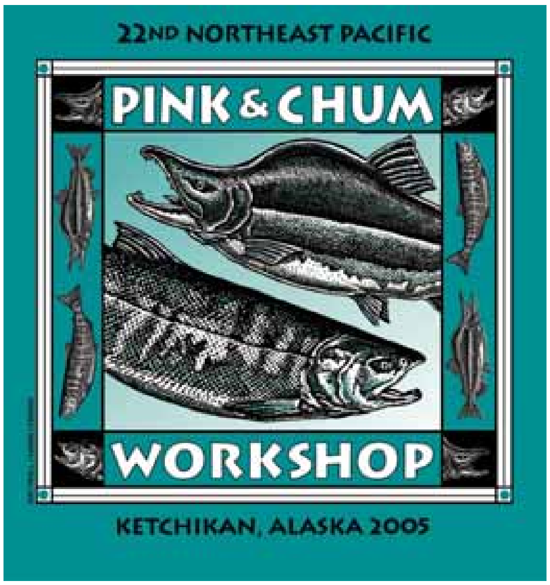

PROCEEDINGS

The 22ND Northeast Pacific Pink and Chum Salmon Workshop

Cape Fox Hotel,
Ketchikan, Alaska
February 23–25, 2005

Rappoteur: Harold J. Geiger

PROCEEDINGS of the 22ND Northeast Pacific Pink and Chum Salmon Workshop

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The following are pleased to have hosted the workshop:

Southern Southeast Regional Aquaculture Association

Alaska Department of Fish and Game)

Prince William Sound Science Center

Pacific Salmon Commission

University of Alaska Fairbanks, Juneau Center, School of Fisheries and Ocean Sciences

Douglas Island Pink and Chum, Inc.

NOAA Fisheries, NMFS, Auke Bay Laboratory

FOREWORD

Pink and Chum Salmon Workshops are intended to promote the informal exchange of new work and work in progress on pink and chum salmon biology and management. The Workshop has been held biennially since the early 1960s. The location alternates between Alaska, British Columbia, and Washington state. The workshops are not sponsored by a particular organization or institution, but have been the product of volunteer scientists from the host regions. Beginning with the 2003 Workshop, the Pacific Salmon Commission has provided web page and publishing assistance, which will hopefully continue as an information nexus for future workshops.

The 2005 Workshop brought together research biologists, fishery managers, aquaculturists, and others to explore and share innovative approaches to improved understanding, conservation, and sustainable use of pink and chum salmon. The Workshop was organized in eight sessions, listed below, that covered a wide array of topics. The Workshop also featured three special speakers. Dr. Tony Gharrett of the University of Alaska School of Fisheries and Ocean Sciences was the keynote speaker, and spoke on “Genetic, Local Adaptation, and Population Structure of Pink Salmon in a Small Alaskan Stream.” Dr. Tom Quinn, of the University of Washington School of Aquatic and Fisheries Sciences spoke on “Some Things I’d Like to Know About Salmon and Trout.” The Banquet Speaker was Mary Kapsner, Representative to the Alaska State Legislature from Bethel, Alaska, who talked of the importance of salmon and fishing to the subsistence lifestyle and culture of Western Alaska.

The material provided by the authors for printing in these proceedings has not been peer reviewed and has been compiled with only necessary editorial modification. This has been a tradition of the workshops, to encourage participants to present current work. Because the material is not peer-reviewed, items in these proceedings should not be cited except as personal communication with the author’s permission.

The 23rd Northeast Pacific Pink and Chum Salmon Workshop will be held February 19–21, 2007, in Seattle, Washington. The meeting will be held at the Seattle Museum of History and Industry, located near the University of Washington and the NMFS Northwest Science Center. Contact persons for the 2007 Workshop are Orlay Johnson (Orlay.Johnson@noaa.gov) and Jeff Hard (Jeff.Hard@noaa.gov), NMFS Northwest Science Center, and Laurie Weitkamp (Laurie.Weitkamp@noaa.gov), NMFS Hatfield Marine Science Center.

SESSIONS AND SESSION LEADERS

Session I.	Habitat Management and Restoration	K Koski
Session II.	Salmon Farming and Impacts on Pink and Chum Salmon	Bill Heard
Session III.	Enhancement Production and Management	Steve Reifenstuhl
Session IV.	Forecasting and Recruitment Prediction	Kalei Shotwell
Session V.	Western Alaska Issues	Nicola Hillgruber Hal Geiger
Session VI.	Ocean Ecology of Pink and Chum Salmon	Molly Sturdevant Jamal Moss
Session VII.	Contributed Papers	Rick Focht
Session VIII.	Contributed Posters	Gary Freitag

ACKNOWLEDGEMENTS

We would like to thank the following people for generously donating their time and energy to help put the 22nd Pink and Chum Salmon Workshop together: Todd Johnson and Glenn Hollowell provided audio-visual and technical assistance, Amy Holm assisted with registration, Ray Troll provided the artwork for the logo, Lucy Leitz for technical assistance, Bruce White (PSC) provided information about the 21st Pink and Chum Salmon Workshop, and Sandi Gibson (PSC) maintained the Pink and Chum Salmon Workshop information on the PSC website. We would also like to thank the Ketchikan Visitors Bureau and Karen Lynch and the staff at the Westcoast Cape Fox Lodge. Thanks also to Jenny Stahl (ADF&G) for editoral help with the proceedings.

Table of Contents

Keynote Talk

Genetics, Local Adaptation, and Population Structure of Pink Salmon in a Small Alaskan Stream or Two Decades of Squeezing Humpies

A.J. Gharrett
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More than 20 years of studying a naturally producing run of pink salmon in Auke Creek, near Juneau, Alaska, has provided insight into the role of genetics in the success of anadromous populations and has repeatedly shown the existence of local adaptation. A genetic marking program initiated in 1979 showed that returning Auke Creek pink salmon had strong genetic structure related to return timing, which was observed in outmigrants and persisted in subsequent generations. Genetic studies of population structure in Auke Creek, as well as of other local pink salmon populations, demonstrated significant effects of return timing on allozyme frequencies in both even- and odd-year (genetically isolated and independent) broodlines. The influence of spawning time on genetic structure exceeded spatial location within runs and differences among streams. Breeding studies that examined migration timing as a quantitative genetic trait showed that variation in timing of return had a significant basis in additive genetic variance.

Searching for determinants of timing, we studied development rate in early- and late-returning fish in both early- and late-run thermal environments encountered by the two population segments. Development rates differed between the segments in ways that can be generally explained as adaptation to environmental conditions. For instance there were significant additive genetic effects on variation of time to hatch, and there were significant genotype by environment interactions on development time to epiboly, eye pigmentation, and hatch. Comparisons of times to mid hatch of Auke Creek control crosses with hybrids between Auke Creek and Pillar Creek (Kodiak Island ca. 1000 km away) and of Pillar Creek controls with Auke Creek-Pillar Creek hybrids demonstrated that Pillar Creek genes resulted in later hatch times.

In comparisons of the survival of hybrids between even and odd brood year pink salmon in Auke Creek to controls from the even brood year, hybrids had reduced survivals in the second generation. Similarly, second generation hybrids between Pillar and Auke creeks had lower survivals than Auke Creek controls in both even- and odd-broodline experiments. The reduced survivals indicated that outbreeding depression resulted from hybridization. The occurrence of outbreeding depression demonstrates that local adaptation takes place and probably involves epistatic as well as additive mechanisms.

Variation within populations provides a buffer against interannual environmental changes. Analysis of family sizes of pink salmon surviving at sea and returning to Auke Creek indicated a significant additive genetic effect on marine survival that is more accentuated in large returns than small returns. The implication is that a small portion of the population contributes disproportionately to the next generation; and, as a consequence of interannual environmental variation, the more successful families vary unpredictably from generation to generation. It is likely that some of the genetic variability in life history traits is maintained as a bet-hedging strategy. Maintenance of genetic variation is a key to the long-term success of a population; however, our studies of inter-brood year hybrids suggest that outbreeding depression may also occur.

It is apparent that local adaptation is important in maximizing pink salmon production in different environments, ranging from geographic provinces to different segments of a run within a stream. Consequently, it is crucial to maintain genetic variation both within and among streams. Because humans are not yet able to determine which of the vast array of variation is most important in any particular generation, care must be taken not to erode inadvertently naturally existing variation.

The author is grateful to his coinvestigator, W. Smoker, and to the many colleagues that contributed to this effort: S. Taylor, R. Reisenbichler, A. McGregor, S. Lane, J. Joyce, K. Hebert, P. Goddard, S. Kelley, M. Fukushima, I. Wang, S. Gilk, A. Gray, H. Geiger, and C. Hoover.

Session 1: Habitat Management and Restoration

Lessons Learned on the Herman Chum Salmon Spawning Channel Near Haines, Alaska

Todd Buxton
Northern Southeast Regional Aquaculture Association

Artificial spawning channels are effective tools for providing chum salmon high-quality spawning habitat in the Chilkat Valley near Haines, Alaska. Constructed in 1989, in an area with abundant groundwater, Herman Channel promotes high chum egg-to-fry survival and aids chum broodstock collection and incubation operations. This spawning channel produced an estimated average of 7,500 adult chum salmon annually. Engineered to accommodate 1,400 spawners, the spawner counts in Herman channel have averaged 4,700. However, chum salmon exhibiting this level of preference for Herman channel has come with a price. Fewer spawners working gravels in Herman channel's tributary stream, Herman Creek, has allowed siltation of spawning riffles, while redd superimposition in and rapid mobilization of gravels from Herman channel have reduced egg to fry survival from 25 percent in 1990 to 2.5 percent in 2004. Steps have been taken to remedy this decline. Last summer, the longitudinal profile of the spawning channel was modified by bulldozing gravels mobilized by redd building back up the channel, and 400 cubic feet of new gravels were imported to the channel. Over-escapement to the channel has been eliminated by erecting moveable weirs, first as a fish trap to aid broodstock collection at the downstream end of the spawning channel, and then as a barrier to migration used to regulate the number of redds constructed in the channel by progressively moving the weir downstream as fish spawn out gravels. Additional advances include the ongoing development of a method to thermal mark otoliths in incubation boxes in the field, and applying knowledge gained with Herman Spawning Channel to site, design, and construct relatively inexpensive spawning channels on the Klehini River floodplain.

A Tidal Habitat Restoration Success Story—The Union Slough Restoration Project

Jonathan Houghton
Pentec Environmental, A Division of Hart Crowser, Inc.

On a 30-acre diked agricultural property in the Snohomish Estuary, Washington, a dendritic channel and graded contours suitable for brackish marsh development were built. Dikes were breached in early 2001. Subsequent use by juvenile salmonids and a variety of other species is high, and marsh development has exceeded expectations.

Restoration of Chum and Coho Salmon Habitat in a Small Urban Stream in Southeast Alaska

K V. Koski
NMFS, Auke Bay Laboratory

Duck Creek, a small coastal stream located in the Mendenhall Valley near Juneau, Alaska, is impaired because of urban runoff and habitat alteration; native runs of 10,000 chum and 600 coho salmon are now extinct. Today, only nomadic coho fry that rear in estuarine waters in summer and migrate into streams in fall to overwinter inhabit Duck Creek and annually produce up to 4,000 smolts. Examination of egg-to-fry survival in the stream by excavation of redds and bioassays with Whitlock-Vibert boxes revealed that survival of coho and chum salmon eggs was zero because of the degraded spawning habitat. Restoration efforts have focused on restoring spawning habitat in an upper reach of stream by reconfiguring the channel and riparian habitat and improving water quality and overwintering habitat by creating instream wetlands from old borrow pit ponds.

Session 2: Salmon Farming and Impacts on Pink and Chum Salmon

Possible Impact of Salmon Farming on the Health of Wild Salmon Populations

Corey Peet
Department of Marine Ecology, University of Victoria

Amplification and transfer of parasites and pathogens to wild fish populations is a serious issue associated with open-net fish farming. The salmon louse (*Lepeoptheirus salmonis)* is a common ecto-parasite of salmonids, with a history of causing significant losses of farm salmon. Over the last several years, salmon lice outbreaks on wild juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon have been documented in a near- shore marine area of British Columbia, Canada, where salmon farming activities are concentrated. As outbreaks of salmon lice on wild salmon are considered rare, concern exists as to what effect the increased lice densities may have on the health of juvenile salmon populations. Currently, no data exist to quantify the potential impact of high lice densities on juvenile salmon health or survivorship. We artificially infected captive populations of juvenile salmon with varying intensities of infective lice larvae. Results show both pink and chum salmon are significantly adversely affected when small, with susceptibility diminishing with size for pink salmon only. Further, spring collections of early marine pink and chum salmon were conducted in three areas of the BC coast using a beach seine. Results suggest that lice numbers are higher where salmon farming is present and that chum salmon have a higher prevalence than pink salmon. Given the results of this study and the risk factors in BC, we suggest that salmon aquaculture could pose a significant threat to the health of juvenile pink and chum salmon populations.

Sea Lice and Pink Salmon Smolts—North Coast of British Columbia

Allen S. Gottesfeld[1], Teresa Ryan[2], Dave Rolston[3], Bart Proctor[3]
[1]Skeena Fisheries Commission, Hazelton, British Columbia
[2]Tsimshian Tribal Council, Prince Rupert, British Columbia
[3]Oona River Resources Association, Oona River, British Columbia

Dip nets and an Ocean Fish Lift (OFL) trawl net were used to sample juvenile salmon and parasitic sea lice in the estuarine waters of the Skeena River in Chatham Sound and Ogden Channel. In May, large numbers of pink smolts were found in the littoral fringe of eastern Porcher Island and on the east coasts of Dunira and Dundas islands. By July, pink smolts were restricted to the more saline waters of the passes on the west side of Chatham Sound and at the south end of Ogden Channel. The OFL net performed well and caught smolts (>55mm) once they left the immediate beaches. We examined 6,249 pink salmon for sea lice. Overall prevalence (louse per sampled fish) was 2.7% *Lepeophtheirus salmonis* and 10.9% *Caligus clemensi.* Intensities (louse per infected fish) were low: 1.20 and 1.23. Motile sea lice of both species first appeared in June and increased in abundance throughout the season. Larger, presumably older, smolts had more motile lice on them. *L. salmonis* chalimus-stage larvae were increasingly abundant on larger fish while *Caligus* larvae abundance decreased. The abundance of *C. clemensi* was three times higher and *L. salmonis* was five times higher in the western portion of Chatham Sound and in the Anger Island area. These high prevalence zones had higher salinity, longer residence time by smolts, some mature sea lice capable of intensifying the infestation, and interaction with incoming mature salmon, which bore sea lice. Identification of high prevalence zones as areas of naturally high incidence and amplification would allow improved siting of salmon farms, which often have severe problems with *L. salmonis* infestations. The potential for amplification of *L. salmonis* infestation in critical juvenile pink salmon habitat is of concern.

Transmission Dynamics of Parasitic Sea Lice From Farm to Wild Salmon

Martin Krkosek, Mark A. Lewis, and John P. Volpe
Centre for Mathematical Biology, University of Alberta

Marine salmon farming has been correlated with parasitic sea lice infestations and concurrent declines of wild salmonids. We report a quantitative analysis of how a single salmon farm altered the natural transmission dynamics of sea lice to juvenile Pacific salmon. We studied infections of sea lice (*Lepeophtheirus salmonis* and *Caligus clemensi*) on juvenile pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) as they passed an isolated salmon farm during their seaward migration down two long and narrow corridors. Using spatially explicit models, we were able to quantify the magnitude and spatial extent of louse transmission from farm salmon to wild juvenile salmon in relation to transmission from naturally occurring wild host populations. Upon initial transmission and infection, two generations of the farm-origin lineage of lice were observed to parasitize the wild juvenile salmon. This may lead to louse population growth and spread into adjacent wild salmon populations. Amplified sea lice infestations due to salmon farms are a potential limiting factor to wild salmonid conservation.

Session 3: Enhancement Production and Management

Salmon Hatcheries in Alaska—Plans, Permits and Policies to Protect Wild Stocks

Craig Farrington
Alaska Department of Fish and Game, P.O. Box 25526, Juneau, Alaska 99802

The Alaska Salmon Enhancement Program began in 1971 when the health of the state's salmon fisheries was in question. The program is unique for having private non-profit corporations (PNP) actively operating salmon hatcheries; the PNPs function to augment the common property fisheries in the state. Contributions to common property fisheries from the PNP salmon hatcheries totaled over 20 million fish in 2004. Alaska's wild salmon stocks have rebounded from the late 1960s, and commercial harvests of wild stocks in Alaska have reached record levels in recent years: over 125 million fish in 2004. Alaska's hatchery program has had little or no detrimental effect on the health of wild stocks largely because of proactive measures taken to insure the protection of wild salmon stocks. These measures include Alaska statutes and Alaska Department of Fish and Game regulations, comprehensive salmon plans, permitting procedures and policies.

Considerations for Management of Both Wild and Hatchery Returns at Baranof Island Hatcheries

Bill Davidson
Alaska Department of Fish and Game, Division of Commercial Fisheries, 304 Lake St., Sitka, AK 99835

Abstract

The addition of hatchery returns in the general vicinity of on-going traditional fisheries always presents a challenge to salmon managers. With the hatcheries on Baranof Island, this addition occurred within a decision-making framework, which includes legal requirements, planning activities, and in-season actions. Commercial fishery area managers were consulted regarding proposed new programs, and these managers are developing and following fishery management plans to deal with this enhancement. Additionally, the managers must deal with hatchery returns in-season, by exercising emergency order authority. At Hidden Falls Hatchery, on east Baranof Island, due consideration is paid to ensuring adequate escapement of wild, ancestral chum salmon stocks returning to Kelp Bay, immediately north of the Terminal Harvest Area fishery. At Port Armstrong Hatchery, on south Baranof Island, permits and funding have been awarded for major new chum salmon production; however, hatchery program managers and the Regional Planning Team must now consider options of where new production can be released and harvested as adult returns. At Medvejie Hatchery on west Baranof Island, a Terminal Harvest Area was established at Deep Inlet. Currently, all three gear groups, plus a substantial hatchery cost recovery fishery, are actively harvesting chum salmon returns in an area superimposed over an area encompassing both traditional and terminal fisheries. This review highlights some of the considerations, which commercial fishery managers have had to address in order to provide for sustainable fisheries.

Introduction

There are five salmon hatcheries in operation on Baranof Island: Little Port Walter, a NMFS-operated research facility; Sheldon Jackson, an educational hatchery; Hidden Falls Hatchery and Medvejie Hatchery, operated by the Northern Southeast Regional Aquaculture Association (NSRAA); and Port Armstrong Hatchery, operated by Armstrong-Keta, Inc. (AKI). The latter four hatcheries are under the umbrella of the Private Non-Profit Hatchery Program (PNP), administered by the State of Alaska. The permitted capacities of the four PNP hatcheries on Baranof totals almost a third of a billion salmon eggs (Table 1)**.** This total permitted production includes 100 million pink salmon and 178 million chum salmon. Although one of the key points is that hatchery permitted capacity is constantly changing, most of the hatchery programs are operating at full capacity and have long established programs. Hidden Falls Hatchery is permitted for on-site releases of 91 million chum salmon; Medvejie Hatchery is permitted for on-site releases of 52 million chum salmon; Port Armstrong Hatchery is permitted for 85 million pink salmon. Recently Port Armstrong Hatchery was permitted for an additional 30 million chum salmon.

Table 1: Permitted Capacities of Baranof Island Hatcheries.

Permitted Capacities of Baranof Island PNP Hatcheries, 2004					
Millions of Eggs					
	Pink	Chum	Coho	Chinook	
Hidden Falls	0	91	3	3.5	
Sheldon Jackson	15	5	0.15	0.1	
Medvejie	0.3	52	3.3	5.2	
Port Armstrong	85	30	2	2	
TOTAL	100.3	178.0	8.5	10.8	

The Alaska Department of Fish and Game in Sitka is primarily responsible for management of traditional wild-stock fisheries and terminal common property fisheries within designated areas spelled out in regulations (ADF&G 2002). Each PNP hatchery is primarily responsible for the conduct of cost recovery fisheries within designated Special Harvest Areas (SHA)[1] associated with the particular hatchery. Terminal Harvest Area (THA)[2] fisheries are co-managed with NSRAA to ensure that cost recovery goals are met. To better understand the elements of managing fisheries, I've grouped management considerations into a framework of three categories: legal framework, planning process, and in-season actions.

Legal considerations involve a working knowledge of appropriate statutes and regulation as they apply to a given situation. The primacy of management for sustainable wild stocks can be found throughout the legal framework. A major component of this management activity is involvement with the Alaska Board of Fisheries to change and develop new regulations each third year. Where allocation between user groups may be a consideration, *regulatory management plans* are formally adopted as law. Such is the case at both Hidden Falls Hatchery and Medvejie Hatchery. Emergency order authority gives fishery managers the power to determine time and area for a fishery with the force and effect of law. Local area managers are thus provided the flexibility to make appropriate decisions in-season based on local knowledge and current information.

[1] Defined as "an area designated by the commissioner or the Board of Fisheries where hatchery returns are to be harvested by the hatchery operators, and in some situation by the common property fishery."

[2] Defined as "an area designated by the commissioner, Board of Fisheries regulation, or department emergency order where hatchery returns have achieved a reasonable degree of segregation from naturally occurring stocks and may be harvested by the common property fishery without adverse effects."

Under the *planning process* category, a variety of meetings occurs each year culminating in a written published *fishery management plan* specific to a gear type and fishery. Such plans outline how a particular fishery will be managed during the coming season. Examples of planning meetings include the following: Fish and Game Advisory Committees, Regional Planning Team (a group that oversees enhancement planning), NSRAA Board, Purse Seine Task Force, Gillnet Task Force, and Spring troll fishery community meetings.

Before each fishery decision, managers must update information from sources including aerial surveys, stream surveys, vessel surveys, port sampling, historical fishery databases, and coordinate with other managers within the region to plan openings. ADF&G managers can issue an *emergency order* to effect openings and closures during the fishing season. These in-season actions are based on the surveys and other information, but they must be consistent with the preseason management plans.

Hidden Falls Hatchery

Hidden Falls Hatchery is situated along Chatham Strait at Kasnyku Bay as shown in Figure 1. The THA defined in regulation is where the fishery harvesting hatchery chum salmon returns primarily occur. The THA is the same area as the SHA where cost recovery is done in between commercial openings by NSRAA to pay for program costs. Chum salmon release locations are in Kasnyku and Takatz bays. Arrows in Figure 1 indicate migration routes of returning adult chum salmon. Note that most adult chum salmon enter the THA from the north after traveling along Catherine Island and from Chatham Strait. Many are observed to migrate through Kelp Bay where a certain amount of schooling and milling occur, sometimes off stream mouths. Later-returning fish may approach the THA from the south. The spawning locations of three stocks of wild chum salmon in Kelp Bay, immediately north of the THA, are also shown in Figure 1. Ralph's Creek is in the middle arm of Kelp Bay. Clear River and Glacial River are in the South Arm of Kelp Bay. Clear River is one of the ancestral broodstocks for the Hidden Falls chum salmon program.

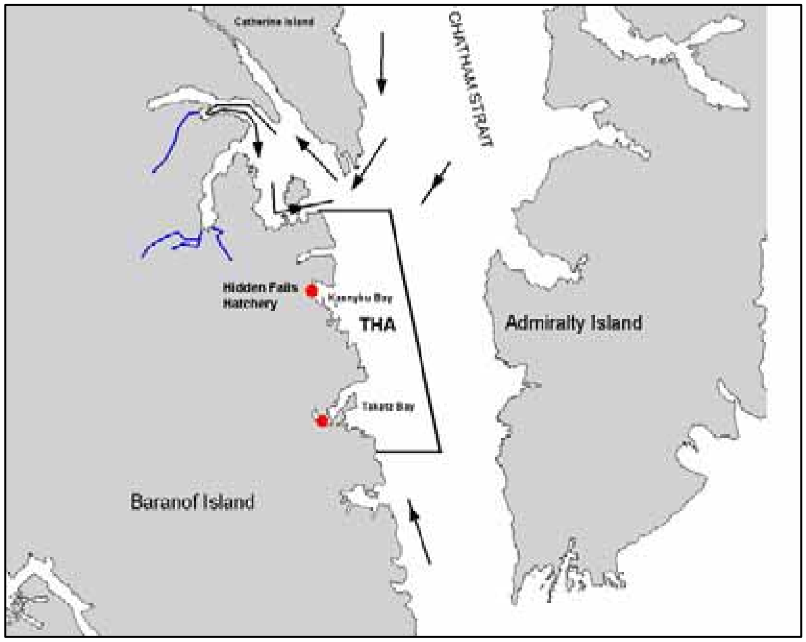

Figure 1: Hidden Falls Hatchery, chum salmon migrations and wild stocks locations.

Range markers are used at the THA to define boundary lines. Considerable congestion of seine boats may occur at these locations. In particular there is usually a line-up of boats at South Point because early chum salmon returns enter the THA from the north.

Boundary lines for the THA fishery may be expanded to include the outer waters of Kelp Bay, or additional area as shown in Figure 2**.** This management approach came about through the Purse Seine Task Force, a forum for the fishing fleets and managers to discuss the management objectives for the seine fisheries. Fishermen requested this modification at times when the ADF&G manager was comfortable that wild-stock escapements would be achieved. The purpose of the expansion was to harvest large buildups, which can occur in Kelp Bay, to improve flesh quality of fish harvested, and also to disperse a congested fleet. To accomplish this, ADF&G monitors Kelp Bay systems for escapement and often peak-season fishery expansions are possible. Also shown in Figure 2 are closed-water areas used to provide a refuge for escapement of wild stocks, and in Kasnyku Bay, to set aside fish needed by NSRAA for broodstock and cost recovery. NSRAA stockpiles broodstock behind a barrier net in a small bay next to the hatchery.

The THA fishery is managed (opened or not opened) in collaboration with NSRAA who must allow for achieving cost recovery goals by the end of the season. To do this NSRAA tracks cost recovery progress and collects data to gauge expected run size in relation to their forecast return.

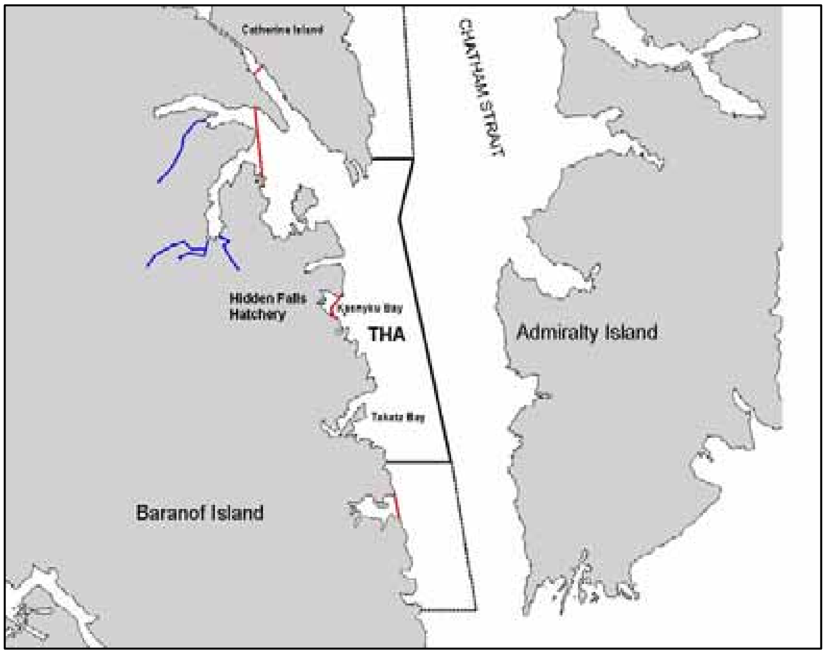

Figure 2: Hidden Falls Hatchery THA expanded.

The Hidden Falls Hatchery saw significant returns in the mid-1980s, and the average run size since 1994 has been about 2.5 million (Figure 3). Terminal common property harvest since 1994 has averaged 2.0 million, 83% of total returns. Broodstock requirements are now 125,000 chum salmon. Cost recovery increased dramatically in 2003 and 2004 due to declining chum prices. Since 1994, an average season total of 223 seine boats made landings in the fishery, although the number of boats has declined steadily from 275 in 2000 to just 121 boats in 2004. The HFH fishery is a recognized mainstay of the July purse seine fishery season. It has effectively lengthened the purse seine season, since wild-stock returns in early July are often insufficient to support significant fishing effort on their own.

At Ralph's Creek, about 12 miles from HFH, peak chum salmon counts have been fairly consistent (Figure 4). At Clear River, Heinl (2003) noted a long-term declining trend (Figure 4). Much of this decline pre-dates the HFH fishery, but there appears to be a continuing decrease into recent years. The management prescription here will likely be more conservative management and additional efforts at stock monitoring. The causes and actual extent of reduced escapement are unknown: there may be fishery effects, but there could also be habitat changes, and in recent years aerial observations of chum salmon may have simply been obscured by increased pink salmon returns.

Otoliths collected at Ralph's Creek a few years ago were from wild-origin chum salmon. This finding is interesting because large schools of HFH chum are often observed off the stream mouth as they migrate along the Kelp Bay shorelines.

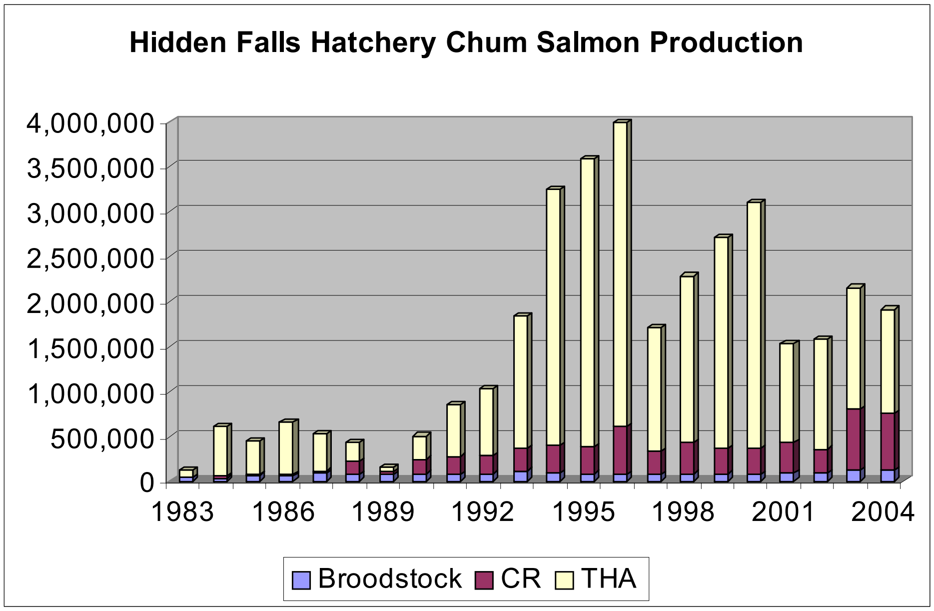

Figure 3: Hidden Falls Hatchery chum salmon production.

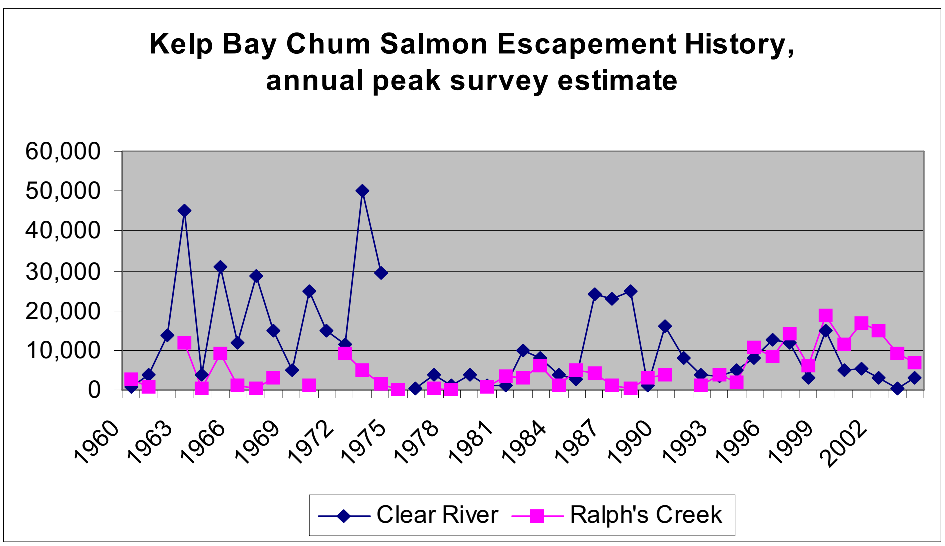

Figure 4: Kelp Bay wild chum salmon escapement history.

Port Armstrong Hatchery

The Port Armstrong Hatchery is located on southeast Baranof Island, just north of the town of Port Alexander (Figure 5). Pink salmon are released directly from this hatchery into Armstrong Bay. There is no THA for common property harvest. Instead, AKI pink salmon contribute to seine fisheries, as the returns pass through existing fisheries in lower Chatham area. AKI stockpiles broodstock inside a barrier seine within Armstrong Bay. All other returns to the SHA are harvested for cost-recovery.

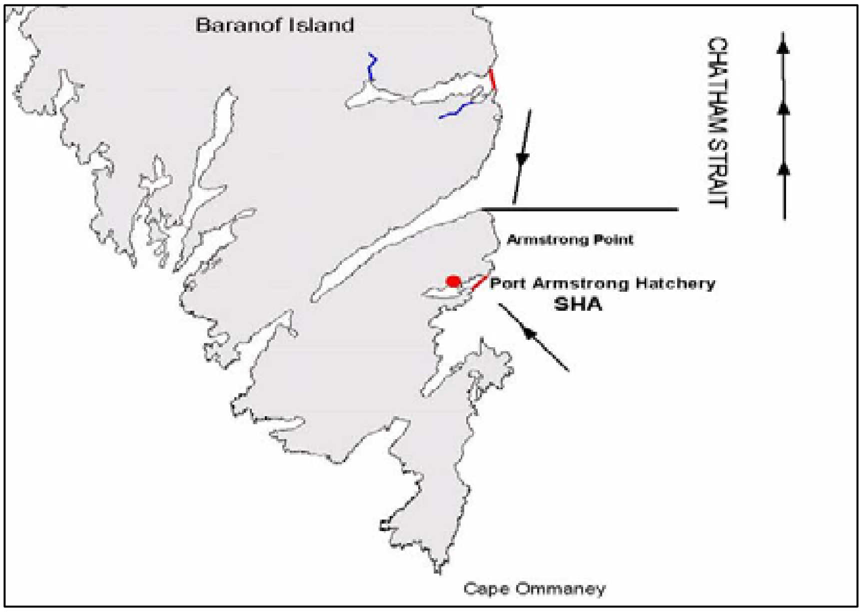

Figure 5: Port Armstrong Hatchery, pink salmon migrations.

Since the hatchery program developed, seine fisheries along southeast Baranof Island have been allowed only north of Armstrong Point. When the hatchery came on line, the seine fishery lost some fishing area, but did not lose access to any wild stocks. The seine fishery gained access to hatchery pink production in existing fisheries.

Since 1990 production within the SHA has averaged about 900,000 fish annually (Figure 6). The actual contribution of AKI pink salmon to common property fisheries has long been a source of speculation. In 2003 otolith marked pink salmon of AKI origin were recovered from purse seine samples taken from along the Kuiu Island shore. While limited sampling suggests that contributions may be substantial, the various times, locations and amounts remain unknown.

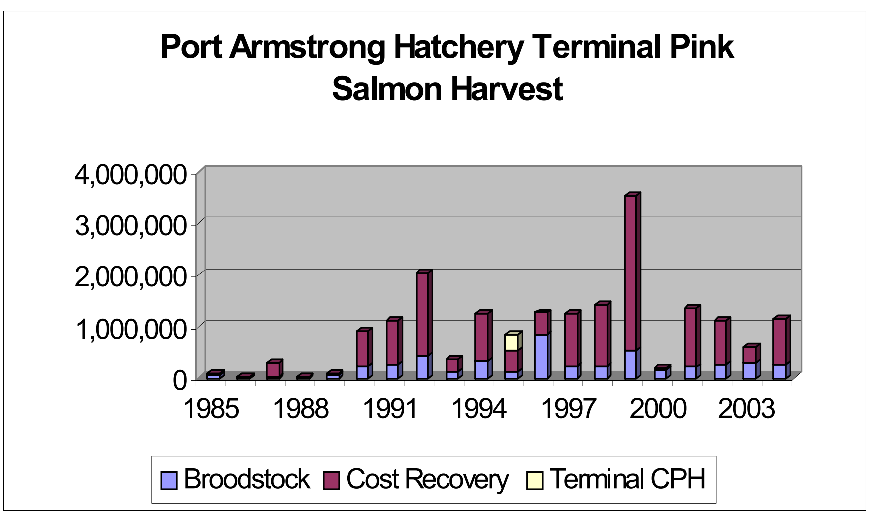

Figure 6: Port Armstrong Hatchery terminal area pink salmon production.

Pink salmon peak escapement counts in the vicinity of large hatchery releases at AKI have cycled from high counts in the late 1990s to very low counts, particularly the last three odd-numbered years at Sashin Creek (Figure 7). How long these trends might persist and what causes them are unknown. Very minimal commercial seine fisheries have targeted these stocks in recent years.

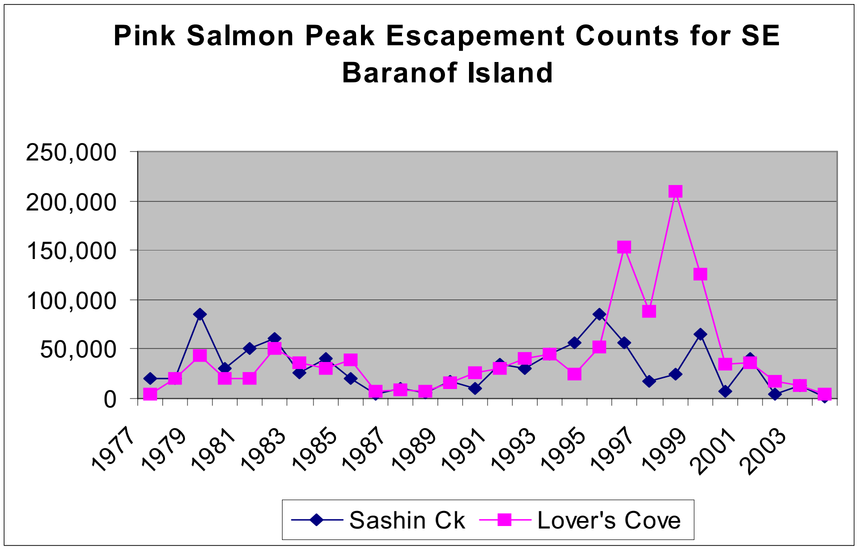

Figure 7: Peak pink salmon escapement counts for two locations near Port Walter, in southeast Baranof Island.

The hatchery's managers at Port Armstrong have had to deal with weak pink salmon prices, which have made marketing of terminal returns difficult. In 1995 when markets failed, ADF&G had to open the SHA to common property seine harvest to prevent waste of salmon and straying of hatchery fish into wild systems. In 2004, after limited markets were satisfied, ADF&G issued AKI a permit to roe-strip and discard pink salmon carcasses at sea. However, ADF&G's policy continues to be full utilization of fish harvested.

In 2003, AKI received $1.4 million in funding and a permit alteration for a new 30 million chum salmon program. Plans to release large portions of these chum salmon into Port Lucy for harvest by trollers and cost recovery have met with strong public opposition from the community of Port Alexander. For its long-range financial security, AKI needs chum salmon revenue to offset the high costs of coho and Chinook programs. These programs are of high value to the troll fleet. Unfortunately, funding, permitting, and construction preceded the full discovery of just where AKI might carry out its new chum salmon program. Also unsettled is the role net gear might eventually play, should a terminal mop-up fishery be required.

