring efforts.

2.5 Fishery Regulation Assessment Model - FRAM

A Fishery Regulation Assessment Model (FRAM) developed by WDFW fishery managers is currently used by the Pacific Fishery Management Council (PFMC) to annually estimate impacts of proposed ocean and terminal fisheries on salmon stocks. This tool has been used in different variations since the 1970's (MEW 2006). FRAM is a single-season modeling tool. The Chinook version evaluates impacts on most stock groups originating from the north-central Oregon coast, Columbia River, Puget Sound, and Southern British Columbia. The FRAM produces a variety of output reports that are used to examine the impacts of proposed fisheries for compliance with management objectives, allocation arrangements, ESA compliance, and domestic and international legal obligations. Only recently has FRAM begun to be used for assessing compliance with

Chinook agreements in international fisheries management forums. The FRAM is a discrete, time-step, age-structured, deterministic computer model used pre-season to predict the impacts from a variety of proposed fishery regulation mechanisms for a single management year. It produces point estimates of fishery impacts by stock for specific time periods and age classes. The FRAM performs bookkeeping functions to track the progress of individual stock groups as the fisheries in each time step exploit them (MEW 2006).

Currently, 33 stock groups are represented in the Chinook FRAM. Each of these groups have both marked and unmarked components to permit assessment of mark-selective fishery regulations. For most wild stocks and hatchery stocks without marking or tagging programs, the cohort size of the marked component is zero; therefore, the current version of FRAM has a virtual total of 66 stock groups for Chinook. Stocks or stock-aggregates represented in the FRAM were chosen based on the level of management interest, their contribution rate to PFMC fisheries, and the availability of representative coded wire tag (CWT) recoveries in the historical CWT database (MEW 2006). The FRAM includes pre-terminal and terminal fisheries in southeast Alaska, Canada, Puget Sound, and off the coasts of Washington, Oregon, and California. There are 73 fisheries in Chinook FRAM. The intent is to encompass all fishery impacts to modeled Chinook salmon stocks in order to account for all fishing-related impacts and thereby improve model accuracy (MEW 2006). Terminal fisheries in Chinook FRAM are aggregations of gears and management areas.

Major assumptions and limitations of FRAM:

- CWT fish accurately represent the modeled stock. Many "model" stocks are aggregates of stocks that are represented by CWT's from only one production type, usually hatchery origin. For example, in nearly all cases wild stocks are aggregated with hatchery stocks and both are represented by the hatchery stock's CWT data. Therefore, for each modeled stock aggregate, it is assumed that the CWT data accurately represent the exploitation rate and distribution pattern of all the untagged fish in the modeled stock.

- Length at age of Chinook is stock specific and is constant from year to year. Von Bertalanffy (1934) growth functions are used for Chinook in determining the proportion of the age class that is of legal size in size-limit fisheries. Parameters for the growth curves were estimated from data collected over a number of years. It is assumed that growth in the year to be modeled is similar to that in the years used to estimate the parameters.

- Stock distribution and migration is constant from year to year and is represented by the average distribution of CWT recoveries during the base period. Fishery managers currently lack data on the annual variability in distribution and migration patterns of Chinook salmon stocks. In the absence of such estimates, fishery-specific exploitation rates are computed relative to the entire cohort. Differences between the distribution and migration pattern of stocks during the base period and the year being modeled will decrease the accuracy of the estimates of stock composition and stock-specific exploitation rates for a modeled fishery.

- There are not multiple encounters with the gear by the fish in a specific time/area/fishery stratum. Within each time/area/fishery stratum, fish are assumed to be vulnerable to the gear only once. The catch equations used in the model are discrete and not instantaneous. Potential bias in the estimates may increase with large selective fisheries or longer time intervals, both of which increase the likelihood that fish will encounter a gear more than once.

While it is difficult to directly test the validity of these assumptions, results of validation exercises provide one assessment of how well these assumptions are met and the sensitivity of the model to the assumptions (MEW 2006). Additionally, one study conducted in Canada looking at behavior and subsequent mortality rates of adult Chinook salmon caught and released from purse seine fisheries in Johnstone Strait revealed that mortality is based on several variables such as size, landing procedure, landing time, catch size and degree of external injury (Candy et. all 1996). This study also confirmed that Chinook caught and released from purse seine fisheries can be recaptured in the same fishery, or concurrent fisheries utilizing different gear types, within the original capture site vicinity.

The WDFW FRAM relies heavily upon spawner survey data and escapement numbers. Unfortunately, these data and escapement numbers can often be inaccurate (Knudsen 2000). This is due to the fact that escapement numbers are provided by the use of combination of both indirect methods such as counting parts, or spawned adult salmon at spawning grounds, counting redds, etc. and direct methods such as recovering coded wire tags during each fishery (Section 2.1). It is impossible to sample 100% of the stock composition present in a fishery using these sampling methods. Further, the ability of FRAM, or any fishery model, to predict reality is limited by our lack of full understanding of ecological processes controlling populations, our inability to measure those processes accurately, and to incorporate all the relevant processes in a single model. Currently, there are no existing modeling approaches that could produce an unambiguous risk classification for weak salmon stocks (Wainwright and Waples 1998).

An effort to assess the accuracy of pre-season FRAM reporting with the Genetic Stock Identification data collected in-season after the close of the season could significantly help the pre-season forecasting for the subsequent year. Using the pre-season estimates and in-season data to readjust the model inputs could help fine tune the error provided by both methods of estimation (Blankenship 2007).

2.6 Genetic Stock Identification

Genetic Mixed Stock Analysis (MSA), or Genetic Stock Identification, (GSI) are used interchangeably in WDFW fishery management reports. This genetic tool has been used infrequently over the last ten years as an in-season tool in an attempt to validate FRAM pre-season predictions of mortality on stocks of Chinook salmon caught as bycatch in Puget Sound commercial fisheries which target other salmon species. Data provided from GSI analysis can offer an actual impact per stock as encountered in a fishery, rather than theorized impacts predicted by fishery models which have been solely relied upon in the past. There are known issues with the GSI approach however. ONCOR, a computer simulation program WDFW uses to run GSI simulations and theorize stock impacts, has been known to incorrectly assign a small proportion of the overall fish sampled to any of the represented populations sampled during its simulations (Blankenship 2007). This error, although accounted for in the probable error of running any computer simulation, could result in fishery managers reporting inaccurate impacts on ESA-listed fish populations. The benefit to using GSI in light of this error is that errors reported are usually very small percentages, usually within a confidence interval (Blankenship 2007). This type of error also does not result in a false assignment of mortality to a stock which was not present in the fishery, as the simulation can only assign mortality to stocks present in the samples collected during the fishery and provided for laboratory analysis. Lastly, the Genetic Analysis of Pacific Salmonids (GAPS) database must contain an exhaustive collection of DNA profiles in order to match the sampled fish from the fishery back to the known stock of origin. This database is not entirely complete, but is revised every year to include each new West Coast salmonid stock genetically identified. A coast wide effort to complete the GAPS profiles of all Chinook salmon stocks has been initiated by genetics labs from Alaska to California in order to strengthen the abilities of fishery managers to report stock impacts in their entirety (Blankenship 2007; OSU 2008).

The draft 2006-2008 Research and Data Needs for the PFMC identifies as its highest priority the development of GSI for fisheries management applications. The report states: "Advances in genetic stock identification, and other techniques may make it feasible to use a variety of stock identification technologies to assess fishery impacts and migration patterns: The increasing necessity for weak-stock management puts a premium on the ability to identify naturally reproducing stocks and stocks that contribute to fisheries at low rates. The CWT marking system is not suitable for these needs. The Council should encourage efforts to apply these techniques to management" (OSU 2008).

A DNA analysis was initially conducted on bycatch from WDFW Marine Areas 7, 7A, 7B and 7C commercial and recreational fisheries in 1998 by Anne Marshall of the WDFW genetics unit. This original analysis was performed by identifying allozyme genotypes which are detectable in collected fin tissues

(Marshall 1998). The GAPS database is currently being used to perform a more comprehensive genetic analysis on fin clipped tissues using microsatellite analysis and SNP markers (Warheit 2006, Blankenship 2007). This new microsatellite analysis provides the probability that each fish originated from the genetic stock identity stored in the GAPS database. Fish that show a weak overall probability, roughly less than 70%, of matching a known stock of origin present in the GAPS database are excluded from mortality assessments (Blankenship 2007).

A general lack of funding prevented genetic samples from being obtained and analyzed in the years following 1998. Since the 1998 genetic analysis, GSI data was also collected and analyzed for 2006 and 2007. However, forecasts for poor sockeye returns limited the days the Marine Area 7 and 7A commercial fisheries were open in these years, thus sample sizes for 2006 and 2007 fell drastically below the desired numbers (Hawkins and Adicks 2007). As such, these data are limited in what they can be used to infer about the presence and distribution of Chinook salmon stocks in Marine Area 7 and 7A fisheries.