Sitka Sound: Sheldon Jackson Hatchery and Medvejie Hatchery
The situation in the southern portion of Sitka Sound is even more complex than in the other examples presented. There are two hatcheries in this area (Figure 8). The SJC SHA has been inactive over the past several years. Extreme pink salmon escapements to Indian River along with deferred maintenance have overwhelmed the SJC Hatchery's surface water supply.

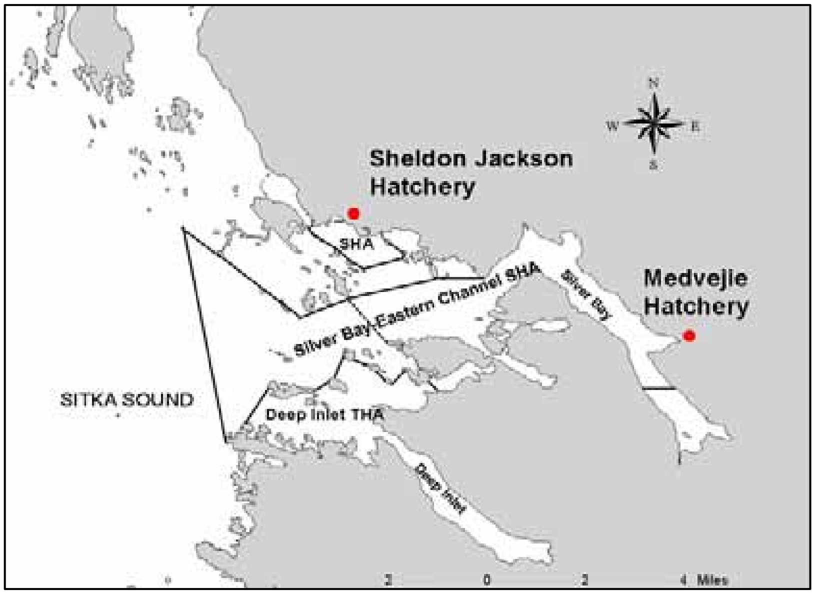

Figure 8: Sheldon Jackson and Medvejie Hatcheries SHAs, and THAs.

NSRAA has two SHAs. The Silver Bay/Eastern Channel SHA is expanded early and later in the season to provide troll access in the westernmost portions of Eastern Channel. Deep Inlet THA as shown serves as both a SHA for cost recovery and a THA for common property harvest of hatchery returns.

Actual fish behavior is weather dependant and varies year to year, but Figure 9 roughly indicates terminal chum migrations to the two release locations in Deep Inlet and at the hatchery in Silver Bay. Last season under warm, dry conditions, chum salmon remained below 20 fathoms in depth and within Eastern Channel for prolonged periods. Under such conditions only troll gear has continuous access to the fish. The majority of hatchery-bound chum salmon are returning to the Deep Inlet THA. Both seine and gillnet gear harvest fish inside the THA. Before fish reach the THA they are harvested by either troll or seine gear.

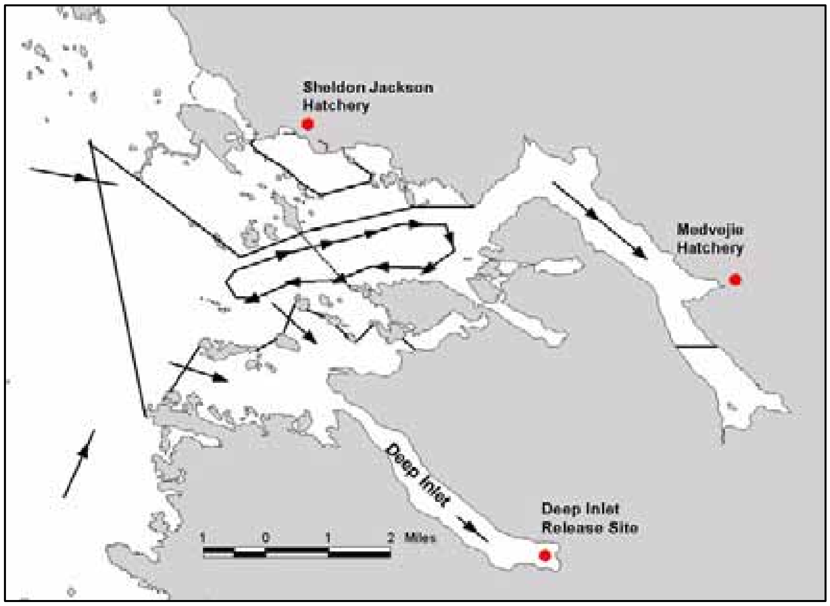

Figure 9: Sitka Sound hatchery chum salmon migrations.

Figure 10 shows Sitka Sound wild-stock locations, seine fishery boundaries, and waters that are closed for managing the seine fishery. To harvest hatchery chum returns, the initial Deep Inlet THA was confined to Deep Inlet proper, an area free of wild-stock conflicts. The THA was later expanded to the current boundaries to provide for quality of fish and timely access in shallower areas where fish were available to net gear. Next, as larger returns materialized, and in order to distribute economic benefits, the THA became both a seine and a gillnet area. Finally, as large schools of chum salmon developed in the Eastern Channel area immediately outside the THA, trollers adapted gear and methods to target chum salmon.

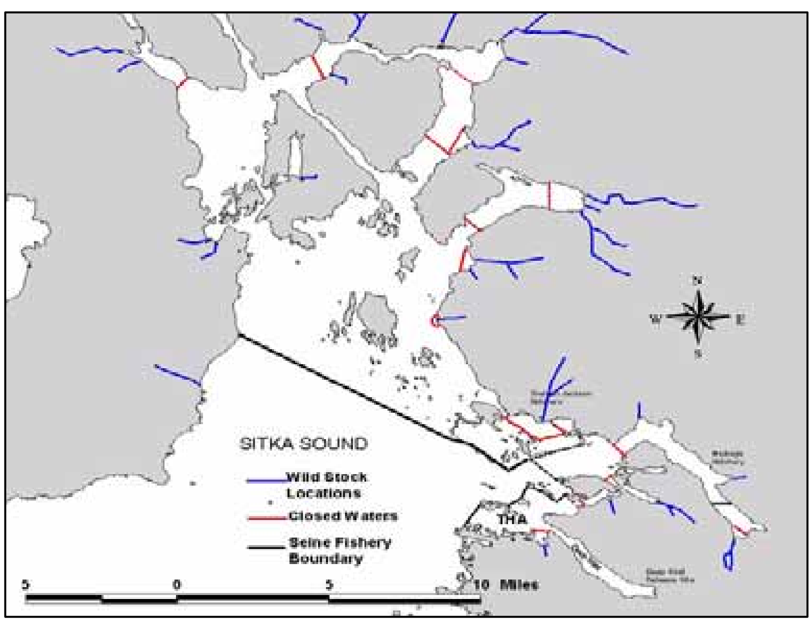

Figure 10: Sitka Sound wild stocks and seine fishery boundaries.

The problem faced by management became one of how to maintain the traditional seine fishery's access to wild stocks.

The southern geographic boundary of the Sitka Sound purse seine fishery, shown as a line crossing Sitka Sound in Figure 10, creates a modest separation of seine gear from the THA, or destination where most chum salmon eventually return. ADF&G has changed lines to close areas in the seine fishery to focus this traditional fishery on wild-stock harvest. The inner portion of Eastern Channel, however, is the last remaining area where seine access can be provided to major wild pink stocks originating in Southern Sitka Sound. Dotted extensions of the seine line indicate that this area sometimes may be open for seine harvest. Silver Bay is managed as a broodstock protection area for chum salmon returning to the Medvejie Hatchery, so this area is largely not available to seine gear.

Since 1993 total harvest has averaged just about 2.0 million chum salmon and the total Deep Inlet chum production has been over 3.5 million twice (Figure 11). The Deep Inlet program has benefited all gear groups by providing a fishing option to spread out the fleet and by adding value to catch.

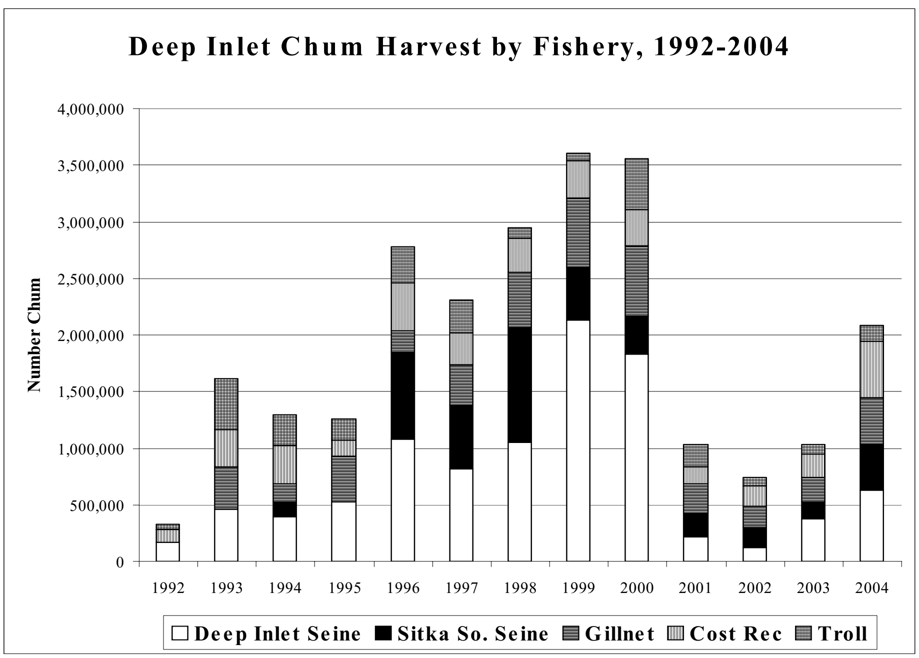

Figure 11: Deep Inlet chum salmon production by fishery.

Department managers, however, have been in the position where any in-season decision made might appear as allocative and to favor one gear group over another. At the 2003 Board of Fisheries meeting, the board elected to leave in-season management programs as they have evolved in place.

Traditional seine fisheries harvest both pink and chum salmon in Sitka Sound (Figure 12). The chum harvest shown in the graph is that which is taken outside the Deep Inlet THA and is largely composed of hatchery chum salmon. Strong pink returns ended dramatically in 1986 and rebounded sharply in 1996.

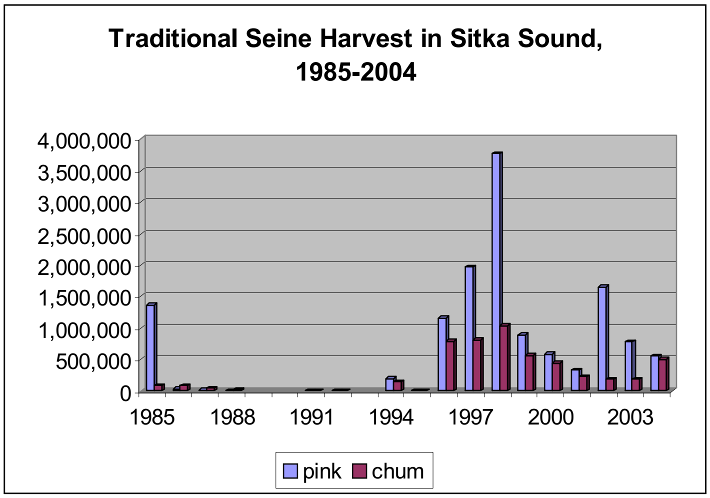

Figure 12: Traditional seine pink and chum harvest in Sitka Sound.

Escapements of wild pink salmon in southern Sitka Sound have reached unprecedented high levels during recent years (Figure 13).

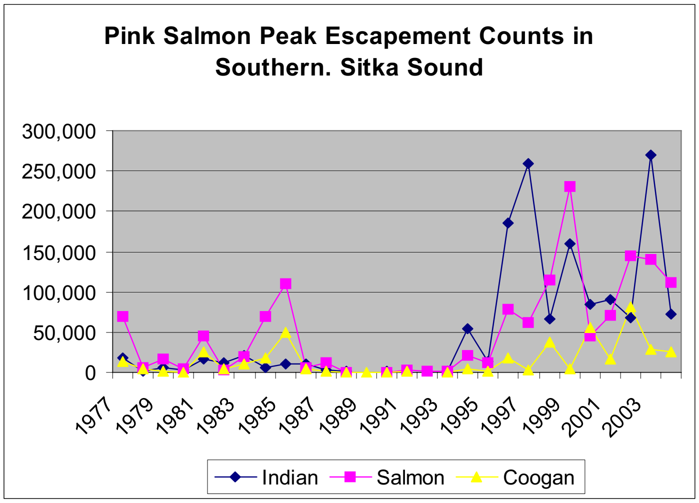

Figure 13: Southern Sitka Sound wild pink stock escapement history.

We have escapement estimates for sockeye and coho salmon (Table 2, information supplied by Robert Chadwick, ADF&G, Sitka, Alaska, personal communication) at Salmon Lake, a lake located at the head of Silver Bay. Although exploitation was higher than usual at the end of a "gauntlet" of fisheries, escapements were maintained. ADF&G plans to continue studying this system into the future, as new hatchery programs come on line, and to then develop a management approach that will protect these stocks.

Managers are trying to deal with new hatchery projects or ones that are recently in progress (Figure 14).

Table 2: Salmon Lake sockeye and coho salmon escapement estimates.

Salmon Lake Summary						
Schmidt (1996) estimated increased exploitation from 35% in 1985 to 72% in 1989						
Harvest of Salmon Lake coho in 1995 included 1,740 from sport and commercial fisheries						
Concerns were expressed about sustainability of coho returns in years of lower marine survival						
Peterson Mark-Recapture Estimates of Adult Escapement by ADF&G, SFD						
year	sockeye	SE	coho	SE	coho	exploitation rate
2001	1,941	282	1,424	64		
2002	815	20	1,104	39		
2003	1,203	75	869	78		77%
2004	780	preliminary	1,657	preliminary		69%
2005	Plans for STA sockeye, ADF&G coho					
2006-2009	NSRAA to operate coho weir as permit condition for new summer coho program					
Post weir	Need cost effective method of indexing return					
	Possibly, Lake mark-recapture					

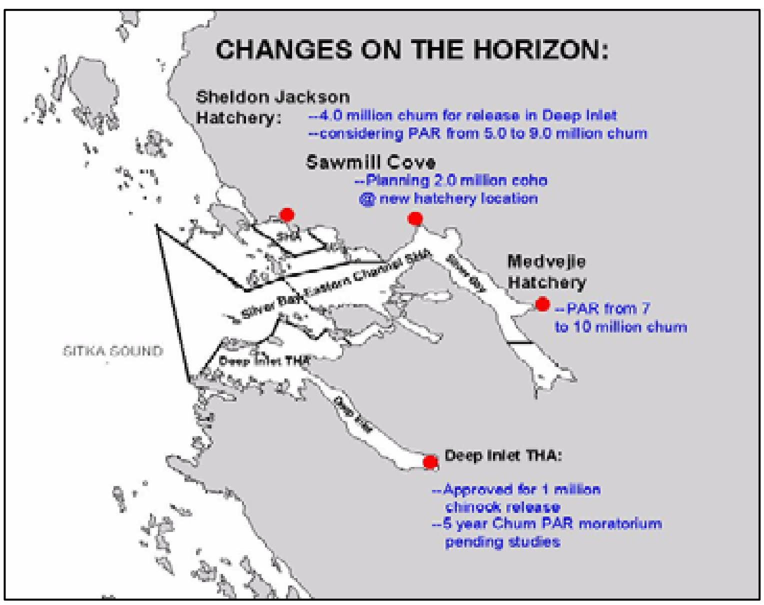

Figure 14: Changes on the horizon in southern Sitka Sound.

At Sheldon Jackson College (SJC), a new partnership arrangement with NSRAA is in effect to assist SJC to utilize Deep Inlet as a remote release site and to cooperate on bringing the college's program into the future. The current program allows release of 4 million chum salmon into Deep Inlet. SJC is considering requesting changes to their permit, allowing up to 9 million eggs.

At Sawmill Cove, NSRAA is planning a new facility to release 2.0 million summer-stock coho salmon. These operators have received funding of $2.5 million, and they will be requesting a new hatchery permit.

At Medvejie Hatchery, NSRAA will request increasing their chum salmon releases to 10 million.

The Deep Inlet THA was just approved for 1.0 million Chinook salmon releases. This would extend Deep Inlet to a fishery beginning in May and ending in October. There is presently a 5-year moratorium on further chum salmon permit increases, pending studies by NSRAA to address ecological interactions in Sitka Sound.

Summary

The private-non-profit hatchery programs around Baranof Island are productive, successful, and they continuously strive to increase their output. They represent a powerful economic force propelled by support from fishermen from each gear group. ADF&G is making an on-going effort to conserve wild stocks and to manage fisheries of both wild and hatchery stocks for sustainability.

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Chum Salmon Otolith Marking in Alaska: For Hatchery Operators and Fishery Managers

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Thermal otolith marking in Alaska was first pursued in response to a requirement for marking 100% of enhanced sockeye salmon on the Stikine and Taku transboundary rivers. The method was soon adopted by a number of hatcheries, especially for pink and chum salmon. Coded wire tags are no longer used for pink, chum, or sockeye salmon, in favor of the otolith mark. Otolith marking has reduced sampling needs and provided managers and hatchery operators with reliable estimates of hatchery catches and wild-stock component of the catch. While developed for terminal management concerns, otolith marks are now used for a wide range of unrelated research including near-shore rearing, ocean carrying capacity, and ocean range studies. The Alaska Department of Fish and Game operates two thermal mark labs and there are a number of private aquaculture labs. These labs all provide specialized services for thermal mark analysis. The ADF&G Lab provides open access to Alaska release information including thermally marked otolith images through the web at http://taglab.org. The North Pacific Anadromous Fish Commission has a similar web site that provides images and release information for all thermal marking in the North Pacific at http://npafc.taglab.org.

Utilization and Value of Salmon Carcass Waste

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Carcass waste from the processing of fish and shellfish represents an abundant, under-utilized, and potentially valuable source of marine protein, oil, and mineral nutrients. The protein is of high quality and contains good levels and ideal ratios of essential and non-essential amino acids. The oil can be a source of omega-3 fatty acids, and the minerals are in natural, organic complexes. Research during the past 25 years has greatly increased our understanding of seafood waste and explored ways this raw material can be utilized. Economic utilization of salmon carcass waste will occur when: 1) efficient industrial processes are developed that convert the raw material into multiple, profitable products that have sustainable demand and 2) products derived from carcass waste are supported by a strategic marketing plan. Bio-Oregon has been processing seafood waste, including salmon, for more that 40 years and has developed technology to convert this raw material into a variety of products including hydrolyzed liquid concentrates, protein meals, feed flavors, marine oil, bone meals, and hydrolyzed meals. Our markets include segments of the aquaculture, agriculture, and pet food industries. The value of salmon carcass waste is related to: 1) its efficiency of conversion to finished products, 2) the innovation of the finished products, and 3) the cost of processing. Converting fish and shellfish carcass waste into novel products that meet identified customer needs and support long-term customer solutions is the best way to increase the value of this raw material.

Tracking Adult Chum Salmon in Sitka Sound Using Sonar Tags

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Adult chum salmon (*Oncorhynchus keta*) returning to Sitka Sound in 2002 and 2003 were observed to move more frequently than anticipated, often rapidly transiting from point to point. These fish often had complex patterns of migration amongst various points within Sitka Sound before committing to their final destination or being captured. During August and early September of 2002 and 2003, the Northern Southeast Regional Aquaculture Association (NSRAA) monitored adult chum salmon migrations in Sitka Sound using surgically implanted Vemco V16-5H sonar pingers. Vemco VR-2 sonar receivers, anchored in several key locations throughout Sitka Sound, provided monitoring points. The purpose of the study was to identify migratory patterns and timing of Medvejie hatchery chum salmon, specifically those fish needed for broodstock, returning in late summer to Sitka Sound. In 2002, 23 adult chum salmon were tagged and found to migrate throughout Sitka Sound for up to 18.8 days before being captured or lost. Females tended to remain available to the fishery slightly longer than their male counterparts and had slightly more complex migratory patterns with up to 15 migratory segments in one case. In 2003, 29 adult chum salmon were tagged and released. One male chum salmon was available to the fishery for 24 days before being captured at the Medvejie hatchery spawning rack. In 2003, both sexes of chum salmon were available to the fishery approximately an equal number of days, and females again tended to have slightly more complex migratory patterns.

Application of a "Late/Large" Rearing Strategy to Improve Marine Survival of Enhanced Chum Salmon

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Abstract

Alaska private non-profit (PNP) hatcheries face many challenges in today's economic environment when low market prices for salmon and increasing production costs threaten the financial viability of many enhancement programs. Production goals for common property fisheries and economic cost recovery are often in conflict with each other when corporate financial requirements, permitted production levels, and fishery interception rates combine to create competition for a finite resource. One way to improve this situation is to increase the survival rate of enhanced salmon fry. We tested the effects of an alternate rearing strategy on marine survival of chum salmon by releasing two groups of pen-reared fry approximately two weeks apart. Fry were differentially marked by release group to allow identification as returning adult salmon. Adult returns from the 1999 and 2000 brood year releases (BY99 and BY00) were analyzed to evaluate differences in marine survival, age composition, run timing, and mean size at harvest. Results indicated that the cumulative marine survival rates of the BY99 returns (total ages 3 through 5) were 2.9% for the control ("regular") group and 14.3% for the treatment ("late/large") group. Similarly, marine survivals of the BY00 release groups were 1.2% and 5.1%, respectively (age-3 and age-4 fish only). Comparisons of relative age composition, run timing, and average weight indicated no significant differences between regular and late/large groups. A benefit-cost analysis of a hypothetical enhancement program showed that an improvement in marine survival of 0.23% would produce enough extra fish to offset the added cost of rearing the fry for an additional two weeks (i.e., break-even point). Returns greater than the break-even point would produce a positive net benefit that increases rapidly with increasing marine survival. This suggests that substantial additional benefits, in terms of increased salmon production, may be possible with relatively little additional cost.

Introduction

Douglas Island Pink & Chum, Inc. (DIPAC), located in Juneau, Alaska, operates a large chum salmon enhancement program in northern southeast Alaska. The program produces substantial numbers of salmon for commercial fisheries in the region and is also a major source of cost recovery revenue for the corporation. In an attempt to improve marine survival and overall productivity of the program, we tested the effects of an alternate rearing strategy on chum salmon by releasing differentially marked groups of pen-reared fry and evaluating the returning adults.

Methods

Chum salmon fry from brood years 1999 and 2000 (BY99 and BY00) were reared at DIPAC's Amalga Harbor net pen site located approximately 25 miles north of Juneau, in the spring of 2000 and 2001, respectively. Two groups of fish were released each year: a "regular" (control) group and a "late/large" (treatment) group. Both groups were marked with unique otolith thermal marks (OTM) and transferred to net pens as newly emergent chum salmon in early to mid-March. The regular groups were reared for approximately 2 1/2 months prior to being released around the third week of May each year. The mean weight of fry in these releases was 1.55g and 1.41g in 1999 and 2000, respectively. The late/large groups were held and reared for an additional 2-1/2 to 3 weeks and released with mean weights in excess of 4g each year (Table 1).

Table 1: Number of fish, release date, and mean weight of brood 1999 (BY99) and brood 2000 (BY00) chum salmon fry released at Amalga Harbor in 2000 and 2001.

Release Group		Brood Year 1999	Brood Year 2000
Regular	Number of Fry	44,496,455	38,423,671
	Release Date	5/19/00	5/21/01
	Mean Size (g)	1.55	1.41
Late/Large	Number of Fry	8,722,507	7,604,465
	Release Date	6/4/00	6/12/01
	Mean Size (g)	4.04	4.07

Chum salmon harvested in commercial gillnet and seine fisheries, as well as DIPAC's cost recovery harvest, were sampled in 2002, 2003, and 2004. Harvest and OTM recovery data were analyzed to evaluate differences in marine survival, age composition, run timing, and mean size of Amalga Harbor chum salmon. Estimates of the number of fish harvested from each release group were calculated by multiplying the total fish harvested for each stratum (brood year, treatment group, fishery, weekly period) by the percentage of OTMs in the sample. A summary of returns to date is presented in Table 2.

Table 2: Summary of estimated numbers of fish by age, return to date and cumulative marine survival for Amalga Harbor chum salmon harvested in 2002-2004, by brood year and treatment group.

BY99						
Rearing Strategy	Fry Released	Age-3	Age-4	Age-5	Return to Date	Cumulative % M/S
Regular	44,496,455	54,041	893,039	344,553	1,291,633	2.90%
Late/Large	8,722,507	48,801	924,090	278,072	1,250,963	14.34%

BY00					
Rearing Strategy	Fry Released	Age-3	Age-4	Return to Date	Cumulative % M/S
Regular	38,423,671	32,735	424,385	457,121	1.19%
Late/Large	7,604,465	20,138	365,797	385,934	5.08%

Results and Discussion

Cumulative marine survival of BY99 chum differed substantially between regular and late/large groups. Survival of the regular release group (ages 3–5) was 2.9% compared with the late/large fish, which was 14.3%, or nearly five times as high (Table 2, Figure 1). Similarly, the BY00 regular release group had a cumulative survival of 1.2% compared with the late/large fish at 5.1%, over four times as high.

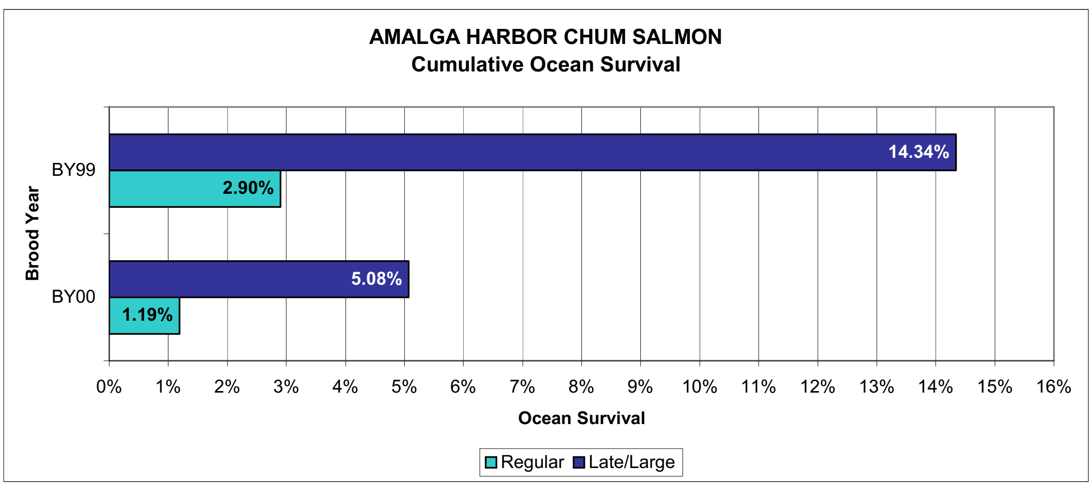


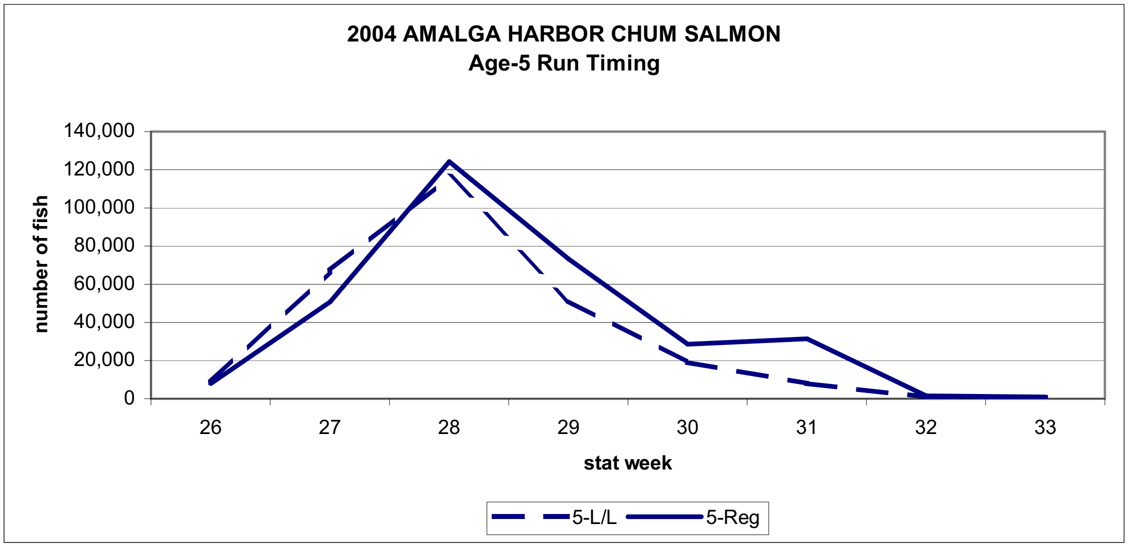
Figure 1: Comparison of cumulative ocean survival of Amalga Harbor chum salmon reared under "regular" and "late/large" strategies.

Comparison of relative age composition between the two groups of BY99 chum salmon (essentially a complete brood return) revealed no substantial differences. For each age class, the relative number of fish from each release group was similar to each other and similar to the long-term average for this stock (Table 3).

Table 3: Comparison of age composition of BY99 Amalga Harbor chum salmon reared under two different strategies and harvested in commercial and cost recovery fisheries from 2002 - 2004.

	Fish Harvested			
Rearing Strategy	Age-3	Age-4	Age-5	Total
Regular	54,041	893,039	344,553	1,291,633
	4.2%	69.1%	26.7%	100.0%
Late/Large	48,801	924,090	278,072	1,250,963
	3.9%	73.9%	22.2%	100.0%
Average (BY91-BY98)	3.5%	66.9%	29.6%	

Analysis of 2004 run timing for both age-5 and age-4 cohorts also revealed no substantial differences. Comparisons of weekly catch estimates of age-5 fish from each release group were very similar throughout the season. Likewise, catches of age-4 fish were also similar for each group from week to week (Figure 2).



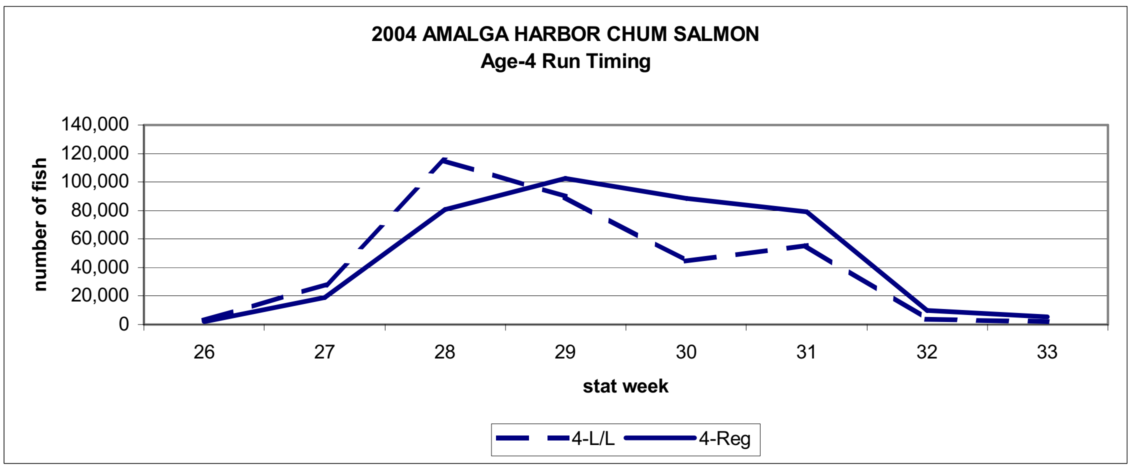


Figure 2: Comparison of run timing of age-5 and age-4 Amalga Harbor chum salmon during cost recovery harvest in 2004, by rearing strategy.

I also compared the average adult size of both age-4 (BY00) and age-5 (BY99) fish in the 2004 cost recovery harvest. In both age classes, mean weight (lbs) was similar for both release groups, with substantial overlap in the range of individual values observed (Table 4).

Table 4: Comparison of mean weight of chum salmon harvested in the 2004 cost recovery harvest at Amalga Harbor, by age and rearing strategy.

Rearing Strategy	Age-4			Age-5		
	obs.	mean	st. dev.	obs.	mean	st. dev.
Regular	260	7.03	1.42	172	8.87	2.20
Late/Large	198	7.50	1.45	157	8.66	2.15

To measure the cost-effectiveness of the late/large rearing strategy I performed a benefit-cost analysis for a hypothetical example using the assumptions outlined in Table 5.

Table 5: Benefit: cost analysis assumptions.

Fry:	20,000,000
Wt gain (g):	2.5
FCR:	0.95
Feed cost ($/kg):	$1.90
Rearing days:	14
Labor cost ($/day):	$200
Total Cost:	$93,050
Marine survival:	2.00%
Adult weight (lbs):	8.0
Average Price ($/lb):	$0.20

Results were calculated in terms of multiples of the assumed marine survival rate. I also calculated a break-even point, which was defined as the survival rate that produced a zero net benefit (i.e., where the additional value of returning salmon equaled the additional cost of rearing the fry to the late/large release point; Table 6). In this case the break-even survival rate was 2.23%, or 0.23% above the assumed average. Correspondingly, in this example the net benefit in terms of value of salmon produced increases rapidly with increasing survival rates.

Table 6: Results of a benefit: cost analysis of a hypothetical chum salmon enhancement program using a "late/large" rearing strategy.

M/S Multiplier	Marine Survival	Total Value	Net Benefit
1	2.00%	$640,000	($93,050)
Break Even	2.23%	$73,050	$0
2	4.00%	$1,280,000	$546,950
3	6.00%	$1,920,000	$1,186,950
4	8.00%	$2,560,000	$1,826,950
5	10.00%	$3,200,000	$2,466,950

I also calculated benefit-cost ratios for survival rates of 2.23%, 6%, and 10%, representing the break-even point, three- and five-times the assumed survival, respectively (Figure 3). These results further suggest that even minor improvements in marine survival can justify the cost rearing chum fry for an additional two weeks and that further improvements can lead to substantial increases in salmon for either common property or cost recovery fisheries.

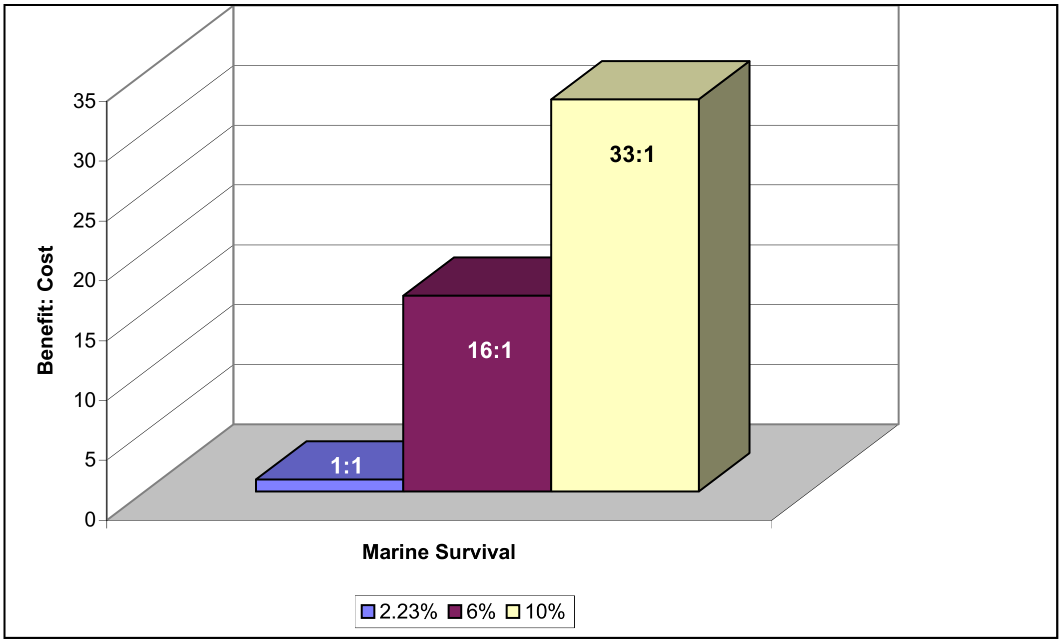


Figure 3: Benefit: cost ratios for a hypothetical chum enhancement program using a "late/large" rearing strategy, at three marine survival rates.

Conclusion

Early results of adult returns indicate the "late/large" rearing strategy had a substantial positive effect on marine survival of enhanced chum salmon fry released at Amalga Harbor. Also, age composition, run timing, and average weight of adult chum salmon treated with this strategy as juveniles, did not appear to be significantly different from "regular" (control) groups. These results, plus analysis of the cost-effectiveness of this strategy, suggest there is significant potential to provide substantial additional benefits to common property and cost recovery fisheries by rearing chum fry to a large size before release.

However, more evaluation is required to better quantify the long-range impacts of this strategy. While initial results are impressive, more data are needed over a longer time period in order to assess the potential range in effects under a variety of environmental conditions, geographic locations, and other factors that affect general survivability of juvenile chum salmon.

Session 4: Forecasting and Recruitment Prediction

Forecasting Recruitment of Pink and Chum Salmon: A Potpourri of Methods With Application to Spawner and Recruit Data

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Simple spawner-recruit models often explain little of the variation in annual recruitment of pink and chum salmon. Recently, more complicated models have been proposed that include explicit time-series components, spatial structure (multiple stocks), environmental variables, or linkages between pink and chum salmon productivity. To examine the applicability of such models, we compared recruitment predictions for a suite of models applied to roughly 80 spawner-recruit data sets of Northeast Pacific pink and chum salmon. Although results varied considerably across stocks and performance measures, the simple models tended to outperform the more complicated models. In general, the best-ranked models explained little of the variation in observed recruitment.

Forecasting Neets Bay Summer Chum Salmon Using a Sibling Multiple Regression Technique with Chum Salmon Length at Age, Chum Salmon Return Number at Age and Pink Salmon Returns as the Independent Variables

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Abstract

The Southern Southeast Regional Aquaculture Association (SSRAA) has been releasing summer chum salmon from the Neets Bay Hatchery since 1983. SSRAA depends on returns from these releases for broodstock for several programs as well as for cost recovery to operate the association. Planning for both harvest and broodstock is dependent on forecasting the returns. SSRAA uses a multiple regression approach to independently forecast the three age classes that will return during the harvest season. The estimated return of each age class is plotted over time related to historic return patterns. The total return is determined by summing the independent curves over time. The variables used are fork length of each age class harvested by purse seine gear in the terminal area, total return of each age class and estimated total return of pink salmon to southern southeast Alaska (ADF&G Districts 1-8), by year. Forecasts using this method have been very useful for planning upcoming harvest seasons. Most returns have been within 10 % of forecasted total return.

Introduction

Forecasting salmon returns is a common technique for planning the management strategy for the utilization of the salmon returns in an upcoming season. For SSRAA, forecasting the summer chum salmon (*Oncorhynchus keta*) return to Neets Bay Alaska is essential for planning the optimum use of the return. SSRAA uses this return as broodstock for all of the remote summer chum releases. In addition to the release at Neets Bay, significant releases of summer chum salmon occur in Kendrick Bay targeting the purse seine fleet, Nakat Inlet targeting the drift gillnet fleet, and Anita Bay targeting all gear groups.

The Neets Bay summer chum return is also used for generating the majority of SSRAA's cost recovery needs. Cost recovery makes up the greater part of the revenue needs for operating the association. Any fish in excess of the broodstock and cost recovery needs are harvested by a terminal common property fishery in the special harvest area (SHA). SSRAA balances the allocation of return to these three uses by incorporating the pre-season forecast into its planning process.

To forecast the summer chum return, SSRAA examined several techniques and found that a multiple regression technique provided satisfactory projections to plan for the upcoming season. SSRAA has been coded wire tagging (CWT) a portion of all the chum salmon releases through the 2002 brood year. Since the 2003 brood year, all SSRAA chum salmon were thermally marked. Sampling the return for these tags provides the data necessary to break down each year's return into their age and length characteristics furnishing key variables for the analysis. The sibling return of a brood year is believed to be an indicator of the early marine survival. For example, the age-3 return of chum salmon is an indicator of the early marine survival of a brood that will be reflected in the age-4 and -5- returns from the same brood. The mean length of the age classes in the SHA may also have a relationship to marine conditions that the fish have been exposed to that affects the ocean survival. In addition, the release number and a pink salmon abundance index are also used in the prediction. The release number is used in most predictive models. It is assumed that without estuarine or marine limiting factors, the number released is directly related to the number of adults that return from a brood class. Using pink salmon (*Oncorhynchus gorbuscha*) information in the chum salmon forecast model helps increase the predictability somewhat, primarily for predicting the age-3 component of a return. In this case we use the pink salmon return as a surrogate for age-2 chum salmon returning to the region.

Because both chum and pink salmon have similar early marine entry timing, they are exposed to similar predator/prey relationships and nearshore abundance of feed. This may have a correlation with the early marine survival of both species. Because the pink salmon return a year earlier than the age-3 chum salmon of the same brood year, the pink salmon return can reflect what can be expected for the age-3 chum salmon the next year. Using pink salmon return information to predict age-4 and -5 chum salmon may have some value, but it is minor compared to the chum sibling relationships.

Using the prediction from this model with historical timing and weights of the returns, a forecast of the number and weight by statistical week is generated and used to optimize the use of the return.

Methods

Data used in the forecasting model is gathered both in the commercial and SHA fisheries. Alaska Department of Fish and Game (ADF&G) procedures are used to collect fish that have been marked using CWTs. CWTs recovered from this sampling are processed by ADF&G at their Mark, Tag, and Age Laboratory, located in Juneau, Alaska. Data resulting from their processing is then downloaded utilizing their web site's (http://tagotoweb.adfg.state.ak.us/CWT/reports/) online report query capability. An estimate of the harvest of Neets Bay summer chum salmon in both the traditional commercial fisheries and the terminal SHA is then made. The traditional commercial estimate is based on the contribution field from the agency report. The estimate of the SHA harvest is calculated by taking the total harvest figures from the fish tickets of harvested fish and proportioning them to each age class using the percent-by-age statistic derived from each statistical week's CWT recovery information. To estimate the broodstock return by age, the total number of fish used for broodstock is proportioned to each age class using the CWT information.

All CWT marked recovered fish are measured for length. This provides a source for estimating the mean fork length of each age class of fish returning to the terminal area. Total release numbers are retrieved from the hatchery production reports. Pink salmon return numbers are the total return estimate from ADF&G Ketchikan office for Districts 1–8. Districts 1–8 were chosen because it assumed that the early marine intermingling between the Neets Bay chum and pink salmon would occur in the lower half of SE Alaska.

The forecast procedure first involves putting the data into a Microsoft Excel worksheet (Table 1).

Table 1 Neets Bay Summer Chum Data table

BY	Release #	age 3 return	age 3 lth	age 4 return	age 4 lth	age 5 return	Pink #	Pink #/10^6
1989	9,022,000	14.8	540	235	680	88	49,417,731	49.4
1990	20,740,000	186.7	629	863	701	250.5	25,320,836	25.3
1991	23,282,000	111.1	637	402	716	34.4	47,012,636	47
1992	32,524,700	367.2	644	1075.5	738	61.7	26,898,400	26.9
1993	40,000,000	512	678	1489	755	220.7	51,345,658	51.3
1994	43,377,000	266.9	713	1214.8	761	81.4	21,265,240	21.3
1995	45,195,000	765.9	728	1753.7	768	112.5	32,300,131	32.3
1996	45,292,435	535.2	707	1198.8	760	110	53,617,377	53.6
1997	45,106,000	76	728	200	784	12	18,509,112	18.5
1998	45,374,700	497.6	695	1541	706	199.7	63,786,590	63.8
2000	45,977,158	137.1	655	357.3	729		33,232,801	33.2
2001	36,494,000	247	693				40,110,804	40.1
2002	39,026,000						29,422,363	29.4

Returns= return #/1000
Lengths = fork lenghts in mm

SSRAA uses the "NCSS 2000" statistical analysis and graphics software (www.ncss.com) to perform a multivariable regression analysis on the data. Data from the Excel spreadsheet can be directly copied into the package. This program allows for easy selection of the dependent and independent variables and weighting of variables. The variety of outputs is very large and easy to interpret. Although the statistics package supplied with excel has similar analyses, the NCSS package provides added flexibility.

Each age class is analyzed separately by selecting the independent variables that logically may have an effect on the survival of that return. For age-3 chum salmon, the brood year release number and a pink salmon index (Table 1) are used. For age 4, the return number of age 3 and the mean length of age 3 are also included (Table 1). For age 5, the return number of age 4 and the mean length of age-4 terminal returns are also included (Table 1).

Table 2 SSRAA Neets Bay Summer Chum
Age 4 Chum Prediction

Predicted Values with Confidence Limits of Means

	In thousands of fish		Std Error	95% LCL	95% UCL
Row	Actual	Predicted	of Predicted	of Mean	of Mean
1989	235				
1990	863	757	181	315	1,199
1991	402	574	192	105	1,043
1992	1,076	1,078	110	809	1,347
1993	1,489	1,373	116	1,088	1,657
1995	1,215	816	132	494	1,138
1996	1,754	1,940	206	1,435	2,446
1997	1,199	1,404	127	1,094	1,715
1998	200	383	176	-49	814
1999	1,541	1,310	170	894	1,726
2000	357	456	164	56	856
2001		815	99	573	1,056

R-Squared ***0.9698***

The selected output tables give both actual and model predicted returns, standard error of predicted, and upper and lower 95% confidence levels. Table 2 is an example presenting the age-4 prediction for 2005 of a total of 815,000 returning 2001 brood summer chum salmon. For planning purposes SSRAA simply uses the predicted point estimate.

The predictions for the upcoming season for each age class are then proportioned to traditional common property fisheries and to the terminal area based on the recent 5-year average percent of each age class in each of the two potential harvest areas. Traditional common property fisheries are managed by ADF&G and are not part of SSRAA's planning for utilization. The terminal fishery is managed by SSRAA based on this forecast. The forecast for each age class is entered into a spreadsheet or prediction matrix (Table 3).

Table 3

Prediction Matrix for 2005 Neets Bay Terminal Summer Chum Harvest

Mid point -- **Best Guess**

				Predicted # /1000					
				Age 3	Age 4	Age 5	**All Ages**		
% of each age by Statistical Week				209.3	765.8	35.0	1,010.0		
Based on trend analysis of 1996-2000 data				Predicted return numbers					**Avail. For**
St Wk	**Age 3**	**Age 4**	**Age 5**	**Age 3**	**Age 4**	**Age 5**	**All Ages**	**Less Brood**	**Harvest**
27	1%	2%	3%	1.0	17.6	1.0	19.7		19.7
28	3%	8%	6%	6.3	61.3	2.1	69.6		69.6
29	5%	18%	13%	10.5	137.8	4.6	152.8		152.8
30	11%	23%	20%	23.0	177.7	6.8	207.5	40	167.5
31	20%	22%	22%	40.8	168.5	7.8	217.0	40	177.0
32	24%	16%	20%	50.2	118.7	7.0	175.9		175.9
33	23%	8%	13%	48.1	59.7	4.6	112.4		112.4
34	13%	3%	4%	27.2	19.1	1.4	47.7		47.7
35	0%	1%	0%	0.4	8.4	0.0	8.8		8.8
36	1%	0%	0%	2.1	0.0	0.0	2.1		2.1

Predicted Pounds by Statistical Week
Based on 1995-2001 average length and regression for pounds

	Age 3	Age 4	Age 5
Mean Lth	695	748	780
Lbs	8.0	10.6	12.0

1,680,000 Lbs Capacity Summer

Stat.Wk	**Begin**	**End**	**Age 3**	**Age 4**	**Age 5**	**Total Lbs**	**Lbs Brood**	**Total Pounds** Avail Harv	**Signature Pounds** Avail Harv	**Surplus Pounds** Avail Harv
27	6/30	7/6	8,370	186,690	12,180	207,240	0	207,240	207,240	0
28	7/7	7/13	50,220	649,356	25,200	724,776	0	724,776	724,776	0
29	7/14	7/20	83,700	1,461,051	54,600	1,599,351	0	1,599,351	1,599,351	0
30	7/21	7/27	184,140	1,883,132	81,900	2,149,172	424,000	1,725,172	1,680,000	45,172
31	7/28	8/3	326,430	1,785,729	93,240	2,205,399	424,000	1,781,399	1,680,000	101,399
32	8/4	8/10	401,760	1,258,127	84,000	1,743,887	0	1,743,887	1,680,000	63,887
33	8/11	8/17	385,020	633,122	54,600	1,072,742	0	1,072,742	1,072,742	0
34	8/18	8/24	217,620	202,924	16,800	437,344	0	437,344	437,344	0
35	8/25	8/31	3,348	89,286	0	92,634	0	92,634	92,634	0
36	9/1	9/7	16,740	0	0	16,740	0	16,740	16,740	0
							Totals	**9,401,286**	**9,190,827**	**210,459**
								240,000 lb/Day Cap.		

This spreadsheet proportions the returns by statistical week by utilizing terminal harvest timing information for each age. It also subtracts out the number of fish needed for broodstock and presents the number of each class that will be available for harvest by statistical week. The lower half of the spreadsheet then presents the information in pounds of fish. This is based on a 1995 regression analysis of fork length to pounds using measurements from 500 terminal harvested Neets Bay adult summer chum salmon and the 1995–2001 average length of each age class.

Results

Variations of this forecast method have provided SSRAA with a planning tool that has helped optimize the utilization of the returns to Neets bay. Both the age-4 and age-5 model predictions compare well with the actual returns and meet the needs for SSRAA planning purposes. This can be seen in Figures 1 and 2, showing the actual return with the model predicted returns. The age-3 prediction doesn't perform as well and can be seen in Figure 3. When the age classes are combined, SSRAA has used this forecast to determine both harvest and processing capacity preseason. In 2003 the forecast was large enough to allow for a SHA troll fishery. In that case the SSRAA board of directors wanted the forecast to be used as an in-season management tool . A cumulative harvest by week was plotted for the predicted return and upper and lower confidence limits were added. The management plan called for terminating the troll SHA fishery if the cumulative actual return dropped below the lower predicted confidence line. Figure 4 shows the results of the 2003 harvest. As can be seen from this figure the actual and predicted number were very close and no adjustments were necessary to the preseason plan for utilization of the 2003 Neets Bay summer chum return.

Figure 1 - SSRAA Age 4 Summer Chum Model Output

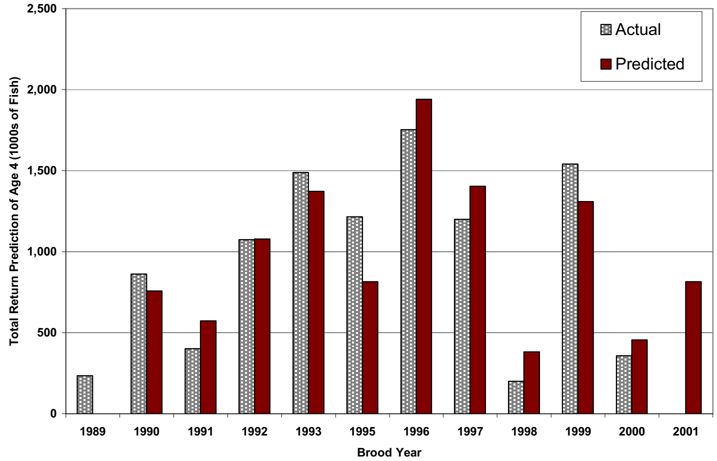


Figure 2 - SSRAA Age 5 Summer Chum Model Output

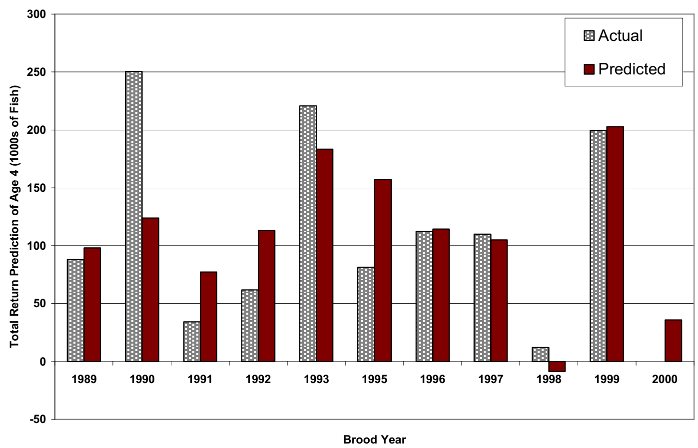


Figure 3 - SSRAA Age3 Summer Chum Model Output

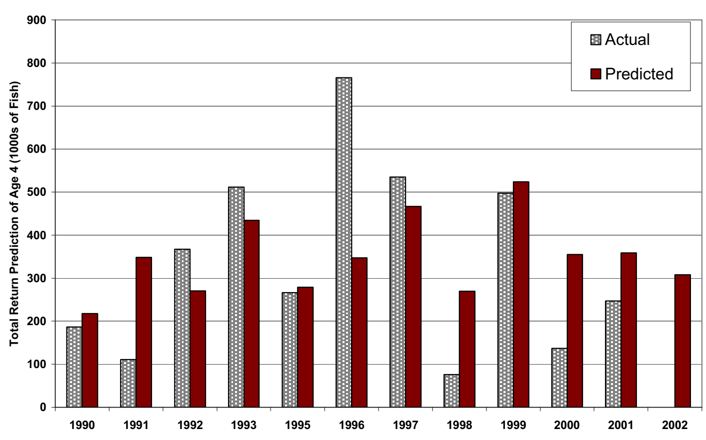
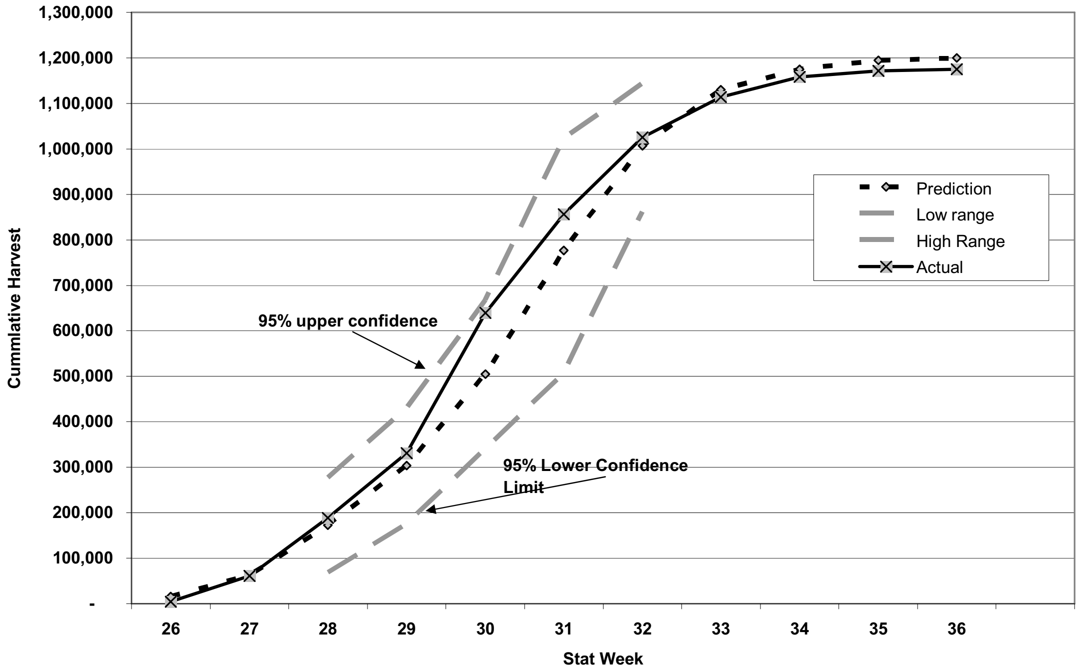


Figure 4 - 2003 Neets Bay Summer Chum Predicted Terminal Harvest with 95% CFI Decision Window



Discussion

The forecast model SSRAA uses has provided successful planning to make the optimum use of the returns to Neets Bay. It has been somewhat successful because SSRAA has made a concerted effort to acquire good terminal and common property harvest data based on CWT marked releases. SSRAA also makes an attempt to catch the fish daily with purse seine gear as they enter Neets Bay, providing good size and age information by time. Starting with the 2002 brood, SSRAA has initiated an otolith-marking program that should improve the quality of the assessment data and ultimately the forecast predictions.

Acknowledgments

Sincere thanks go to Ron Josephson and the staff at the ADF&G Mark, Tag, and Age Laboratory for the CWT processing. Also we would like to thank Glen Hollowell (Ketchikan Port Sampling) and the other ADF&G staff responsible for port sampling for helping us in the recovery of SSRAA marked fish in the traditional and remote SHA fisheries. Lastly, I'd like to thank Louie Munch and Mike Lindgren for their dedication to managing the cost recovery at Neets Bay and for making a special effort to recover high quality return data.

Southeast Alaska Pink Salmon Escapement Estimates and Implications for Pink Salmon Forecasting

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Escapement estimates are a key part of nearly all pink salmon forecasting models. In Southeast Alaska, the Alaska Department of Fish and Game (ADF&G) annually calculates an "index" of pink salmon escapement. By "index" we mean a series on an ordinal scale—that is, a series that is useful to rank escapement levels, but a series that does not contain information on escapement magnitude. This index is based on observer calibrated "peak," or maximum, aerial survey counts for each of 718 index streams. In the past, ADF&G forecasters have multiplied the index by 2.5 to expand it to an estimate of the total escapement in southeast Alaska. We have found that applying the 2.5 multiplier does not result in a reliable measure of escapement magnitude suitable for forecasting or for other models of recruitment. For this method to be useful for forecasting, it is important that the relationship between total escapement and the escapement index remains constant from year-to-year, but apparently this has not been the case. We have conducted a series of calibration studies at Traitors Creek, near Ketchikan, Alaska, since 1996. These studies provided information on aerial observer counting rates, including comparison of counting rates among observers, and comparison of peak aerial surveys to the total spawning population of pink salmon in the creek. Our data show that the relationship between "peak" survey estimates and the total escapement is quite variable on an annual basis, and the amount of measurement error associated with aerial survey estimates can be enormous. In addition, applying the observer calibrations that were used in the creation of the pink salmon escapement index to our data results in an increase in this measurement error. While the ADF&G pink salmon escapement index is useful for tracking long-term trends in population size, the index may have too much measurement error to be useful for forecasting.

Introduction

The Alaska Department of Fish and Game has annually provided formal, published forecasts of salmon production and catches for the upcoming season, going back at least to the 1970 season (ADF&G 1969). In Alaska, these forecasts have not been used for the management of the fisheries, but rather the forecasts were mainly offered for government and industry planning. Pink salmon forecasts, in particular, have been inaccurate over the years. In 1991, ADF&G held a three-day forecasting workshop in Anchorage, Alaska, to improve salmon forecasting though an upgrade in forecasting methods. While there was no formal evaluation of the effects of that workshop, the consensus of the workshop organizers (H.J. Geiger was one) was that this workshop did not bring about improvements in pink salmon forecasts, although the workshop did produce improvements in the Bristol Bay sockeye forecast.

Over the years, ADF&G biologists have usually assumed that the Ricker model (Ricker 1975) or similar regression models were the most direct and obvious way to forecast pink salmon recruitment. For example, in 1998 (Hart et al. 1998) the forecasts for all major Alaskan wild-stock pink salmon catches (Prince William Sound, Lower Cook Inlet, and Kodiak Island) were based on Ricker curves or other regression models involving "escapement" as an independent variable. Similarly these models have been used to set escapement goals for pink salmon. Out of the last 29 pink salmon forecasts for Southeast Alaska, the actual harvest was within 20% of the forecast harvest only eight times. The evidence that these regression approaches have not worked was right out in the open, and not hard to find. In Southeast Alaska, the total-return forecast has been accompanied by a forecast range, expressed as an 80% or higher confidence interval. The published post-season run forecast has been outside this 80% (or higher) preseason confidence interval over 50% of the time since 1981.

As far as we know, no one actually showed that these regression models are poor forecasting tools until Haesker et al. (2005) pointed out that "naive models," also described as "those without explicitly modeled mechanisms," generally performed better than models that used population dynamics principles. That result seemed to have surprised Haeseker et al. (2005), and it certainly surprised our colleagues involved in pink salmon forecasting in Alaska.

We attempted to carefully review the pink salmon forecasting methods for Southeast Alaska, in extreme detail, to help explain the reasons for Haesker et al.'s results. To reach that goal, we first tried to explain the forecast in plain, common-sense terms, and understand its shortcomings on an intuitive basis. Usually, these regression models involving biological mechanisms were simply a linear scaling relationship between some function of escapement and some function of recruitment. Consider the Ricker model, for example. With α denoting a productivity parameter, β denoting a carrying capacity parameter, and ε denoting an independent, normally distributed random variable, typically the Ricker model is parameterized as follows:

$$R = \alpha S \exp(-\beta S + \varepsilon) .$$

Then substituting a for ln(α) and b for - β, the model is then algebraically reordered as,

$$\ln(R / S) = a - bS + \varepsilon.$$

Further reordering, we will explicitly define $\varepsilon = \ln(R / S) - a - bS$ as the *deviation* in a Ricker-based forecast. This deviation is what is economically important. If the return or potential catch is going to be unusually large, and if industry knows that, the catch can be made more valuable by being prepared with markets, investing in people and processing materials, and clearing inventories. However, if the forecasters tell the industry to plan for an unusually large harvest, and the harvest is small, the industry will loose a substantial investment. Similarly, if poor forecasts lead to a decision to not plan for a large catch, resources will not be utilized, leading to a loss of economic opportunity.

This is a point worth dwelling on. A forecast that correctly predicts "surprise" is a valuable industry tool. A forecast that simply reflects the average level of the recruitment or catch over the last several years is not helpful to the industry, but it is not harmful either. A forecast that bounces around randomly, providing incorrect predictions about unusually large or unusually small runs—falsely predicting "surprises"—is actually causing economic harm, at least to anyone that believes the forecast.

From the above equations we can see that using statistical techniques to fit the unknown parameters is equivalent to just scaling the measured escapement to the simple function of the estimated recruitment. In practice, the scaling constant is chosen so that the past estimated annual deviations are small. This point is important for two critical reasons. The underlying assumption is that all forecastable surprising features of next year's deviation in productivity must be in the escapement measure. Because the random unknown part of the deviation is, well, random and unknown, all of the predicted surprising features of the forecast must be the result of unusual features of the escapement measure. The second important point is that the escapement measure contains at least two inseparable components: random measurement error and an underlying escapement signal. If the measurement error is large, then obviously the forecast will simply reflect scaled random numbers and the forecast will drift around uselessly—regardless of the biological principles that underlie the model. Also, if the true underlying escapement does not vary much, then logically, the escapement measure would be a poor predictor of future recruitment, and worthless as a predictor of surprisingly high or low recruitments.

The escapement measure

In Southeast Alaska, the Alaska Department of Fish and Game's annual index of escapement has been based on a standardized set of 718 *index streams* that were observed at intervals each year during salmon spawning (Van Alen 2000). Area management biologists and their assistants have estimated the number of pink salmon in at least a subset of these streams, by visual impression during aerial surveys, as far back as statehood. These surveys were predominately done using small, fixed wing aircraft, usually a Piper Supercub, as this aircraft can fly at slower speeds and observers have excellent visibility on either side of the aircraft. For each survey, and for each stream, fish counts were divided into four categories: mouth, intertidal, stream live, and stream dead. Mouth counts normally consisted of fish in saltwater that were in proximity to the stream being surveyed. Intertidal counts included fish in the area from low tide to the approximate high tide mark. Stream counts normally included any fish above the high-tide mark.

These stream-specific observations were statistically adjusted in an attempt to make the estimates of the number of fish comparable among observers, and comparable with historical observations (Dangel and Jones 1988). To do this, previous forecast biologists developed a set of *observer bias adjustments*. The current set was developed in 1995.

Each area management biologist at that time was designated as *the principal observer* with a bias adjustment set at a value of 1.0; all other observers, both prior and after, have been adjusted to this level of the principal observer's counting, for each management area. These observer calibrations have not been updated for several years.

The final observations going into the index were the largest of the visual counts of fish, for each particular stream, adjusted to the level of the senior manager in the 1995 base year. We refer to these as the *adjusted counts*. The largest count for the year—the one observation retained for each stream in the survey—is termed the *peak-adjusted count*. Each year, the final index for each stock group was calculated as the sum of these peak-adjusted counts, with missing values imputed, summed over this standard set of *index streams*, for a particular area.

Without any kind of sophisticated analysis, we can see an obvious upward trend in the Southeast Alaska pink salmon catch series (Figure 1). There is a strong corresponding trend in the published escapement measure (Figure 2). Obviously, these two series will be correlated because they have similar trends. Also, without any sophisticated analysis, we should be able to see that these series will remain correlated under moderate transformations, like logarithms, or by lagging the series forwards or backwards one or two years.

The index was initially intended as a unitless measure that would track trends in abundance. However, for the purpose of forecasting, at some point, a value of 2.5 was used to scale the index to what was assumed to be a measure of total escapement (e.g., see the Southeast pink salmon forecast in Hart et al. 1998). Before using the index in forecasting, especially in a Ricker model, we identified three questions that need to be fully addressed. First, does the scaling factor of 2.5 realistically scale the index series to the true escapement level? Next, does the index linearly track trends in escapement level, or is this relationship nonlinear? Third, are there obvious sources of measurement error that are simply converted into forecast error through the modeling process? In an attempt to answer those questions we will review a series of escapement studies at Traitors Cove, near Ketchikan, and take a close look at the observer calibration estimates.

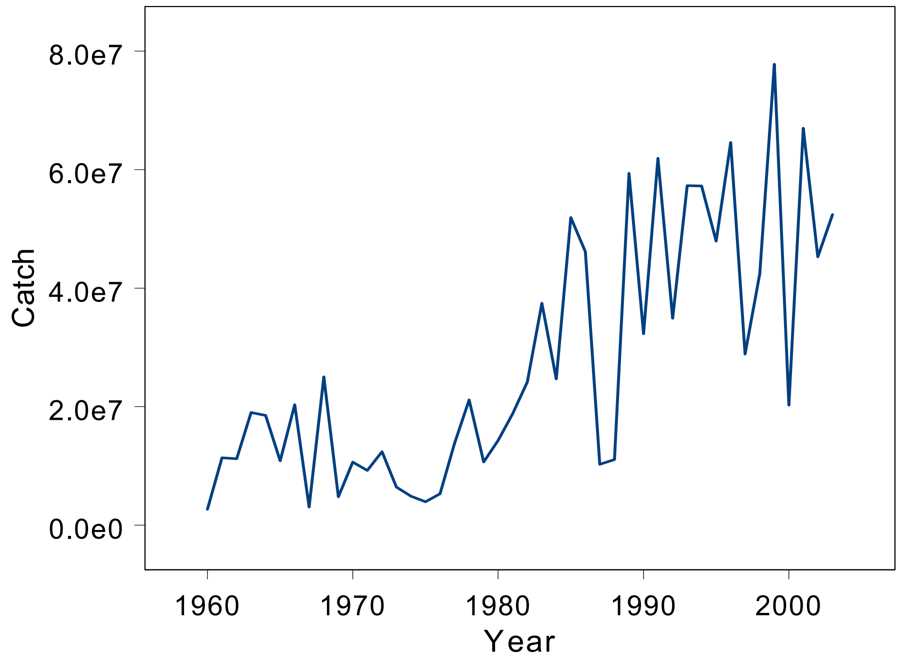

Figure 1. The Southeast Alaska pink salmon commercial catch series from 1960 to 2003.

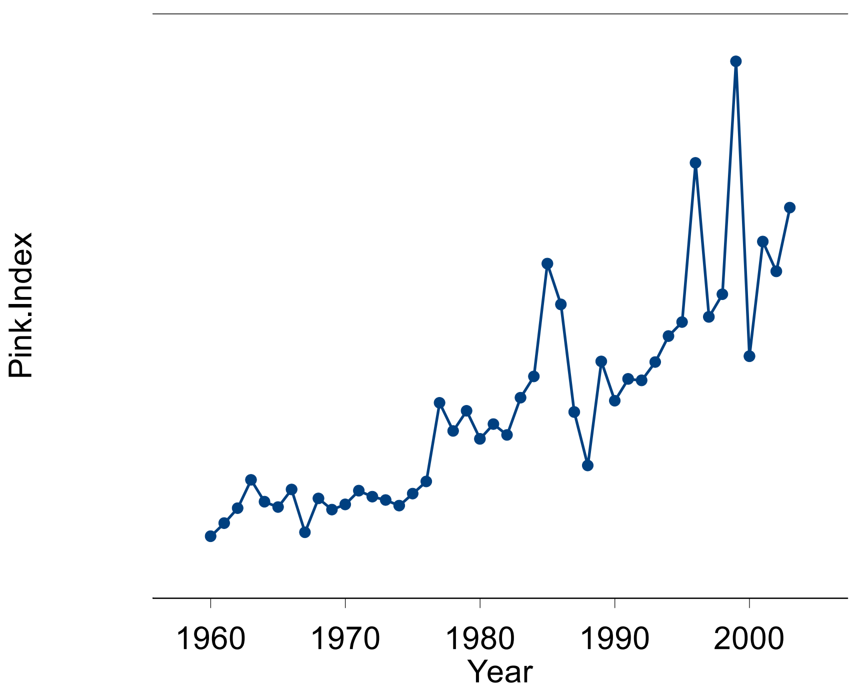

Figure 2. The Southeast Alaska pink salmon escapement index (in units with no practical meaning on the *y* axis) from 1960 to 2003.

Traitors Cove Study

We have conducted a series of calibration studies at Traitors Creek, near Ketchikan, Alaska, since 1996. These studies provided information on aerial observer counting rates, including comparison of counting rates among observers, and comparison of peak aerial surveys to the total spawning population of pink salmon in the creek. Our data show that the relationship between "peak" survey estimates and the total escapement is quite variable on an annual basis, and the amount of measurement error associated with aerial survey estimates can be enormous. In addition, applying the observer calibrations used in the creation of the pink salmon escapement index to our data results in an increase in this measurement error.

From 1996 to 2005, a two-sample mark-recapture population study was conducted annually to estimate the total spawning population of pink and chum salmon at Traitors Creek. Throughout the season, fish were captured with a beach seine and marked with readily identifiable fin clips in the lower part of the creek. We conducted surveys to sample carcasses for marks once the fish began to spawn and die, and continued the mark recovery phase until few fish were left in the creek. In addition, in 2004 and 2005 the number of salmon in a closed study area at Traitors Creek was estimated through a two-sample mark-recapture study conducted near the peak of the run. We temporarily fenced off the creek, spent one day marking fish in the study area (with marks distributed throughout the study area), and spent another day recapturing fish and recording the number of marked and unmarked pink salmon. We then calculated a Petersen estimate of the salmon abundance in the study area using the mark-recapture data. During the mark-recapture study of the closed study area, management biologists from all four area offices in Southeast Alaska conducted aerial surveys of the creek. Aerial surveyors flew the creek in a manner consistent with their usual style or method, and estimated the total number of live fish, both in the study area, and in the entire Traitors Creek system. We were then able to compare the total spawning population of pink salmon to the peak aerial survey estimate, and to the peak observer bias-adjusted survey estimate, and the surveyor's estimates of what was in the fenced off study area to what was actually present in that area at the time of the survey.

Similar to other studies (Dangel and Jones 1988; Jones et al. 1998), our studies at Traitors Creek have shown that "peak" or maximum aerial surveyor estimates generally underestimate the total spawning population of fish in a given creek (Figures 3–6). The relationship of the "peak" or maximum aerial survey estimate and the total escapement is quite variable on an annual basis. The peak Ketchikan Management survey at Traitors Creek has averaged 67% of the total escapement (range 20% to 139%; Figure 3). Adjusting observer counts to a principal observer, using the current method, may simply be adding more bias and more year-to-year measurement error to the estimates. Either way, the average proportional difference between the mark-recapture estimate and the aerial estimate is certainly a function of escapement magnitude, and this problem cannot be fixed by adjusting these observer calibrations. For that reason, multiplying these peak observer-adjusted numbers by 2.5 would clearly not give an accurate approximation of any consistent fraction of the total escapement at Traitors Creek.

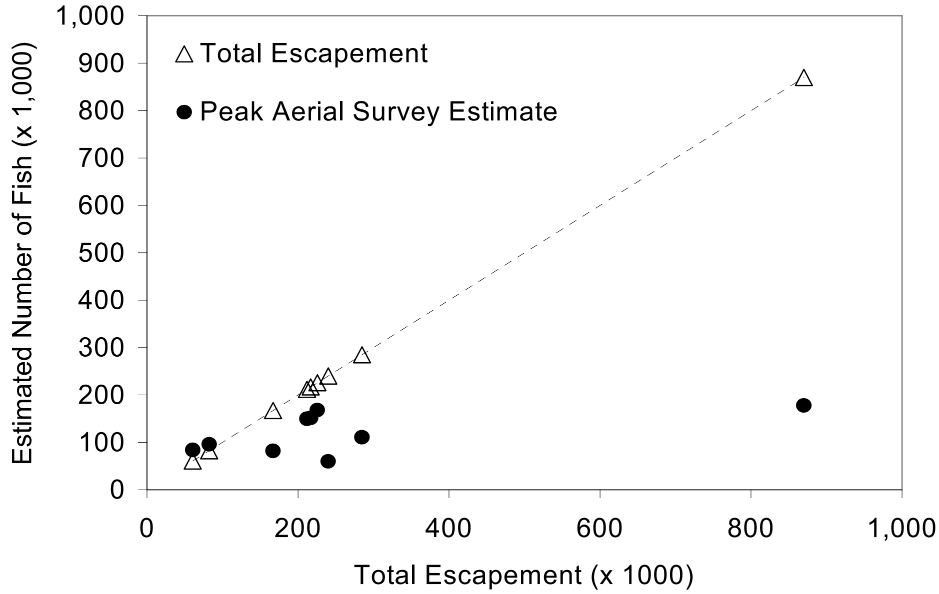

Figure 3. The total pink salmon escapement at Traitors Creek compared to the peak Ketchikan Management aerial survey estimate, 1996–2005. The open triangles on the *x*=*y* line denote the total escapement as determined from the mark-recapture study.

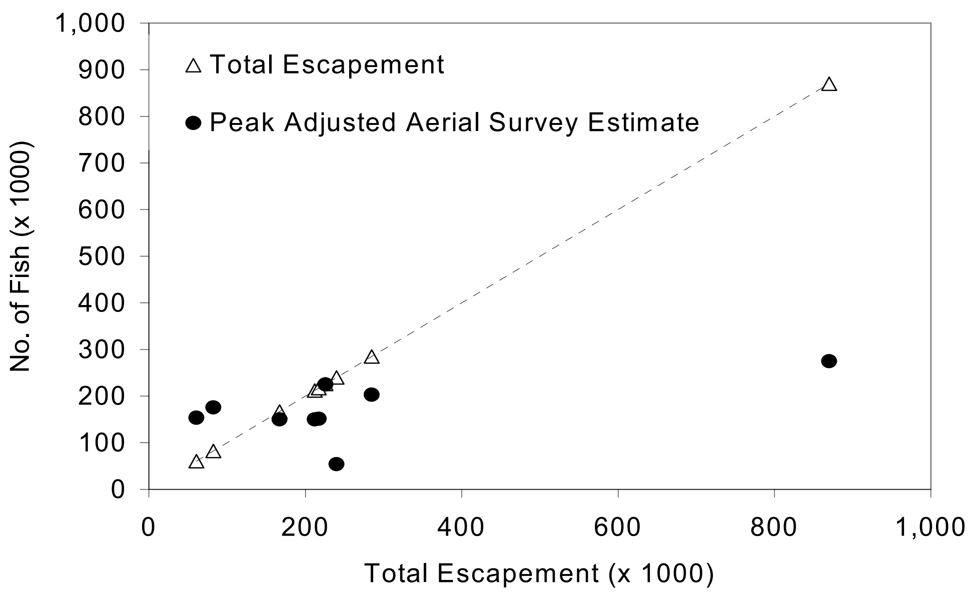

Figure 4. Total pink salmon escapement at Traitors Creek compared to the peak Ketchikan Management *observer-adjusted* survey, 1996–2005. The open triangles on the *x*=*y* line denote the total escapement as determined from the mark-recapture study.

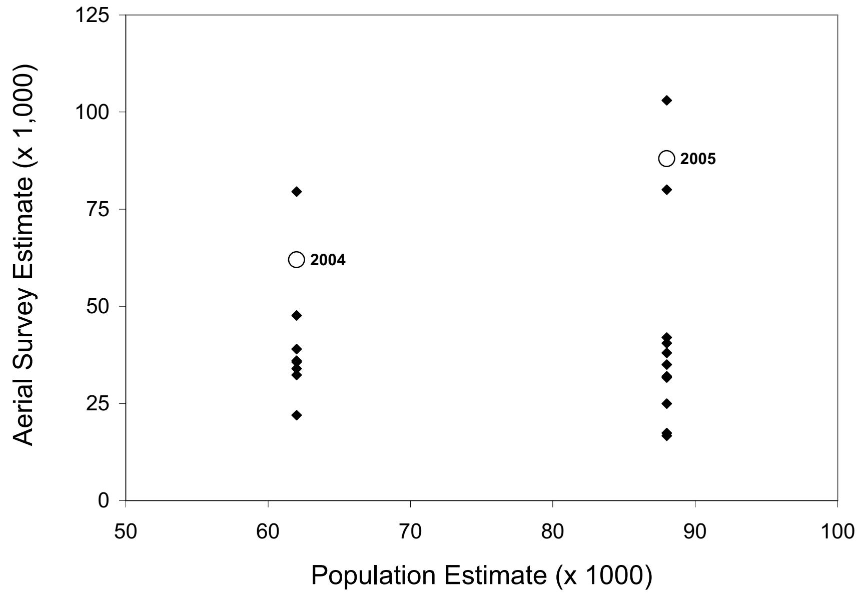

Figure 5. Total pink salmon population within the study area (open circles) at Traitors Creek, compared to aerial observer survey estimates (black markers), 2004–2005.

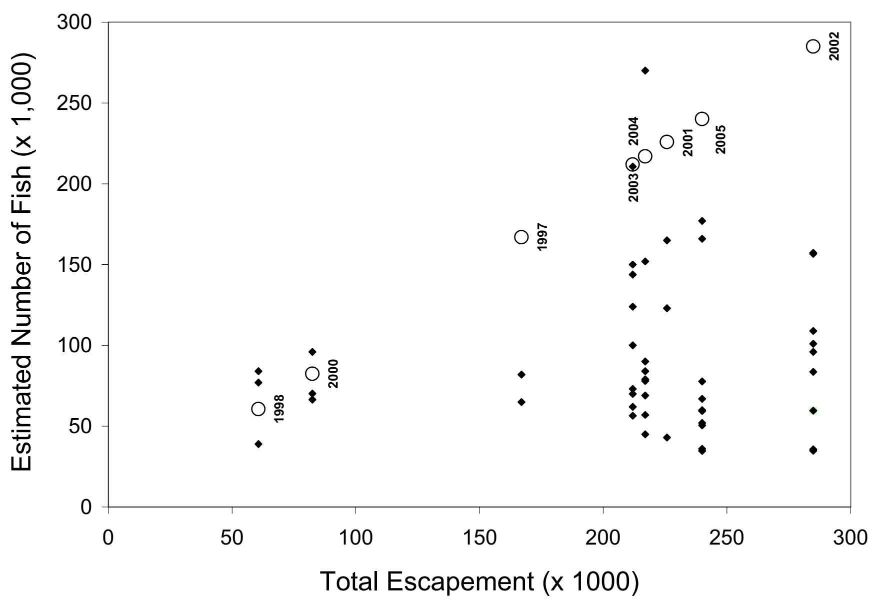

Figure 6. Total pink salmon escapement (open circles) compared to aerial survey estimates (black markers) conducted during the peak of the run at Traitors Creek, 1997–2005.