2.7 Marine Protected Areas

Since the 1998 WDFW Marine Protected Areas (MPA) policy was created, the Director of the Washington Department of Fish and Wildlife has been using marine protected areas as one of the agency's working tools for resource protection and management. The Director has been responsible for plan development and implementation to manage consumptive and non-consumptive uses. The creation of a MPA is not delayed until all the habitat and population assessment questions are answered with scientific studies because the recovery of depressed populations often depends on a timely establishment of these sites. WDFW relies on existing data to determine populations of concern and the selection of MPAs (WDFW 2008). Many fish resources require major reductions in harvest pressure and protection from removal as bycatch to establish productive populations of adults (Cook 2006; WDFW 2008). MPAs provide an important tool fisheries managers can use to recover species from past practices of over-harvesting, and prevent future over harvest (Bohnsack 1993; 1996). They also provide areas for the collection of baseline data on populations found within the site, provide reference areas, and protect endemic or sensitive populations and habitats. Lastly, they facilitate integrated management of all resources within the established MPA. The WDFW Commission's approach to implementing and designating MPAs specifically in the Puget Sound includes:

-*Designed MPAs are needed in Puget Sound to protect a variety of species, to promote the recovery of some over-harvested species and to protect important habitats.*

Current MPAs that encompass WDFW Marine Area 7:

-Yellow and Low Islands Marine Preserve (closed to salmon fishing)

-Shaw /Friday Harbor (open to salmon fishing)

-Argyle Lagoon (open to salmon fishing)

-False Bay (open to salmon fishing)

2.8 *Critical Habitat Designation*

The ESA requires the federal government to designate “critical habitat” for any species it lists under the ESA; in this case, salmon and steelhead populations (Figure 6). “Critical habitat” is defined as: *(1) specific areas within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and (2) specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation (WDFW 2008)*

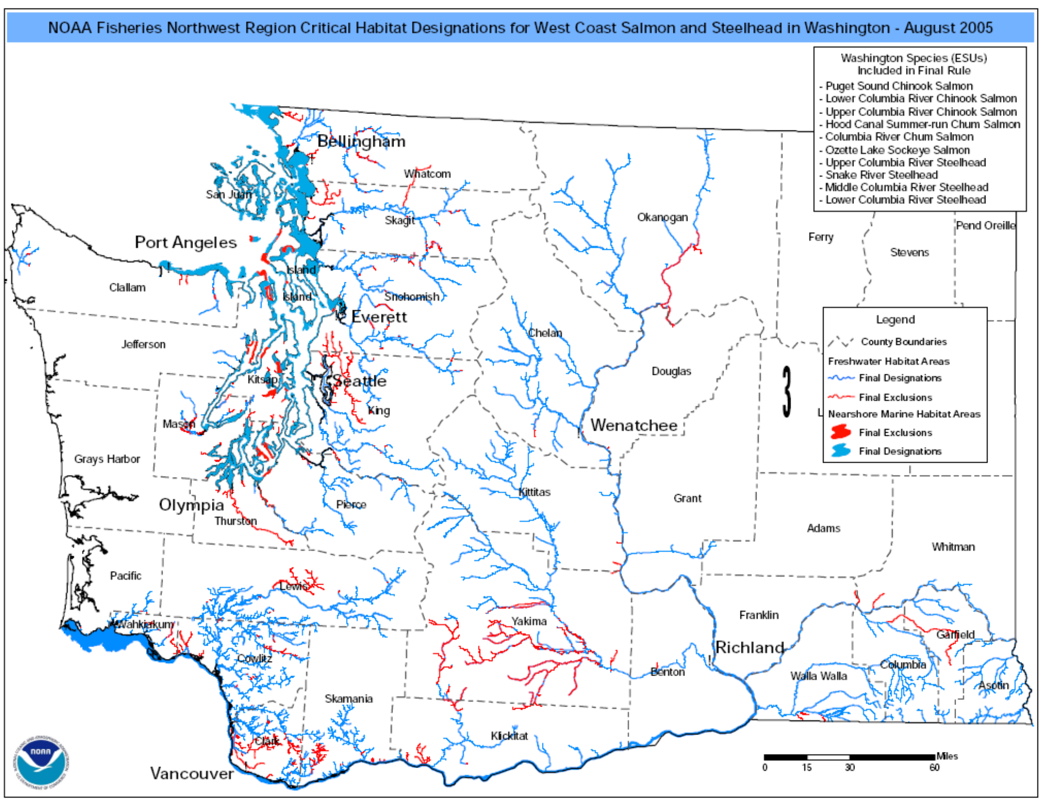

Figure 6. Critical Habitat Map of Washington. http://www.nwr.noaa.gov/Salmon-Habitat/Critical-Habitat/upload/WA-CH-map.pdf.

Critical habitat designations must be based on the best scientific information available, in an open public process, within specific timeframes. Before designating critical habitat, careful consideration is given to the economic impacts, impacts on national security, and other relevant impacts of specifying any particular area as critical habitat. The Secretary of Commerce may exclude an area from critical habitat if the benefits of exclusion outweigh the benefits of designation, unless excluding the area will result in the extinction of the species concerned (WDFW 2008). Under Section 7 of the ESA, *all federal agencies must ensure that any actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of a listed species, or destroy or adversely modify its designated critical habitat*. A critical habitat designation does not set up a preserve or refuge, and applies only when federal funding, permits, or projects are involved; critical habitat requirements also do not apply to citizens engaged in activities on private land that do not involve a federal agency.

3 Methods

3.1 Study Site

The study was conducted in WDFW Marine Area 7, which encompasses Areas 7, 7A, 7B and 7C (Figure 7).

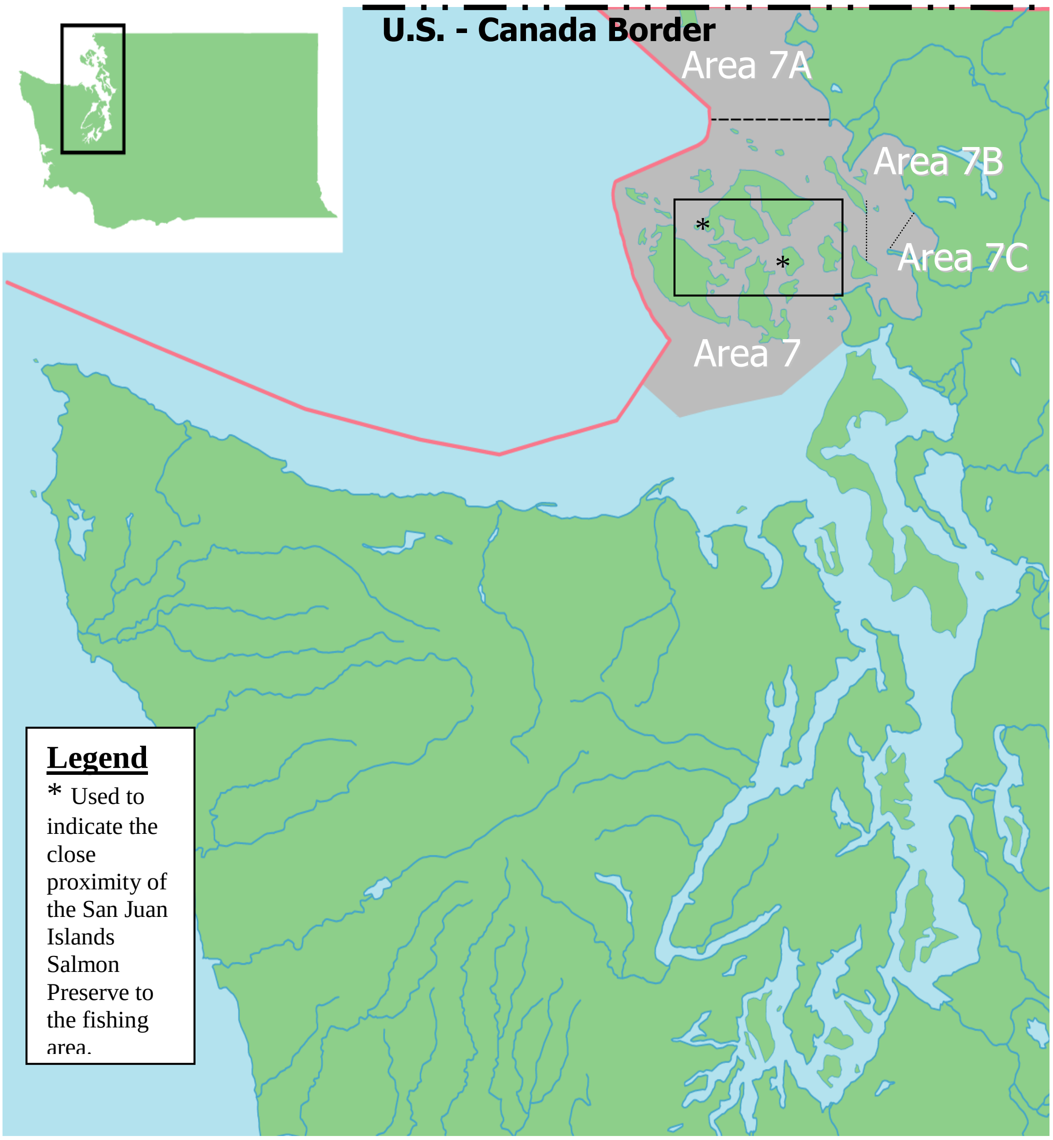

Figure 7. Study Area: WDFW Marine Areas 7, 7A, 7B, and 7C. Courtesy of S. Blankenship, WDFW. 2007.

Pursuant to the North of Falcon (NOF) fishery monitoring agreements, DNA samples were collected during the months of July – September of 2006 and 2007 by WDFW observers placed aboard random fishing vessels throughout each 12 hour commercial fishery open in Marine Areas 7, 7A, 7B and 7C (Hawkins and Adicks 2007). Using sterilized scissors, a small fin-clip (< 10 grams), of dorsal fin tissue from: the first five Chinook salmon caught per set were collected for purse seine vessels targeting sockeye, all Chinook salmon caught for gillnet vessels targeting Chinook salmon, and each landed Chinook salmon for recreational fishermen targeting Chinook salmon. Fin clips were placed in a sterile vial filled with ethanol to avoid cross contamination. In addition, scale samples were also obtained for the first five Chinook sampled aboard purse seine and gillnet vessels and processed separately for age and stock of origin determination in the WDFW scale lab. Additional data collected included latitude and longitude of the fishing vessel, time of capture, fish length and sex (if possible), and the presence or absence of adipose fin (used to indicate a hatchery-origin fish). The DNA sample vials were delivered to the WDFW genetics laboratory within 12 hours of collection and were processed within 48 hours as described below in Section 3.2.