Our aerial observer studies of a closed off section of Traitors creek in 2004 and 2005, revealed extreme variation between the estimates of different management biologists. In 2004, aerial observer estimates of the number of pink salmon present in the study area ranged from 22 thousand to 135 thousand pink salmon (mean = 41,000; median = 36,000, mark-recapture estimate = 62,000). In 2005, aerial observer estimates of the number of pink salmon present in the study area ranged from 17 thousand to 103 thousand pink salmon, compared to a mark-recapture estimate of 88,000, and estimates were again generally biased low: mean 42,000 (-52%) and median 35,000 (-64%). Observers as a group tended to estimate the same number of fish in the study area in 2004 and 2005, though we estimated that there were 40% more fish in the study area in 2005 (Figure 5).

Observer Calibration Study

The observer calibrations actually used in the Southeast Alaska pink salmon index were generated by selecting pairs of aerial survey observations flown by different observers within three days of each other. For each instance of these paired observations, a ratio of the principal observer to the observer in question was formed, and then the overall ratio was averaged over all ratios. We were not able to examine the actual historical data that were used to generate these observer calibrations, but we were able to generate similar, but more complete data sets using all paired observations, for all observers up to 2003. We first formed these ratios with the aerial escapement measure for the principal observer in the numerator and the aerial observation for the observer in question in the denominator. From Figure 7, which is a plot of these ratios for a typical observer, we can see that at times one of the two observers would record many more fish than the other. What is not obvious from Figure 7 is that often there were symmetric discrepancies. In other words, if an observer recorded an impression of 500 on one over flight and the principal observer recorded 1,000 fish, but on the next survey our observer recorded 1,000 fish and the principal observer recorded 500 fish, it would seem that the two observers were, on average, observing the same number of fish. However, a serious problem arose by averaging ratios. In our simplified example with both observers, on average seeing the same number of fish, the estimated observer calibration would be greater than 1: (500/1000+1000/500)/2=1.25.

Indeed, what we found was that the observer calibrations were almost always larger than 1, and often substantially larger than 1, with no real justification for the large values. These individual ratios were bounded by the value of zero on the lower end, but unbounded on the high end. That is, with the observer in question recording fewer fish than the principal observer, this would create a large ratio. When this large ratio was added to the average, the average was pulled far up above the value of 1. Even a substantial number of small ratios couldn't balance out a few large values. For example several ratios of 0.1 (the principal observer recording 10% of the observer in question) would not average out with even one ratio of 10 (the symmetric situation); note that the average of 0.1, 0.1, 0.1, 0.1, 0.1, and 10 is still substantially greater than 1 (the average is 1.75).

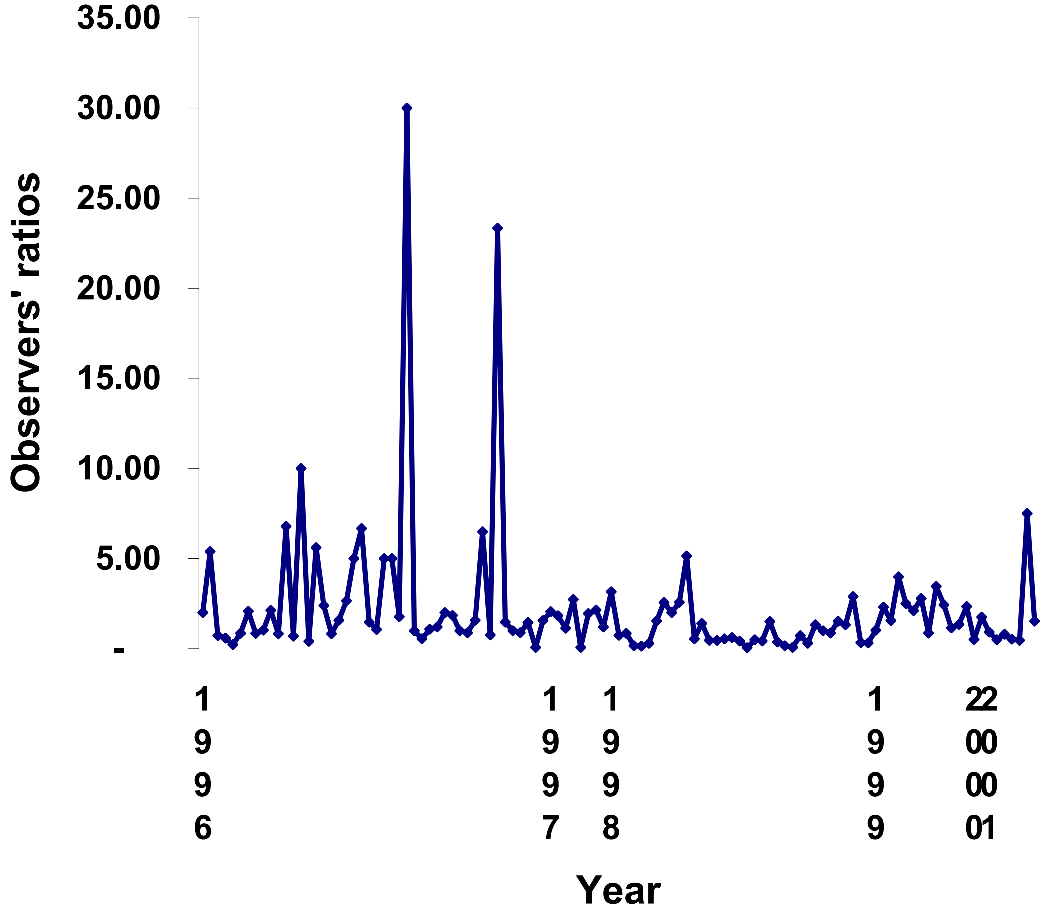

Figure 7. The ratio the counts of the principal observer within a three day period to those of an example junior aerial pink salmon observer.

We also noticed that surveys conducted within three days of each other were often not comparable, due to the fact that numbers of pink salmon in a stream can change dramatically overnight, and viewing conditions can also change significantly in a short amount of time. When we compared some of the long-term management biologists, all who had calibrations of one, to their own counts within three days of themselves, the observer-calibration algorithm produced calibrations as large as many of the calibrated observers in the index—obviously indicating a problem. It is also important to note that these calibrations were not based on calibrating to the actual number of fish in a creek, but rather to a principal observer's level of counting, which may, or may not, be closer to the actual number of fish in the creek than the secondary observer. Also, the fact that each area office is calibrated to a different observer means that the index consists of several non-comparable components. In summary, these observer calibrations have tended to induce substantial measurement error into the process when any observer other than the principal observer collected the peak escapement count.

Discussion

Our first important point is that multiplying the pink salmon index by 2.5 has not produced a reasonable approximation to the total pink salmon escapement in Southeast Alaska. We can find no justification for this expansion. This 2.5 value may approximately expand the observed number of fish in a stream to a crude approximation to the actual number in some cases, but that still does not bring the index up to the level of all pink salmon in Southeast Alaskan streams. We know that only about one third of the pink salmon-producing streams in Southeast Alaska are in the index set, but we have no measure of what fraction of the escapement is in the index streams. Presumably many of the index streams were selected because they are large, important producers, but that is just speculation at this point. We now know that observers do not always see a consistent fraction of the escapement within a single stream, and that large escapements were considerably underestimated by the observers.

We continue to find colleagues surprised that the Ricker model, or some other model that Haeseker et al. (2005) would say is based on, "explicitly modeled mechanisms" performed poorly when used for pink salmon forecasting. Part of the reason may be that parent escapement has a definite cause-and-effect relationship to subsequent recruitment. However, fishery managers are trying, and more or less succeeding, to reduce variation in escapement levels. Escapement has been generally held to similar levels over a period of several years. Much of the variation in the escapement index is measurement error and therefore just random noise. The escapement index simply does not measure anything surprising about pink salmon recruitment or potential catch. That is because managers generally control escapement, which is not well measured.

The same principle extends to many other factors controlling salmon recruitment: a factor involved in a cause-and-effect relationship will not improve a forecast unless it is well measured and unless there is large year-to-year variation in the factor affecting recruitment. For example, if ocean temperature strongly affects salmon recruitment, but the process controlling temperature is slowly evolving, then simply measuring the local temperature (not the integrated temperature over a very large area) will not reliably predict surprising changes in run size.

What we found is that escapement level, catch, and presumably run size, have all changed slowly from 1960 to the present. Changes in escapement level are correlated with catch because of these long-term changes—not because short-term changes in the measured escapement corresponded to short-term changes in catch two years later. The correlation of escapement with catch in the same year is 0.89, but this correlation drops to 0.61 when the correlation is between escapement and catch lagged two years into the past—the latter is the pairing that corresponds to the cause-and-effect relationship. This seems to imply that both escapement and catch are both correlated with some other factor, which is highly dependent on time (Figures 1 and 2). Moreover, we now know both of these series have tended upwards because of ocean-climate changes, not because of changes in escapement level (e.g., Mantua et al. 1997). The implication is that the same long-term information in the escapement index is also in the catch series itself—possibly with less measurement error. Year-to-year, short-term correlation might indicate a potential to predict surprise, but the escapement index, catch, and presumably recruitment are correlated because of long-term similarity. Our recommendation is for ADF&G to simply give up on trying to forecast unusual features of Southeast Alaska pink salmon recruitment with escapement measures alone. We recommend that ADF&G use the catch series itself, with forecasting tools like moving averages, to establish the underlying baseline catch level over a period of several years. Then, if there is sufficient interest, make real improvements to the forecast by direct measurement of the marine environment, where the real year-to-year variability in salmon recruitment actually takes place.

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The Southeast Alaska Pink Salmon Forecast Has Consistently Failed Because the High-Frequency Forecast Indicators Have Been Largely Measurement Error

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Salmon biologists approach pink salmon forecasts with dread, as there is a long and dismal history of failure associated with this enterprise. For example, within the last 29 pink salmon forecasts for Southeast Alaska, the actual harvest was within 20% of the forecast only 8 times. Management agencies are resigned to this failure, and they have accepted it as inevitable. However, this failure is partially a result of consistently using the wrong statistical models for forecasting. In Southeast Alaska, the total-return forecast has been accompanied by a forecast range, expressed as an 80% or higher confidence interval. The proof that the problem is at least partly the result of the forecast model is found by noting that the forecast has been outside this 80% (or higher) confidence interval over 50% of the time since 1981. Usually the forecast models are a modified form of the Ricker recruitment law. This model uses a measurement of escapement magnitude to forecast future return (both future escapement magnitude and catch magnitude added together). We carefully dissected the escapement series used in the Southeast Alaska forecast. First, we noted that this series simply does not capture the true escapement magnitude. Second, we noted that the escapement index series comprises two major components. The first component is a low-frequency pattern that the catch and escapement series both share in common: an underlying track of a low level in the 1960s, lower still in the early 1970s, and increases into the 1990s. The second component is a high-frequency pattern, largely comprised of measurement error. More importantly, this high frequency, year-to-year variation in the index series is statistically independent of the high-frequency variation in the catch series. Interestingly, the catch series contains more high-frequency variation than the escapement index. To the extent there is a pattern that is common in both series, it is the redundant, low frequency pattern, which is not useful for annual forecasting. We have three recommendations. First, we recommend that only the harvest level be forecast, as the measurements of total escapement, and hence total return, are simply incorrect. Second, we recommend that until a reliable high-frequency forecast indicator is developed, forecasters restrict their forecast to the low-frequency component only—that is, forecasting the average catch level. Third, we recommend that management and research agencies look to early marine studies to develop meaningful forecast indicators, especially indicators of *surprise*—the most valuable feature of a pink salmon forecast.

Forecasting Pink Salmon Harvest In Southeast Alaska From Juvenile Salmon Abundance And Associated Environmental Parameters

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Abstract

Understanding factors that influence the marine survival of pink salmon is a major objective of the Auke Bay Laboratory's Southeast Alaska Coastal Monitoring (SECM) Project. From 1997 to 2004, SECM has collected a time series of indices of juvenile salmon abundance and associated biophysical data in neritic habitats of northern Southeast Alaska (SEAK). Simple linear models based on juvenile catch per unit effort (CPUE) provided remarkably accurate forecasts for the 2004 harvest of adult pink salmon. Peak average CPUE for sampling periods within a year gave a harvest forecast of 43 million catch (80% prediction interval (PI) = 34 million–64 million); July average CPUE gave a forecast of 47 million (80% PI = 27 million–70 million). The preliminary SEAK harvest estimate for 2004 is 45 million pink salmon. However, the pattern of the juvenile catch was different in 2004 than in previous years, with high catches in June and low catches in July, resulting in very different forecasts for the 2005 SEAK harvest depending on whether the peak CPUE model (forecast 59 million, PI = 47 million–72 million) or the July CPUE model (forecast 16 million, PI = 2 million–30 million) was used. We discuss biological reasons for choosing between these forecast models.

Introduction

Pink salmon are notoriously difficult to forecast, because their 2-year life history cycle precludes the use of returns of siblings of younger age classes to predict cohort strength (Adkison and Peterman 1999; Adkison and Shotwell 2002; Adkison 2002). Preseason forecasts of pink salmon abundance for Southeast Alaska have focused on spawner/recruit relationships modified by indices of environmental change and juvenile salmon growth (Hofmeister 1994; Adkison and Mathisen 1997; Adkison 2002). However, these forecasts have not been particularly accurate because high variation in marine survival makes parental abundance a weak predictor of returns from the spawners and because environmental variates typically explain little of the variation in productivity and reduce forecasting error only slightly (Adkison and Mathisen 1997; Adkison 2002; Wertheimer et al. 2004). Because of poor pre-season forecasting success and large uncertainty in estimating escapement numbers, ADF&G no longer uses a spawner/recruit approach to forecast Southeast Alaska pink salmon, but instead predicts future harvests from the time series of prior harvest using an exponential smoothing model (Plotnick and Eggers 2004; Eggers 2005). However, uncertainty for this method is also high, and the forecast methodology has no potential to detect large shifts in productivity due to changing environmental conditions

Direct measures of the abundance of juvenile pink salmon may provide a method to improve accuracy and reduce uncertainty of preseason forecasts (Adkison 2002). Mortality of juvenile pink salmon is high and variable during their initial marine residency, and is thought to be a major determinant of year-class strength (Parker 1968; Mortensen et al. 2000; Willette et al. 2001). Sampling juveniles after the period of high initial mortality may provide information that can be used with associated environmental data to forecast abundance.

The average catch per unit effort (CPUE) for juvenile pink salmon captured in late June and July during the SECM project has been highly correlated with the subsequent harvest of adult fish in Southeast Alaska. These relationships were used to develop forecasting models for 2004 that provided remarkably good predictions of the actual catch in 2004. In this paper, we incorporate an additional year of sampling into the data series, reexamine the relationships between fisheries harvest and juvenile CPUE and associated environmental parameters, and predict the 2005 harvest based on these relationships.

Methods

Juvenile salmon were sampled from 1997 to 2004 along transects in Upper Chatham Strait and Icy Strait (Figure 1) with a Nordic 264 rope trawl modified to fish the surface water directly astern of the *John N. Cobb*, a 28-m NOAA fisheries research vessel (Orsi et al. 2000). After each trawl haul, the fish were identified, enumerated, measured, labeled, bagged, and frozen. Juvenile pink salmon were measured to the nearest mm fork length; usually all fish were processed, but very large catches were subsampled due to processing time constraints. Up to 50 juvenile salmon of each species were bagged individually and frozen immediately after measurement. Frozen individual juvenile salmon were weighed in the laboratory to the nearest gram (g), and condition factor ($g/FL^3 \cdot 10^5$) computed from the length and weight data. Oceanographic data were collected at the trawling sites: temperature and salinity profiles to 200 m, and zooplankton samples from the upper 20 m and the integrated water column to 200 m.

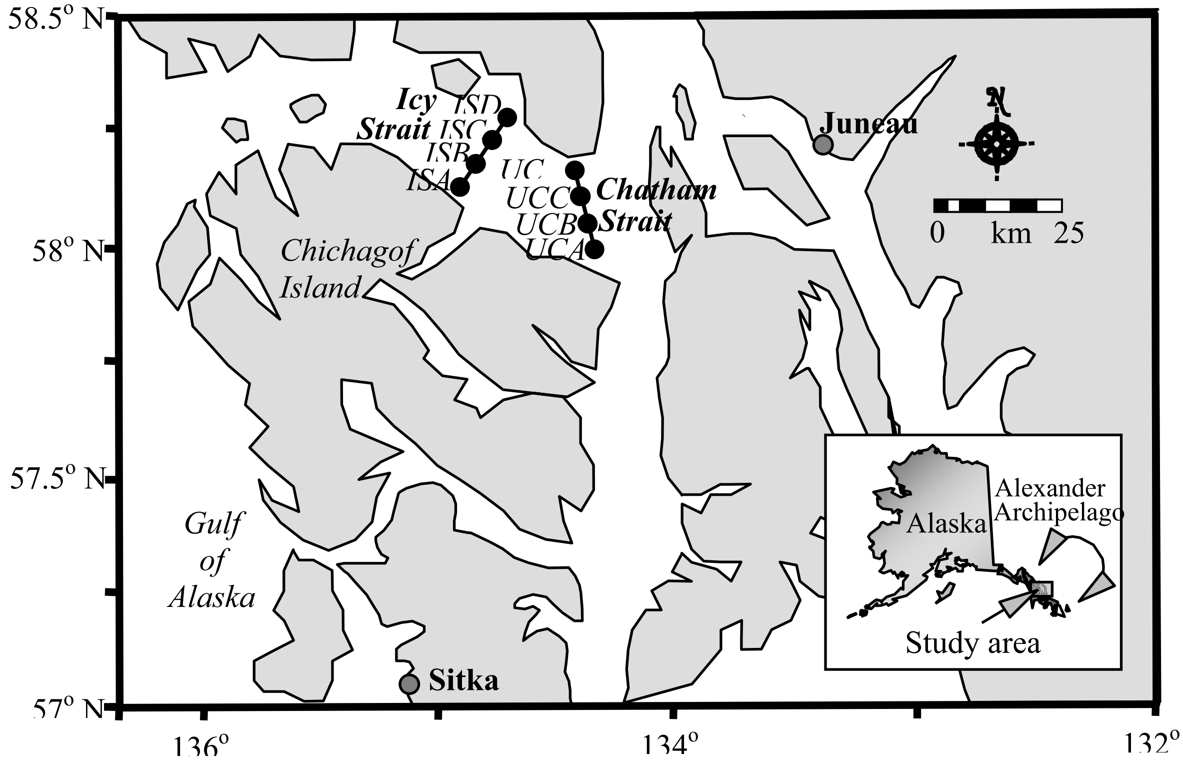

Figure 1. Location of trawl sites in northern Southeast Alaska for indexing abundance of juvenile pink salmon.

We examined three measures of juvenile pink salmon CPUE and a suite of eleven biophysical parameters for data collected in year *y* over the years 1997–2003 for bivariate correlation with the annual commercial harvest of pink salmon in Southeast Alaska in year *y*+1 (Table 1). The three measures of juvenile CPUE were, 1) July CPUE, the average ln(CPUE+1) for July catches; 2) Peak CPUE, the average ln(CPUE+1) for catches in either June or July depending on which month had the highest average catches in a given year; and 3) Average(CPUE), the mean of the average ln(CPUE+1) for June and July. We obtained associated pink salmon harvest data from the Alaska Department of Fish and Game (ADF&G; www.cf.adfg.state.ak.us). We assumed that harvest was proportional to total run and did not include escapement data because of the large uncertainty in estimating escapements from escapement index counts (Plotnick and Eggers 2004). We constructed regression models considering each of the three CPUE measures separately, with harvest as the dependent variable, using forward-backward stepwise regression to determine which, if any, of the biophysical parameters significantly improved model fit. A parameter had to be significant at $P < 0.1$ to be added or to remain in the stepwise model. We also used the corrected Akiake information criterion (Shono 2000) to determine if additional parameters in multi-parameter models identified by the stepwise regression improved information content.

Results and Discussion

All three measures of juvenile pink salmon CPUE were significantly correlated with harvest in the subsequent year (Table 1). None of the other parameters evaluated were significantly correlated with harvest.

Table 1. Correlation coefficient of CPUE of juvenile pink salmon and associated biophysical parameters in year *y* for 1997–2003 with adult pink salmon harvest in Southeast Alaska in year *y*+1.

Parameter	***r***	***P*-value**
ln(July CPUE)	0.94	0.002
ln(Peak CPUE)	0.92	0.003
June/July Average (lnCPUE)	0.81	0.027
May 2-m Water Temperature	0.28	0.550
July 2-m Water Temperature	0.28	0.536
July 2-m Salinity	-0.22	0.638
May/June Average Zooplankton Total Water Column	0.09	0.841
May/June Average Zooplankton 20 m	0.03	0.953
June-July Pink Salmon Increase in Average Size	0.53	0.224
Pink Salmon Size June 22	-0.23	0.628
Pink Salmon Size July 22	0.38	0.404
Fulton's Condition Index July	0.20	0.671
Energy Content (calories/g wet weight)	-0.06	0.917
Releases of Hatchery Chum Fry	-0.11	0.811

Pre-season forecasts from the regression models developed from 1997–2002 juvenile CPUE data (with 2003 CPUE as the predictor) and from the ADF&G exponential smoothing model provided similar point-estimate predictions of pink salmon harvest in 2004: 47 million for the July CPUE model, 44 million for the Peak CPUE model, and 50 million for the ADF&G model (Table 2). These forecasts were all remarkably close to the preliminary ADF&G estimates of 2004 harvest of 45 million pink salmon.

Table 2. Regression models relating juvenile catch per unit effort (CPUE) of pink salmon in year *y* to adult harvest in Southeast Alaska in year *y*+1, forecasts from these regression models, and forecasts from Alaska Department of Fish and Game (ADF&G) for 2004 and 2005. Predictions and harvest values are in millions of fish.

Model	Adjusted R^2 (%)	*P*-Value	Forecast (millions)	80% Prediction Interval
	2004			
Regression Models				
ln(JulyCPUE)	87.2	0.006	47	34-64
ln(PeakCPUE)	78.9	0.011	44	27-70
ADF&G Forecast	na	na	50	24-76
	2005			
Regression Models				
ln(JulyCPUE)	84.9	0.002	16	2-30
ln(JulyCPUE) + May/June Total	92.5	0.002	11	0-21
Water Column Zooplankton				
ln(PeakCPUE)	82.2	0.003	59	47-72
June/July Average ln(CPUE)	58.8	0.027	53	34-72
ADF&G Forecast	na	na	49	25-72

When extended through the 2003 juvenile catches, both the July CPUE model and the ln(PeakCPUE) model provided statistically significant ($P < 0.005$) fits to the harvest data, explaining over 80% of the variation (Table 2). The Average(CPUE) model was also statistically significant ($P = 0.027$), but explained only 59% of the variability. Only the July CPUE model was significantly improved by other biophysical data. The index of total water column zooplankton increased the R^2 of this model to 93% (Table 2), and reduced the Akiake Information Criteria relative to the simple regression model.

In contrast to the 2004 forecasts, predictions from the regression models for 2005 were very divergent. The two models using July CPUE produced forecasts for the 2005 harvest of 11 million–16 million fish, while the models using Peak(CPUE) or the Average(CPUE) produced forecasts of 53 million–59 million fish (Table 2). The differences were driven by an anomalous catch pattern for juvenile pink salmon in 2004. The CPUE in June, 2004, was the highest observed over the eight-year time series, except for 1998, while the July, 2005, CPUE was the lowest July CPUE on record (Figure 2).

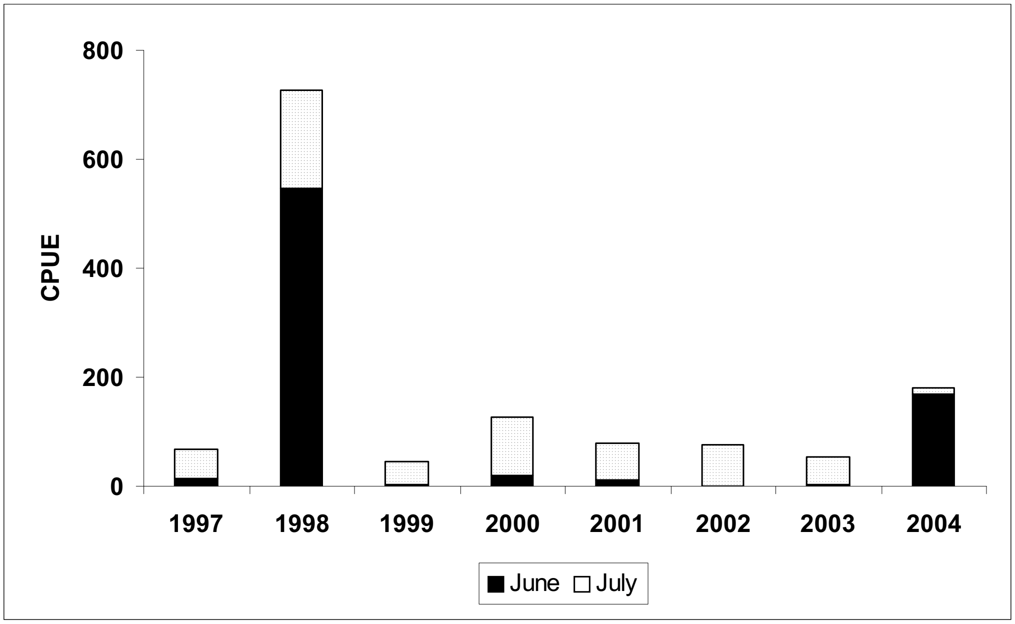

Figure 2. Catch-per-unit effort (CPUE) of juvenile pink salmon in straits habitat of northern Southeast Alaska, June and July 1997–2004.

The unusually low 2004 July CPUE could have been caused by 1) high mortality between June and July sampling periods; 2) stochastic variation in CPUE; or 3) earlier than normal movement of juvenile pink salmon from the sampling area to the Gulf of Alaska. Three factors support the concept of early movement. First, the surface water temperatures in June and July 2004 were the highest that have been observed over the 1997–2004 time series. Second, other juvenile salmon species also showed the same patterns of unusually high catches in June of 2004, and unusually low catches in July of 2004. Third, the predictions from the average and peak CPUE models for 2005 harvest are more consistent with the independent predictions from the ADF&G forecast. For these reasons, we think the average and peak CPUE predictions of 53 million–59 million, with 80% prediction intervals of 34 million–72 million are better preseason forecasts than the July CPUE predictions.

By the 2007 Northeast Pacific Pink and Chum Salmon Workshop, we should have much better insight into use of juvenile CPUE variables as predictors of pink salmon harvest in SEAK. We will have two additional years of data including the 2005 harvest, which will validate whether the peak or average CPUE models were better than the July CPUE models. We will have examined the effect of measurement error on the prediction intervals from the regression models using a bootstrap resampling approach of the trawl data; the intervals presented in Table 2 take into account only process error. We also plan to extend sampling to southern SEAK to evaluate the appropriate geographic scale for the association pink salmon harvest with juvenile CPUE. Northern and southern Southeast Alaska have been considered as separate production areas (e.g., Adkison and Shotwell 2002), and it may be unrealistic to expect sampling in only one specific area to represent the entire region.

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Session 5: Western Alaska Issues

Norton Sound Chum Salmon Stock Status and Estimation of Chum Salmon Abundance and Distribution in the Fish River Complex using Radio Telemetry

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Chum salmon returns to many Norton Sound drainages have been declining since the early 1980s. Consequently, management of commercial and subsistence fisheries has become more restrictive. Northern Norton Sound stocks are now classified as stocks of concern and subsistence fisheries have frequent closures and bag limits. In 1999 the Alaska Board of Fisheries established a tier II subsistence area for chum salmon in Subdistrict 1 (Nome area). Fish River, in Subdistrict 2 (Golovnin Bay), is believed to be the second largest producer of chum salmon in Norton Sound. We conducted radio telemetry mark-recapture studies on chum salmon during 2002–2004 to estimate abundance and spawning distribution. Chum salmon were seined in the lower Fish River and radio tags were attached externally. Ground-based radiotelemetry receivers monitored tagged fish movement and passage. Yearly escapement estimates were made by expanding chum salmon tower counts at Niukluk River, the largest tributary in Fish River drainage, by the proportion of radio-tagged fish past the counting tower. Yearly proportions were 35.6% in 2002, 36.7% in 2003, and 34.4% during 2004, and averaged 35.6%. Total estimated drainage abundance was 93,357 in 2002, 53,465 in 2003, and 30,844 for 2004. Aerial telemetry surveys were conducted to determine drainage-wide distribution.

Summer and Fall Chum Salmon Spawning and Incubation in Western and Interior Alaska: Differences of Scale and Sensitivity?

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Chum salmon populations in western Alaska persist because they are adapted to the rigors of spawning and incubating under harsh winter conditions. It is generally accepted that chum salmon spawning, at the northern limits of their range, are dependant on ground water upwelling areas where intergravel temperatures remain around 4º C. Indeed, this seems to be the case for fall chum salmon and has been confirmed by intensive studies in the Clear Water portion of the Tanana River. Intergravel conditions in summer chum salmon spawning areas, however, suggest otherwise. On the Chena River, we found evidence that relatively small-scale hydrological mechanisms are responsible for creating suitable summer chum salmon spawning habitat. In general, summer chum salmon spawn in lower and middle reaches of the river systems from late June–August and in areas with pronounced thermal variation. Intergravel conditions at these sites are controlled by smaller and more locally scaled hydrological mechanisms. In contrast, fall chum salmon spawn in the upper reaches of the Yukon River and Kuskokwim River drainages and later (September–November) in thermally stable areas controlled by large-scale hydrological drivers. The reproductive strategies of summer and fall chum salmon in western Alaska may have important implications concerning productivity and resilience. For example, fall and summer chum salmon may respond differently to changes in surface water temperature and runoff patterns. Analysis of spawning behavior, habitats, and timing in relation to watershed, reach, and microhabitat scale drivers will provide a better understanding and ability to predict the response of chum salmon to environmental change.

Fisheries Enhancement In Norton Sound

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Abstract

Salmon populations in the Norton Sound area have been in decline since the mid-1960s, resulting in inadequate subsistence harvest for the native people of the region and a realized need for research into the causes of this decline. Many people in Norton Sound have expressed interest in exploring enhancement options as a method to supplement natural production and traditional harvest. Previous enhancement efforts in Norton Sound have proved the feasibility of rearing salmon, however, they have also demonstrated the risks associated with manipulating eggs from depleting salmon stocks. Local support for enhancement has increased as the salmon populations continue to decrease and harvest is further regulated. The depleting salmon populations in Norton Sound, and the resulting restricted harvest, are sources of frustration for local residents, and options need to be discussed and decided at a local level. A Norton Sound Fisheries Enhancement Summit, held November 4—5, 2004, gathered key organizations, invited scientists and experts, and the communities involved together to discuss fisheries enhancement options. Several major outcomes were realized, including general support for and identification of potential specific small-scale enhancement projects in Norton Sound.

Introduction

Norton Sound has suffered a progressive collapse in salmon populations since the mid-1960s, which has affected the lifestyle and culture of most residents. This decline began in the Nome subdistrict, progressed through the Seward Peninsula, and by the late 1990s had affected the Bering Sea summer chum stock as a whole. Salmon populations reached such low levels that the Secretary of Commerce declared the region a Fisheries Disaster on August 8, 2000. Some communities of Norton Sound used to depend on commercial fishing for income, yet most commercial fishing is now closed. Similarly, regulations now dictate when, and if, local residents can fish, and how many fish they may take for subsistence, which is changing the traditions and culture of the residents of Norton Sound. Norton Sound has more rivers declared "yield concern" by the Alaska Department of Fish and Game than any other area in Alaska, and the Nome Subdistrict has the only Tier II fishery in the State (ADFG 2003). However, despite concerted management efforts by the Alaska Department of Fish and Game, the salmon stocks in Norton Sound continue to decline, and now many consider them to be in peril.

Many people in Norton Sound, and especially in northern Norton Sound, have expressed interest in exploring enhancement options as a method to supplement natural production and traditional harvest in the Nome Subdistrict. Hatcheries, and other enhancement options, can also be useful tools for research into little known aspects of the life cycle, such as mortality during saltwater-transition, marine survival, marine migration routes, and adult straying. However, enhancement has many disadvantages and evaluation is necessary to measure success. Therefore, enhancement efforts may be improved by discussing prior experiences and incorporating that knowledge in future plans.

Enhancement efforts in Norton Sound have taken place in the past and are also currently ongoing. Previous aquaculture efforts in Norton Sound include instream incubation boxes, an educational rearing project at Nome-Beltz High School, re-circulating incubators and an incubator facility constructed on Hobson Creek, a tributary to the Nome River. These projects proved the feasibility of rearing salmon, however, they have also demonstrated the risks associated with manipulating eggs from depleting salmon stocks. Current enhancement efforts include an Alaska Department of Fish and Game fertilization project on Salmon Lake, a project at the Hobson Creek facility by Nome Fishermen's Association, and a mist-egg incubation project by the Norton Sound Economic Development Corporation and ARED, Inc. Directed efforts to focus enhancement in Norton Sound may increase the likelihood of a successful outcome, from the perspective of local residents, as well as scientists and managers.

The Norton Sound Fisheries Enhancement Summit, hosted by Kawerak, Inc., was held in Nome on November 4 and 5, 2004. The meeting was intended to gather key organizations and communities together to discuss fisheries enhancement options and to provide an open forum for information sharing and discussion. Local support for enhancement has increased, as the salmon populations continue to decrease, and harvest is further regulated. The depleted salmon populations in northern Norton Sound and the resulting restricted harvest are sources of frustration for local residents, and this Summit provided the opportunity for options to be discussed and decided at a local level.

Methods

The Summit was divided into information sharing and discussion components. The morning session of each day was comprised of informational presentations by invited speakers on a variety of related topics. The afternoon sessions allowed ample opportunity for public participation and discussion and included a panel presentation and discussion from representatives of several applicable organizations. There was also a poster session, which highlighted current enhancement efforts and provided further opportunity for interaction between local residents and visiting scientists.

Results and Discussion

Participation

Over 50 people attended the two-day Summit. Participants included state, federal, and tribal representatives, local subsistence users, interested parties, and representatives from over nine communities in Norton Sound. Public participation was encouraged throughout.

Invited Speakers

Scientists identified to be experts in their field were invited to participate in and give an informational presentation at the Norton Sound Fisheries Enhancement Summit. The presentations were an opportunity to provide all Summit attendees with background information on a variety of topics and to stimulate discussion. A total of six invited speakers gave presentations on topics ranging from genetics, past enhancement work in Oregon, Washington, and Alaska, tribal involvement in enhancement, sea-ranching, and marine factors. The speakers included Jim Lichatowich, retired Oregon Department of Fish and Wildlife, and now a consultant; Dr. Anthony Gharrett, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Juneau campus; Alex Wertheimer, NOAA Fisheries, Juneau; Dr. Kate Myers, High Seas Salmon Research Program, University of Washington, Seattle; Terry Wright, Northwest Indian Fisheries Commission, Washington; and Peter Rob, retired Alaska Department of Fish and Game, Nome. These invited speakers also contributed to discussions, answered questions and provided information throughout the Summit.

A panel of experts was convened to present additional information and discuss enhancement from a variety of perspectives. The panel was comprised of representatives from organizations that had direct experience in enhancement or were to be directly involved in enhancement efforts in Norton Sound. The panelists included Dr. Jim Seeb, Alaska Department of Fish and Game, Gene Conservation Laboratory; Gary Fandrei, Cook Inlet Regional Aquaculture Association; Charlie Lean, National Park Service, Nome; Austin Ahmasuk, Kawerak Subsistence Department; Eugene Asicksik, Norton Sound Economic Development Corporation; and Steve Reifenstuhl, Northern Southeast Regional Aquaculture Association. The panel's charge was to discuss the information presented by the invited speakers, and include information derived from their own knowledge and experiences to develop their own recommendations for enhancement in Norton Sound.

Public Input

Input from local residents was an important component of the Norton Sound Fisheries Enhancement Summit. This information provided perspective on priorities, and insight into ways that communities worked together to ensure harvest for all, yet still focusing on maintaining healthy salmon runs. Most of the local residents were interested in enhancement because it was a tool to increase harvest. However, there were some concerns expressed by members of the public. For example, two members of the public had this to say:

> "Some of the goals we looked at include wanting to make sure that streams that have healthy runs stay that way. We do not want to improve some new streams and have the current good ones go backwards."

> "I am concerned about chums. Their returns have been going down through the years. If the cause of the decline of chums can not be found, it might be that enhancement will just increase someone's catch on the high seas."

Local residents wanted harvest opportunities to increase, yet they understood the call for caution regarding enhancement.

The local residents present at the Summit wanted to be involved, and they wanted to hear the input from the scientists to help ensure success. Examples of comments heard at the meeting included:

> "People that haven't fished are making policy and we need the local people who are fishing to be behind any policy."

> "People want dried chum. Demand is strong for that and all permits will be taken. People know when up and down years occur and when runs arrive. As lay people we rely on scientists to help work these enhancement things out. We have a strong interest in it, but [we] are not the experts."

There was an understanding that success could be achieved through cooperation.

Local residents also provided input regarding the role of fisheries in their culture and traditions. For example:

> "In the tribes that live under the subsistence concept, people were taught to practice custom and culture. When a depletion of certain species occurs, leadership of the community will do everything possible to get that resource for the elders. It has always been the custom to get them what they need to survive the course of the year. That is often a custom that is not understood by the managers and policy makers."

> "The first issue is restoring chum salmon in the Nome sub-district. Doing that would restore subsistence culture to something like it was before recent salmon declines."

It is this cultural tradition that, in part, drives the desire to increase subsistence harvest opportunities in Norton Sound, and therefore drives the interest in enhancement by local residents.

Local residents also explained that communities suffering from the decline of salmon pressure nearby river's stocks for harvest:

> "I would like to see more of [the sockeye run on the Pilgrim River] be available for local people, Nome people, to help with some of the problems with the Niukluk and Fish Rivers because they can target them fairly readily.... Chum salmon are a concern over there but it takes the pressure off some of the other areas."

> "Management has been focused over the years on the road system. We should be considering use in a subsistence, multi-species mindset. People say that they use a number of different types of fish in an opportunistic manner. In the Nome area and on the road system there is a subsistence fishery that is multi-species and multi-location. People are still traveling a great distance to reach their fish."

> "We as a people are very opportunistic [harvesters] and we survive that way. As a fishery goes up and down we use many rivers. We will keep that in mind."

This opportunistic harvest approach has contributed to the progressive decline of salmon stocks throughout much of Norton Sound, affecting multiple communities and multiple rivers.

Meeting Outcomes
The meeting produced several major outcomes. The Norton Sound Fisheries Enhancement Summit convened local residents, invited speakers, panel experts, and representatives from state, federal, regional and tribal organizations together and allowed a rare opportunity for interaction and progress towards a common purpose. An overall expression of support was given for small-scale enhancement projects and the need for evaluation in those projects, an accepted list of rivers and stocks requiring assistance was generated, and a commitment was given to reconstitute and convene the Regional Planning Team. Other important outcomes of the Enhancement Summit included an exchange of information regarding the pros and cons of enhancement efforts in other areas, factors affecting juvenile survival in freshwater and marine environments, salmon genetics, current and historic enhancement efforts in the Nome area and elsewhere, and the interactions of natural systems and stock enhancement projects. Local knowledge was combined with outside expertise to produce a mutually acceptable product.

The attendees formulated a list of stocks in need of enhancement. The Nome subdistrict chum salmon stock was identified as a high priority for all attendees. Chum salmon stocks in the Nome subdistrict are under Tier II management, and this is the only fishery in Alaska under this management regime. Coho salmon in the Nome subdistrict were given precedence, though at a lower priority because of the cultural significance expressed toward chum salmon by the local residents. Niukluk River coho salmon and Sinuk River sockeye salmon were identified as a priority. In fact, all road-accessible rivers were identified as priorities due to the opportunistic tendency for subsistence harvest, and the effect that Nome residents have on rivers within the road system. The Unalakleet River and Shaktoolik River Chinook salmon were also identified as priorities due to the cultural significance of Chinook salmon in Unalakleet and Shaktoolik and the depleted returns in recent years.

Additionally, a list of specific projects were identified. The list was derived from the Regional Planning Team (RPT) report (1996), the Research and Restoration Plan for Norton Sound (2003) and the Alaska Department of Fish and Game Enhancement Team Report (ADFG, Commercial Fisheries Division, unpublished data), as well as local input and expert opinion. Hobson Creek, a tributary of the Nome River, was identified as a potential incubation facility for chum salmon with possible use for coho salmon and pink salmon. There was also a general consensus to expand the mist-egg incubation projects in the Nome area for chum salmon, and as a lesser priority for coho salmon, pending the outcome of the mist-egg project currently underway with chum salmon. The Penny and Sinuk rivers in the Nome Subdistrict were identified as potential locations for chum salmon egg planting due to their numerous areas of upwelling. Ophir and Bear creeks, tributaries of the Niukluk River, were identified as potential locations for egg planting for coho salmon, in response to the expressed concern for coho salmon on the Niukluk River. Glacial Lake, the headwaters of the Sinuk River, was discussed as a location to enhance sockeye salmon runs. There was also an expressed desire to continue current enumeration studies in an effort to monitor escapement in Norton Sound Rivers, which would also perhaps provide a method of evaluation. There was also agreement that the current enhancement efforts would continue, as long as they were evaluated and were considered effective. Finally, there was a discussion regarding how to use enhancement as a tool to conduct research in Norton Sound. Specifically, enhancement was discussed as a tool to investigate fry survival to the marine environment and also to research marine migration patterns and high seas interception using marked fish.

Although most of these ideas were not unique to this summit, this was a rare opportunity for people representing various agencies, corporations, and communities to discuss and agree on these projects. The projects mentioned in this summit are similar to those included in the regional plan team report (Norton Sound/Bering Strait Regional Planning Team 1996), and the Research and Restoration Plan for Norton Sound (Research and Restoration Plan for Norton Sound Salmon. Revised February 18, 2003. Prepared by the Scientific Technical Committee for the Norton Sound Steering Committee), which suggests that the list of projects that were considered accurately addresses the problems and potential solutions. However, some changes have occurred, primarily regarding new enhancements methods, such as mist incubators, and changes in priority in response to more recent and dramatic continuous declines of stocks in Norton Sound Rivers.

The Summit also resulted in a commitment to reactivate and reconvene the Regional Planning Team. A Regional Planning Team had been active in the past, however it had not met for over two years. The Regional Planning Team in Norton Sound consists of three Alaska Department of Fish and Game representatives and three representatives appointed by the Norton Sound Economic Development Corporation. All present at the Summit agreed that it was important for the team to fill vacant seats and begin its process.

Future Developments

The Regional Planning Team has progressed since the Norton Sound Fisheries Enhancement Summit took place on November 4—5, 2004. The Norton Sound Economic Development Corporation Board of Directors appointed three members to the Regional Planning Team in January 2005. The Regional Planning Team met on February 1, 2005 and began to revise and update the Regional Planning Team report.

Acknowledgements

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Characteristics of Fall Chum Salmon in the Kuskokwim River Drainage: Morphology, Fecundity, and Distribution

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Abstract

Fishery managers became aware in the mid-1990s that the Kuskokwim River hosts a race of fall chum salmon (*Oncorhynchus keta*) distinct from the more common summer chum population. Managers do not distinguish the fall race from the summer race of chum salmon, and fall chum escapements are not monitored. Furthermore, distinctive characteristics in the morphology, age and sex composition, spawning distribution, and run timing of fall chum salmon are unknown or undescribed. In this project we describe some of these distinctive characteristics by comparing 336 fall chum salmon sampled from the South Fork Kuskokwim River with 1,964 summer chum salmon sampled from the Kwethluk, George, and Takotna rivers in 2004. Fish were examined for mideye-fork length, maximum dorsal-ventral height, and maximum width. Age and sex were determined for each fish, and 15 to 20 females were sampled from each of the four groups to measure fecundity. Spawning distribution of fall chum salmon was determined through review of historical aerial surveys and augmented with additional surveys in 2004. Multivariate analysis demonstrated a significant difference in morphology between fall and summer chum salmon, with fall chum generally having greater mideye-fork length, smaller maximum height, and smaller maximum width. Fall chum populations had a higher percentage of age-0.2 fish. Sex ratios and fecundities were similar between fall and summer chum salmon. Spawning distribution of fall chum salmon appears to be limited to a subset of tributary streams in the upper Kuskokwim basin characterized by braided channels and glaciated headwaters. Additional investigations are underway to identify the run timing of fall chum salmon through the lower Kuskokwim River drainage.

Introduction

In September 2000, the Alaska State Board of Fisheries (BOF) classified Kuskokwim River chum salmon (*Oncorhynchus keta*) as a “stock of concern” due to the chronic inability, despite the use of specific management measures, to maintain expected harvest above escapement needs (5 AAC 39.222). This finding was the culmination of a string of disastrously low chum salmon runs that began in 1992, and prompted conservation measures aimed at reducing chum salmon harvest and improving escapement (Burkey et al. 2000). This finding was continued by the BOF following deliberation in 2004 (Bergstrom and Whitmore 2004). Although the finding applied to all Kuskokwim River chum salmon, no distinction was made between summer and fall races, which is not surprising given that fall chum salmon in the Kuskokwim River have only been recognized by biologists as a distinct race since the mid-1990s. Therefore, it is of interest whether the conservation measures aimed at improving all chum salmon escapement provided any benefit to fall chum salmon since these fish may enter the Kuskokwim River at a different time than summer chum salmon.

The Alaska Department of Fish and Game (ADFG) currently has no means of monitoring fall chum salmon escapement. Further, distinctive characteristics in the morphology, age and sex composition, spawning distribution, and run timing of fall chum salmon are unknown or undescribed. Without this information, it is difficult to assess the status of Kuskokwim River fall chum stocks and to determine how management decisions might affect this distinct race of chum salmon. In order to begin closing this information gap, we set out to describe distinctive characteristics of Kuskokwim River fall chum salmon, compared to summer chum salmon, by examining spawning distribution, age and sex composition, morphology, fecundity, and run timing.

Methods

Study Area

The Kuskokwim River is the second largest river in Alaska, draining an area of approximately 130,000 km^2, or approximately 11 percent of the Alaska land area (Figure 1). The river arises on the northwestern slope of the Alaska Range, running approximately 1,500 km westward to empty in the Bering Sea in Kuskokwim Bay.

Spawning Distribution

Historical ADFG aerial survey data were summarized to compare the timing and distribution of spawning by summer and fall chum salmon. Along with local knowledge, this information was used to form an itinerary for an aerial survey of fall chum in the upper Kuskokwim River basin on 27 September 2004. The aerial survey was designed to search for and formally document fall chum salmon spawning areas.

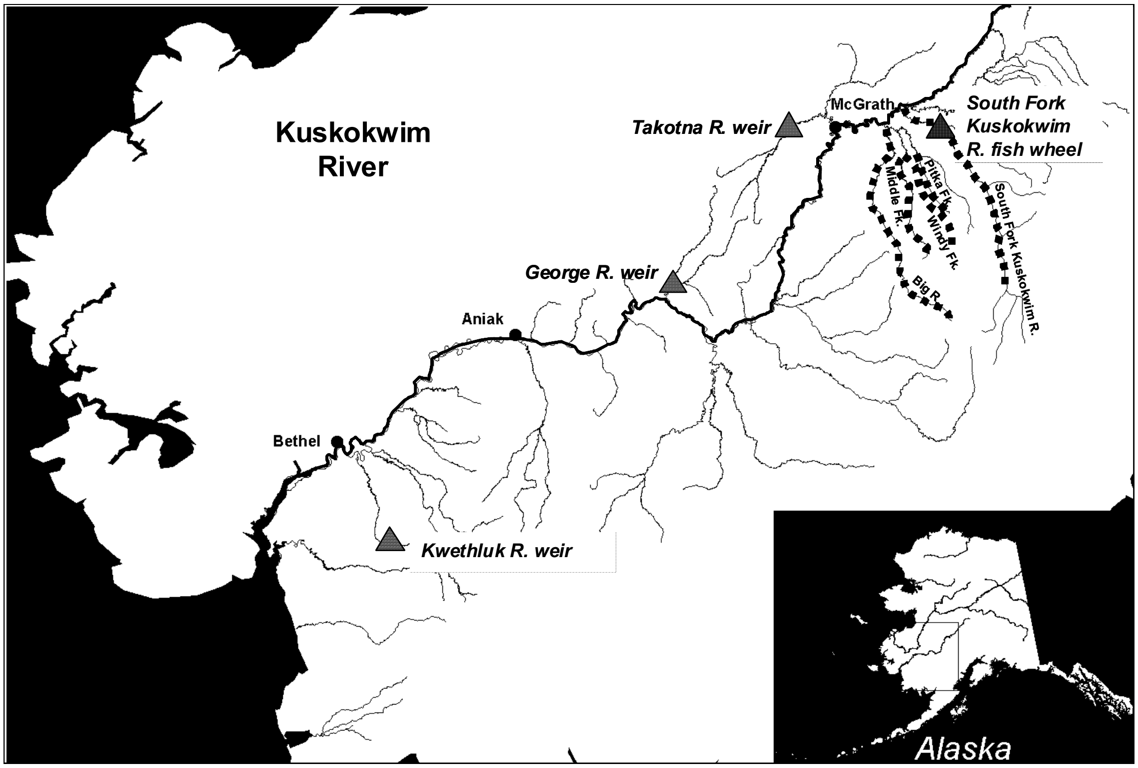

Figure 1. The Kuskokwim River drainage, showing sampling locations for summer (Kwethluk, George, and Takotna river weirs) and fall (South Fork Kuskokwim River fish wheel) chum salmon, 2004. Rivers with known fall chum spawning locations are marked with a dashed line.

Morphology, Age, and Sex

A total of 1,964 summer chum salmon were captured at weirs on the Kwethluk (rkm 190), George (rkm 453), and Takotna (rkm 835) rivers for comparison with 336 fall chum salmon captured at a fish wheel located on the South Fork Kuskokwim River (rkm 941; Figure 1). The summer chum salmon populations were selected as representatives of lower, middle, and upper river populations. Data collected at each sample site were drawn from at least three temporally distributed pulse samples. Fish were examined for three morphometric features measured to the nearest mm: 1) length from mideye to fork-of-tail, 2) maximum dorsal-ventral height, and 3) maximum width. Sex was recorded for each fish, and scales were taken for age determination. Variability in morphometric measurements of both males and females among age classes for summer and fall chum salmon was examined using a multivariate analysis of variance. Sex and age compositions were compared using X^2 tests of independence.

Fecundity

A total of 15 to 20 unspawned summer and fall chum salmon were sampled at each site for fecundity estimates. Whole skeins were collected from each female and preserved in 70% ethyl alcohol until processing. Three subsamples of 100 eggs were weighed to the nearest 0.01 g on a digital balance. Fecundity was estimated by dividing the total egg skein weight by the subsample weight, then multiplying by the number of eggs in the subsample (100). This was replicated for each of the subsamples, and the number of eggs per fish was estimated as the average of the three replicates. This is reported as absolute fecundity. Since fecundity is reported to vary with length, relative fecundity was calculated by dividing the fecundity by body length to obtain the number of eggs per cm of body length. Fecundities between summer and fall chum salmon were compared using analysis of variance. The effects of length, age, and run timing on fecundity were tested using analysis of variance.

Results and Discussion

Spawning Distribution

According to historical ADFG aerial survey records and knowledge of local residents, the distribution of fall chum salmon is confined to the upper reaches of the Kuskokwim River drainage. Therefore, a partial aerial survey was conducted on many of the tributaries in the upper Kuskokwim River basin on 27 September, 2004. Spawning aggregates were seen only in the South Fork Kuskokwim, upper Pitka Fork, Middle Fork, Windy Fork, and Big Rivers (Figure 1). These streams are characterized by braided channels and glaciated headwaters and may contain areas of groundwater upwelling.

These findings are similar to other studies, where summer chum salmon are reported to spawn in lower basin tributaries while fall chum salmon spawn in upper basin tributaries (Sano 1966). According to Birman (1951), fall chum salmon are adapted to reproduction in areas of upwelling groundwater and to negotiate river migrations in high water conditions. In the Yukon River, summer chum salmon generally spawn in runoff tributaries of the lower river, while fall chum salmon spawn primarily in upper drainage channels, sloughs, springs, and heads of main tributaries where upwelling groundwater prevents freezing in most years (Buklis and Barton 1984). It is likely that Kuskokwim River fall chum salmon utilize areas of groundwater upwelling, where relatively warmer water would allow for a shorter incubation period compared to summer chum. Because of their later spawning time, a shorter incubation period would be necessary for outmigrating fall chum fry to take advantage of ocean conditions optimal for survival.

Age and Sex Composition

There was a significant difference in age compositions between summer and fall chum salmon populations in the Kuskokwim River drainage in 2004 ($P < 0.0001$). There was a higher proportion of younger (age-0.2) fish in the South Fork Kuskokwim River fall chum salmon population compared to summer chum populations (54.6% and 15.7%, respectively), although these findings may be confounded by differences in capture methods (weirs versus fish wheel).

Most escapement monitoring programs located throughout the Kuskokwim drainage reported unusually high numbers of returning age-0.2 chum salmon in 2004 (D.B. Molyneaux, ADFG Anchorage, personal communication). Although age-0.3 fish usually dominate chum salmon populations, fall chum salmon have been reported to have a greater proportion of age-0.2 fish in both Asian and North American stocks (Sano 1966; Beacham 1984). A lower mean age at return in fall chum salmon may indicate that population growth rates are faster or that there is a genetic component to age of return in chum salmon.

There was no significant difference in sex compositions between summer and fall chum salmon populations in the Kuskokwim River drainage in 2004. The percentage of females for both summer and fall populations (47.0% and 45.5%, respectively) was lower than that for males. No difference in sex composition has been reported for other populations of summer and fall chum salmon.

Morphology
Kuskokwim River fall and summer chum salmon had significantly different morphology measurements among age and sex classes in 2004 (Table 1). Fall chum salmon had greater mideye-fork lengths than summer chum salmon for all sex and age classes, with the exception of age-0.3 males. Fall chum salmon had smaller maximum height than summer chum salmon among all sex and age classes. Fall chum salmon had smaller maximum width than summer chum salmon for all female age classes, but there was no difference in maximum width among males. However, unlike on the Yukon River, these differences are not great and may not be readily distinguishable.

Table 1. Multivariate analysis results of body measurements for Kuskokwim River summer and fall chum salmon, 2004. "Summer chum" includes fish sampled from the Kwethluk, George, and Takotna river weirs. "Fall chum" includes fish sampled from the South Fork Kuskokwim River fish wheel.

Sex	Age	Measurement (mm)	Summer chum N	Summer chum Mean	Summer chum CV	Fall chum N	Fall chum Mean	Fall chum CV	F Value	p	Wilks' λ	F value	p
F	0.2	**MEF length**	145	511.9	0.054	89	528.3	0.039	22.87	<0.0001	0.539	65.38	<0.0001
		max height		113.1	0.076		106.1	0.075	39.73	<0.0001			
		max width		71.6	0.099		66.8	0.081	30.52	<0.0001			
	0.3	**MEF length**	389	535.4	0.056	36	549.7	0.047	7.58	0.0061	0.808	33.92	<0.0001
		max height		119.8	0.093		109.9	0.092	26.14	<0.0001			
		max width		75.1	0.095		68.3	0.157	27.43	<0.0001			
	0.4	**MEF length**	307	545.5	0.055	18	562.8	0.045	5.84	0.0162	0.855	18.1	<0.0001
		max height		121.2	0.090		113.0	0.112	9.35	0.0024			
		max width		77.0	0.100		69.6	0.168	14.69	0.0002			
M	0.2	**MEF length**	136	535.1	0.051	64	549.3	0.051	11.44	0.0009	0.494	67.03	<0.0001
		max height		135.9	0.083		123.0	0.097	54.84	<0.0001			
		max width		65.9	0.099		65.8	0.127	0.01	0.9247			
	0.3	**MEF length**	362	566.0	0.057	39	572.3	0.045	1.37	0.2422	0.916	12.27	<0.0001
		max height		143.2	0.146		128.6	0.097	19.66	<0.0001			
		max width		70.5	0.099		69.7	0.105	0.74	0.3911			
	0.4	**MEF length**	443	584.7	0.056	34	599.1	0.056	6.05	0.0142	0.816	35.46	<0.0001
		max height		146.4	0.091		134.5	0.101	25.34	<0.0001			
		max width		72.4	0.094		72.2	0.104	0.03	0.8638			

In other river systems, fall chum salmon differ morphologically from summer chum salmon. Berg (1934) and Grigo (1953) found greater lengths of fall chum compared to summer chum salmon in the Amur River of Russia. Intraseasonal variation in the mean length of males and females within age classes was found in Prince William Sound chum salmon (Helle 1960), and fall chum salmon in the Yukon River are reportedly larger than summer chum (Buklis and Barton 1984). However, in southern British Columbia, no consistent differences in mean length at age for early and late spawning stocks were found (Beacham 1984). The smaller maximum height and width for Kuskokwim River fall chum relative to summer chum salmon is similar to that seen in the Amur River (Grigo 1953).

Morphological differences are likely the result of selection producing stocks adapted to the environments they encounter. Other studies have reported morphological differences in *Oncorhynchus sp.* according to distance of upstream migration, with more interior populations having smaller body shapes (Eniutina 1954; Taylor and McPhail 1985). The more streamlined body shape seen in Kuskokwim River fall chum salmon may be an adaptation to longer migrations, helping these fish to minimize energy consumption during upstream migration. Still, it should be considered that the fall chum salmon were sampled near their spawning grounds and have a greater distance to travel than summer chum salmon. Fall chum salmon may be larger when they first enter the Kuskokwim River, but experience disproportionate weight loss compared to summer chum salmon by the time they arrive at the spawning grounds.

Fecundity

There was no significant difference in fecundity between summer and fall chum salmon populations in the Kuskokwim River drainage in 2004. Average fecundity for fall chum females was 2,440 eggs and ranged from 1,789 to 3,453 eggs. In comparison, average fecundity for summer chum females was 2,342 eggs and ranged from 1,469 to 3,270 eggs. Average relative fecundity (the number of eggs per cm of length) was 43.8 eggs per cm for summer chum and 45.4 eggs per cm for fall chum salmon.

Absolute and relative fecundities of Kuskokwim River chum salmon were similar to those reported for chum salmon in other river systems in North America (Salo 1991). However, in many systems fall chum salmon typically have a greater fecundity than summer chum salmon (Sano 1966; Bakkala 1970), although in the Yukon River there is little difference in fecundity between fall (Trasky 1974) and summer chum salmon (Andersen 1983).

There was no effect of age on fecundity for Kuskokwim River summer and fall chum salmon;. however, as expected, fecundity increased with increasing mideye-fork length ($P < 0.05$). These findings are consistent with those reported in literature (Salo 1991). There was no change in fecundity over time for summer or fall chum salmon.

Conclusions

This project is the first to formally document biological characteristics of Kuskokwim River fall chum salmon. Fall chum salmon appear to be distinct from summer chum salmon, exhibiting a younger average age, a longer and thinner body shape near the spawning grounds, and a spawning distribution limited to upper river tributaries. There do not appear to be differences in sex composition or fecundity. Further work is warranted to include other Kuskokwim River populations of fall chum salmon, to examine possible interannual variation, and to characterize spawning habitats. Genetics work currently being conducted to identify fall chum in mixtures of chum salmon collected in the lower Kuskokwim River will provide an initial appraisal of the run timing of these unique populations of fall chum salmon and will provide important information for including fall chum salmon into a sustainable salmon fishery management program of the Kuskokwim River.

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Estuarine Ecology of Juvenile Chum Salmon (*Oncorhynchus keta*) in Kuskokwim Bay, Alaska

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Abstract

Recent declines in chum salmon (*Oncorhynchus keta*) returns to western Alaska have focused research interests on the potentially critical stage of early estuarine residence of out-migrating chum salmon juveniles. Suboptimal rearing conditions at this period might be responsible for reduced growth and condition and subsequently increased mortality. This study examines prey abundance and composition, juvenile distribution and timing of offshore migration, feeding, and condition of chum salmon in Kuskokwim Bay, Alaska. Juvenile chum salmon were sampled on a station grid with a modified Kvichak trawl, from June through August in 2003, and from May through June in 2004. Physical data were recorded with a CTD system and zooplankton were collected. In both years, rainbow smelt (*Osmerus mordax*) and pond smelt (*Hypomesus olidus*) were the most abundant fish species throughout the bay. In 2003, the proportionate abundance of chum salmon decreased from 7.7% of the total catch in June to 0.1% in July. No chum smolts were collected in August. Mean fork length (FL) of chum salmon increased from 49.2 mm (n=56, SD=3.895) in June to 55.8 mm (n=3, SD=6.028) in July of 2003. Mean energy density of juvenile chum salmon was 4751.494 cal/g (n=56, SD=115.375) in June and 4709.446 cal/g (n=3, SD=30.088) in July of 2003. In 2004, proportional abundance of juvenile chum salmon gradually increased from 0.3% in May to 47.8% in June. Mean FL of chum salmon increased from 38.3 mm (n=11, SD=2.490) in May to 51.3 mm (n=276, SD=4.516) in June of 2004. In both years, density of juvenile chum salmon was highest closest to the river mouth. Out-migrating chum salmon juveniles appeared to be following the main river channels and the eastern shore. Preliminary results on diet suggest that juvenile chum salmon frequently included adult dipterans indicating that chum salmon were feeding at the water surface.

Introduction

In response to recent declines in chum salmon returns to Kuskokwim Bay, western Alaska, the University of Alaska Fairbanks (UAF) and U.S. Geological Survey (USGS) conducted a joint study looking at distribution, feeding habits, and condition of juvenile chum salmon during their residence in Kuskokwim Bay. Kuskokwim Bay is a large, shallow bay. The bottom depth throughout much of the bay is between 1 and 3 fathoms. Due to the input of the Kuskokwim River, a glacially fed river with a high silt load, much of the bay is very turbid. The majority of the inhabitants of the Kuskokwim bay/river area subsist off the salmon returns for their main food source. Chum salmon make up a sizeable portion of their subsistence catches. However, for the past few years the chum salmon returns to the Kuskokwim River have been experiencing low numbers, which has caused much concern (Alaska Department of Fish and Game 2000).

Transition from freshwater to saltwater is a period of high mortality for juvenile salmonids, making this a critical period for survival (Pearcy et al. 1989; Willette 2001). The transition from freshwater to water of increasing salinity requires juvenile salmonids to undergo energetically costly physiological adaptations to deal with their changing osmoregulatory needs. Densities of predators, many of which are size selective (Bakshtanskiy 1964; Willette 2001; Fukuwaka and Suzuki 2002), make it necessary for juvenile salmonids to allocate the majority of their consumed energy towards growth in order to reduce the period during which the fish are susceptible to high rates of size-selective mortality. Since growth is such an important aspect of juvenile salmonid survival, it is essential to understand factors impacting changes in the composition and selection of prey items to the diet of salmon juveniles.

Very little is known concerning early marine life of chum salmon, particularly from western Alaska. The purpose of this research is to gain more information on feeding behavior, prey composition and concentration, energetic density, and offshore migration timing of juvenile Kuskokwim River chum salmon during their residence in Kuskokwim Bay.

Methods

Field Methods

As part of a two-year study (2003 and 2004), 22 stations were sampled along a station grid in Kuskokwim Bay (Table 1). At all stations, one CTD cast was conducted to within 1 m of the bottom to measure conductivity, temperature, and density using a SeaBird Electronics SBE-19 Seacat profiler. The CTD was equipped with a WetStar fluorometer for measuring chlorophyll content and a D&A Instruments turbidity meter (in 2004) for measuring turbidity. In addition, the transparency of the water column was determined with Secchi disk readings at each station.

Table 1: Cruise dates and number of station sampled in the 2003 and 2004 research years.

Year	Cruise	Dates	# Stations
2003	1	June 23-25	8
	2	July 24-26	12
	3	August 26-30	8
2004	1	May 17-20	12
	2	May 21	4
	3	May 24-25	12
	4	May 28-31	15
	5	June 1	6
	6	June 5-9	17
	7	June 9-11	9

At each station zooplankton were collected using either a 1-m^2 NIO Tucker Trawl equipped with 250 µm mesh (2003) or a 0.75-m diameter ring net equipped with 335 µm mesh (2004). A flow meter positioned in the net opening recorded the flow of water through the net, thus allowing us to estimate the amount of water filtered by the sampling gear. Upon retrieval, the plankton net was rinsed from the outside with seawater. The collected zooplankton were preserved in a 10 % buffered formalin seawater solution.

At each station, we conducted one 30-minute tow with a modified Kvichak trawl. The Kvichak trawl was equipped with two doors to provide horizontal spread for the net. Floats at the headrope and weights at the footrope provided vertical spread and assured that the net was fishing at the surface. All fish collected were anesthetized in MS-222 prior to handling. Collected fish were identified to species, and measurements of fork length (FL) were taken of a sub-sample of 40 fish. All chum salmon juveniles were frozen for later analysis. Non-target fish species were sub-sampled (10 individuals) and preserved in 90% ethanol or frozen. All fish that could not be properly identified on board were preserved for later identification at the lab.

Laboratory Methods

Zooplankton Analysis: All samples were strained on a 45 µm screen filter and rinsed several times with tap water to remove any trace of formalin. Plankton were split into a manageable volume using a Folsom plankton splitter. All zooplankton species of one split sub-sample were identified to the lowest taxonomic level and developmental stage possible and counted. For each new taxonomic group, a number of organisms were collected in vials and stored in 70% ethanol solution as voucher specimens for future reference.

Fish Processing: In the lab, chum salmon juveniles were measured for both standard length (SL) and FL to the nearest 0.5 mm. Wet weight of each fish was determined to the nearest 0.001 g. Both saggital otoliths were removed and placed in cryo-vials for later analysis of age and microchemistry. The stomachs were removed and separated at the pylorus and at the beginning of the esophagus. Only the prey contained in the cardiac and pyloric section of the stomach were used for analysis of juvenile diet. The full stomach was weighed to the nearest 0.001 g. All prey were carefully removed from stomachs and fixed in 10% formalin tapwater solution. The empty stomach was weighed to nearest 0.001 g and returned into the body cavity in order to retain all body tissue for the analysis of energetic body content. Prior to bomb calorimetry the frozen juveniles were placed in a freeze dryer (VirTis, Freezemobile 12) at -60 °C until weight stabilization had occurred, confirming minimal moisture content of the sample. Each individual was pulverized, pressed into a 0.150 g pellet and processed in a semimicro Parr 1425 calorimeter.

Results and Discussion

In 2003, the highest density of chum juveniles was observed during Cruise 1, with chum salmon juveniles accounting for 7.7% of the total catch (Table 2). On Cruise 2, chum salmon juveniles made up only 0.1% of the total catch, and no chum salmon were caught on Cruise 3 (Table 2). Rainbow smelt (*Osmerus mordax*) and pond smelt (*Hypomesus olidus*) made up the majority of fish species caught for all cruises, followed by three-spined (*Gasterosteus aculeatus*) and nine-spined (*Pungitius pungitius*) sticklebacks (Table 2).

Table 2: Percent composition of species caught to total catch for each cruise during the 2003 Kuskokwim Bay research cruises.

	Cruise		
Species	**1**	**2**	**3**
Oncorhynchus keta	7.7	0.1	0.0
Oncorhynchus tshawytscha	0.8	0.0	0.0
Oncorhynchus gorbuscha	0.1	0.0	0.0
Oncorhynchus kisutch	0.0	0.0	0.0
Oncorhynchus nerka	0.0	0.1	0.0
Hypomesus olidus	54.1	24.8	75.1
Osmerus mordax	29.3	5.0	0.4
Gasterosteus aculeatus	0.0	2.6	6.2
Pungitius pungitius	6.8	17.4	15.0
Clupea pallasi	0.1	49.8	3.3
Eleginus gracilis	0.0	0.0	0.0
Lota lota	0.0	0.0	0.0
Lampetra camtschatica	0.8	0.0	0.0
Pleuronectidae	0.1	0.0	0.0

In 2004, the proportionate abundance of juvenile chum salmon caught gradually increased from 0.3% during cruise 1 to 47.8% during cruise 7 (Table 3). Juvenile chum salmon catch data suggest that the peak outmigration occurs during mid-June. Both rainbow smelt and pond smelt were the most abundant fish species caught during all but cruise 7 (Table 3).

Table 3: Percent composition of species caught to total catch for each cruise during the 2004 Kuskokwim Bay research cruises.

	Cruise						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Oncorhynchus keta	0.3	0.5	0.7	1.0	1.5	9.8	47.8
Oncorhynchus nerka	0.0	0.0	0.1	0.1	0.1	0.1	1.0
Oncorhynchus gorbuscha	0.5	0.1	0.6	0.1	0.1	0.1	0.0
Oncorhynchus kisutch	0.7	0.0	0.8	0.7	1.2	0.7	0.2
Oncorhynchus tshawytscha	0.0	0.0	0.0	0.0	0.0	0.6	1.7
Salmonidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salvelinus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coregoninae	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Gasterosteus aculeatus	0.8	0.3	0.4	0.3	0.2	0.1	0.1
Pungitius pungitius	2.3	1.4	0.7	0.9	0.2	22.1	1.7
Hypomesus olidus	13.8	30.8	61.3	36.4	59.2	47.6	27.4
Osmerus mordax	60.2	66.7	35.5	58.7	37.5	14.6	19.3
Ammodytes hexapterus	20.5	0.0	0.1	1.8	0.0	3.0	0.0
Other	0.7	0.0	0.0	0.0	0.0	1.4	0.9

Adult *dipteran* insects were frequently found in the diet of juvenile chum salmon for both research years, indicating juvenile feeding at the water surface. Stomach contents were often composed of approximately 50% *dipteran* insects and 50% small copepods, possibly indicating that feeding behavior of juvenile chum salmon might be affected by the tidal cycle. Sea surface salinity measurements ranged from 0 ppt in the upper estuary to 22 ppt at the outer most station. The majority of chum salmon caught were in the upper estuary for both 2003 and 2004 research cruises. Juvenile chum salmon were present in the estuary from mid-May up through mid June of 2004 and from late June to late August 2003 (Figure 1). During the time of out-migration (mid-June 2004) juvenile chum salmon appeared to follow the main river channels and the eastern shore.

For Cruise 1 of 2003, the average FL for juvenile chum salmon was 49.18 mm (n=56, SD=3.895), and the average weight was 1.0258 g (n=56, SD=0.2867). Cruise 2 juvenile chum salmon had an average FL of 55.67 mm (n=3, SD=6.028), and an average weight of 1.497 g (n=3, SD=0.224). Average energy density for Cruise 1 juveniles was 4751.49 cal/g (n=56, SD=115.37) and for Cruise 2 juveniles 4709.44 cal/g (n=3, SD=30.08).

In 2004 the average FL for chum salmon juveniles increased from Cruise 1, with 38.25 mm (n=11, SD=2.49), to Cruise 7, with 51.33 mm (n=276, SD=4.52; Figure 2). Average energy density of juvenile chum salmon gradually decreased over time from 5371.43 cal/g (n=11, SD=169.36) for Cruise 1 fish to 5108.98 cal/g (n=29, SD=91.71) for Cruise 4 fish (Figure 3).

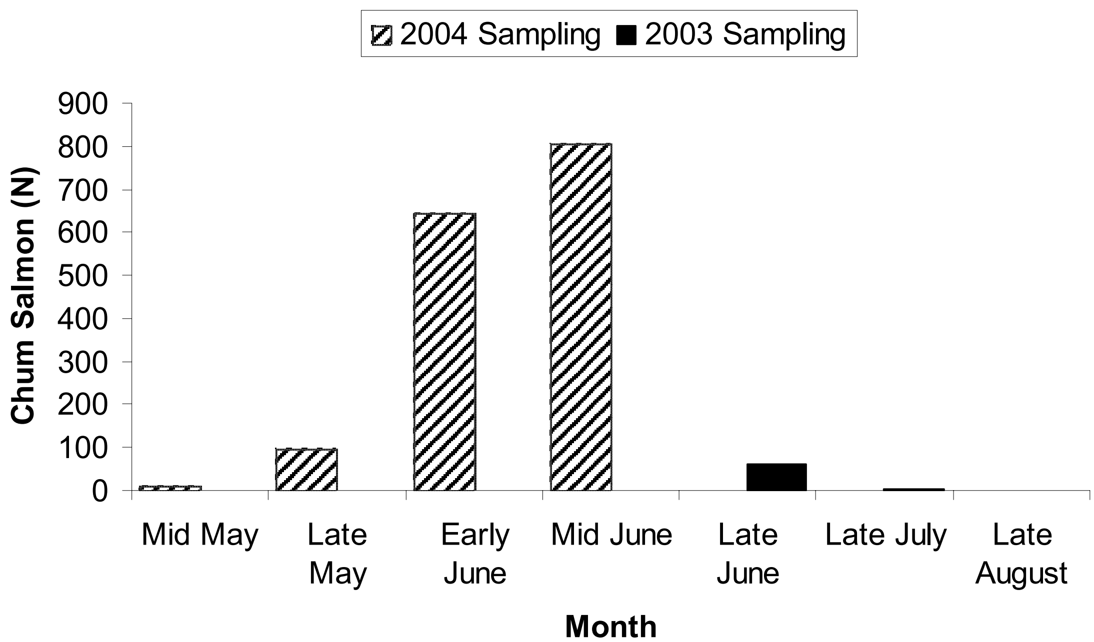

Figure 1. Total catch of juvenile chum salmon by month for 2003 and 2004 cruises.

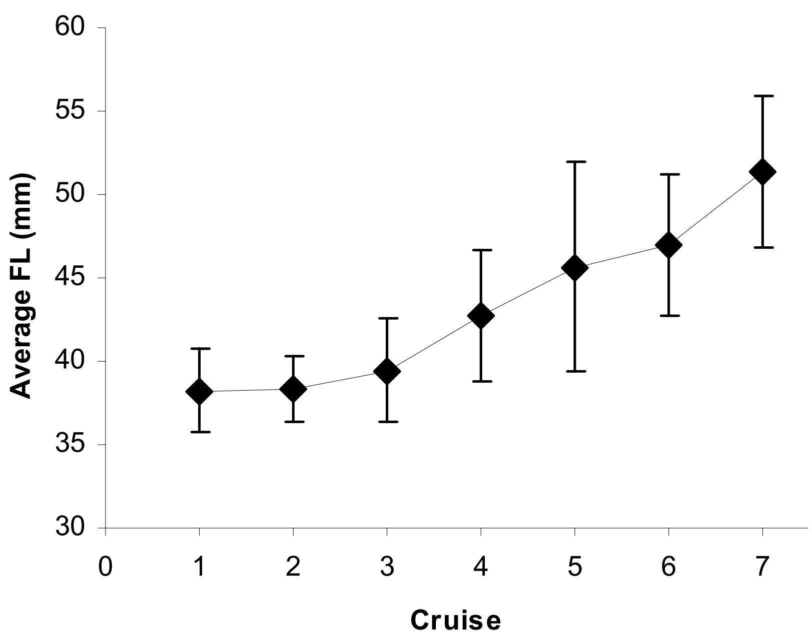

Figure 2. Average FL of juvenile chum salmon in Kuskokwim Bay during the 2004 research cruises (error bars represent +/- 1 SD about the mean).

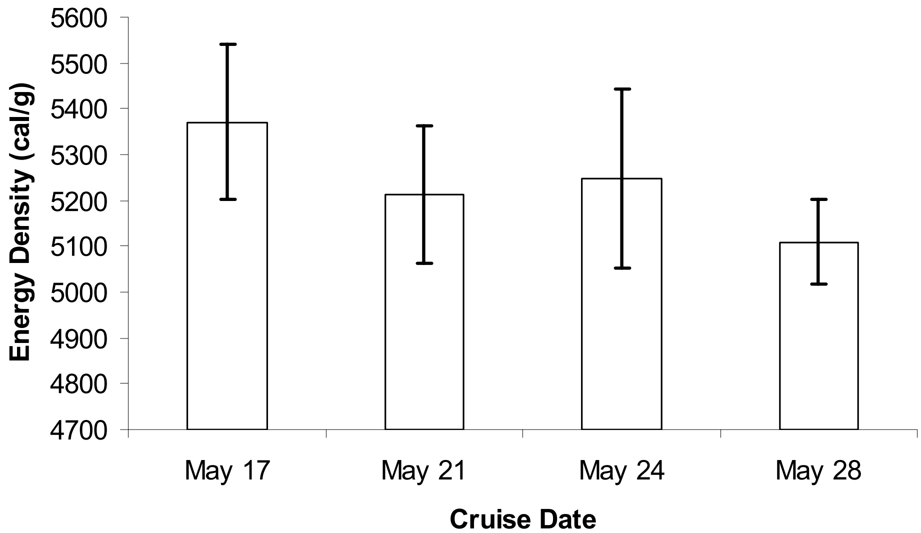

Figure 3. Average energy density for juvenile chum salmon caught from Cruise 1 through Cruise 4 of 2004 (Error bars represent ±1 SD about the mean). Samples sizes are *n*= 11, 8, 27, and 29 for Cruises 1 through 4, respectively.

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Energy Reserves and Body Condition of Kuskokwim River Chum Salmon Fry During Outmigration and Estuarine Residence

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The marine environment has been identified as the primary influence to salmon survival; however, the uses of freshwater and estuarine habitat during early life history are also considered critical stages influencing ocean survival. Chum salmon (*Oncorhynchus keta*) in western Alaska, unlike other regions, are frequently characterized by long river migrations between the ocean and spawning habitats. As a result, it is important to describe the role of migration distance and energy reserves on growth and condition of juvenile chum salmon as they transition to the marine environment. In this study, we examined energy reserves (proximate analysis) and body condition of chum salmon fry from two Kuskokwim River tributaries, the Takotna River (> 800 km from estuary) and Kwethluk River (< 200 km from estuary), and from Kuskokwim Bay. We did this to help gain an understanding of the factors related to migration distance that can influence survival during the smolt transition from freshwater to estuarine life history stages. Body condition (i.e., weight/length residuals index) and weight (g) were significantly greater in chum salmon fry from the Takotna River compared to Kwethluk River fry, and the size and condition of Kuskokwim Bay fish were significantly greater than for river fish. Kwethluk River fry had higher lipid content and a greater percentage of lipid energy compared to Takotna River fry. Takotna River fry had higher protein content and a greater percentage of protein energy compared to Kwethluk River fry. Kuskokwim Bay fish had lower lipid content and higher protein content compared to river fish. These results suggest that Takotna River fry were larger, in better condition, and allocated more of their energy to protein synthesis presumably to survive the long distance migration to the estuary. The low lipid and high protein content of Kuskokwim Bay fish suggests fish are maximizing growth and protein synthesis during estuary residence.