3.2 Data Analysis

The following methods were performed to obtain and analyze genetic material in the WDFW genetics laboratory; DNA extraction, Polymerase Chain Reaction (PCR) Amplification and Genotyping. This process began with the extraction of DNA from fin tissue samples and the purification of the obtained DNA material using Macherey-Nagel silica membrane kits. PCR reactions were run using MJ Research PTC-200 and AB 9700 thermal cyclers. The 13 microsatellite DNA loci which currently comprise the coast wide Chinook salmon DNA screening protocol (*Ogo-2, Ogo-4, Oki-100, Omm-1080, Ots-3M, Ots-9, Ots-201b, Ots-208b, Ots-211, Ots-212, Ots-213, Ots-G474,* and *Ssa-408)* were screened using an ABI-3730 DNA Analyzer with in-lane size standards (ABI-GeneScan-500 liz) and GeneMapper 3.7 software. Allele binning and naming was accomplished using MicrosatelliteBinner-v.1h, where MicrosatelliteBinner creates groups (bins) of alleles with similar mobilities (alleles with the same number of repeat units), and the upper and lower bounds of the bins are determined by identifying clusters of alleles separated by gaps (nominally 4.0 base pairs in size) in the distribution of allele sizes. Each bin is then named as the mean allele size for the cluster rounded to an integer (Hawkins and Adicks 2007).

The mixed stock analysis program used the 13 standardized microsatellite loci from the GAPS consortium (GAPS v2.1 dataset; release date Aug. 25, 2006), which contains genetic data for 167 stocks categorized into 44 regional reporting units by the Pacific Salmon Commission (PSC). Estimates of stock of origin for each individual were generated using a Bayesian procedure based on the probability that a genotype from the fishery samples was derived from a stock/population, given the baseline allele frequencies for that population. Genotype probabilities were generated using the algorithm of Rannala and Mountain (1997). A Markov chain procedure was used to refine the fishery proportion estimates derived from the genotype probabilities. The stock contribution estimates are the mean posterior probabilities from the Markov chain. Estimates of error for the stock assignments were generated through simulation. One thousand datasets were constructed, each containing 100 individuals, where the stock composition was identical to that of the stock composition estimated from the actual bycatch samples. Each simulated sample was analyzed as described above, with the mean and variance of stock assignments recorded. This procedure allowed us to calculate an error (as a standard deviation) for the stock composition estimated from the actual bycatch samples. GMA (Kalinowski 2003) software was used to estimate stock composition and its associated error, and Genclass2 (Piry et al., 2004) to conduct individual-based assignments for the 2006 data (Warheit 2006). ONCOR software was used for the individual-based assignments of the 2007 data (Blankenship 2007).

4 Results

4.1 Comparison of Chinook Bycatch Observed in Marine Areas 7 and 7A

With the exception of year 2004, Marine Area 7A consistently provided a larger sample size of Chinook bycatch than Marine Area 7 over the ten years observed (Table 3). (The validity of the 2004 outlier was verbally verified with the Puget Sound Salmon Management Unit supervisor. He confirmed that data from 2004 was entered into the database correctly from the original observer datasheet). A Shapiro-Wilk normality test was performed on the raw data collected over the ten years from Marine Areas 7 and 7A. The normality test provided an insignificant result, with a p-value of 0.1523 (Tables 12-14). Thus, the null hypothesis, that these data came from a normally distributed data set, could not be rejected. These data were then considered to fit a normal distribution curve and were analyzed as such. A t-Test: Paired Two Sample for Means using a one tailed t-Test, to test if the number of Chinook salmon observed in Marine Area 7 differed significantly from the number of Chinook salmon observed as bycatch per year in Marine Area 7A over the ten year period, was performed using both MS Excel and R Version 2007. The results from both programs yielded significant results, with a p-value of 0.00899 (Tables 12-14). Thus the number of Chinook salmon observed per year in Marine Area 7A does differ significantly from the number of Chinook salmon observed in Marine Area 7 the ten year period.

Table 3

Chinook Salmon Bycatch Observed 1997-2007
As Reported by WDFW Marine Area

Year	Area 7	Area 7A
1997	69	498
1998	67	219
2000	56	70
2001	78	109
2002	67	81
2003	159	811
2004	56	6
2005	8	599
2006	116	467
2007	2	149

Table 3. WDFW Observer MS Access Database 2007.

4.2 Genetic Stock Identification Data for 1998, 2006 and 2007

The Chinook salmon genetic data collected and analyzed for stock of origin in 1998, 2006 and 2007 demonstrate a consistency in stock composition over time (Figure 8, Tables 5-9). The analysis of these data revealed that Canadian Chinook salmon stocks present were consistently dominant in these three years, and the presence of Puget Sound Chinook salmon stocks was very low. Further statistical analysis of these data was not possible due to the small and varied sample sizes, the differing methods used to provide these values, and the natural variance present in the MSA analysis process (Blankenship 2007). A Chi-squared analysis was not possible as these data did not meet requirements to run such a test. Additionally, GSI data was historically combined for Marine Areas 7 and 7A. As Marine Area 7 consistently provided significantly smaller sample sizes these data may have been combined to increase the overall sample sizes for power in statistical analyses (Table 3, 5-7).

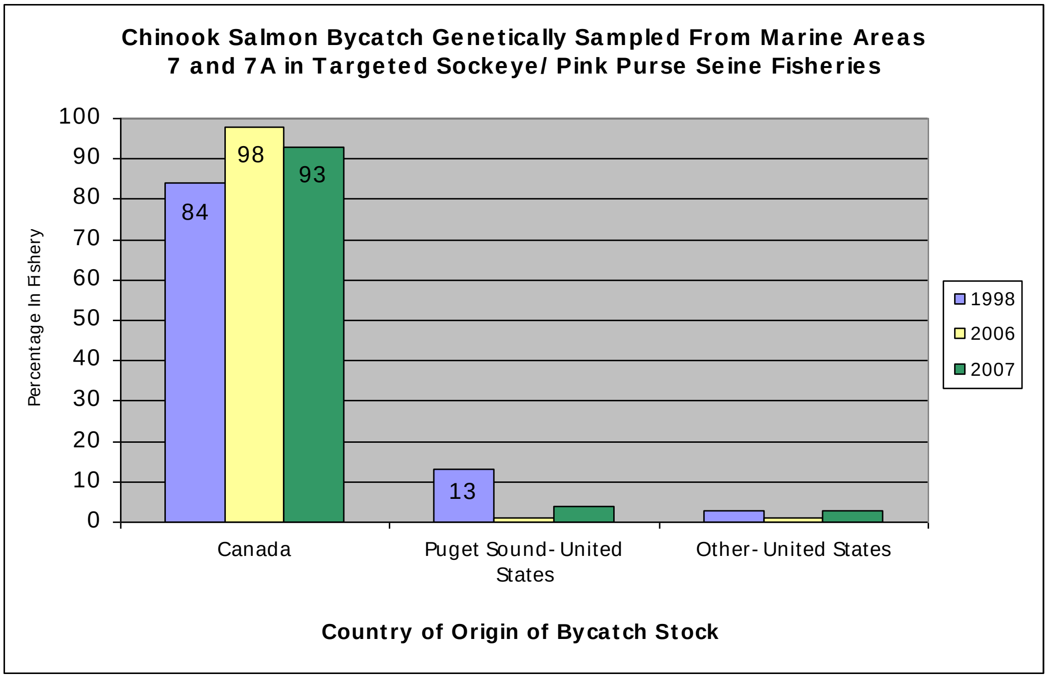

Figure 8. Assignment of stock of origin of genetic samples obtained from Chinook salmon bycatch during commercial sockeye and pink purse seine fisheries in Marine Areas 7 and 7A for 1998, 2006 and 2007. WDFW Memos 2006, 2007.

4.3 Comparison of Fishery Regulation Assessment Model (FRAM) Predictions and Genetic Stock Identification (GSI) Data for 2007

The 2007 pre-season non-treaty FRAM mortality estimate for Chinook salmon as bycatch in the sockeye directed purse seine fishery for Marine Areas 7 and 7A was 1,931. Of the 1,931 Chinook salmon 1,184, or 61.32%, were expected to be specifically of Puget Sound origin (Figure 9). The total Puget Sound Chinook salmon bycatch ceiling computed by FRAM was 1,421* (* computed as 1,184 x 120% = 1,421 cap (Blankenship 2007). Due to the unusually low number of returning sockeye salmon in 2007, the purse seine fishery in Marine Areas 7 and 7A was not opened for commercial fishing of sockeye. However, it was an odd numbered calendar year, and pink salmon spawn in large numbers during odd numbered years. A commercial fishery targeting pink salmon was open in Marine Areas 7 and 7A during 2007. As the sockeye and pink salmon fisheries overlap by a few statistical weeks on the WDFW fishery regulation calendar, fishery managers operated under the assumption that the composition of bycatch stocks present in the pink salmon purse seine fishery should closely mimic that which would be sampled during those same statistical weeks of the sockeye salmon purse seine fishery in Marine Areas 7 and 7A (Blankenship 2007). Genetic samples collected during the 2007 pink directed purse seine commercial fishery revealed that the Puget Sound Chinook salmon presence during the Marine Area 7 and 7A fishery was 4%, and significantly lower than the pre-season FRAM predicted mortality (Figure 8, Tables 9-10). This discrepancy between the pre-season FRAM prediction and the in-season GSI data may be accounted for by the shortened fishery season, and lack of a commercial sockeye directed fishery.