Arctic-Yukon-Kuskokwim Salmon Management: Past, Present, and Future

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Development and evolution of salmon fisheries management in the Arctic-Yukon-Kuskokwim (AYK) Region from statehood in 1959 to the present is described. AYK Region covers approximately three-quarters of the landmass of Alaska. With the exception of Fairbanks (population 84,000), the region's 50,000 rural residents live in approximately 100 remote villages and small towns. Subsistence and commercial fisheries are an integral and significant part of the cultural and economic fabric of the region. Recreational salmon fisheries are growing and becoming an increasingly important economic element in some areas. The Alaska Board of Fisheries has identified the "Amount Necessary for Subsistence" in the region as 500,000 to 800,000 salmon. Fisheries are skiff and fish wheel based. Chinook, summer and fall chum, sockeye, pink, and coho salmon are all harvested for subsistence. Poor pink and chum salmon markets in recent years have severely curtailed commercial fisheries for those species, but Chinook, sockeye, and coho salmon continue to have good commercial markets. Commercial and subsistence fisheries are intertwined. Boats and gear are often used in both fisheries and the cash provided by commercial fishing allows fishers to gear up for the move to fish camp, or to make necessary repairs to gear and boats, in order to subsistence fish. In many areas of the region, restrictions to commercial fisheries result in impacts to subsistence harvest because of this relationship.

Before statehood in 1959, subsistence fisheries were unrestricted and commercial fisheries in the region were managed using a combination of quotas and closures with the aim of protecting the large subsistence fisheries. Little was known about stocks throughout the region. Few spawning areas were identified and little biological data on the fish had been collected. Limited commercial and subsistence catch data existed. No escapement goals had been set. Some aspects of management developed during the Federal era are still part of management today, such as the subsistence preference, use of quotas or guideline harvest ranges in some fisheries, districts and subdistricts, and seasons and gear restrictions.

After statehood, the newly formed Alaska Department of Fish and Game (Department) and the Alaska Board of Fish and Game (Board) developed a more flexible approach to commercial fisheries management, based more on fishing time rather than quotas, to allow harvest to vary with run strength. Management of fisheries by local biologists knowledgeable about the area, through inseason emergency orders, made management more responsive to inseason conditions. Collection of detailed catch and escapement data as well as biological information such as age, sex, and length laid the foundation for better understanding the runs and setting escapement goals. Public input was increased by use of local Fish and Game Advisory Committees. Department biologists began to identify spawning areas, determine available harvests, conduct aerial surveys, tag salmon to determine migratory routes and timing, and develop data upon which to base escapement goals.

These goals were first established during the years from 1979 to 1984 (Buklis 1993) and were based on average escapements under the principle that maintaining average, or better, escapements should maintain harvests at historical levels. Many of these goals were based on relatively few years of data when first established. It was unknown how these new goals related to escapements that would produce maximum sustained yield or escapements that would only replace themselves. During the 1980s, goals were used primarily as a post-season tool to assess run strength and management success, create outlooks for future returns, and adjust future management for increasing boat and gear efficiency. In the 1990s, management evolved toward more closely regulating fisheries to ensure escapement goals were met. Escapement goals came to be used as inseason targets. In response to criticism for not consistently achieving goals, the goals evolved into minimum levels of desired escapement. Whereas the previous goals represented averages that one would expect to meet only about half the time, management evolved to attempt meeting goals every year. The combination of more stringent management, reduced fishing time to adjust for increased efficiency, and reduced run strengths for some stocks led to a more contentious management atmosphere.

During this time, the Department began working cooperatively with resource users in the region through groups such as the Kuskokwim River Salmon Management Working Group and the Yukon River Drainage Fisheries Association. This relationship helped reduce conflict between managers and users, improved public input and use of local knowledge in fishery management, and developed support for increased funding for research. The Kuskokwim working group was very controversial when it was formed, but today both these groups have become a respected and integral part of management.

In the late 1990s, run failures throughout the region led to disaster declarations and the designation of many AYK salmon stocks as stocks of concern under the state's Policy for the Management of Sustainable Salmon Fisheries. Management of salmon since 2000 has focused on refining escapement goals through spawner-recruit analyses, developing management strategies to help rebuild stocks designated as stocks of concern, and developing a better research program.

Biological escapement goals (BEGs) are levels of escapement that provide the greatest potential for producing maximum sustained yield. BEGs exist for only eight stocks in the AYK Region: Chena and Salcha Chinook salmon (Evenson 2002), Andreafsky summer chum salmon (Clark 2001a), Anvik summer chum salmon (Clark and Sandone 2001), Yukon fall chum salmon (Eggers 2001), and chum salmon in Norton Sound Subdistrict 1 and the Kwiniuk and Tubutulik rivers (Clark 2001b, 2001c). Insufficient data exists to establish BEGs for most other stocks in the region. Those stocks that do have escapement goals have sustainable escapement goals (SEGs) that are defined as a level of escapement known to provide sustained yield over a period of five to ten years. The most common difficulty in establishing a BEG is the short time series of escapement data and the inability to apportion catches. Under the Policy for the Management of Sustainable Salmon Fisheries, SEGs are required to be ranges rather than point goals. These SEG ranges were set in 2004 (ADF&G 2004) using the Bue and Hasbrouck (2001) method, which establishes a trimmed range from historical escapements based on a prescribed algorithm. This method was selected because it had been previously used to set SEG ranges in Cook Inlet (Bue and Hasbrouck 2001), Prince William Sound (Bue et al. 2002), and Lower Cook Inlet (Otis 2001).

In order to see how BEGs, SEGs, and average escapements compare in utility as escapement goals, the Anvik River summer chum salmon run was used as an example. The recommended BEG for this stock is 350,000 to 700,000 spawners. This escapement range includes most of the escapements that have produced large yields and only 25% of escapements in this range (three of twelve) have failed to replace themselves. Seven of eleven (64%) escapements above the upper end of this range produced returns below one return per spawner. Creating a sustainable escapement goal range using Bue and Hasbrouck's method results in a goal of 380,000 to 1,125,000. Seven of seventeen escapements (41%) in this range failed to replace themselves and three of four (75%) escapements above the upper end of the range were below replacement. Finally, using the average escapement of 671,000 as the goal produced seven of eleven escapements (64%) that failed to replace themselves.

This is a critical issue because of the designation of "stocks of concern" in the Policy for the Management of Sustainable Salmon Fisheries. A "yield concern" designates a stock that fails to maintain expected yields. Seven AYK Region stocks have been designated as yield concerns: Kuskokwim Chinook and chum salmon, Yukon Chinook and fall chum salmon, Norton Sound chum salmon in Subdistricts 2 and 3 (Golovin and Moses Point) and Chinook salmon in Subdistricts 5 and 6 (Shaktoolik and Unalakleet). Two additional stocks have been designated as "management concerns," meaning a chronic failure to meet escapement goals. These are Yukon summer chum and Norton Sound Subdistrict 1 (Nome) chum salmon. No stocks in the state have been designated as "conservation concerns" due to lack of a definition of sustainable escapement threshold.

In order to deal with these stocks of concern, the Department, public, and Board have developed management plans aimed at rebuilding stocks. There is also much broader research aimed at understanding these problems. Norton Sound Salmon Research and Restoration fund, AYK Sustainable Salmon Initiative, and other funding sources such as Office of Subsistence management, NOAA, and USFWS Yukon Treaty Implementation fund this work.

Through these funding sources, program development has focused in four main areas: total run assessment using sonar and mark/recapture methods; genetic stock identification to identify migratory characteristics of stocks and apportion catches; tributary escapement monitoring to ensure good quality and distribution of escapement; radio telemetry to study distribution and migratory characteristics of stocks, assess total run, and identify stock components missing from genetics baselines. The goal of management for the future is to set scientifically defensible escapement goals that provide the greatest likelihood of sustaining salmon runs and maintaining viable subsistence and commercial fisheries throughout the region. Each of these elements is a critical part of the information needed for that purpose.

Future challenges include dealing with declining state budgets, which creates a reliance on finding other sources of funding. These other sources often require substantial extra work from staff including writing conceptual proposals, detailed proposals, draft reports, final reports, and semi-annual progress reports. Research planning to prioritize work is underway throughout much of the region. The Yukon Panel restoration and enhancement budget priorities framework and the Yukon River Joint Technical Committee strategic plan are both finished. Norton Sound Research and Restoration Plan is nearly final, Kuskokwim Fisheries Resource Coalition and AYK Sustainable Salmon Initiative research plans are in development. Management planning continues to fine tune strategies to meet changing conditions among salmon stocks and the fisheries that target them.

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Session 6. Ocean Ecology of Pink and Chum Salmon

Decadal Change in Temperature Selection of Pacific Salmon in the Ocean

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Abstract

Recent studies indicate that passive transport by ocean currents and selection of water parcels with preferred temperatures played important roles in ocean migration of Pacific salmon. To better understand mechanisms influencing salmon migration in the ocean, we examined temporal changes in selection of thermal environments by salmon. Salmon were distributed in wider geographic and sea surface temprature ranges in 1972–1976 than the more recent time periods (1977–1989, 1990–1998, and 1999–2003). Mean salmon density was higher in odd- than in even-numbered years because of the dominance of odd-numbered year pink salmon in the study area. However, salmon distribution did not change substantially between odd- and even-numbered years. Salmon distribution fitted a bell-shaped function of SST better than a step function, and the SST preferred by salmon was not fixed. This supported the hypothesis that salmon change their distribution to maximize somatic growth rate. Habitat selection and passive transport by ocean currents may determine migration routes of Pacific salmon.

Introduction

Recent studies indicate that passive transport by ocean currents and selection of water parcels with preferred temperatures were important factors in ocean migration of Pacific salmon. To better understand mechanisms influencing salmon migration in the ocean, we examined temporal changes in selection of thermal environments by salmon. Two alternative hypotheses have been proposed relating ocean salmon distribution to water temperature (Welch et al. 1995; Rand 2002). The thermal limit hypothesis suggests that salmon do not inhabit waters above a thermal limit temperature. However, at water temperatures below the thermal limit, salmon are evenly distributed (Welch et al. 1995). The growth maximizing hypothesis suggests that salmon select water masses with an optimal temperature to maximize growth rate (Rand 2002). We tested these two hypotheses to determine which are best fit to salmon catch data observed in offshore waters.

Japanese salmon research vessels conducted surveys on salmon abundance and distribution using a standardized research gillnet consisting of ten different mesh sizes.

We used the CPUE (number of fish caught by 30 tans of research gillnet; 1 tan equals 50 m) of sockeye, chum, and pink salmon and sea surface temperature (SST) collected in high-seas areas of the central North Pacific and Bering Sea during the summers of 1972 to 2003. We then used these statistics to construct models of salmon distribution. Salmon distribution was modeled following a step or bell-shaped function of SST, and the relationship between salmon distribution and SST was explored among decadal time periods, even- and odd-numbered years, and year by year (Table 1). We used the maximum likelihood method to fit the data to salmon distribution models and Akaike's Information Criterion (AIC, smaller value indicates a better fit) to evaluate which model best fit the data.

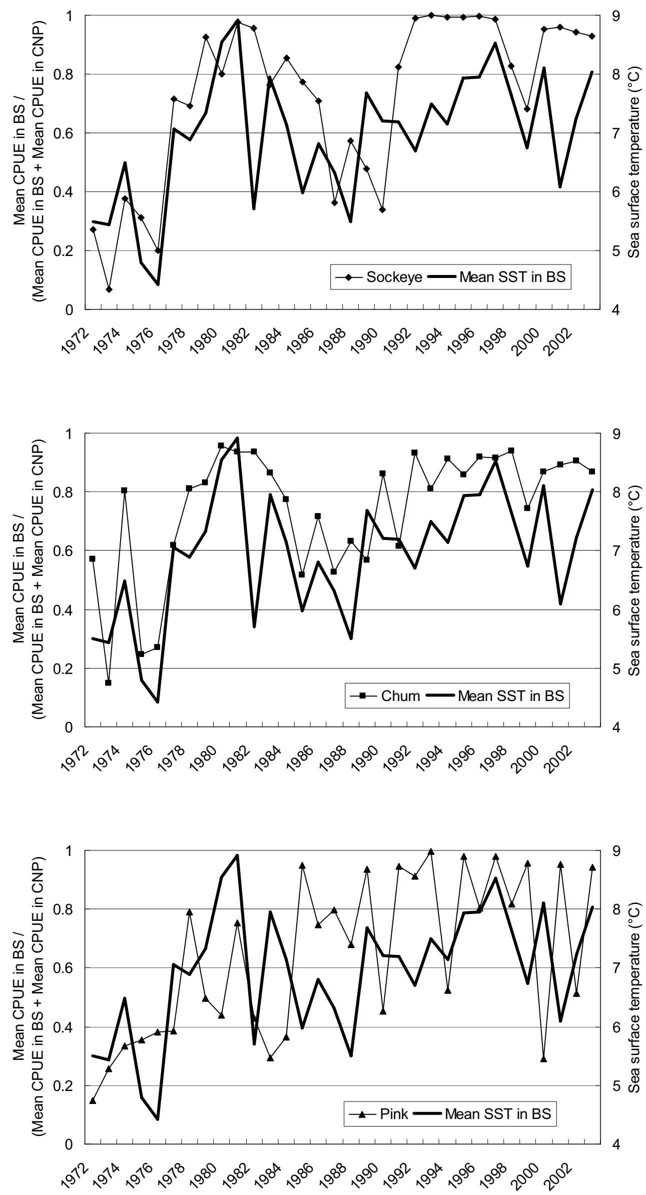
In the 1972–1976 period, surface water was cool and sockeye, chum, and pink salmon were distributed mainly in the central North Pacific (Figure 1). After 1976, SST in the Bering Sea and central North Pacific was warm and salmon were distributed mainly in the Bering Sea. The relationship of salmon distribution to SST was bell-shaped and changed temporally (Table 1). The estimated mode of salmon distribution correlated positively with mean SST, and when salmon abundance was high the mode of CPUE shift to lower SSTs. These results supported the hypothesis that salmon change their distribution to maximize their somatic growth rate. Habitat selection and passive transport by ocean currents may determine migration routes of Pacific salmon.

Table 1. Salmon distribution models and Akaike's Information Criterion (AIC) values for goodness of fit to CPUE data of sockeye, chum, and pink salmon in high-seas area of the central North Pacific and Bering Sea, 1972–2003.

Model[1,2,3]	AIC		
	Sockeye	Chum	Pink
$\text{CPUE}=\bar{\mu}_{\text{year}}\left\{\phi\left(T_i\middle|\bar{T},\sigma\right)\right\}+\varepsilon$ (Fixed range)	34200	67780	60003
$\text{CPUE}=\bar{\mu}_{\text{year}}\left\{\phi\left(T_i\middle|\bar{T}_{\text{period}},\sigma_{\text{period}}\right)\right\}+\varepsilon$	33146	66943	59455
$\text{CPUE}=\bar{\mu}_{\text{year}}\left\{\phi\left(T_i\middle|\bar{T}_{\text{period, even/odd}},\sigma_{\text{period, even/odd}}\right)\right\}+\varepsilon$	32433	65637	58028
$\text{CPUE}=\bar{\mu}_{\text{year}}\left\{\phi\left(T_i\middle|\bar{T}_{\text{year}},\sigma_{\text{year}}\right)\right\}+\varepsilon$ (Bellshape)	28684	57822	50303
$\text{CPUE}=\bar{\mu}_{\text{year}}\left\{1-\Phi\left(T_i\middle|\bar{T}_{\text{year}},\sigma_{\text{year}}\right)\right\}+\varepsilon$ (Step)	28913	60983	51807

[1] $\phi\left(T_i\middle|\bar{T},\sigma\right)$ was the normal probability density function at T_i, with mean $\bar{T}$ and standard deviation σ.
[2] $\Phi\left(T_i\middle|\bar{T},\sigma\right)$ was the cumulative normal probability function from $-\infty$ to T_i, with mean $\bar{T}$ and standard deviation σ.
[3] ε was the error term, following the Poisson distribution.

Figure 1. Annual change in the ratio of CPUE (mean CPUE in Bering Sea (BS) / (mean CPUE in BS + mean CPUE in central North Pacific (CNP))) of sockeye (upper), chum (middle), and pink salmon (lower) together with the sea surface temperature in the Bering Sea.



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Functional Response of Juvenile Pink (*Oncorhynchus gorbuscha*) and Chum (*Oncorhynchus keta*) Salmon to Two Types of Zooplankton Prey

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Juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon were presented with varying densities of small copepod (*Tisbi sp.*) and large mysid shrimp (*Mysidopsis bahia*) prey at varying densities ranging from 1–235 prey·L^{-1}, in feeding rate experiments conducted at water temperatures ranging from 10.5–12.0 ºC under high light and low turbidity conditions. Both species demonstrated a Type II functional response to zooplankton prey. Estimates of maximum feeding rate for juvenile pink (12.3 prey·min^{-1}) and chum (11.5 prey·min^{-1}) salmon foraging on mysid prey were similar, and higher than those estimated from experiments where copepods were presented (pink = 0.4 prey·min^{-1}, chum =3.8 prey·min^{-1}). Pink salmon fry demonstrated a Type II functional response to copepod prey and fed at a higher maximum consumption rate than larger juvenile pink salmon. Functional response models parameterized for specific sizes of juvenile salmon and zooplankton prey can offer insight into the mechanistic limitations on consumption given biological and physical foraging conditions experienced by the fish.

Seasonal Patterns in Diel Feeding, Gastric Evacuation, and Energy Density of Juvenile Chum Salmon in Icy Strait, Southeast Alaska, 2001

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We report on the seasonal diel feeding, gastric evacuation rate, and energy density of juvenile chum salmon, *Oncorhynchus keta* (*n* = 524), in the Icy Strait migration corridor of northern Southeast Alaska, from May–September, 2001. This study is a component of the Southeast Coastal Monitoring Project investigating annual juvenile salmon abundance, distribution, stock composition, and habitat parameters since 1997. We collected fish during seven periods over 24 hours, with a beach seine near shore in May and a surface trawl offshore from June–September. Concurrently, surface (2 m) temperature and prey fields were sampled (243-, 333- and 505-µm mesh zooplankton nets, to 20-m depth). Diel patterns in diet composition varied by month, but prey percent body weight and numbers generally increased late in the day, along with zooplankton density. Surface temperatures and zooplankton biomass and density peaked in June. Seasonal diets of juvenile chum salmon reflected changes in monthly zooplankton composition, and after May, fish selected for larger, less abundant prey. Juvenile chum salmon consumption (percent body weight) was significantly higher in May and June than later months, although monthly mean stomach fullness (73%–87% full) did not differ. From May to July, evacuation rates increased concurrent with increases in temperature and fish size, diets changed from crustacean to larvacean prey, and prey numbers increased. Monthly daily rations ranged from 17%–27% of body weight. Mean whole body energy content values, determined by bomb calorimetry, were significantly greater in May and September (5,183 cal/g dry weight) than those in June-August (4,788 cal/g). These results can be applied in bioenergetic models to increase our understanding of carrying capacity of marine ecosytems for juvenile salmon and other planktivores.

Seasonal Distribution, Size, and Condition of Juvenile Pink Salmon in Relation to Prince William Sound, Alaska Coastal Current, and Shelf Water Habitats, 2001–2004

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The Alaska Coastal Current (ACC) runs along the coast of Alaska from Southeast Alaska around the Gulf of Alaska (GOA) and further westward. It is characterized by a strong freshwater signal in the surface layer relative to Shelf water during summer, due to runoff and glacial melt. The ACC is the first habitat that juvenile pink salmon (*Oncorhynchus gorbuscha*) encounter upon leaving Prince William Sound (PWS) on their sea-ward migration. Differences in feeding and growth conditions among PWS, ACC, and Shelf habitats, therefore, are likely to play an important role in determining if pink salmon are able to attain a "critical size" during their first summer of growth. The critical size hypothesis states that salmon entering their first winter at a larger size have a greater survival rate than those entering their first winter at a smaller size. If the critical size hypothesis holds for pink salmon in the GOA, then fish that are larger at the end of the first summer should be more likely to survive and return as adults the following year. We tested this hypothesis using data on juvenile pink salmon collected from 2001 to 2004 in PWS, ACC and Shelf habitats, including catch per trawl hour, fish size, diet, and condition. We also collected zooplankton to compare prey availability with diet. For 2001–2003, July catch rates were relatively large in PWS and ACC and small in Shelf water. By August this pattern had reversed, with most fish being caught in Shelf water. In 2004 fish were already in Shelf water by July, and catch rates in PWS and ACC were small in both July and August. Using thermally marked PWS hatchery cohorts, we compared the size and condition of fish from the same release cohort in the different habitats, and modeled their growth. For 2001—2003, our results generally support the critical size hypothesis: larger, better-condition fish on the Shelf in August 2002 were correlated with near-record high pink salmon returns in 2003; smaller, poorer-condition fish on the Shelf in August 2001 and 2003 were correlated with poor returns in 2002 and 2004. Ongoing analysis includes comparing 2004 juvenile catches with survival of adults in 2005, electivity indices for diet data, additional modeling of cohort growth, and additional analysis of condition indices.

Ecological Interactions Between Hatchery and Wild Juvenile Chum Salmon (*Oncorhynchus keta*) in the Taku River Estuary

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This cooperative effort among the Alaska Department of Fish and Game, Douglas Island Pink and Chum, Inc., NOAA (Auke Bay Lab), and University of Alaska Fairbanks (Juneau Center), investigated potential interactions of wild and hatchery juvenile chum salmon (*Oncorhynchus keta*) in Taku Inlet. In 2004, we collected juvenile chum salmon throughout the April-June outmigration period, using beach seines and Kodiak trawls. Otolith thermal marks were used to distinguish among Gastineau Hatchery "Regular" and "Late large" and wild (unmarked) stocks. Only wild fish were caught before mid-May; hatchery fish were detected in mid-May, shortly after releases. Overall, hatchery fish caught in seines comprised > 90% of the catch in the outer estuary and only 10% in the inner estuary. Hatchery fish comprised > 90% of trawl catches in both the inner and outer estuary, but overall, few chum salmon were caught in inner estuary trawls. Wild chum salmon caught in seines and trawls had mean weights of 0.4 g and 0.7 g, respectively. "Late Large" hatchery fish (released May 26th at 4.0 g) were caught in both gears for two weeks post-release, while "Regular" hatchery fish (released May 10th at 2.0 g) were caught from May 13–June 17. Mean weight of "Regular" hatchery fish was 1.4 g in seines and 1.6 g in trawls. Mean weight of "Late Large" hatchery fish was 2.1 g in seines and 2.7 g in trawls. Chum salmon from both release groups caught in both gears were smaller than their mean sizes upon release, indicating smaller fish may spend more time in the inlet. "Regular" fish grew during their three weeks in the estuary from 1.2 g in early May to 3.2 g in late May. Wild fish grew by a similar factor, from 0.33 g in late April to 0.79 g in mid-June. However, "Late Large" hatchery fish appeared to spend less time in the estuary and apparent size did not change substantially.

Energy Density of Juvenile Pink Salmon, *Oncorhynchus gorbuscha*, in the Gulf of Alaska

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Abstract

Juvenile pink salmon were collected from the Gulf of Alaska during July 2001 and 2002 as part of Global Ocean Ecosystem Dynamics (GLOBEC) research cruises. Energy density (J/g of wet weight) was estimated using bomb calorimetry. The Prince William Sound hatchery stock and release group of collected salmon were identified from otolith thermal marks, and non-thermally marked fish were assumed to be wild. Juvenile pink salmon energy density differed significantly by transect ($P < 0.0001$), year ($P < 0.0001$) and by hatchery stock ($P = 0.04$). Body size was not correlated with energy density. Percent dry weight (dry weight/wet weight) was highly correlated with energy density ($R^2 = 0.93$); therefore, estimating energy density from this newly parameterized relationship may be more cost effective than processing samples with a bomb calorimeter. Acquiring accurate and cost effective estimates of consumer energy density is an important component of studies where bioenergetics modeling is used.

Introduction

About 600 million hatchery pink salmon fry are released each spring into Prince William Sound (PWS) where they spend their first 60–90 days feeding in protected coves and nearshore waters. Juvenile salmon then move into the deeper channels of the sound and follow a southwestern migration into the Gulf of Alaska (GOA) (Wertheimer and Celewycz 1996; Willette 1996). Once in the GOA, juvenile salmon follow a northwest migration along the continental shelf before entering the deep open water of the GOA where the salmon spend one winter (Hartt and Dell 1986).

Since the mid 1980s wild pink salmon returns to PWS have noticeably declined, but overall returns have remained constant. In addition to decreased returns of wild pink salmon, body size of salmon returning to PWS and coastal GOA has continually decreased since the 1970s (Peterman 1987; Bigler et al. 1996). Hatchery fish, which are fed prior to their release, may have an advantage over wild fish because they are entering the marine environment at a larger size with possibly more energy to put towards growth. Some studies have reported that larger, more rapidly growing fish are less prone to predation than smaller fish (Parker 1971; Beamish and Mahnken 2001). Because early marine growth is critical to survival and return strength, it is important to understand the energy requirements of salmon during their early life history.

Energy density (ED) can indicate overall health and growth potential (Metcalfe and Thorpe 1992; Boldt 1996; Boldt and Haldorson 2002). Boldt and Haldorson (2004) conducted a study in PWS and found little variation in ED between wild and hatchery pink salmon. In this paper, we examined the differences in ED between wild and hatchery juvenile salmon that have left PWS and entered the GOA.

Methods

Sampling and Laboratory Methods

From 2001 to 2004, the Ocean Carrying Capacity Program (OCC) at Auke Bay Laboratory (National Marine Fisheries Service) joined with Global Ocean Ecosystem Dynamics (GLOBEC) to determine the relationship between juvenile salmon distribution and biological and physical ocean conditions along the coastal GOA. Cruises for this study were conducted in the central GOA on board the F/V *Great Pacific*, a 125 ft long stern-trawling vessel. Fish were collected with a 198 m long mid-water rope trawl with a spread of 52 m horizontally and 18 m vertically that was towed for 30 minutes.

We measured fork lengths and weights to the nearest millimeter and the nearest gram. Otoliths were removed and examined for thermally induced markings to determine if fish were of hatchery origin. We assumed that fish lacking thermal marks were wild. A gravity convection oven dried the fish for 2–7 days at 55–60 °C. We homogenized the dried fish to a fine powder using a Warring pulverizer and mortar and pestle and pressed a subsample of the powder into 0.15 g pellets. We estimated energy content with a Parr 1425 Semi micro Bomb Calorimeter following methods outlined in the Parr 1425 manual (Parr Instrument Co. 1991).

Analysis

We examined juvenile pink salmon from three transects just southwest of PWS (Figure 1). We used an Analysis of Variance (ANOVA) to test for differences in the EDs of the pink salmon by the origin (hatchery or wild), year sampled, and survey transect. The hatchery salmon were classified as either Armin F. Keornig, Wally Noerenberg, or Solomon Gulch (PWS hatcheries). We used a multiple comparison Tukey-Kramer HSD test to look for pairwise differences between transects and origins. We also examined the relationships between ED and more easily measured variables (length, weight, condition factor, and percent dry weight) to determine if the variables correlated with ED and could thus be used to predict ED. We then used predicted ED values and associated error estimates in bioenergetic modeling simulations to quantify the magnitude of difference in growth estimates.

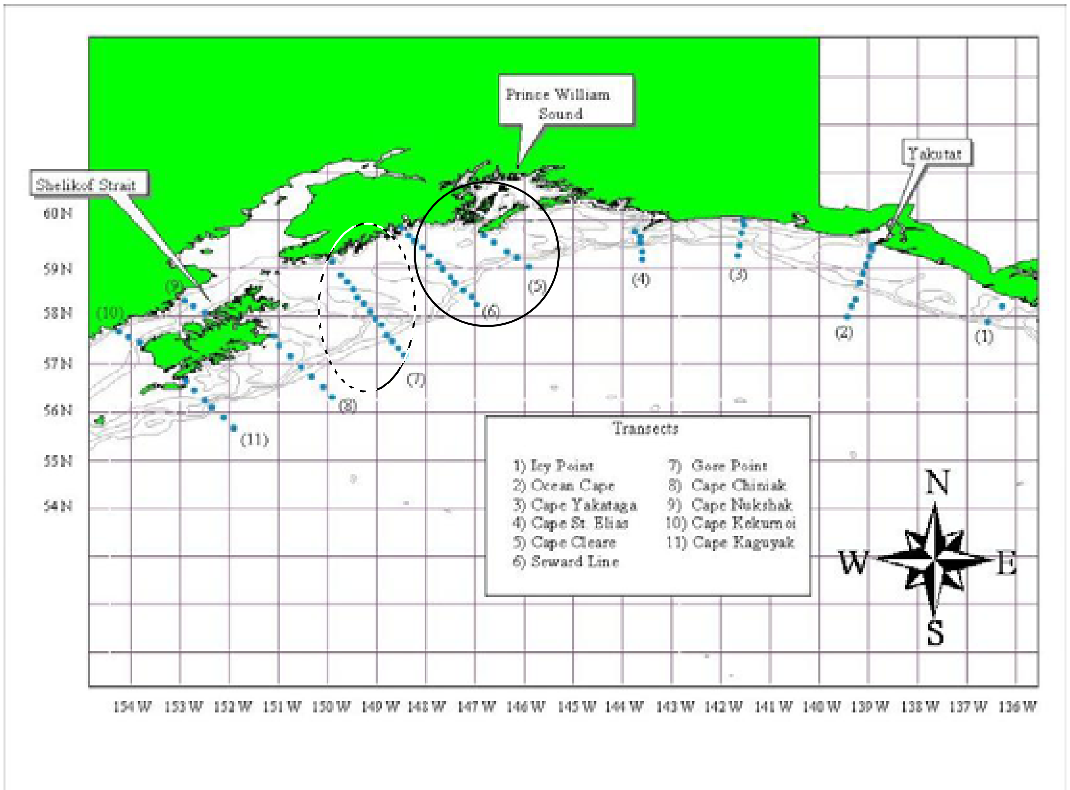

Figure 1. Transects sampled on GLOBEC cruises in July of 2001–2002. The three circled transects southwest of Prince William Sound (PWS) were used in this analysis. The energy densities (ED) of pink salmon from the two transects closest to PWS, circled together in black, had lower EDs than the transect farthest from PWS, circled with a dashed line.

Results and Discussion

ANOVA

Year ($P < 0.001$), transect ($P < 0.001$), and origin ($P = 0.04$) all explained a significant amount of the variation in EDs. The two transects closest to PWS had significantly lower EDs than the transect farthest from the sound (Figure 1). The only two hatcheries that differed statistically were Armin F. Koernig and Wally Noerenberg ($P < 0.001$). Overall, Wally Noerenberg hatchery had the highest ED in both years, followed closely by wild fish (average ED = 4422, 4367 J/g of wet weight, respectively). Armin F. Koernig and Solomon Gulch fish had lower EDs in both years (average ED = 4,243, 4,274 J/g of wet weight, respectively).

Regressions

There were no strong correlations between length, weight, or condition factor and ED (range of R^2: 0.07–0.14). Therefore, the size of the fish is not a good predictor of caloric density. Conversely, the correlation of percent dry weight and ED was strong ($R^2 = 0.94$, Figure 2). Because bomb calorimetry is time consuming and expensive, it is desirable to find a more efficient way of measuring energy content. A strong correlation between ED and other variables could be useful for predicting EDs from regressions.

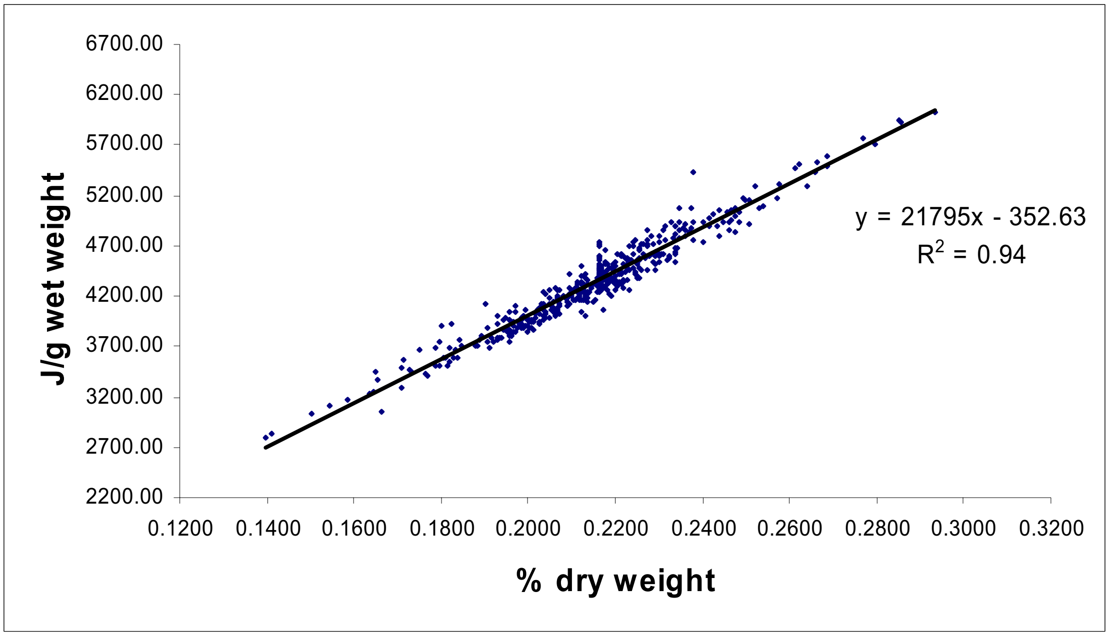

Figure 2. Linear regression of energy density and percent dry weight of pink salmon on GLOBEC cruises in July of 2001–2002. The linear trendline is presented with its formula and coefficient of determination (R^2).

Example 1: Pooled data in one regression

We investigated the relationship between ED and percent dry weight as a way to predict EDs. We first did a regression of all of the data and subtracted each dependent-variable value from the predicted value to get a residual (Figure 2). The residuals had a standard deviation of 112 and the largest residual was 607 J/g of wet weight. A difference of up to about 50 is acceptable because the bomb calorimeter has a margin of error about this large. Sixty-six percent of the residuals were over 50, so this single line may not be acceptable for predicting EDs for a large group of fish from many origins, areas, and years.

Example 2: Many regressions, data not pooled

To further investigate the variability in the relationships between ED and percent dry weight, we made a regression line for each transect for each hatchery for each year, for a total of 24 regression lines instead of just one as in the previous example (Figure 3). We then used these lines to predict ED values for several fixed percent dry weights of 16%, 18%, 20%, and 22%. The largest variability was seen at the smallest percent dry weight with a standard deviation (SD) of 141 J/g of wet weight (Figure 3). This large SD shows that the relationship between ED and percent dry weight can vary depending on variables such as the area of capture, the year, and the hatchery of origin. If there was no variability between years, areas, and hatcheries the standard deviation would be zero or close to zero, showing that the regression lines were all very similar. Separate regressions may need to be calculated to predict fish's EDs based on specific parameters to reduce the error in predictions.

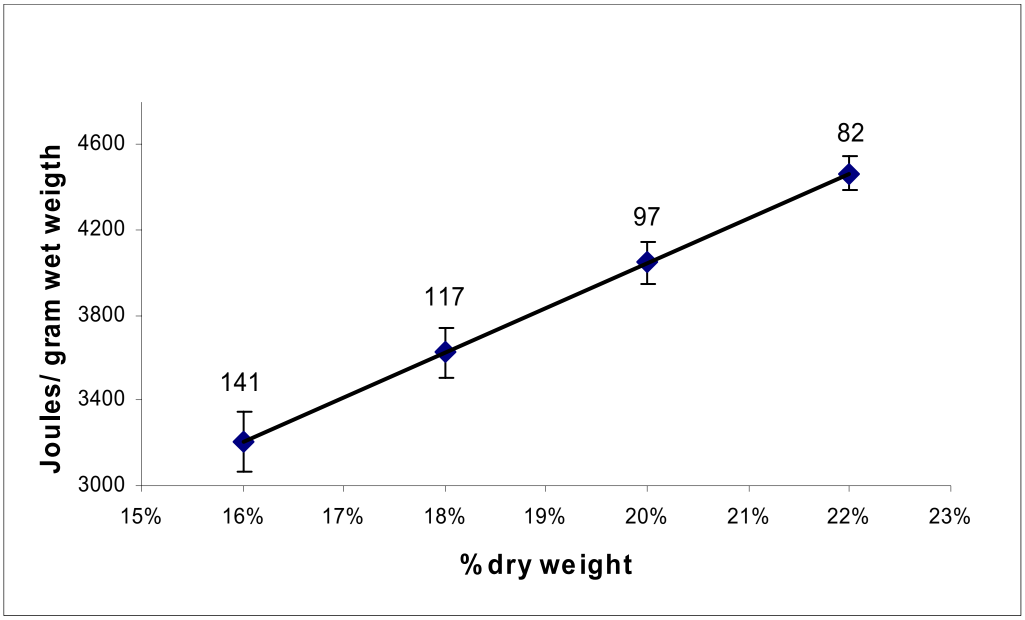

Figure 3. Linear regressions of energy density and percent dry weight of pink salmon on GLOBEC cruises in July of 2001–2002. One regression line has been fitted for each combination of transect, year and hatchery of origin for a total of 24 trendlines.

Bioenergetic Model Simulations
Energy density can be an important parameter for bioenergetics models that predict growth and other bioenergetic processes. We used real and predicted EDs from the single regression line (Example 1) in a bioenergetic model to examine the sensitivity of the model to ED while keeping all other parameters constant. We examined whether the predictions caused a significant error in the output of the models.

We modeled end weight after 30 days of growth when all parameters were held constant except for ED (Figure 4). The lower the percent dry weight, the higher the variability was in the residuals. At 16% dry weight, using two standard deviations in ED, the error in the predictions caused an error of up to 6.5 g in the bioenergetic model (Figure 4), which is an error of 7%–8% (Figure 3). This error decreased as percent dry weight increased (Figure 5). It is up to researchers to decide what level of error they are comfortable with for their models. The largest residual we saw in Example 1 (607 J/g wet weight) would have produced a much greater error in end weight than what we observed in this simulation. With models that simulate growth further into the future, these errors would also be greater.

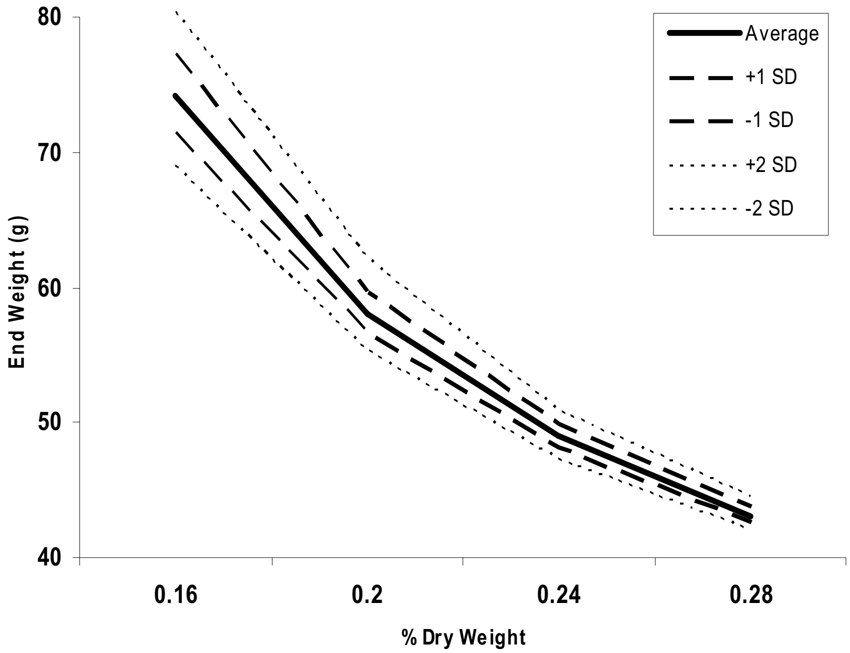

Figure 4. Bioenergetic simulation of weight after 30 days, when all variables were held constant except energy density (ED). The solid line shows the underlying growth from the regression (or the predicted ED values). The lines with large dashes are plus or minus one standard deviation from the predicted line, and the lines with small dashes are plus or minus two standard deviations from the regression of ED and percent dry weight. The standard deviation is a measure of the variability between the EDs predicted from the regression and the true values.