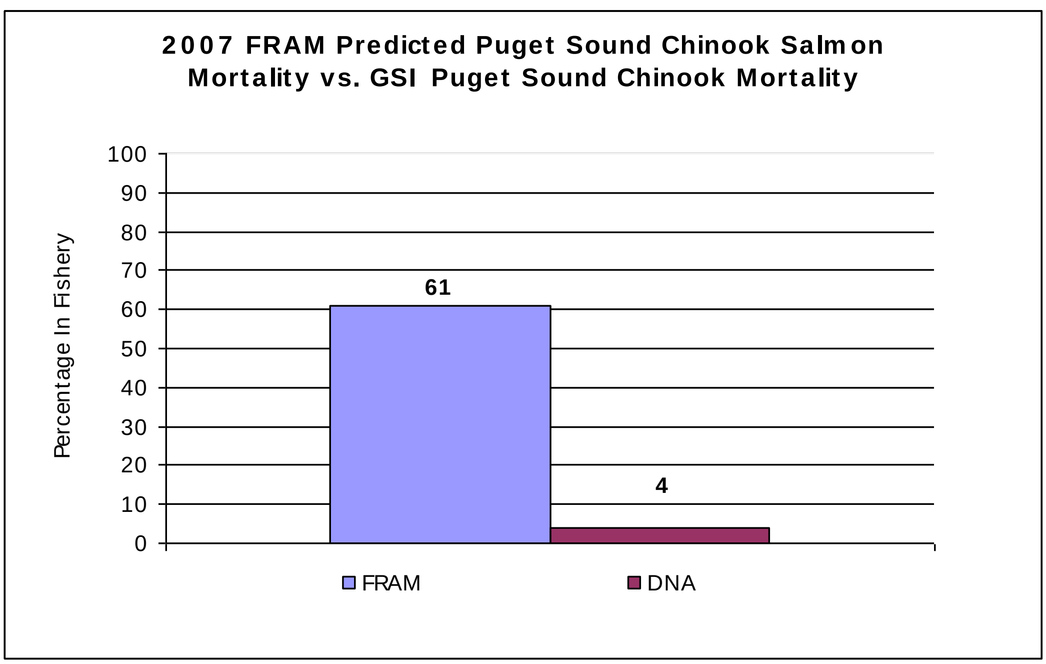

Figure 9. 2007 FRAM predicted percentage of Puget Sound Chinook salmon mortality in purse seine fisheries from Marine Area 7 and 7A and GSI percentage reported from samples collected during these fisheries. (Blankenship 2007).

4.4 Stock Composition Trends Over Time in the Marine Area 7B and 7C Bellingham Bay Gill Net Fishery

Genetic samples obtained during the 2007 Marine Areas 7B and 7C Bellingham Bay Chinook Directed Gill Net Fishery were simultaneously processed by myself, and the staff of the WDFW genetics laboratory for this analysis (Table 10). Results suggest that the catch composition was consistent with the data processed in the WDFW genetics laboratory by Anne Marshall in 1998. The catch composition reported in 1998 was 98% Puget Sound Chinook salmon, and 2% Canadian origin Chinook salmon (Table 6). The 2007 results maintained a strong Puget Sound Chinook salmon stock composition of 98%, and 2% of Oregon origin Chinook stocks were present (Table 9-10). Of the 98% Puget Sound Chinook salmon present in the 1998 sample, it was not possible to detect the exact Chinook salmon stocks these represented, as the GAPS database was not complete for all Puget Sound Chinook stocks, hatchery or wild, at that time. Since 1998 the GAPS database has been expanded to include a more comprehensive collection of wild and hatchery West Coast salmonids, including Puget Sound Chinook salmon stocks previously excluded from the GAPS database. A distinction between North and South Puget Sound Chinook populations can also now be made, in an attempt to try to isolate geographical impacts as well. Due to the GAPS database expansion the 2007 Bellingham Bay Gill Net fishery results were reported to include, with finite precision, which specific Puget Sound Chinook salmon stocks were impacted. The results are listed in Table 4.

Table 4

WDFW REPORTING GROUP	Proportion	Percentage
L_Columbia_R._fall	0.00	
N_Oregon_Coast	0.00	
Mid_and_Upper_Columbia_R._spring	0.00	
SSE_Alaska	0.00	
Rogue_River_Oregon	0.02	1.53%
Central_BC_Coast	0.00	
U_Skeena_River	0.00	
Central_Valley_fall	0.00	
S_Puget_Sound	0.37	36.84%
NSE_Alaska	0.00	
E_Vancouver_Island	0.00	
L_Fraser_River	0.00	
Central_Valley_spring	0.00	
Washington_Coast	0.00	
N_California/S_Oregon_Coast	0.00	
Mid_Fraser_River	0.00	
N_Thompson_River	0.00	
W_Vancouver_Island	0.00	
Mid_Oregon_Coast	0.00	
L_Columbia_R._spring	0.00	
Nass_River	0.00	
Straits_Juan_de_Fuca	0.00	
L_Skeena_River	0.00	
California_Coast	0.00	
Hood_Canal	0.07	7.39%
U_Columbia_R._summer/fall	0.00	
Snake_River_spring/summer	0.00	
Klamath_River	0.00	
S_BC_Mainland	0.00	
N_Gulf_Coast	0.00	
Taku_R.	0.00	
S_Thompson_River	0.00	
Deschutes_River_fall	0.00	
N_Puget_Sound	0.54	54.24%
U_Stikine_R.	0.00	
Snake_River_fall	0.00	
Willamette_River	0.00	
U_Fraser_River	0.00	
L_Thompson_River	0.00	
Central_Valley_winter	0.00	
Mid_Columbia_R._tule_fall	0.00	

Table 4. ONCOR Results from 2007 DNA analysis of Marine Areas 7B/7C Bellingham Bay Chinook Directed Gill Net Fishery Samples. Iverson and Blankenship 2008.

The resolution of the WDFW reporting groups can also now be broken down to provide even more precise population impacts. Data from the individual fish each reporting group is comprised of can be separated out and subsequently assigned back to their exact stock of origin. For example, in the South Puget Sound reporting group above in Table 4, Chinook salmon originating from the Voights Creek Hatchery contributed 7%, Issaquah Hatchery 2%, Nisqually River 6%, Soos Creek Hatchery 9%, and Cedar River 13% respectively (Table 11).

4.5 Comparison of Effects by Gear Type and Species Targeted

As expected, when directly targeted by fishers Puget Sound Chinook salmon mortality greatly increases (Figure 10). (These data do not reflect a mark-selective fishery regulation for recreational fisheries as these fisheries have only recently begun to be implemented, and were not used in 1998). Of the gear types discussed here, those gear types allowed to directly target Chinook salmon in Marine Areas 7/7A/7B/7C are those fishing recreationally and those using gill nets.

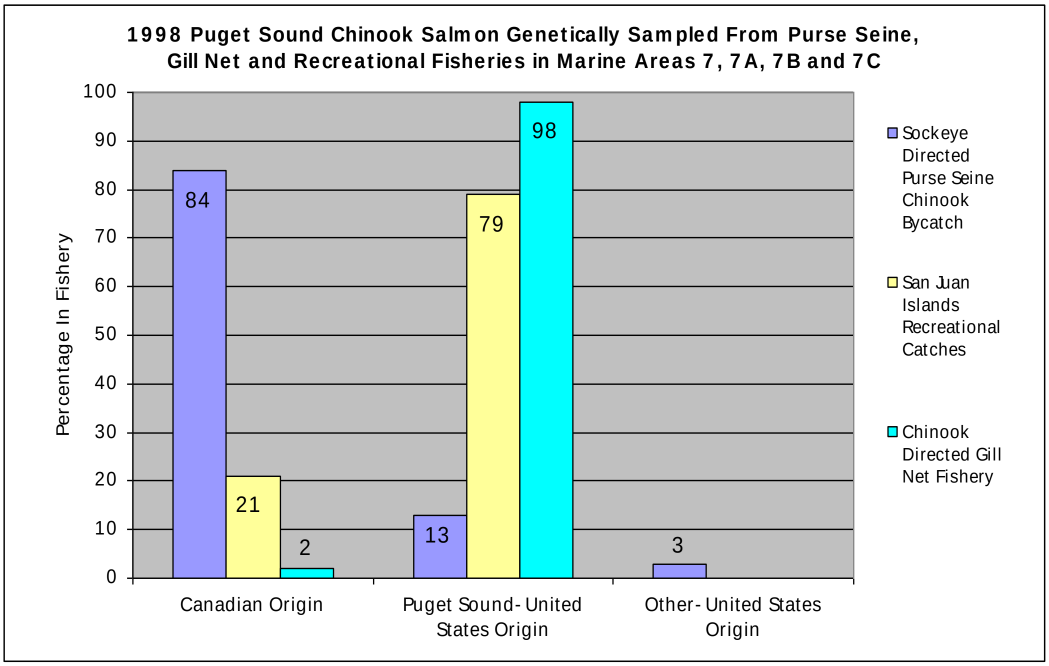

Figure 10. Total Fishery Impacts Accounted for by genetic sampling on Puget Sound Chinook in 1998 for Marine Areas 7, 7A, 7B and 7C. (Marshall 1998).

Upon comparing the pre-season FRAM predicted percentages of mortality of specific Puget Sound Chinook salmon stocks to the data actual in-season genetic samples obtained from the 2007 recreational fisheries, it appears that FRAM was unable to predict precise stock impacts with an error of less than 6-15% (Figures 11 and 12).

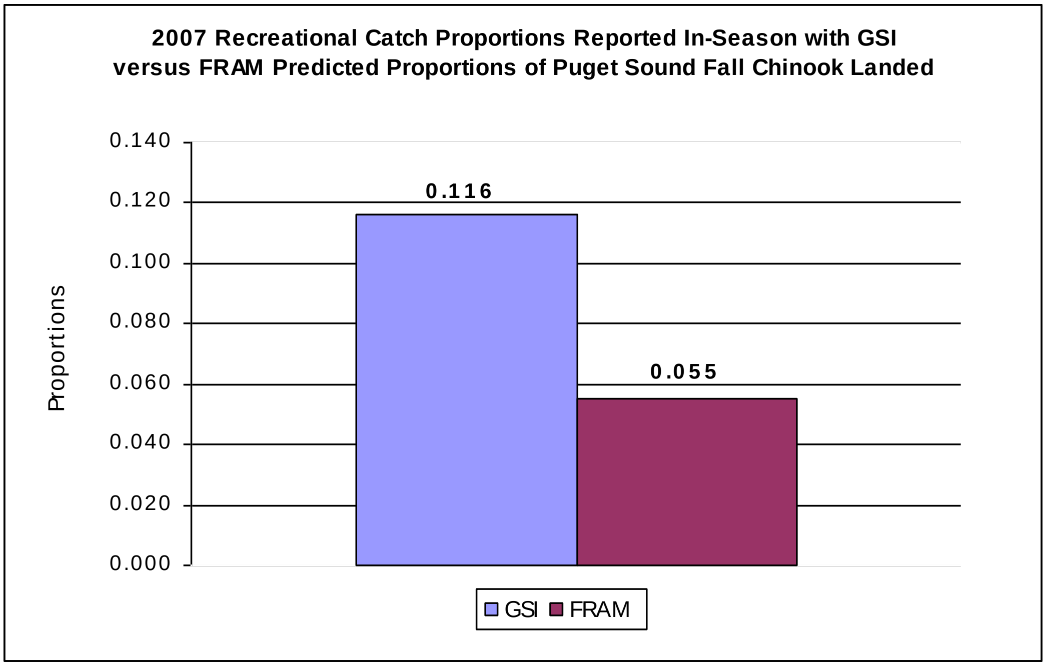

Figure 11. 2007 FRAM pre-season predictions for recreational Puget Sound Fall Chinook mortality in the Marine Area 7 fisheries versus in-season GSI data reported. (Blankenship 2007).

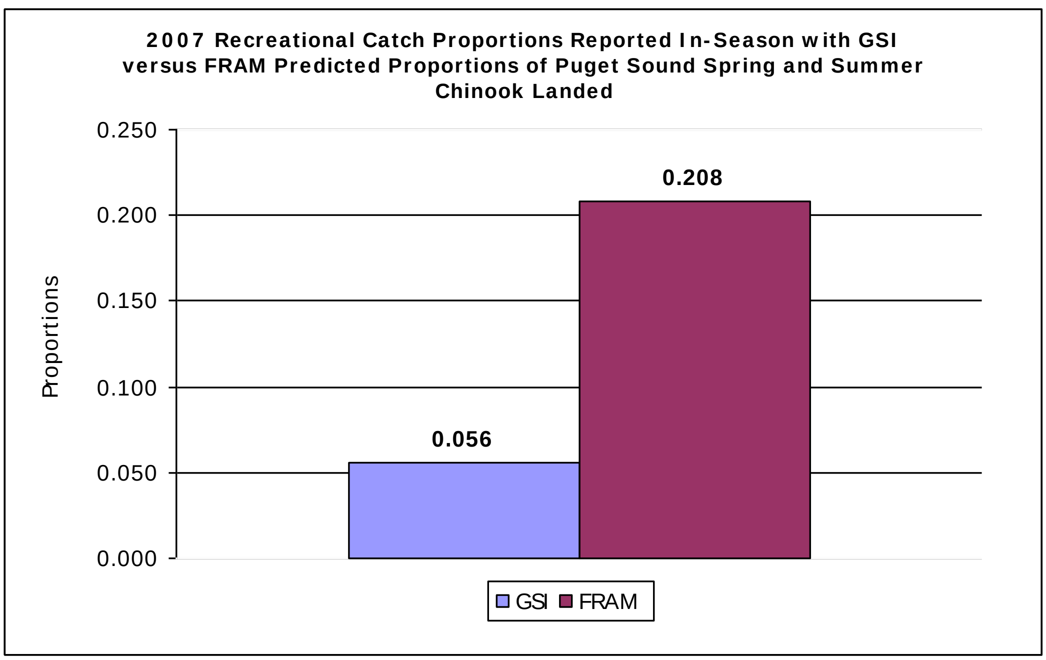

Figure 12. 2007 FRAM pre-season predictions for recreational Puget Sound Spring and Summer Chinook mortality in Marine Area 7 fisheries versus in-season GSI data reported. (Blankenship 2007).

5 Discussion

These analyses suggest that the sole use of FRAM pre-season to predict mortality of ESA-listed Chinook salmon stocks in-season during both targeted and non-target fisheries in Marine Areas 7, 7A, 7B and 7C may not provide the finest resolution possible on impacts to ESA-listed Puget Sound Chinook salmon stocks as federally mandated. These analyses also suggest that Marine Area 7 and 7A could be managed separately, as the Chinook salmon stocks present in these two geographically distinct areas have significantly differed in observed abundance consistently over the last ten years. As often hypothesized by fishers and fishery managers alike, the Chinook salmon stocks present in Marine Areas 7 and 7A visually appear to be returning to different geographically located spawning locations. As such, the historical practice of lumping data from Marine Areas 7 and 7A together in order to increase sample sizes to have the ability to perform more powerful statistical analyses has prevented this from being examined in more detail. It should be noted that the 1998 data was examined separately for Marine Area 7A stock composition due to the larger sample size (n=219), (Marine Area 7 n=67, Total Marine Area 7/7A used in reported statistical analyses was n=286) and the variation was determined to be statistically insignificant from the total sample of n=286 (Table 5).

Since GSI technologies for identifying Chinook salmon stocks have now developed to a point where GSI is useful for in-season fishery management, we may now begin to use this tool on a regular basis to modify how stock impacts are reported in-season when combined with the pre-season modeling methods previously used. When GSI is used we get ‘real-time’ data on the stocks impacted in a fishery which was not possible in the past using modeling techniques alone.

Still, GSI analysis is not a panacea. As stated by Wainwright and Waples (1998), ‘there is no single, easy method for conducting salmonid risk evaluations over broad geographic areas: differences in species biology, natural resource management, and the degree and methods of population monitoring require that different considerations be emphasized for different species and geographic areas’. There are still no perfect methods to assess stock specific mortality and population risks. Reporting errors (such as those mentioned in Section 2.6) were detected when a GSI analysis was performed to predict stock specific mortality estimates with the 2007 Bellingham Bay data I acquired. I was able to detect some biases in the assigned reporting groups which were assigned by the GSI software ONCOR during my simulations (Blankenship 2007). This was discovered when the GSI output was compared to the known origin of the samples, and before the 1000 simulations were run (Table 10).

Additionally limitations of collecting GSI samples due to the short time the fishery is open, and in recent years, the complete closure of some commercial fisheries due to low population estimates of returning stocks of sockeye salmon have severely limited the data available for GSI analysis. Also, small sample sizes of fish are insufficient to estimate stock proportion from stocks which are occurring as a small percentage of the overall mixture collected (i.e. stocks less than 5% of mixture). This may make it difficult to detect these fish as even present in the fishery with the use of these tools.

Finally, at this time the GAPS genetic baseline is still incomplete for Puget Sound salmonid populations. Between-region estimates such as those reported as Canadian Chinook salmon versus United States Chinook salmon for pre-season FRAM predictions of mortality would likely be correct; however estimates for specific stocks within the US population could still be inaccurate. Within-region assignments would be affected by stocks not being present in the GAPS baseline at the time of GSI analysis, or being represented by a significantly small sample size in the analysis (Warheit 2006).

However, the long-term goal of using GSI in addition to FRAM is not only to provide finer scale stock impacts, but to increase the information available to managers on the temporal and spatial distribution of specific West Coast salmonid stocks. If GSI data confirms that substantial variation in temporal and spatial distribution exists, this may allow commercial fishermen access to relatively abundant stocks of salmon while protecting weak stocks. The next step in applying GSI technologies to fisheries management is to explore and map the distributions and migration patterns of stocks in Council-managed fisheries Coast Wide. However, the most significant advancement will ultimately come from an improved understanding of stock-specific marine distributions and migration pathways in relation to submarine topography and oceanic conditions. This will facilitate another much needed step toward a future of ecosystem-based management for salmonids (Pitcher 2001).

The primary objective of implementing GSI in the yearly NOF monitoring process would be to improve information on spatio-temporal distribution of West Coast Chinook salmon for use as precise in-season ESA-listed stock impact management. In addition, the information gathered will also start to answer questions about the relative distributions and abundance of Chinook salmon. This information is vital to reducing weak stock impacts. Such finite information will greatly reduce the level of uncertainty associated with historically derived stock assessments. When genetic samples obtained during a fishery confirm that there are so few Puget Sound Chinook salmon present in a Chinook salmon directed fishery (Figures 11 and 12), continuously reporting an error even as minimal as 6-15% each year could potentially have seriously detrimental effects on severely depressed stocks. For some severely depressed stocks a reporting error of 6-15 % could feasibly represent the entire remaining population.

It is essential to collect time- and location-specific genetic samples, scale samples and oceanographic data during each open commercial and recreational fishery (Barnett-Johnson et al., 2007). These data collections will develop a complete database of stock distributions through GSI analysis for comparison with the historically used CWT database, but with fewer assumptions, such as having fewer hatchery indicator stocks representing natural production stocks, and much higher resolution in space and time. This will enable fishery managers to precisely examine migration routes, evaluate the presence and duration of large congregations of fish, relate fish distributions to ocean conditions, and generally expand the range of information available on Pacific salmon. Compilation of such a database will require that GSI sampling continue for several years (OSU 2008).