Summary

We found that the ED of juvenile pink salmon was highly correlated with their percent dry weight. This relationship can vary depending on the area they are caught, the hatchery of origin, and the year. Consequently, separate regressions may need to be calculated to predict fish's EDs based on specific parameters to reduce the error in predicting ED values. A bioenergetic simulation showed that there is error in modeling growth when one regression is used to predict EDs instead of several regressions.

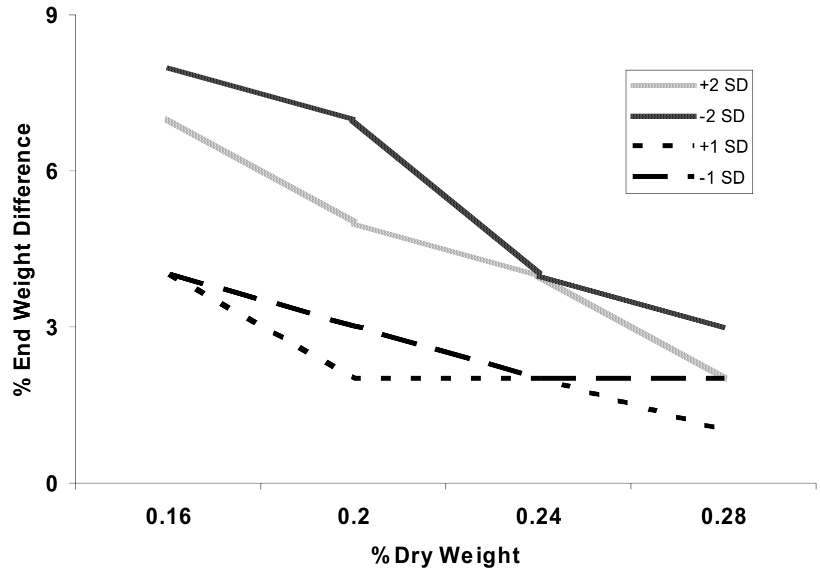

Figure 5. Percent difference in weight after a 30 day bioenergetic simulation. The solid lines are plus or minus 2 standard deviations (SD) from the regression of ED and percent dry weight. The dashed lines are 1 SD from the regression. The standard deviations illustrate how much error can be expected when EDs are predicted from regressions of percent dry weight and energy density instead of being directly measured.

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Influence of Large Zooplankton on Pink Salmon Survival in Prince William Sound, Alaska

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Abstract
Research conducted under the Sound Ecosystem Assessment (SEA) Program during the mid-1990s indicated that juvenile pink salmon survival in Prince William Sound was positively correlated with the abundance of the large-bodied copepod, *Neocalanus*, and negatively correlated with the abundance of pollock. *Neocalanus* serves both as a valuable food supply for the juveniles and as a prey-sheltering mechanism. In spring 2000, the Prince William Sound Science Center initiated annual monitoring of the spring abundance and distribution of both macrozooplankton and fish predator populations. The program has now completed five years of measurements with four associated adult pink salmon returns. The adult salmon returns are positively correlated with the abundance of large-bodied copepods during the nursery year, $R^2 = 0.61$. However, another large zooplankton group, euphausids, is also implicated in high pink salmon survival. The highest survival was associated with 2002 nursery conditions, which were characterized by moderately high *Neocalanus* abundance and exceptionally high euphausid abundance. Overall, adult salmon returns showed a slightly higher correlation with the abundance of euphausids, $R^2 = 0.70$, than with large bodied copepods. Euphausids may play a similar prey-sheltering role as that previously demonstrated for the large-bodied copepods. However, other factors, such as temporal and spatial variation in the zooplankton and predator distributions, may affect pink salmon survival.

Introduction

Research conducted by the Sound Ecosystem Assessment (SEA) program in the 1990s demonstrated that the survival of pink salmon fry (*Oncorhynchus gorbuscha*) in Prince William Sound (PWS) is dependent on the zooplankton food availability and predator abundance. Large calanoid copepods, mainly of the genus *Neocalanus,* typically consist of more than 50% of the biomass of PWS zooplankton in April and May. They are a valuable source of food for many fishes, including pink salmon fry, because of their relatively large size and high energy content (Cooney 1986). Cooney et al. (2001) also showed that most pink salmon fry rearing in PWS are consumed by predators during their initial 45-60 days of early marine residence. When *Neocalanus* abundance is low, walleye pollock (*Theragra chalcogramma*) become piscivorous and are the dominant pelagic predator of pink salmon fry (Willette et al. 2001). Pacific herring (*Clupea pallasi)* exhibit a similar prey switching behavior.

Subsequent to the SEA program, the Prince William Sound Science Center (PWSSC) initiated a program in FY00 to begin monitoring the spring predator and prey densities of juvenile pink salmon (Thorne 2000; Thorne and Thomas 2001; Thorne 2002; Thorne 2003; Thorne 2004). The goals were to monitor the abundance of zooplankton and predators. The program has completed five years of fieldwork, associated with four subsequent years of pink salmon returns. This paper examines the zooplankton net catches from the first four years and compares the results with subsequent adult salmon returns.

Methods

The zooplankton net tows were made along acoustic transects in six areas in Prince William Sound (Figure 1). Three of the areas extended along the main basin of PWS from Bligh Island to the Hinchinbrook Entrance (Figure 1), and three extended from Perry Island Passage out through Knight Island Passage, a well-documented pink salmon nursery and out-migration corridor (Cooney et al. 1995; Willette et al. 2001). Surveys were conducted three times during the spring between late April and early June. The sampling was accomplished with a 50 m vertical tow using a 0.335 mm mesh size 0.5-m-diameter ring net, following procedures of Cooney et al. (1995). At least two zooplankton tows were made within every area, every cruise. Data collection was limited to daytime hours to reduce confounding effects from diel vertical migrators.

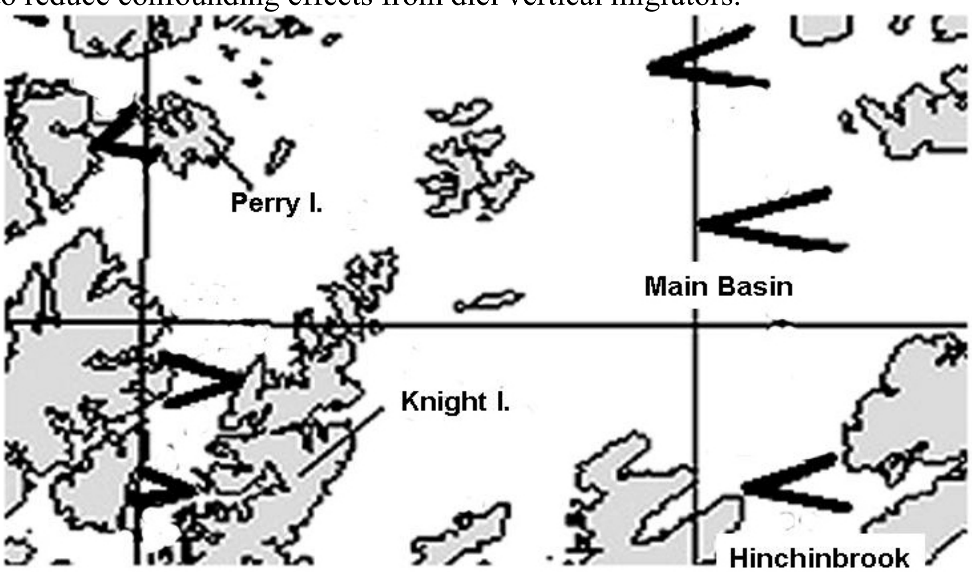

Figure 1. Location of acoustic transects for zooplankton surveys. At least two zooplankton tows were made along the transects in each of the six areas.

The plankton samples were analyzed to determine both size and frequency of the major components following procedures detailed in Kirsch et al. (2000). Copepods were separated into small and large-bodied categories, where large-bodied was Stage IV and V *Neocalanus* or equivalent size.

Results

Copepods dominated the zooplankton net catches in all years. Large copepods ranged from 3.0% to 8.9% numerically, but were often over 50% of the zooplankton biomass. The average net catch of large copepods ranged from a high of 1,869 in 2000 to a low of 284 in 2003 (Table 1). Larvacea were the second most abundant category, followed by pteropods and euphausids.

Pink salmon spend slightly over one year at sea before returning as adults. Harvests in PWS were high in 2001 and 2003, and low in 2002 and 2004 (Table 2). The pink salmon harvests are highly correlated (R^2 = 0.61) with large-copepod abundance in the nursery year (Figure 2). One other component of the zooplankton, euphausids, showed a high correlation with subsequent pink salmon harvests. The pink salmon harvest in 2003 was exceptional, and corresponded to an exceptional abundance of euphausids in 2002. The correlation between pink salmon harvests and euphausid abundance is slightly higher (R^2 = 0.70) than for the large-bodied copepods (Figure 3). The two components combined were very highly correlated with pink salmon harvests. The highest correlation (R^2 = 0.9882) occurred when the relative abundance of the two components was given equal weighting (Figure 4).

Table 1. Average catches by category for the five-year period, 2000–2004.

	Small Copepods	Large Copepods	Larvacea	Pteropods	Euphausids
2000	17,055	1,869	1,113	75	109
2001	11,071	442	403	689	114
2002	14,062	1,545	438	425	220
2003	9,926	284	596	114	127
Average	12208	995	581	306	129

Table 2. Total PWS pink salmon harvests, 2001–2004, in millions of fish.

Year	2001	2002	2003	2004
Harvest	35.2	18.9	51.1	23.3

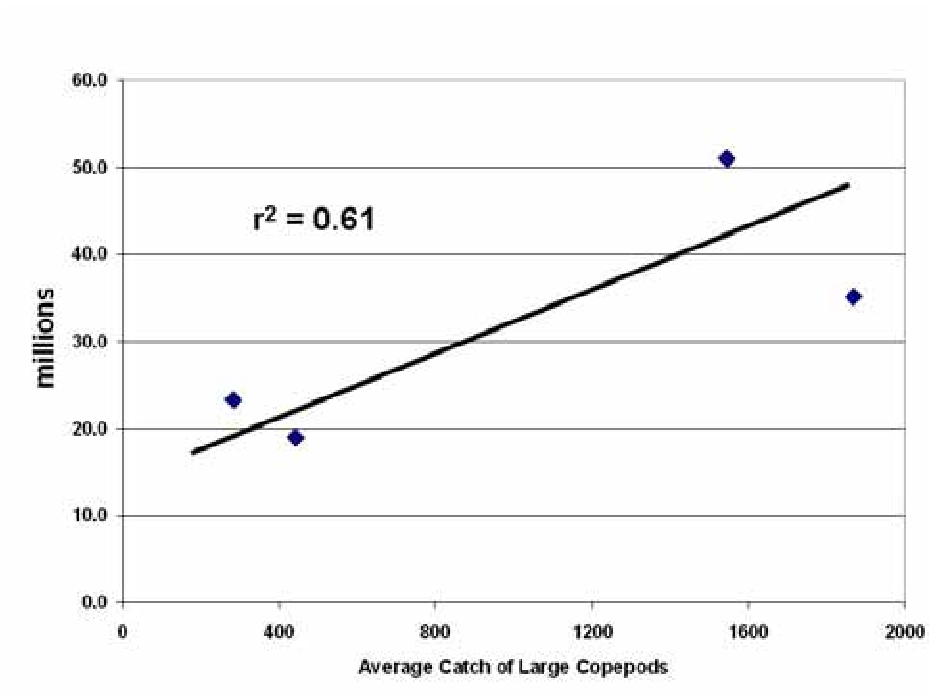

Figure 2. Comparison of pink salmon returns with average catch of large-bodied copepods during the nursery year.

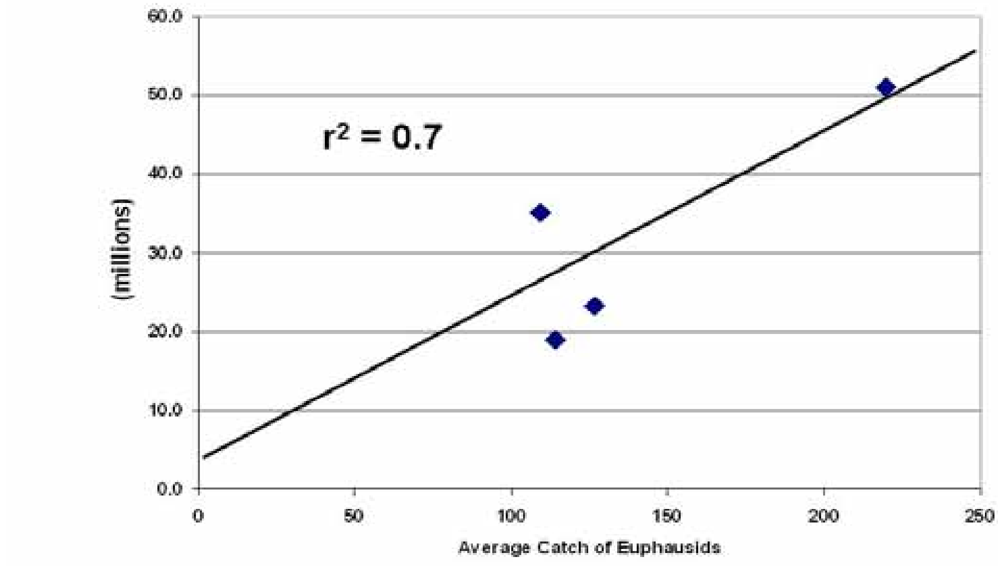

Figure 3. Comparison of total PWS pink salmon harvest with euphausid abundance during the nursery year.

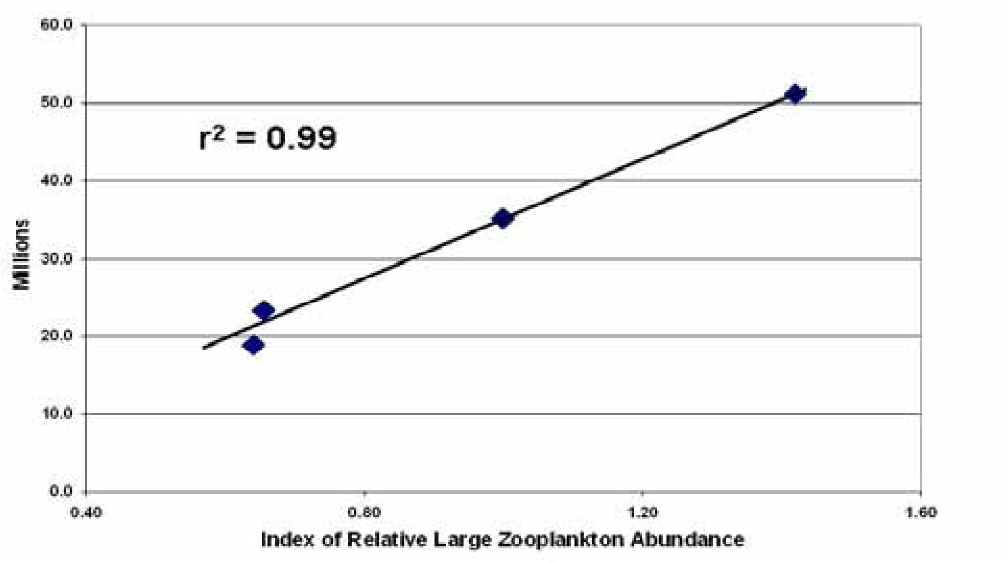

Figure 4. Relationship between total pink salmon harvest and relative abundance of large-bodied copepods and euphausids during nursery year (equal weighting; spring 2000 conditions equal 1.0).

Discussion

The above analysis correlates pink salmon harvests with nursery conditions. In this case, harvest is a surrogate for pink salmon survival. For many pink salmon runs, that would not be a valid assumption. However, most PWS pink salmon are of hatchery origin and thermally marked, so survival is measured. Hatchery releases are relatively consistent from year to year, and wild stocks are a relatively minor component. Harvest has been shown to be a reasonable index of total returns and overall survival (Cooney et al. 2001; Willette et al. (2001).

The zooplankton net catches were originally intended to provide species composition in order to interpret the acoustic backscatter information (Thorne and Thomas 2001). They were not intended to be the primary measure of abundance because it was assumed the spatial variability would be too high. However, the trends in net catches among areas have been consistent, indicating reasonable precision. In contrast, the acoustic data are confounded by the variation in the zooplankton scatter among several major components. While this variation can be accounted for in the acoustic data, the process, referred to as "deconvolution", is laborious (Weibe et al. 1997). The average abundance of specific components from the zooplankton catches appears to be adequately robust and a much simpler measure of the processes impacting pink salmon survival.

The correlation between large-bodied copepods and subsequent returns of pink salmon is not surprising based on previous research. However, there has been no previous indication that euphausids might be an important factor. The lower abundance of euphausids compared to *Neocalanus* in the 50-m vertical tows may have contributed to underestimating the importance of this component. Euphausids are vertical migrators, and are undoubtedly much more abundant than indicated in the net tows. Furthermore, it is well documented that euphausids are a favored prey of both walleye pollock and herring. If the dominant factor in pink salmon survival is prey sheltering, as concluded by Willette et al. (2001), then the contribution of euphausids to pink salmon survival is understandable.

On the other hand, the strong correlation between euphausid abundance and pink salmon survival is driven by a single year, and there are alternative hypotheses. The record harvest in 2003 correlates with unusually high euphausid abundance and cannot be explained by the average *Neocalanus* abundance. However, survival may be impacted by more complex spatial and temporal variation than reflected in the average net catches. There were substantial differences in the timing of the *Neocalanus* abundance between the 2000 and 2002 nursery years. *Neocalanus* abundance in 2000 was very high during the first cruise (May 1–3), but decreased substantially during the month (Figure 5). In contrast, abundance in 2002 increased dramatically by the third cruise. In addition, substantial spatial variation has been observed on occasion for both *Neocalanus* and the fish predators. These complexities may be important, and can only be resolved through a longer time series. The relative importance of large-bodied copepods and euphausids should be further elucidated by the returns in 2005, since large copepod abundance in 2004 was relatively high, but euphausid abundance was low.

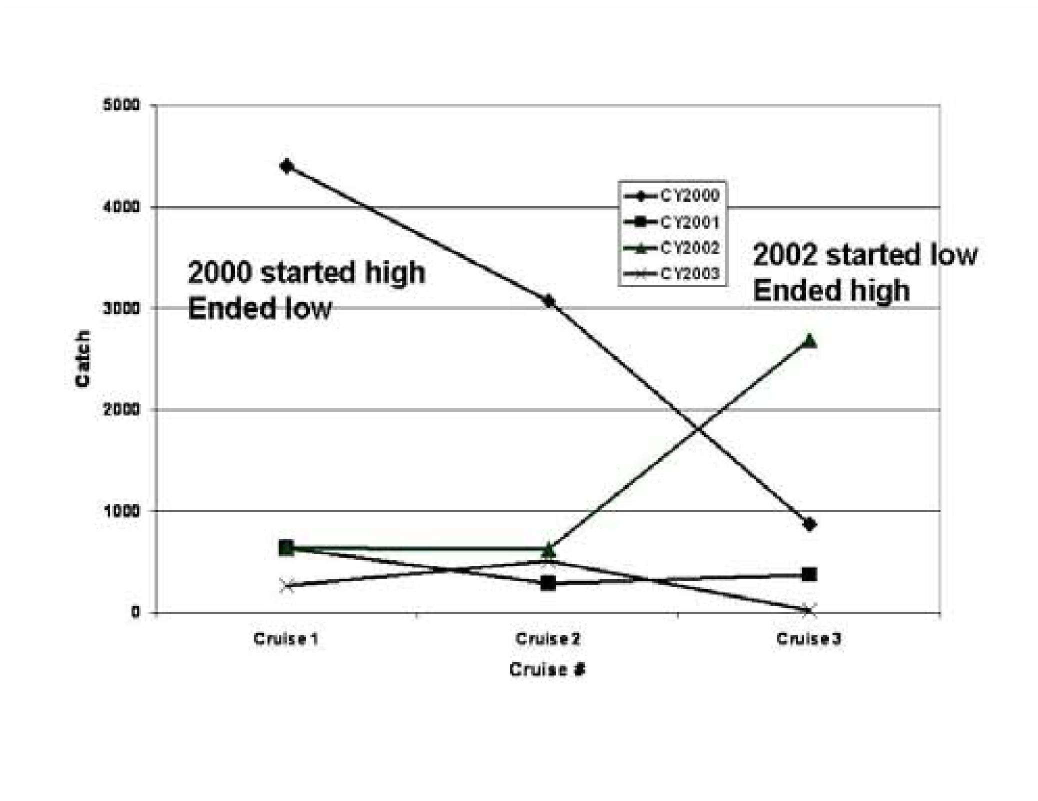

Figure 5. Variation in timing of large copepod abundance, 2000 to 2003.

Conclusions

The important role of *Neocalanus* in PWS pink salmon survival appears to be verified by the zooplankton monitoring that has been conducted during spring since 2000. Euphausids may play a similarly important role. Alternately, the role of *Neocalanus* may be more complex than seen in simple averages. Resolution of this uncertainty should be obtainable through continuation of the time series. If the alternative hypothesis is correct, then a more intense survey coverage may be required to obtain useable predictive capability.

Acknowledgments

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Juvenile Pink and Chum Salmon in the Northern California Current

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Abstract

Juvenile Chinook and coho salmon are the dominant salmon species in the northern California Current (NCC), but juvenile pink and chum salmon are also found in this current. In addition, because pink and chum salmon are numerically minor species, they have received little attention. In this paper we review juvenile pink and chum salmon marine ecology in the NCC (off the coasts of Washington and Oregon), based on summer catches from 1998 through 2004. The most striking differences between juvenile pink and chum salmon in the NCC are their spatial and temporal distributions. Chum salmon occur throughout the general study area, from Newport, Oregon, to Cape Flattery, Washington. By contrast, pink salmon are generally restricted to the northern-most area. Highest chum salmon catches occurred earlier than pink salmon catches: May and June versus September. These differences likely reflect geographic differences in source populations and migratory behavior. Chum salmon inhabit most river basins along the Washington and northern Oregon coasts, while pink salmon are largely absent from coastal basins and fish observed in the study area likely originated from basins in the Strait of Georgia or Puget Sound. In addition to these distributional differences, information on catches of both species with respect to biological and physical parameters, length, and estimated growth rates is presented. Information on the marine ecology of pink and chum salmon at the southern ends of their ranges provides a unique contrast to Alaska and British Columbia, where pink and chum salmon are the dominant salmon species.

Introduction

The northern California Current (NCC), off the coasts of Washington and Oregon, has been the location for juvenile salmon ocean ecology studies since 1980 (Pearcy 1992). Although juveniles of both pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon are caught in these studies, most analysis has focused on juvenile Chinook (*O. tshawytscha*) and coho (*O. kisutch*) salmon (e.g., Emmett et al. 1986; Fisher and Pearcy 1988; Schabetsberger et al. 2003), the numerically dominant salmon species.

Chinook and coho salmon have large populations in Oregon and California, but the NCC represents the southern end of pink and chum salmon ranges. While pink and chum salmon have been sporadically reported from rivers as far south as Monterey Bay, California (Heard 1991; Salo 1991), persistent populations (those annually returning to the same river over decades) are located much further north. For example, there are no persistent pink salmon populations on the Washington or Oregon coasts, and the southern-most recognized pink salmon population occurs in Puget Sound (Hard et al. 1996). Persistent but relatively small chum salmon runs inhabit Tillamook Bay, Oregon (Kostow 1995), but the nearest large coastal populations (tens of thousands of spawners) occur in Grays Harbor and Willapa Bay on the Washington coast (WDFW 2005). For both species, large populations (millions of spawners) exist in major river basins of Puget Sound and the Strait of Georgia (CDFO 1999, PFMC 2004, WDFW 2005).

Here, we summarize information on the marine ecology of juvenile chum and pink salmon in the NCC during the summers of 1998 to 2004. This information includes distribution and abundance by season and location, physical and biological associations, size, and estimated growth rates. Because relatively few juvenile pink salmon were caught, this information largely focuses on juvenile chum salmon. Information on the marine ecology of juvenile pink and chum salmon in the NCC provides a unique contrast to studies occurring in Alaska and British Columbia, where pink and chum are in the center of their geographic range and are the dominant salmon species.

Methods

Juvenile salmon were collected during spring and summer months of 1998–2004 off the Washington and Oregon coasts in four related studies (Plume, Front, Predator, and Eddy). The Plume Study sampled along transects from Tatoosh Island, Washington (48° 23'N), to Newport, Oregon (44° 41'N), in May, June, and September of each year (Figure 1), although the number of stations sampled varied by cruise. Two studies, Front and Predator, were conducted near the mouth of the Columbia River. The Predator Study sampled the Willapa Bay and Columbia River transects at biweekly intervals from approximately April to August. The Front Study sampled areas in the Columbia River plume, the plume front, and adjacent marine habitats in May 2001 and 2002 (de Robertis et al. *In review*). The Eddy Study occurred in September 2002 off the north coast of Washington, where a series of stations associated with the Juan de Fuca eddy (~48° 16'N, 125° 6'W) were sampled. All samples were conducted during daylight except the Predator Study, which was sampled at night.

All juvenile salmon were sampled with a Nordic 264 rope trawl (18 m deep × 30 m wide when deployed) towed at 6 km hr^{-1}; active fishing occurred for 15–30 minutes for each tow and covered an average distance of 2.65 km. Concurrent oceanographic and biological sampling was conducted at most sampling stations in the Plume and Front Studies. All collected fish were identified and enumerated, and up to 50 (non-salmonids) or 100 (salmonids) individuals were measured (length to the nearest 1 mm). All measured juvenile salmon were individually tagged, bagged, and immediately frozen; the remainder were frozen together. In the laboratory, salmon were re-measured (length) and weighed (to the nearest 0.01g).

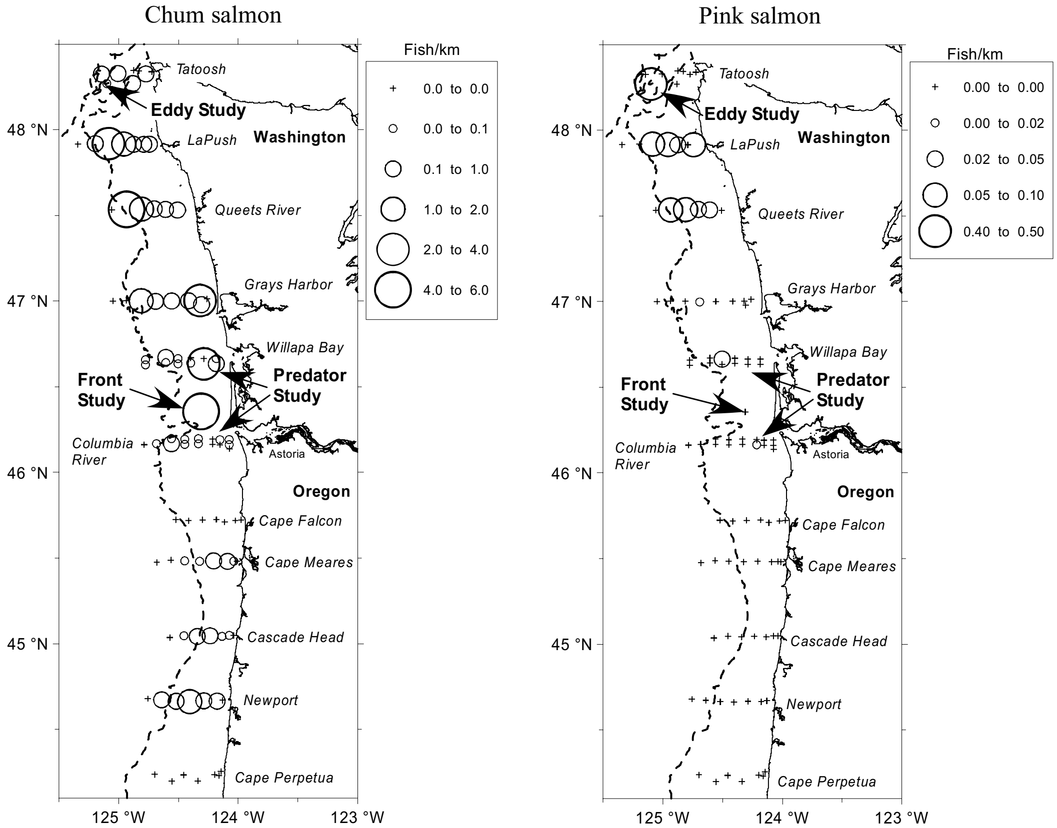

Figure 1. Mean catch of juvenile chum (left) and pink (right) salmon per distance (km) towed in the northern California Current. The transects were sampled in the Plume Study; locations of the three minor studies (Front, Predator, Eddy) are indicated. All stations did not receive identical sampling effort.

Temperature and salinity differences in areas where pink and chum salmon were present or absent were investigated using a two-sample *t* test. Associations between pink and chum salmon and other fishes were explored using Spearman correlation coefficients. Both explorations only involved fish collected in the Plume and Front Studies.

Results

A total of 2,122 juvenile chum salmon were caught in 147 tows and 42 juvenile pink salmon were caught in 18 tows, out of a total 1,526 tows. Juvenile pink and chum salmon catches varied between species, both by location and in time (seasonally and annually). The geographic distributions of these catches were species specific: pink salmon were largely caught off the northern Washington coast, while chum salmon were caught throughout the sampling area (Figure 1). The two species were also caught during different months; juvenile chum salmon catch per effort (CPUE, where effort = km towed) was highest in May and June, while pink salmon CPUE was highest in September (Figure 2). The year of maximum pink or chum CPUE also varied; juvenile pink salmon CPUE was highest in 2002, while chum salmon CPUE was highest in 2001 (Figure 3).

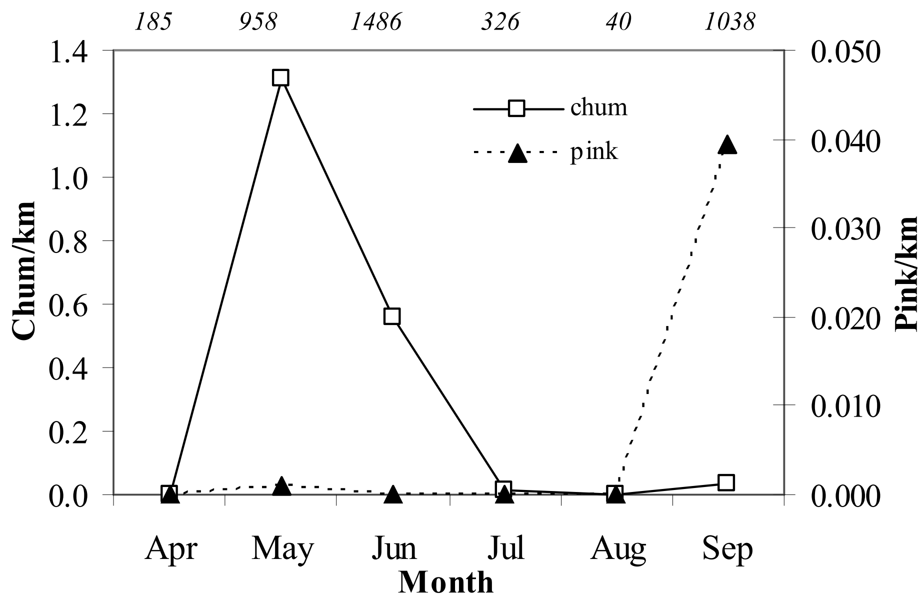

Figure 2. Number of juvenile chum or pink salmon caught in the Northern California current, by month, per distance (km) towed. The distance towed each month is indicated. Note the different scales for the two species.

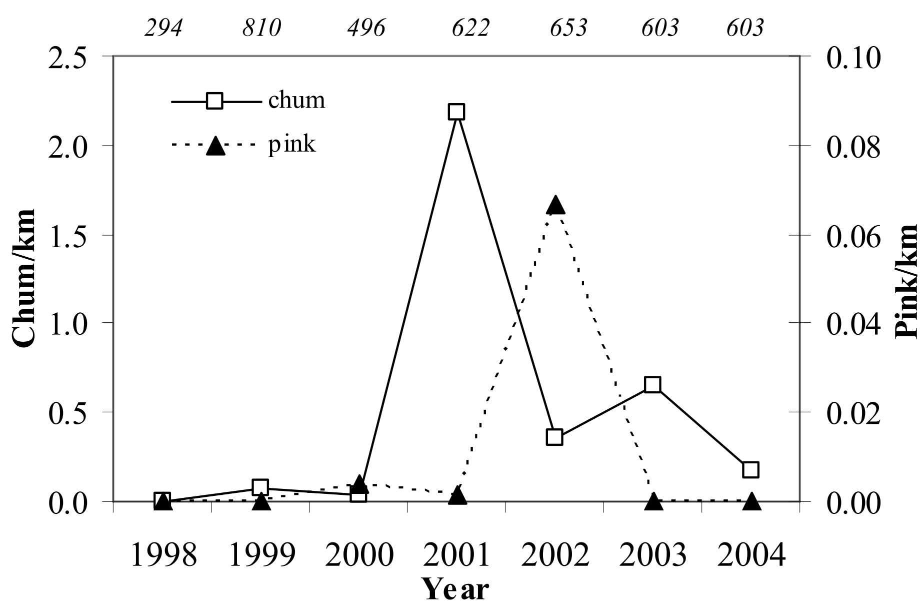

Figure 3. Number of juvenile chum or pink salmon caught in the Northern California Current, per distance (km) towed, by year. The distance towed each year is indicated. Note different scales for pink and chum salmon.

Physical properties (temperature, salinity) in areas where pink and chum salmon were present versus where they were absent were not significantly different. For example, surface (1 m) temperature and salinities where chum (13.2°C, 30.7‰) and pink (13.1°C, 31.4‰) salmon were collected were similar to areas where the species were absent (13.0°C and 30.2‰ for both species; $t_{927} \leq 1.60$, $P > 0.05$). The higher salinity of pink salmon catches likely reflects the timing of the catches (September), when salinities were generally higher.

The abundance of juvenile chum salmon was also compared to the abundances of five other species (juvenile Chinook and coho salmon, northern anchovy [*Engraulis mordax*], Pacific herring [*Clupea harengus*], and Pacific sardine [*Sardinops sagax*]), caught together in the same tow. Catches of chum salmon were significantly positively correlated with only catches of juvenile coho salmon (Spearman $r = 0.32$, $P < 0.01$; Figure 4).

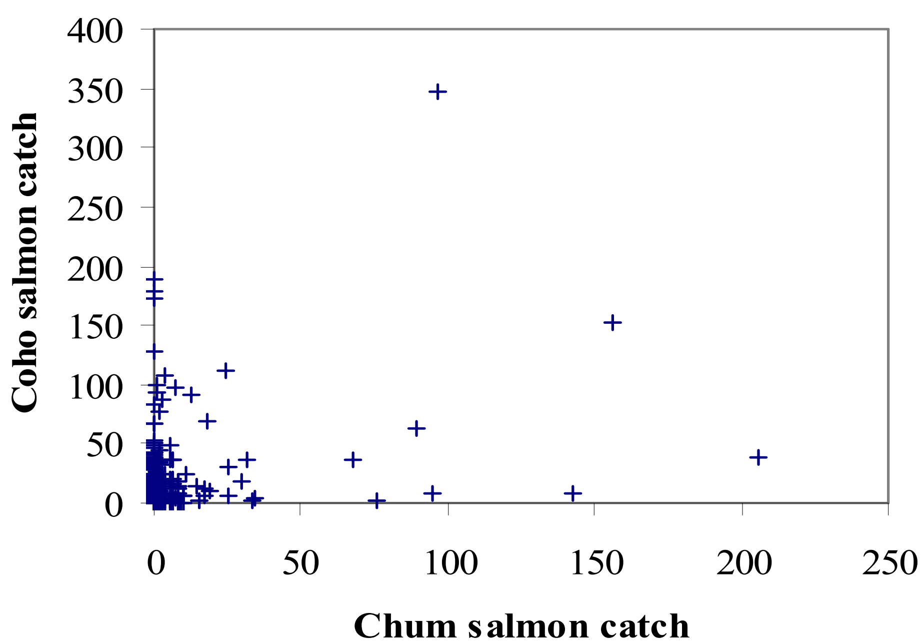

Figure 4. The number of juvenile chum and coho salmon caught together in the same tow in the Plume and Front Studies.

The size of both juvenile pink and chum salmon increased seasonally. Juvenile pink and chum salmon were smallest in May (80 and 96 mm FL, respectively) and largest in September (157 and 176 mm FL, respectively; Figure 5). Chum caught in the Plume and Predator Studies were similar in size during common time periods, while pink salmon caught in the Eddy Study were slightly, but not statistically larger than those from the Plume Study in September ($t_{39} = 0.98$, $P > 0.05$). Based on sizes observed in the Plume Study, chum salmon growth rates early in the summer (May to June) were higher (0.92 mm d^{-1}, 2.8% body weight [BW] day^{-1}) than growth rates estimated across the entire summer (May–Sept.; 0.64 mm d^{-1}, 1.6% BW d^{-1}).

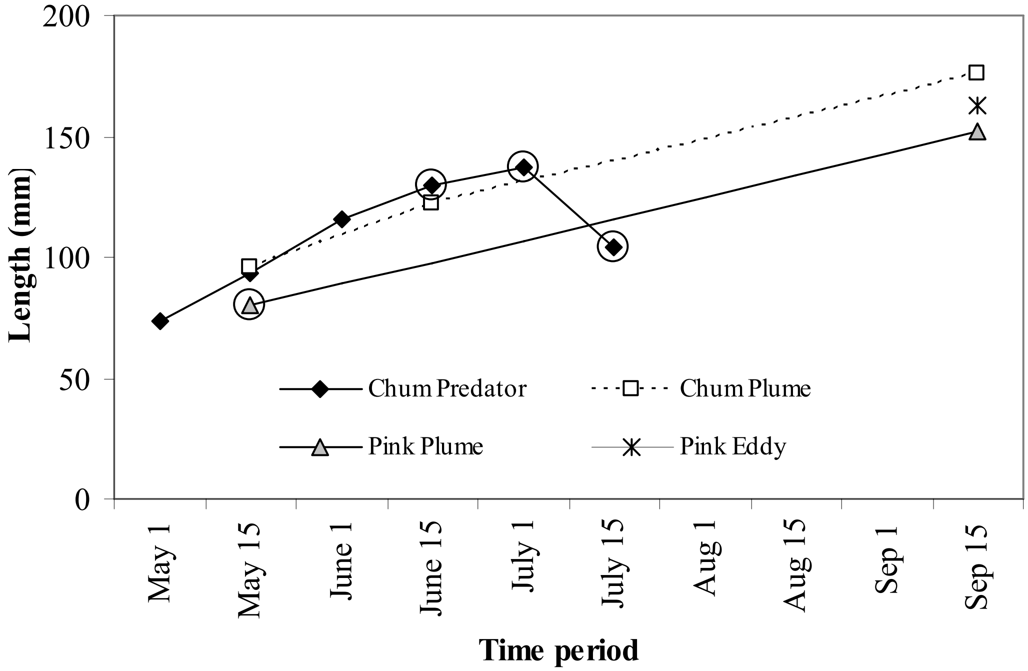

Figure 5. Mean length (mm FL) of juvenile pink and chum salmon in the Northern California current, by study (Plume, Predator, Eddy), over two-week time intervals, averaged over all years (1998–2004). Circled values represent means based on less than five individuals.