The use of GSI for stock specific distribution patterns and abundance of Puget Sound Chinook salmon populations could also benefit the recovery of other ESA-listed species in Puget Sound, such as the Southern Resident Killer Whale (*Orca orcinus*). Southern Resident Orca populations primarily located in the Puget Sound and San Juan Islands were recently listed for protection under the ESA. The risk assessment was provided by results from a prey selection study on the resident San Juan Islands Orca population during the summers of 2004-2007. During this study a team of researchers followed whales and collected fish scales and remains after observed feeding events. The scales were then examined using GSI to identify the main prey of these Orcas. The research found that Chinook salmon were the significantly preferred prey species (Hempelmann et al., 2008). The recovery plan identified reduced prey availability as a possible risk to the population (Hempelmann et al., 2008).

6 Recommendations and Suggested Future Research

As the overall Puget Sound Chinook salmon abundance has been significantly lower over the past ten years of observing in Marine Area 7, I suggest the following; provide these weak stocks with adequate recovery habitat, and the time necessary to propagate a surplus of new recruits. This may require that this fishing area be closed to all fisheries for a period of up to five years. This amount of time will allow Puget Sound Chinook salmon populations outmigrating as juveniles in year one and two of the closure to completely mature and return to spawn, as Chinook salmon are sexually mature as early as age three, but can spawn at age four or five as well (Quinn 2005). Data collected from spawning surveys completed at spawning grounds of ESA-listed Puget Sound Chinook salmon populations would provide the baseline of the current reproductive success of these weak stocks. Over the next five years, even with all things being constant, such as continued ‘poor’ ocean conditions providing an inadequate food supply and high harvest rates in Alaska and Canada, etc., fishery managers should expect to see some improvement in the number of spawned adults if in fact the use of fishery closures will benefit a weak population in the long run. Fishery managers have been closing fisheries for many years, as needed, to limit impacts to weak and ESA-listed stocks. Therefore, the cost-benefit analysis for continuing to keep Marine Area 7 open at this time does not make sense. To use the fishery closure tool as it was intended, to limit impacts on ESA-listed populations, I believe that closing Marine Area 7 for a period of five years would be using this tool for such purpose.

Additionally, closing Marine Area 7 in its entirety to certain gear types which are directly targeting Chinook salmon also would benefit the recovery of ESA-listed Puget Sound Chinook salmon populations. As discussed in Sections 4.1.4 and 4.1.5 (See Figure 10), the gear types which appear to be causing the most impact to ESA-listed Chinook populations would be the gillnet and recreational fisheries. These two gear types are currently allowed to directly target Chinook salmon populations, therefore it would make sense to close all Chinook salmon directed fishing of these two gear types in Marine Area 7 for a period of at least five years. Fish stocks can be highly resilient, thus a closure period of even five years could allow marginally weak stocks to build a surplus of recruits and new age classes to naturally supplement the population (Cook 2006; Quinn 2005). For some severely depressed stocks, it may be too late to naturally recover these populations in this manner. However, limiting further impacts on all fish stocks can only benefit the overall health of the Puget Sound marine ecosystem. As it has been documented that wild origin fish have higher survival and reproduction rates in the natural environment than hatchery fish (Jonsson et al., 2003; McIsaac 1990) the cost-effective way to rebuild ESA-listed populations in Puget Sound would be to limit impacts to wild origin populations where the benefits clearly outweigh the costs.

With tools already in place such as MPAs and the designation of Critical Habitat for ESA-listed species, we have already begun to use these new tools to aid in our efforts to recover weak fish populations (Bohnsack 1993; 1996). Natural fish populations are resilient, and, given a chance, they can rebound unbelievably fast (Quinn 2005). Now that we have the tools to examine salmon stock impacts at the fine scale of genetic stock of origin, we need to use these tools responsibly for the recovery of those species.

Oregon State University has already begun a pilot program called Project CROOS, which uses the knowledge and skills of local commercial fishermen to gather much needed fish distribution data. Fishermen are chartered to collect samples while fishing their normal and accustomed troll fisheries; during fishery closures, they work with OSU researchers to gather genetic data on fish present in much of the coastal waters of Oregon. Washington has recently begun to suggest collaboration with OSU to expand this project coast wide in an effort to collect fish migration data for all west coast salmonid stocks (Blankenship 2007). Additionally, as we become more educated as a society about the food we consume, the ability to verify the catch location, or home basin, of a fish could be used to market more abundant stocks. This may lead to an increase in the market value of sustainably harvested fish to local Pacific Northwest salmon fishermen. GSI is a tool that offers such verification in a relatively quick and efficient manner through projects such as Project CROOS.

The development of future fishery management models depends on results of the continued study as well as sustained genetic sampling efforts over the next several years. Understanding aspects of the life history of fish stocks will be of increasing importance in the management of existing marine resources. Describing migratory and distribution patterns, habitat use, age, growth, mortality, age structure, sex ratios, and reproductive biology will be essential information for natural resource managers to optimize sustainability and harvest opportunities of these resources. The improved understanding of ocean distributions that will result from conducting GSI studies over a period of years will help us characterize discrete stocks and design much needed stock-specific management measures. Many factors, both natural and human-related, affect the status of fish stocks, protected species and ecosystems (NRC 1996). Although these factors cannot all be controlled, newly available technology and fishery management tools such as

GSI enable natural resource management agencies charged with the task of monitoring impacts to ESA-listed species to have the ability to closely monitor and adjust protection as necessary.

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Table 5

1998 Purse Seine Bycatch Proportions as Reported by WDFW

MAJOR REGIONAL STOCK GROUP/ REGIONAL STOCK SUB-GROUP	%	(SD)	%	(SD)
COLUMBIA/SNAKE			3	(2)
Lower Columbia SP	0	(0)		
Lower Columbia FA	1	(1)		
Upper Columbia SP	1	(1)		
Upper Columbia SU & *FA* Snake FA	1	(1)		
Snake SP & SU	0	(1)		
WASHINGTON COASTAL & STRAIT	0	(0)	0	(0)
PUGET SOUND			13	(2)
Skagit *SP* Skagit/Still. SU & FA (wild)	0	(1)		
Other Puget Sound SU "-~A~	11	(3)		
Other Puget Sound SP	1	(1)		
B.C.-FRASER RIVER			82	(3)
Lower Fraser SP & SU	0	(0)		
1; Lower Fraser FA	6	(2)		
Thompson 3U	66	(4)		
Mid-Fraser SP & 3U	9	(3)		
Upper Fraser SP	1	(1)		
B.C.-VANCOUVER ISLAND/MAINLAND COAST			2	(2)
West Vancouver Island FA	1	(1)		
Upper Georgia Strait SU & FA	1	(2)		
Lower Georgia Strait SU & FA	-1.	(1)		
TOTAL	100		100	

MA 7 n = 67, MA 7A n = 219, n = 286 total. Anne Marshall WDFW Memo 1998.

Table 6

1998 Gill Net Bycatch Proportions as Reported by WDFW

MAJOR REGIONAL STOCK REGIONAL STOCK SUB-GROUP	%	(SD)	%	(SD)
COLUMBIA/SNAKE			0	(0)
Lower Columbia SP	0	(0)		
Lower Columbia FA	0	(0)		
Upper Columbia SP	0	(0)		
Upper Columbia SU & FA	0	(0)		
Snake SP & SU	0	(0)		
WASHINGTON COASTAL & STRAIT	0	(0)	0	(0)
PUGET SOUND			98	(1)
Skagit *SP* Skagit/Still. SU & FA (wild)	0	(0)		
Other Puget Sound SU & FA	98	(1)		
Other Puget Sound SP	0	(0)		
B.C.-FRASER RIVER			1	(1)
Lower Fraser SP & SU	0	(0)		H
Lower Fraser FA	0	(1)		
Thompson SU	0	(0)		
Mid-Fraser SP ~ SU	0	(0)		
Upper Fraser SP	1	(1)		
B.C.-VANCOUVER ISLAND/MAINLAND COAST			1.	(1.)
West Vancouver Island FA	0	(0)		
Upper Georgia Strait SU & FA	0	(1)		
Lower Georgia Strait SU & FA	__ 1	(1)		
TOTAL	lob		100	

MA 7B n = 140, MA 7C n = 160, n = 300 total. Anne Marshall WDFW Memo 1998.

Table 7

1998 Recreational Catch as Reported by WDFW

MAJOR REGIONAL STOCK GROUP/ REGIONAL STOCK SUB-GROUP	%	(SD)	%	(SD)
COLUMBIA/SNAKE			0	(0)
Lower Columbia SP	0	(0)		
Lower Columbia FA	0	(0)		
Upper Columbia SP	0	(0)		
Upper Columbia SU & FA Snake FA	0	(0)		
Snake SP & SU	0	(0)		
WASHINGTON COASTAL & STRAIT	0	(0)	0	(0)
PUGET SOUND			79	(5)
Skagit *SP* Skagit/Still. SU & FA (wild)	0. (0)			
Other Puget Sound SU & FA	79	(5)		
Other Puget Sound SP	0	(0)		
B.C.-FRASER RIVER			10	(6)
Lower Fraser SP & SD	0	(0)		
1; Lower Fraser FA	5	(4)		
Thompson 3U	5	(4)		
Mid-Fraser SP & SU	0	(0)		
Upper Fraser SP	0	(0)		
B.C.-VANCOUVER ISLAND/MAINLAND COAST			11	(7)
West Vancouver Island FA	0	(0)		
Upper Georgia Strait SU & FA	0	(1)		
Lower Georgia Strait SU & FA	-11.	(7)		
TOTAL	100		100	

MA 7 n = 138 total. Anne Marshall WDFW Memo 1998.

Table 8

2006 Bycatch Data as Reported by WDFW

Pacific Salmon Commission Reporting Groups	Area 7A Non-Treaty Fishery N = 44	Area 7A Treaty Fishery N = 275	Individual Fish Assigned to Puget Sound Treaty Fishery (Area 7A)
S. Thompson River	76%-84%	82%-86%	
E. Vancouver Island	0%-4%	5%-7%	
Lower Fraser River	10%-18%	2%-4%	
Middle Fraser River	-	1%-3%	
N. Thompson River	0%-4%	1%-3%	
North Puget Sound	-	1%-3%	N = 2; Samish Hatchery
W. Vancouver Island	-	0%-2%	
South Puget Sound	0%-2%	0%-1%	N = 1; S. Prairie Creek or Voights Creek Hatchery
Upper Columbia River - summer/fall	-	0%-1%	
Washington Coast	-	0%-1%	
CA Central Valley - spring	-	0%-1%	

Ken Warheit WDFW Memo 2006.

Table 8. Stock composition estimates are based on a sample size n = 44 individual Chinook salmon; therefore, one fish is approximately equal to 2%. Of the 167 stocks present in the baseline, only a small number were estimated to occur in the bycatch sample. The following mixed-stock proportions are percent ranges that incorporate the mean estimate and its associated error: (1) South Puget Sound, 0-2%; (2) Lower Fraser River, 10-18%; (3) South Thompson River, 76-84%; (4) North Thompson River, 0-4%; and (5) East Vancouver Island, 0-4%. Therefore, these 44 samples were composed of fish from Puget Sound (0-2%) and stocks from Canada (98-100%).

Table 9

2007 Bycatch Data as Reported by WDFW

Pacific Salmon Commission Reporting Groups	Area 7/7A Non-Treaty Fishery Proportions N = 115	Individual Fish Assigned to Puget Sound Non-Treaty Fishery (Areas 7/ 7A)
Rogue River	0.009	
Upper Col. River Summer/Fall	0.010	
Washington Coast	0.005	
Hood Canal	0.009	
Straits of Juan de Fuca	0.013	
South Puget Sound	0.009	N = 1; Clear Creek Hatchery
North Puget Sound	0.008	N = 3; S.F. Skokomish, Elwha Hatchery, Marblemount Hatchery
Lower Fraser River	0.204	
South Thompson River	0.615	
Upper Fraser River	0.009	
East Vancouver Island	0.091	
Central BC Coast	0.011	
SSE Alaska	0.009	

MA 7/7A total n = 115. Scott Blankenship. WDFW Report 2007.

Table 10

2007 Marine Area 7B/C Gill Net Genetic Data as Reported by ONCOR

Populations Reporting Groups	Actual Value	GSI SIM	ST DEV	(95% INT)	
L_Columbia_R._fall	0	0.00	0.00	0.00	0.01
N_Oregon_Coast	0	0.00	0.00	0.00	0.00
Mid_and_Upper_Columbia_R._spring	0	0.00	0.00	0.00	0.00
SSE_Alaska	0	0.00	0.00	0.00	0.01
Rogue_River	0.0153	0.01	0.01	0.00	0.04
Central_BC_Coast	0	0.00	0.00	0.00	0.01
U_Skeena_River	0	0.00	0.00	0.00	0.00
Central_Valley_fall	0	0.00	0.00	0.00	0.00
S_Puget_Sound	0.3683	0.59	0.07	0.45	0.72
NSE_Alaska	0	0.00	0.00	0.00	0.00
E_Vancouver_Island	0	0.00	0.00	0.00	0.01
L_Fraser_River	0	0.00	0.00	0.00	0.00
Central_Valley_spring	0	0.00	0.00	0.00	0.00
Washington_Coast	0	0.00	0.00	0.00	0.01
N_California/S_Oregon_Coast	0	0.00	0.00	0.00	0.00
Mid_Fraser_River	0	0.00	0.00	0.00	0.00
N_Thompson_River	0	0.00	0.00	0.00	0.00
W_Vancouver_Island	0	0.00	0.00	0.00	0.00
Mid_Oregon_Coast	0	0.00	0.01	0.00	0.02
L_Columbia_R._spring	0	0.00	0.00	0.00	0.01
Nass_River	0	0.00	0.00	0.00	0.00
Straits_Juan_de_Fuca	0	0.00	0.00	0.00	0.01
L_Skeena_River	0	0.00	0.00	0.00	0.00
California_Coast	0	0.00	0.00	0.00	0.00
Hood_Canal	0.074	0.11	0.05	0.03	0.21
U_Columbia_R._summer/fall	0	0.00	0.00	0.00	0.01
Snake_River_spring/summer	0	0.00	0.00	0.00	0.00

Klamath_River	0	0.00	0.00	0.00	0.00
S_BC_Mainland	0	0.00	0.00	0.00	0.00
N_Gulf_Coast	0	0.00	0.00	0.00	0.00
Taku_R.	0	0.00	0.00	0.00	0.01
S_Thompson_River	0	0.00	0.00	0.00	0.01
Deschutes_River_fall	0	0.00	0.00	0.00	0.00
N_Puget_Sound	0.5424	0.27	0.06	0.16	0.39
U_Stikine_R.	0	0.00	0.00	0.00	0.00
Snake_River_fall	0	0.00	0.00	0.00	0.00
Willamette_River	0	0.00	0.00	0.00	0.00
U_Fraser_River	0	0.00	0.00	0.00	0.00
L_Thompson_River	0	0.00	0.00	0.00	0.00
Central_Valley_winter	0	0.00	0.00	0.00	0.00
Mid_Columbia_R._tule_fall	0	0.00	0.00	0.00	0.00

MA 7B/7C n = 64 total. WDFW Genetic Data and generated ONCOR Output. Christina Iverson and Scott Blankenship 2008.

Table 11

ONCOR Assignments of Individuals from Reporting Groups for 2007 Gill Net Data in Proportion and Percentage

POPULATION ESTIMATES	Proportion	%
Alsea_R	0.00	
Andrew_Cr	0.00	
Andrew_CryH	0.00	
Andrew_MacH	0.00	
Andrew_MedH	0.00	
Applegate_Cr	0.00	
Atnarko_H	0.00	
Babine_H	0.00	
Battle_Cr	0.00	
Big_Boulder_Cr	0.00	
Big_Qual_H	0.00	
Birkenhead_H	0.00	
Bulkley_R	0.00	
Butte_Cr_Sp	0.00	
Carson_H	0.00	
Chetco_R	0.00	
Chickam_WhitH	0.00	
Chickamin_R	0.00	
Chilko_R	0.00	
Clear_Cr	0.00	
Clear_Cr_H	0.00	
Clearwater_R	0.00	
Cole_Rivers_H	0.02	1.53%
Conuma_H	0.00	
Coos_H	0.00	
Coquille_R	0.00	
Cowichan_H	0.00	
Cowlitz_H_fa	0.00	
Cowlitz_H_sp	0.00	
Cripple_Cr	0.00	
Damdochax_R	0.00	
Deadman_H	0.00	
Deer_Cr_sp	0.00	
Dungeness_R	0.00	
Ecstall_R	0.00	
Eel_R	0.00	
Elk_H	0.00	
Elwha_H	0.00	
Elwha_R	0.00	
Feather_H_fa	0.00	
Feather_H_sp	0.00	
Forks_Cr_H	0.00	
GeorgeAdams_H	0.01	0.69%
Hamma_Hamma_R	0.00	
Hanford_Reach	0.00	
Hoh_R	0.00	

Humptulips_H	0.00
Hupp_Sp_H	0.00
Imnaha_R	0.00
John_Day_R	0.00
Kalama_H_sp	0.00
Keta_R	0.00
Kilchis_R	0.00
Kincolith_R	0.00
King_Cr	0.00
King_Salmon_R	0.00
Kitimat_H	0.00
Klamath_R_fa	0.00
Klinaklini_R	0.00
Klukshu_R	0.00
Kowatua_Cr	0.00
Kwinageese_R	0.00
L_Adams_H	0.00
L_Deschutes_R	0.00
L_Kalum_R	0.00
L_Sauk_R	0.00
L_Tahltan_R	0.00
L_Thom_R	0.00
Lewis_H_sp	0.00
Lewis_R_f	0.00
Louis_Cr	0.00
Lyons_Ferry_H	0.00
M_Shuswap_H	0.00
Makah_H	0.00
Hoko_H_Fa	0.00
Marble_H	0.00
Marblemount_H_sp	0.00
Marblemount_H_su	0.00
Maria_Slough	0.00
McKenzie_H	0.00
Methow_R	0.00
Mill_Cr_sp	0.00
Millicoma_R	0.00
Minam_R	0.00
Morkill_R	0.00
N_Santiam_H	0.00
Nakina_R	0.00
Nanaimo_H_f	0.00
Necanicum_H	0.00
Nechako_R	0.00
Nehalem_R	0.00
Nestucca_H	0.00
Newsome_Cr	0.00
NF_Nooksack_H	0.00
NF_Stilliguamish_H	0.00
Nicola_H	0.00

Nitinat_H	0.00	
Owegee_R	0.00	
Porteau_Cove_H	0.00	
Puntledge_H_f	0.00	
Queets_R	0.00	
Quesnel_R	0.00	
Quilayute_R	0.00	
Quinsam_H	0.00	
Raft_R	0.00	
Rapid_R_H	0.00	
Robertson_H	0.00	
Russian_R	0.00	
S_Coos_H	0.00	
S_Prairie_Cr	0.00	
S_Umpqua_H	0.00	
Sacramento_H	0.00	
Salmon_R_f_Fraser	0.00	
Salmon_R_f_OR	0.00	
Samish_H	0.48	47.94%
Sandy_R	0.00	
Sarita_H	0.00	
Secesh_R	0.00	
Siletz_R	0.00	
Situk_R	0.00	
Siuslaw_R	0.00	
Sixes_R	0.00	
Skykomish_R	0.00	
Snoqualmie_R	0.02	1.88%
Sol_Duc_H	0.00	
Soos_H	0.09	8.93%
Spius_H	0.00	
Spring_Cr_H	0.00	
Stanislaus_R	0.00	
Stillaguamish_H	0.00	
Stuart_R	0.00	
Suiattle_R	0.00	
Sustut_R	0.00	
Swift_R	0.00	
Tahini_R	0.00	
Tahsis_R	0.00	
Tatsatua_Cr	0.00	
Torpy_R	0.00	
Tranquil_R	0.00	
Trask_R	0.00	
Trinity_H_f	0.00	
Trinity_H_sp	0.00	
Tucannon_H	0.00	
Tucannon_R	0.00	
Tuolumne_R	0.00	
U_Cascade_R_Sp	0.00	

U_Chilcotin_R	0.00	
U_Deschutes_R	0.00	
U_Nahlin_R	0.00	
U_Sauk_R	0.00	
U_Skagit_Su	0.00	
U_Yakima_Sp	0.00	
Umpqua_H	0.00	
Voights_H	0.07	6.64%
W_Chilliwack_H	0.00	
Wallace_H	0.00	
Wannock_H	0.00	
Warm_Springs_H	0.00	
Wells_H	0.00	
Wenatchee_H_sp	0.00	
Wenatchee_R_sp	0.00	
Wenatchee_R_s/f	0.00	
WF_Yankee_Frk	0.00	
White_H	0.00	
Wilson_R	0.00	
Yaquina_R	0.00	
L_Skagit_R_Fa	0.03	2.82%
U_Sauk_R_SpSu	0.02	1.60%
Skykomish_H_Su	0.00	
Skykomish_R_Su	0.00	
Nisqually_R_SuFa	0.06	6.09%
Bear_Cr_SuFa	0.00	
Cedar_R_SuFa	0.13	12.74%
Grovers_Cr_H	0.00	
Issaquah_Cr_SuFa	0.00	
Issaquah_H_SuFa	0.02	2.16%
UW_H_SuFa	0.00	
NF_Skokomish_R_Fa	0.01	0.82%
SF_Skokomish_R_SuFa	0.06	5.88%
Hoh_R_SpSu	0.00	
Quinault_NFH_Fa	0.00	
Quinalt_R_Fa	0.00	
Chehalis_R_Fa	0.00	
Elochoman_R_Fa	0.00	
Abernathy_NFH_Fa	0.00	
Abernathy_Cr_Fa	0.00	
Coweeman_R_Fa	0.00	
Green_R_Fa	0.00	
Lewis_R_Fa	0.00	
Lewis_R_LFa	0.00	
Washougal_R_Fa	0.00	
Klickitat_R_Su	0.00	
L_Yakima_Fa	0.00	
Marion_Drain_Fa	0.00	
Yakima_bright_Fa	0.00	
Priest_Rapids_H_Fa	0.00	

Umatilla_H_Fa	0.00	
American_R_Sp	0.00	
Little_Naches_Sp	0.00	
Naches_Sp	0.00	
Twisp_R_Sp	0.00	
TOTALS	1.00	99.99%

Christina Iverson and Scott Blankenship. WDFW Genetic Data and ONCOR Output 2008.

Table 12

Shapiro-Wilk normality test results using R Version 2007

Chinook in 7	Chinook in 7A	Diff
69	498	-429
67	219	-152
56	70	-14
78	109	-31
67	81	-14
159	811	-652
56	6	50
8	599	-591
116	467	-351
2	149	-147

> shapiro.test(Fish_Diff$Diff)			
Shapiro-Wilk normality test results:			
data: Fish_Diff$Diff			
W = 0.8859, p-value = 0.1523			

Table 13

t-Test: Paired Two Sample for Means performed with R Version 2007

> t.test(Fish_Diff$Diff, alternative='less', mu=0.0, conf.level=.95)							
One Sample t-test results:							
data: Fish_Diff$Diff							
t = -2.8867, df = 9, p-value = 0.00899							
alternative hypothesis: true mean is less than 0							
95 percent confidence interval:							
-Inf -85.07786							
sample estimates:							
mean of x = -233.1							

Table 14

t-Test: Paired Two Sample for Means performed with MS Excel according to Section 12.4 of Applied Statistics with Microsoft Excel. (Keller 2001).

t-Test: Paired Two Sample for Means		
	Chinook in 7	*Chinook in 7A*
Mean	67.8	300.9
Variance	2103.511	74527.43
Observations	10	10
Pearson Correlation	0.456	
Hypothesized Mean Difference	0	
df	9	
t Stat	**-2.886**	
P(T<=t) one-tail	**0.00899**	
t Critical one-tail	**1.833**	
P(T<=t) two-tail	**0.0179**	
t Critical two-tail	**2.262**	

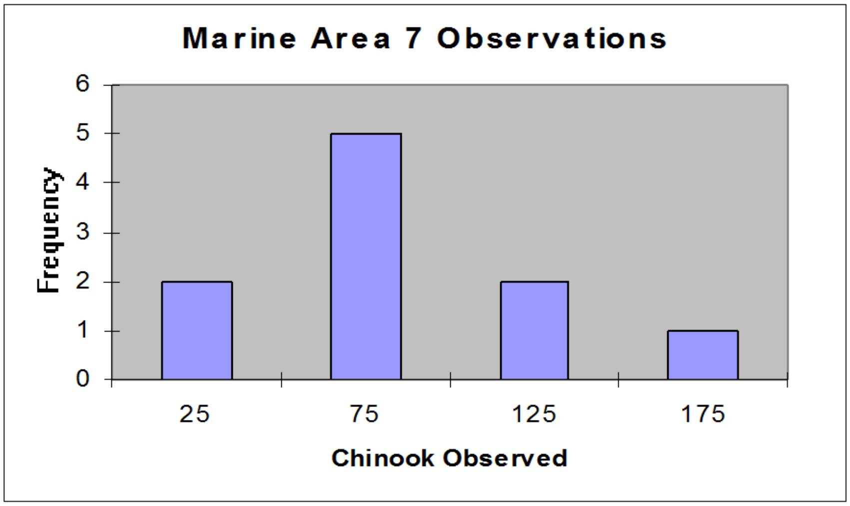

Figure 13. Data Distribution Histograms for Raw Data of Marine Area 7 Observations from 1997-2007.

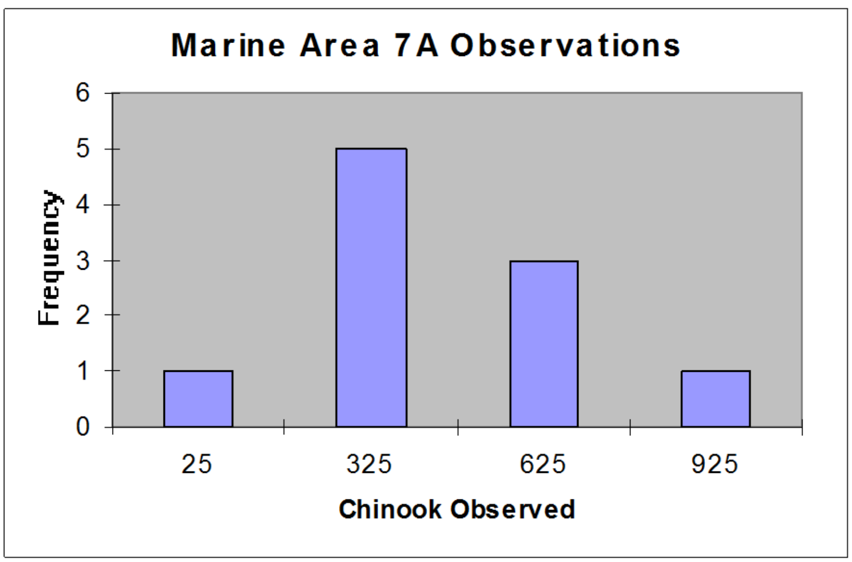

Figure 14. Data Distribution Histograms for Raw Data of Marine Area 7A Observations 1997-2007.

APPENDIX A

ACRONYMS:

NOAA-National Oceanic and Atmospheric Administration
USFWS- United States Fish and Wildlife Service
WDFW-Washington State Department of Fish and Wildlife
NMFS-National Marine Fisheries Service (fisheries branch of NOAA)
PMFC-Pacific Marine Fisheries Commission
DFO-Department of Fisheries and Oceans, Canada
PSVOA- Purse Seine Vessel Owners Association
MSA- Magnuson-Stevens Fishery Conservation and Management Act
ESA- Endangered Species Act
ESU- Evolutionarily Significant Units
TAC- Total Allowable Catch

DEFINITIONS: (As Listed in SEC. 3. 16 U.S.C. 1802 Of the Magnuson-Stevens Act)

Anadromous species - species of fish which spawn in fresh or estuarine waters of the United States and which migrate to ocean waters.

Bycatch - fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards. Such term does not include fish released alive under a recreational catch such as a mark selective fishery.

Commercial fishing - fishing in which the fish harvested, either in whole or in part, are intended to enter commerce or enter commerce through sale, barter or trade.

Conservation and management - refers to all of the rules, regulations, conditions, methods, and other measures **(A)** which are required to rebuild, restore, or maintain, and which are useful in rebuilding, restoring, or maintaining, any fishery resource and the marine environment; and **(B)** which are designed to assure that--

(i) a supply of food and other products may be taken, and that recreational benefits may be obtained, on a continuing basis;

(ii) irreversible or long-term adverse effects on fishery resources and the marine environment are avoided; and

(iii) there will be a multiplicity of options available with respect to future uses of these resources.