Discussion

Geographic and temporal patterns of juvenile pink and chum salmon abundance were quite different in the NCC, with highest chum salmon densities in May and June throughout the study area, and the highest pink salmon densities in September in the northern section of the study area. These patterns, paired with the location of possible source populations, suggest that chum salmon likely originated from coastal basins, resided in coastal waters during the early summer, and then were largely dispersed by late summer. By contrast, juvenile pink salmon likely originated in Puget Sound or Strait of Georgia (since there are no populations on the Washington or Oregon Coasts), and were caught in the NCC as they exited the Strait of Juan de Fuca in late summer. High juvenile chum salmon density in 2001 corresponds to large adult returns to Willapa Bay and the Columbia River in 2000 (WDFW 2005), while the high pink salmon density in 2002 is consistent with high pink salmon adult returns to the Fraser River and Puget Sound in 2001 (PFMC 2004).

Pearcy and Fisher (1990) sampled many of the same transects used by the Plume Study in the early 1980s and observed similar distributional patterns for juvenile pink and chum salmon (pink restricted to the north, chum throughout the sampling area). However, the seasonal patterns of abundance for the two species were different: in the early 1980s chum salmon were abundant throughout the summer, while pink salmon were also caught early in the summer (May–July). The reason for these differences between the early

1980s and the present are unclear, but likely reflect different physical and biological ocean conditions, as well as different abundances and distributions of source populations.

Juvenile pink and chum salmon at the southern end of their range experience marine conditions that are quite different from the same species in northern British Columbia or Alaska. For example, compared to studies conducted in southeast Alaska (Orsi et al. 2000), pink and chum salmon in the NCC experience much warmer and more saline waters, are a minor, rather than major, component of surface fish community, and experience much slower growth rates. Further understanding of the ocean ecology of juvenile pink and chum salmon in the NCC and comparisons to the same species in northern areas should yield valuable information about the ability of these species to adapt to diverse environments, how these environments, in turn, effect survival, and the potential factors that limit their southern distribution.

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Session 7: Contributed Paper

Growth of Juvenile Pink Salmon in Lake Aleknagik, Alaska, and Comparison to Sympatric Sockeye Salmon

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Abstract

Juvenile pink salmon, *Oncorhynchus gorbuscha* (Walbaum), typically migrate to sea directly after emergence, exhibiting little feeding and growth in freshwater, although they feed actively and grow rapidly at sea. In contrast, sockeye salmon, *O. nerka* (Walbaum), typically feed in lakes for one or two years, and grow slowly at sea. The naturally sympatric populations in Lake Aleknagik, Alaska, offered an opportunity to compare their growth in the common lacustrine environment. Length frequency distributions of juvenile pink salmon caught in the lake during the summer in 1991 and 1999–2003 indicated a growth rate of 0.54 mm d^{-1}, 54% greater than the estimated growth rate of juvenile sockeye salmon sampled from 1958–2003 (0.35 mm d^{-1}). Examination of daily growth rings on otoliths indicated that pink salmon in Lake Aleknagik grew an average of 1.34 mm d^{-1} in 2003 but sockeye salmon grew only 0.63 mm d^{-1} (average specific growth rates were 3.0 and 1.8, respectively). After experiencing these rapid growth rates, the pink salmon seem to leave the lake by late July in most years. The diets of pink and sockeye salmon in the littoral zone of the lake were very similar; > 80% of the stomach contents consisted of adult and pupal insects and the remainder were zooplankton. This high degree of diet overlap suggests that the observed differences in growth rate are not attributable to variation in prey composition. These observations and studies of pink salmon elsewhere suggest that they may grow more rapidly than sockeye salmon through a combination of less risk-averse behavior (feeding near the surface in the day rather than vertically migrating), feeding more often, and perhaps also having a different metabolic rate.

Introduction

Pacific salmon vary greatly in the length of time spent in freshwater and at sea, and the growth achieved in these environments. Pink salmon, *Oncorhynchus gorbuscha* (Walbaum), are the most fully anadromous salmonid. They often spawn in the lower reaches of rivers (Helle 1970), and the juveniles typically migrate downstream immediately after emergence from the gravel (Heard 1991). Usually, pink salmon scarcely feed in freshwater during seaward migration (Levanidov and Levanidova 1957; Bailey et al. 1975), and reach marine waters at about 32 mm in length (Bailey et al. 1976) and 0.25 g in weight (Cooney 1993). After leaving freshwater, pink salmon initially rear in nearshore marine regions, then move offshore (Willette 2001), where they remain until sexually mature in the summer or fall of their second year of life.

The life history of pink salmon contrasts with that of sockeye salmon, *O. nerka* (Walbaum). In this species, the small fry (about 27 mm long) typically reside in a lake for one or two years prior to seaward migration, and then spend two or three years at sea. Despite being larger than pink salmon when they enter the ocean (about 10 vs. 0.25 g) and spending one or two more years at sea, sockeye salmon are only slightly larger than pink salmon at maturity (about 2.7 vs. 1.6 kg; Quinn, 2005). Thus, these species apparently differ greatly in growth rates. However, because pink salmon rarely spawn above lakes, direct comparisons between juveniles of comparable initial size are seldom possible, and the lacustrine behavior of juvenile pink salmon has not been studied in detail.

The Wood River lakes of southwestern Alaska provide an unusual but natural exception to the general patterns of pink salmon ecology; the species is abundant in even-numbered years as adults, and as juveniles the following summer. From the Agulowak River the fry migrate approximately 60 km through Lake Aleknagik and down the Wood River to its confluence with the Nushagak River before entering the marine environment of Bristol Bay. Passage through Lake Aleknagik provides the fry with an opportunity to feed and grow prior to entering the ocean, and they can be caught in the lake for one to three months in summer before they apparently all leave (Rogers and Burgner 1967). The much more numerous sockeye salmon fry reside in the littoral zone of the lake for about a month and then move to the limnetic zone (Burgner 1962) where they exhibit diel vertical migrations, feeding near the surface during the brief summer nights (Scheuerell and Schindler 2003). The sockeye salmon remain in the lake for one or, less commonly, two years prior to seaward migration (Rogers 1987). The objective of this study was to take advantage of the unusual situation in Lake Aleknagik to study the patterns of growth of juvenile pink salmon in a lacustrine environment and make comparisons with sympatric juvenile sockeye salmon.

Methods

Sampling was performed in Lake Aleknagik from late June through early September from 1958–2003 as part of a long-term study of the ecology of sockeye salmon (e.g., Rogers 1973; Hilborn et al. 2003; Schindler et al. *in press*). Sampling in June and July focused on the littoral zone, as the sockeye fry tend to concentrate there in those months. The upper portion of the limnetic water column was sampled on August 1 and September 1, 1958–2003. Additional weekly sampling of limnetic surface waters was performed at dusk during late July and August of 1991 and during July of 2003.

The growth rates of juvenile pink and sockeye salmon in Lake Aleknagik were estimated by linear regression of the distribution of average lengths against sampling dates. Sampling dates were standardized into weekly units to account for slight interannual variation in the date of sampling (e.g., sampling conducted between 29 June and 5 July in different years was combined into one sampling date labeled ”2 July”). The initial analysis of pink salmon growth was based on the average lengths of all individuals measured on each sampling date in 1991 and 1999–2003 (all years from which data were available). Sockeye salmon growth rates were estimated based on sampling in all years from 1958–2003 using weekly average lengths, averaged for all years.

Ideally, analyses of growth rates based on catch data would be conducted on closed populations, but the Lake Aleknagik populations experienced recruitment of newly emerged fry, mortality of fish in the lake, and migration from the lake in the case of the pink salmon. Accordingly, the second approach to studying comparative growth rates of pink and sockeye salmon was based on their length and age in days as estimated by otolith microstructure analysis (counts of daily rings). Otoliths were extracted from fish (n=19 pink salmon and 18 sockeye salmon) caught between 18 June and 16 July, 2003. Otoliths were mounted in ethyl acetate on glass microscope slides and ground to the core using a regimen of progressively finer grain lapping film (13, 9 and 3 μ) according to methods described by Campana (1992). Photographs, taken with a digital camera mounted on a compound microscope, were used for counting the number of daily rings in the otolith microstructure following the emergence check, producing age estimates for each fish. Counts were conducted blind to fish characteristics (e.g., length and date of sample) by two readers, each of whom had gained experience by examining otoliths from known-age juvenile sockeye salmon. The specific growth rate of each fish was estimated based on the standardized change in length from an emergence size of 32 mm for pink salmon and 27 mm for sockeye salmon (Beacham and Murray 1990) since its date of emergence (i.e., $G = ((\ln length_t - \ln length_{\mathrm{emergence}}) / time)100$); Wootton 1990). An analysis of covariance was used to confirm that the rate of change in specific growth rate over the four-week sample period was not different between the two species, with time functioning as the covariate. An independent-sample t-test was then used to compare the mean specific growth rates in each species.

In 2003, diets of 97 juvenile pink and 76 sockeye salmon were compared by recording prey composition as the percent volume of zooplankton and insects within the stomach. Fish were preserved in 95% EtOH for 48 hours prior to analysis. All prey types were identified as insects or zooplankton (no other prey types were observed in these samples), and the percent volume of each was estimated based on visual assessment by the technician. Given the markedly higher energy composition of insects compared to zooplankton (4,428 J/g vs. 2,105 J/g; Cummins and Wuycheck 1971; Beauchamp et al. 1989), this allowed for a general comparison of the overlap in feeding niches of the two sympatric species. The proportion of feeding niche overlap was calculated as

$$\eta = 1 - 0.5(\sum p_{xi} - p_{yi}),$$

where p_{xi} was the proportion of prey type i in the diet in species x, then summed over all prey types (see Wootton 1990 for summary).

Results

Regression analysis of historical length data indicated that juvenile pink salmon achieved a greater increase in size than juvenile sockeye in Lake Aleknagik, despite relatively similar lengths at emergence. Absolute growth rates were 0.54 and 0.35 mm d^{-1} for pink and sockeye salmon, respectively. However, the specific growth rates of the two species over this time period, based on the historical length-frequency data, were not significantly different from one another (G = 0.70 for pink and 0.54 for sockeye salmon; ANCOVA interaction term $P = 0.10$).

In both species of juvenile salmon the analysis of otolith microstructures indicated higher growth rates than were estimated from the historical catch data. Both species exhibited an increase in specific growth rate over the course of the sampling period, but no significant difference was found between the slopes of the two lines (ANCOVA interaction term $P = 0.2$). This enabled the direct comparison of the mean specific growth rates of the two species. Specific growth of these juvenile pink salmon (3.0, SE = 0.2, n = 19) was significantly higher than that of the sockeye salmon (1.8, SE = 0.3, n = 18; $t_{obs} = 3.9$, $P < 0.001$). The average emergence dates of these fish were similar between species (pink salmon: 16 June, sockeye salmon: 12 June, $t_{obs} = 1.04$, $P = 0.31$), thus the comparison of growth rates was not confounded by differences in environmental conditions when they emerged.

At a broad taxonomic scale, the diets of pink and sockeye salmon fry overlapped considerably, with a proportional similarity index of 0.92 (Wootton 1990). Pink salmon diets were comprised of 89% adult and pupal insects, and 11% zooplankton by volume. Sockeye salmon diets were comprised of 81% insects and 19% zooplankton by volume. Thus, these species exploit the same general feeding niche, with most of their diets comprised of the energetically-rich insect prey types.

Historically, juvenile pink salmon have been observed in both the littoral and limnetic habitats in Lake Aleknagik. Pink salmon densities were highest during June and early July, suggesting that they vacate the littoral zone, and perhaps the lake as a whole, midway through the summer. Fully 78% of all pink salmon were caught in the first half of the season whereas only 67% of the sockeye salmon were caught during this period. In 2003, juvenile pink salmon were only observed in the nearshore habitat between 18 June and 3 July and offshore only between 3 July and 16 July, despite continued sampling in both habitats during July and August. Sockeye salmon continued to be found in the nearshore habitat through 14 July, and were not recorded in the limnetic region until 4 August.

Discussion

This study indicated that juvenile pink salmon grew 30%–67% faster than sympatric sockeye fry in the lake as based on the comparison of mean population lengths and otolith microstructure analysis, despite similar diets of insects and zooplankton and similar emergence dates. Nevertheless, pink salmon largely vacate the littoral zone and probably the lake as a whole by late July, and individuals may spend only a few weeks in the lake prior to seaward migration.

Juvenile pink salmon in Lake Aleknagik more than doubled their length prior to migration. Typical average emergence size is approximately 32 mm and 0.13–0.26 g

(Beacham and Murray 1990; Heard 1991). Pink salmon fry from small coastal streams migrate directly to sea without notable freshwater feeding, and have been estimated to enter saltwater at an average size of 32 mm (Bailey et al. 1976) and 0.25 g (Cooney 1993). In contrast, pink salmon fry sampled in July 2003 in Lake Aleknagik were up to 80 mm and 3.0 g. The pink salmon grew 0.54 mm d^{-1}, based on the historical catch records, and 1.35 mm d^{-1} (SE 0.10) based on otolith analysis from 2003. These growth rates are comparable to the 0.97 mm d^{-1} reported by Healey (1980) for pink salmon from 35–100 mm in length in nearshore marine waters British Columbia.

The much faster growth rate estimated from otolith analysis may be more accurate than the length-frequency analysis. However, the otolith analysis represented a much smaller number of individuals and so runs the risk of being less representative of growth within or among years (Robins et al. *in press*). The absolute rates of growth observed in both pink and sockeye salmon fry during 2003 may not have been representative of all years because of very favorable environmental conditions in the lake. Spring air temperatures were warmer than usual, leading to early ice break-up on the lake, warmer water temperatures, and higher than average zooplankton densities early in the season. These conditions increase the growth rate of juvenile sockeye salmon in Lake Aleknagik (Schindler et al., *in press*), and a similar response would be expected in pink salmon fry.

Pink salmon fry sampled in both the littoral and limnetic regions of Lake Aleknagik were feeding on aquatic insects and zooplankton. Rogers and Burgner (1967) also reported that juvenile sockeye and pink salmon in Lake Aleknagik both fed exclusively on zooplankton and insects, although in 1967 the stomach contents of pink salmon contained a higher proportion of zooplankton than the sockeye salmon. The similarity in diets was also evident in juvenile salmon caught in the limnetic zone in 1999 (D. E. Schindler & T. P. Quinn, unpublished data). Interannual and seasonal differences in prey composition of diets may be expected due to variation in zooplankton abundance, and the tendency for pink fry to be opportunistic and diurnal feeders (Healey 1980; Godin 1984).

This study documented lacustrine feeding by a natural population of anadromous pink salmon, and growth rate more rapid than that of sympatric sockeye salmon. The marked differences in growth rates between the two species, despite similar emergence dates, prey and habitat availability, may arise from differences in feeding rate, behavior, and physiological processes related to growth efficiency. In addition, the evidence that juvenile pink salmon can grow rapidly in a lake may help explain why this species successfully colonized the Great Lakes after an accidental release of a small number of juveniles (Crawford 2001), despite being the most strongly anadromous of all the Pacific salmon (Rounsefell 1958).

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Mortality Rates of Chum Salmon During Their Initial Marine Residency

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Mortality of chum salmon during their early marine residency is thought to be high, variable, and a major contributor to the recruitment success of a year class. However, few estimates of daily mortality are available for chum salmon during this period, and average literature values are unrealistically high when used in a simple life-history model. We used adult survival data for seven groups of marked chum salmon released at different times and sizes at Little Port Walter, Alaska, to estimate average daily mortality during early marine residency for an "early release" cohort released on March 12 and a "late release" cohort released on April 2. Initial releases for both cohorts were of unfed fry marked and released to the estuary after volitional emergence from deep-matrix gravel incubators. Subsequent releases from the two cohorts consisted of fed fry reared in estuarine net-pens for 1–3 months after emergence. We assumed that differences in survival rates for the initial releases and subsequent releases for each cohort were due to natural mortality during the time interval between releases. For both cohorts, mortality was highest during the period immediately following release, then declined rapidly. Average daily mortality was 8.6% for the early release during their first 21 days in the marine environment, and 3.9% for the late release during the first 32 days in the marine environment. After May 4 (54 d and 33 d post-release, respectively, for the early and late cohorts), average daily mortality was < 0.6% for both cohorts. These results support the paradigm that most of the ocean mortality of chum salmon occurs early in their marine residency, and provide realistic rates useful for demographic modeling of abundance in marine habitats.

Update on a Study of Chum Salmon (*Oncorhynchus keta*) in the Southern Portion of the Species Range (Columbia River, Oregon, and California)

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Last year we proposed a study on chum salmon in the southern portion of the species range from Columbia River to California. Although chum salmon are listed under the Endangered Species Act in the Columbia River, there is a lack of genetic and other biological information available on these potential southern stocks. Although estimates of the numbers of spawning adults and out-migrating smolts are reported each year, it is not known if these are sustainable populations or strays from other regions. This information will be critical as recovery programs begin to be implemented on listed populations.

Last year we were able to begin the study with collections of tissue samples, life history, and morphological information from spawning chum salmon in Oregon and the lower Columbia River. We also were able to obtain a handful of tissue samples of chum salmon from northern California. We are presently in the process of analyzing these samples using DNA-based microsatellite techniques developed by the Washington Department of Fish and Wildlife and our Northwest Fisheries Science Center DNA lab.

We have also developed a database on population status and life-history data, including presence or absence of spawning populations, age structure from scale collections, timing of migrations from historical and recent commercial catch records, smolt trapping data, spawning ground surveys, and morphological characters.

We hope to be able to compare the DNA-based microsatellite data from these fish to other chum salmon studies in Canada and Puget Sound as well as to the extensive allozyme database already developed for northern populations that was used to develop information for evolutionary significant unit identification in our status reviews. The microsatellite data on these populations should provide significantly greater power to separate genetically distinct groups than allozymes, and give us a clearer understanding of the origin of populations and which ones would be most appropriate for supplementation and recovery programs.

Sitka Sound Chum Salmon Fry Monitoring: Growth, Distribution, Migration Timing and Food Habits

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Results from the first two years (2002 and 2003) of a monitoring program of chum salmon (*Oncorhynchus keta)* fry in Sitka Sound show that once chum fry are released from net pens in late April and early May at about 2 grams, they rear along the rocky shoreline for the next month, where they feed primarily on copepods, crustaceans, and cirripedia as well as other near-shore larvae. Once these fry have reached approximately 2.5 grams and 65 to 70 mm fork length, they begin to move offshore and become more pelagic. While still within a kilometer or so of shore, and within the inner portion of Sitka Sound, these fry become much more smolt like, and their diet consists primarily of copepods and miscellaneous crustacean larvae. They rear and reside in this more pelagic habitat until late June when at the size of 4.5 to 5.0 grams they begin to migrate out of the inner confines of Sitka Sound. It is evident that growth rates and timing can be dramatically influenced by the physical conditions and productivity of the zooplankton populations within Sitka Sound. It appears that one of the most important factors influencing this productivity is water temperature.

Building a Collaborative Chum Salmon Microsatellite Baseline for the Yukon River Genetic Stock ID

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Abstract

A baseline of 17 Yukon River chum salmon populations common to both labs was screened using microsatellite genetic markers in a collaborative project between the Conservation Genetics Laboratory, U.S. Fish and Wildlife Service (USFWS) and the Molecular Genetics Laboratory, Canadian Department of Fisheries and Oceans Canada (CDFO). Each laboratory developed and screened a suite of microsatellite loci for the same baseline fish samples as well as analyzed 1,200 mixed-stock fish from the lower river (Pilot Station). A combined marker set of 22 loci was used to define nine reporting regions: Lower River summer, Tanana summer, Koyukuk summer, Tanana falls, Upper Alaska, Canadian Porcupine, White River, Teslin River, and Canadian mainstem. The degree that these reporting regions are identifiable in the mixtures was tested with 100% single-population simulations. Correct mean allocations from single-population simulations achieved the 90% threshold for seven of the nine regional groups. Analysis of accuracy and precision indicate that ~300 alleles are required to exceed an average correct allocation greater than 90% for all reporting regions with a standard deviation of less than 3%. The Pilot Station mixed-stock sample indicates that both CDFO and USFWS baselines provide very similar regional estimates of stock composition over the six sampling intervals. Summer-run chum salmon contributed ~40% of the first sampling interval. Following sampling intervals showed an increase in Border Canada and Border US fall-run populations, followed by an increase in Tanana Fall populations by the end of August.

Introduction

Yukon River chum salmon undertake the longest freshwater migration of chum salmon in North America, some individuals traveling over 2,700 kilometers upstream (Beacham et al. 1988). Effective management of fisheries within this major drainage requires the knowledge of exploitation rates on specific population or population groups. Accurate and timely estimates of stock composition from the lower river are required to meet target allocations and escapement goals for both Canada and the US under the Yukon River Salmon Agreement (YRSA). For Yukon chum salmon, lower-river migration timing and abundance estimates are determined at Pilot Station using acoustic counters and a gillnet drift test fishery (Maxwell and Huttunen 1998).

Previous work using allozymes on Yukon River chum salmon (Beacham et al. 1988; ADFG unpub. data) indicate five regional groups can be identified; these are Lower Summers, Tanana Fall, Boarder US/Canada, White River, and Teslin River. However, allozyme analysis failed to discriminate the border populations well enough for management needs. Microsatellite variation in a number of species has been useful in providing increased level of stock discrimination for salmonid populations passing through lower-river mixed-stock fisheries (Beacham and Wood 1999; Beacham et al. 2000). In this paper we look at the discrimination power of a combined microsatellite dataset from the USFWS and CDFO labs for Yukon River chum salmon and compare results from two independent baselines for the same lower river mixed-stock fishery samples.

Methods

Microsatellite loci

The CDFO lab screened baseline populations with 13 microsatellite loci with 11 to 87 alleles per loci and the USFWS lab screened for 11 microsatellite loci with between 2 to 36 alleles per loci (Table 1). Two loci, *Oke3* and *Ots3*, were run by both labs resulting in a combined maker set of 22 loci.

Table 1**.** – List of loci and number of alleles found in Yukon River chum salmon, where A is the USFWS lab loci and B is the CDFO lab loci.

A			**B**	
Locus	**# alleles**		**Locus**	**# alleles**
Oke3	8		Oke3	11
Oke4	5		Oki100	24
Oke8	2		Oki2	19
Oke11	5		Omy1011	32
Oki1L	3		One101	39
Oki1U	18		One102	37
Oki23.1	4		One103	31
Ots2.1L	3		One104	28
Ots2.1U	6		One111	87
Ots 3.1	16		One114	35
Ots103	36		Ots3	24
			Otsg68	39
			Ssa419	17

DNA was extracted from the samples either as described by Withler et al. (2000) or by using proteinase K with the Dneasy™ DNA isolation kit (Quiagen Inc. Valencia, CA). At the CDFO laboratory, PCR products from 13 microsatellite loci (*Ots3* [Banks et al. 1999], *Oke3* , *Oki2* [Smith et al. 1998], *Oki100* , *Omy 1011*, *One101, One102, One103, One104, One111,* and *One114* [Olsen et al. 2000], *Ssa419* [Cairney et al. 2000], and *OtsG68* [Williamson et al. 2002]) were size fractionated on denaturing polyacrylamide gels with the ABI 377 automated DNA sequencer. Allele sizes were determined with Genescan 3.1 and Genotyper 2.5 software (PE Biosystems, Foster City, CA).

The USFWS laboratory, analyzed PCR products from 11 microsatellite loci: *Oke3, Oke4, Oke8, Oke11*, *Oki1, Oki23.1* (Smith et al. 1998.), *Ots2.1, Ots3.1* (Banks et al. 1999), and *Ots103* (Small et al. 1998). One µl of PCR product was electrophoresed and visualized on a denaturing 6% polyacrylamide gel using a Li-Cor IR2® DNA scanner. The sizes of bands were estimated and scored by the computer program Saga GT version 3.1 (Li-Cor, Lincoln, NE). Li-Cor size standards (50bp–350bp) and allele ladders were run every 16 lanes to ensure consistency of allele scores. All scores were verified by eye. Alleles were scored by two independent researchers, with any discrepancies being resolved by re-running the samples in question and repeating the double-scoring process until scores matched.

Baseline populations

The USFWS lab analysed samples from 18 populations, while the CDFO lab analysed samples from 23 populations providing a baseline of 17 populations in common between the two labs (Table 2). Due to poor sample quality and low DNA amplification success the Big Salt sample was left out of the analysis. The reporting regions differed slightly between the two labs. CDFO defined reporting regions on a finer scale than the USFWS. This was due to higher level of discrimination from the CDFO loci and greater number of populations present in the CDFO baseline. Allele frequencies for each population were derived from combining annual sampling using methods of Waples (1990). Sampling locations for the 23 populations can be seen in Figure 1.

Table 2. List of Yukon Chum populations, sampling year, and number of fish surveyed by each lab for baseline, where A is the USFWS baseline and B is the CDFO baseline.

A

Population/Regional Group	N
Lower Summer	
Chulinak 1989	100
Middle Summer	
Chena 1992, 1994	186
Salcha 1994, 2001	185
Jim 2002	160
S F Koyukuk Early 1996	100
S F Koyukuk Late 1996	100
Big Salt 2001	71
Tanana Fall	
Delta 1990	80
Toklat 1994	200
Kantishna 2001	161
Border USA	
Chandalar 1989, 2001	250
Sheenjek 1988, 1989	154
Black 1995	112
Border Canada	
Fishing Branch 1989, 1992	150
Tatchun 1992	100
Big Creek 1992	100
Upper Canada	
Kluane 1992, 2001	250
Teslin 1992	100

B

Population/Regional Group	N
Lower Summer	
Chulinak 1989	100
Andreafsky 1987	61
Tozitna 2002	200
Koyukuk Summer	
Jim 2002	159
S F Koyukuk Early 1996	100
S F Koyukuk Late 1996	100
Tanana Summer	
Chena 1992, 1994	186
Salcha 1994, 2001	185
Tanana Fall	
Delta 1990	80
Toklat 1994	200
Kantishna 2001	161
Upper Alaska	
Big Salt 2001	71
Chandalar 2001	200
Sheenjek 1987, 1988, 1989	263
Black 1995	95
Canadian Porcupine	
Fishing Branch 1987, 1994, 1997	331
Chandindu River	
Chandindu	55
White	
Kluane 1987, 1992, 2001	462
Teslin 1992, 2001	143
Donjek 1994	72
Teslin	
Teslin 1992, 2002	143
Mainstem Yukon	
Tatchun 1987	75
Big Creek 1995	100
Pelly 1993	84
Minto 1989, 2002	166

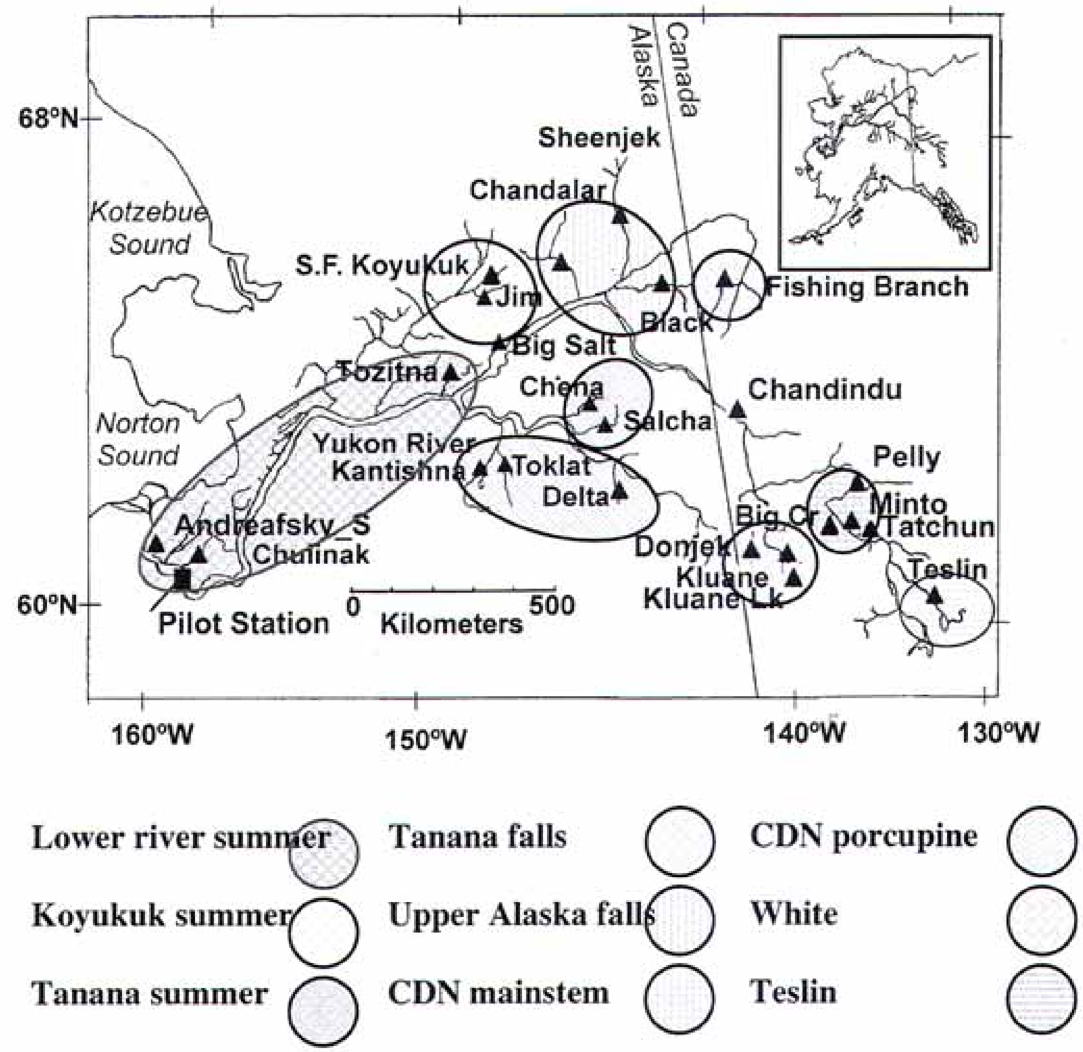


Figure 1 – A map of sampling sites and regional groups of Yukon River chum salmon determined from 22 microsatellite loci using the USFWS/CDFO baseline.

Analysis of the combined USFWS/CDFO 17-population baseline included visualization of genetic structure using cord distance (Cavalli-Sforza and Edwards 1967) and neighbor joining tree from the program PHYLIP (Felsenstein 1993). The ability to discriminate to reporting groups was assessed using 100% single-population simulations using SPAM version 3.7 (Debevec et al. 2000). The program was run with the Rannala and Mountain (1997) data augmentation routine to avoid having fish in the mixture with alleles not observed in the baseline. The number of alleles required for accurate estimation to reporting group was also tested using 100% single-population mixtures, where increasing cumulative number of alleles varied for each run of the estimation.

Pilot Station samples

Every chum salmon caught in Pilot Station sonar test fisheries from July 19–Aug 31, 2004 was sampled (Figure 1). For management purposes, fish entering the river after July 19 are assumed to be "fall-run" fish (Bue et al. 2004). The Pilot Station samples were stratified by run pulse; 200 fish per stratum were analyzed. The periods were designated "build-up" (July 19–Aug 2), "Pulse 1" (Aug 3–9), "Pulse 2" (Aug 10–15), "Pulse 3" (Aug 16–21), "Pulse 4" (Aug 22–26), and "Pulse 5" (Aug 27–31). The tissue samples from the Pilot Station test fisheries were sub-sampled, proportional to the daily sonar passage estimate, at the USFWS lab and sent to the CDFO lab. The samples were genotyped by each lab using the respective suites of loci used in the two baselines. The USFWS lab provided stock composition estimates for each sample strata using Bayes mixture model (Pella and Masuda 2001), and an 18-population baseline. The CDFO lab analyzed the same mixture samples using CBayes (a C++ rewrite of the Bayes program by CDFO), and a 23-population baseline. Results were reported by USFWS reporting regions.

Results and Discussion

The USFWS lab identified six regional groups: Lower River Summer, Middle Summer, Tanana fall, Border USA, Border Canada and Upper Canada (Table 2). Nine reporting regions were identified using the combined baseline dataset. These are Lower River summer, Tanana summer, Koyukuk summer, Tanana falls, Upper Alaska, Canadian Porcupine, White River, Teslin River, and Canadian mainstem. Figure 2 shows the unrooted dendrogram of genetic distances between the 17 populations using the combined dataset of 22 loci and an overlay of the 9 regional groups. The lower left of the dendrogram consists of populations geographically located in the lower river, and the upper right of the dendrogram consists of upper river fall run populations. Figure 1 shows the location of these sample sites and geographic relationships among these regional groupings.

Mean allocation from simulated mixtures composed of 100% single reporting regions are thought to perform well if the mean contribution is greater than 90%. Reporting regions that had correct allocations greater than 90% were Lower River summer, Tanana summer, Tanana falls, Upper Alaska, Canadian Porcupine, White River, and Teslin River (Table 3). Two regional group contributions were slightly less than 90%; Koyukuk summer at 89.7%, with allocation lost to Lower summer, and Canadian mainstem (84.2%), with allocation lost to Upper Alaska. Inclusion of new baseline populations and increasing sample sizes of existing populations should allow better characterization of these two under performing reporting groups.

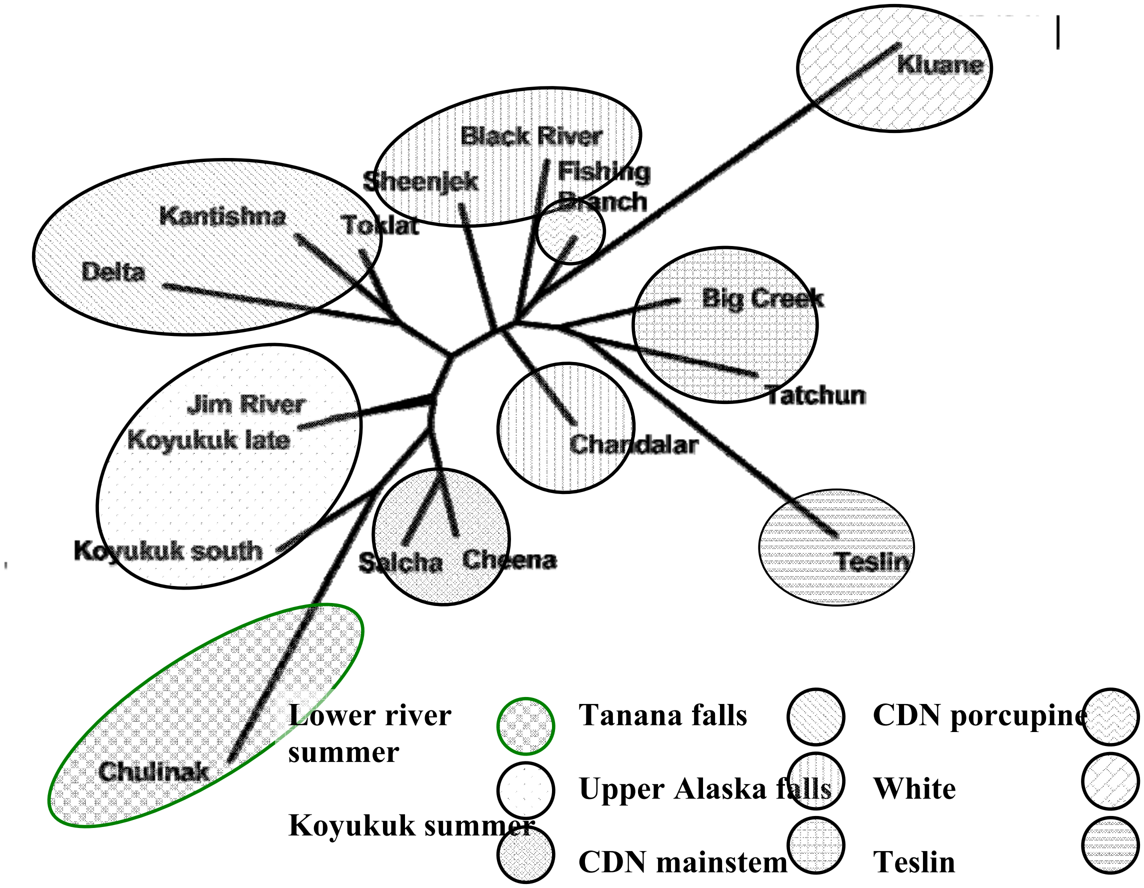


Figure 2. Unrooted dendrogram of genetic distances (Cavalli-Sforza and Edwards 1967) for 17 Yukon River chum salmon populations using 22 microsatellite loci from the combined USFWS/CDFO baseline.

The relationship between the number of alleles present in the analysis and accuracy to reporting region is non-linear; estimates approach 100% asymptotically as the allele number increases (Figure 3). Using just the USFWS loci with 106 alleles average accuracy to regional group was 87% with a standard deviation of 4%. By using the additional 400 CDFO loci alleles the accuracy to regional group increased to 92% with a standard deviation of 1.7%. It took approximately 300 alleles to exceed the 90% threshold thought to be required for accurate stock identification in mixture analysis.

Table 3. Region estimates assuming 100% single population in mixture (N=400) using 22 loci from the combined USFWS/CDFO baseline. *indicates less than 90% allocation required for accurate estimate to region.

	Estimate	**Std. Dev.**
Lower river summer	93.3	(1.5)
Koyukuk summer	89.7*	(2.1)
Tanana summer	93.7	(1.7)
Tanana fall	93.2	(1.6)
Upper Alaska fall	91.4	(2.0)
Canadian mainstem	84.2*	(2.6)
White	98.7	(0.6)
Canadian Porcupine	93.5	(1.8)
Teslin	94.2	(1.3)

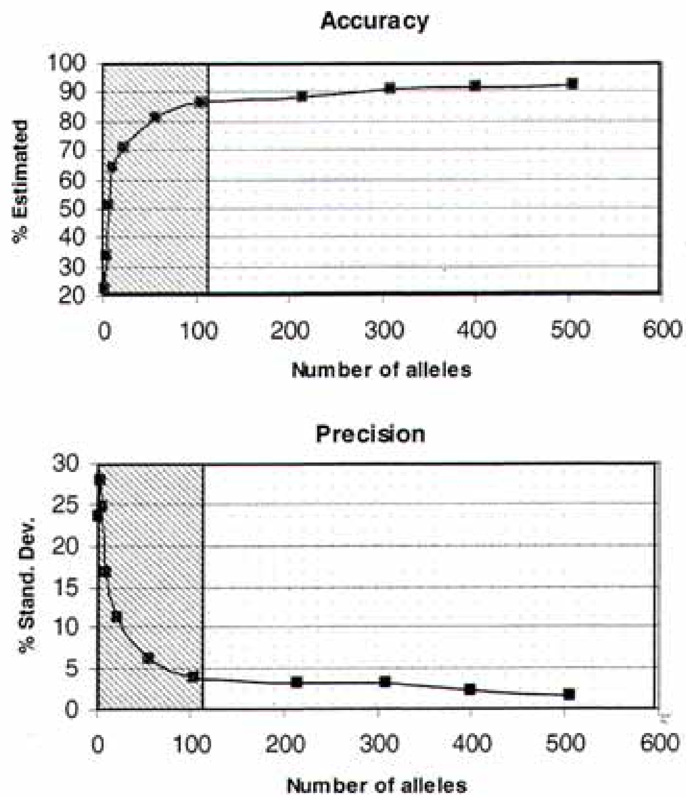
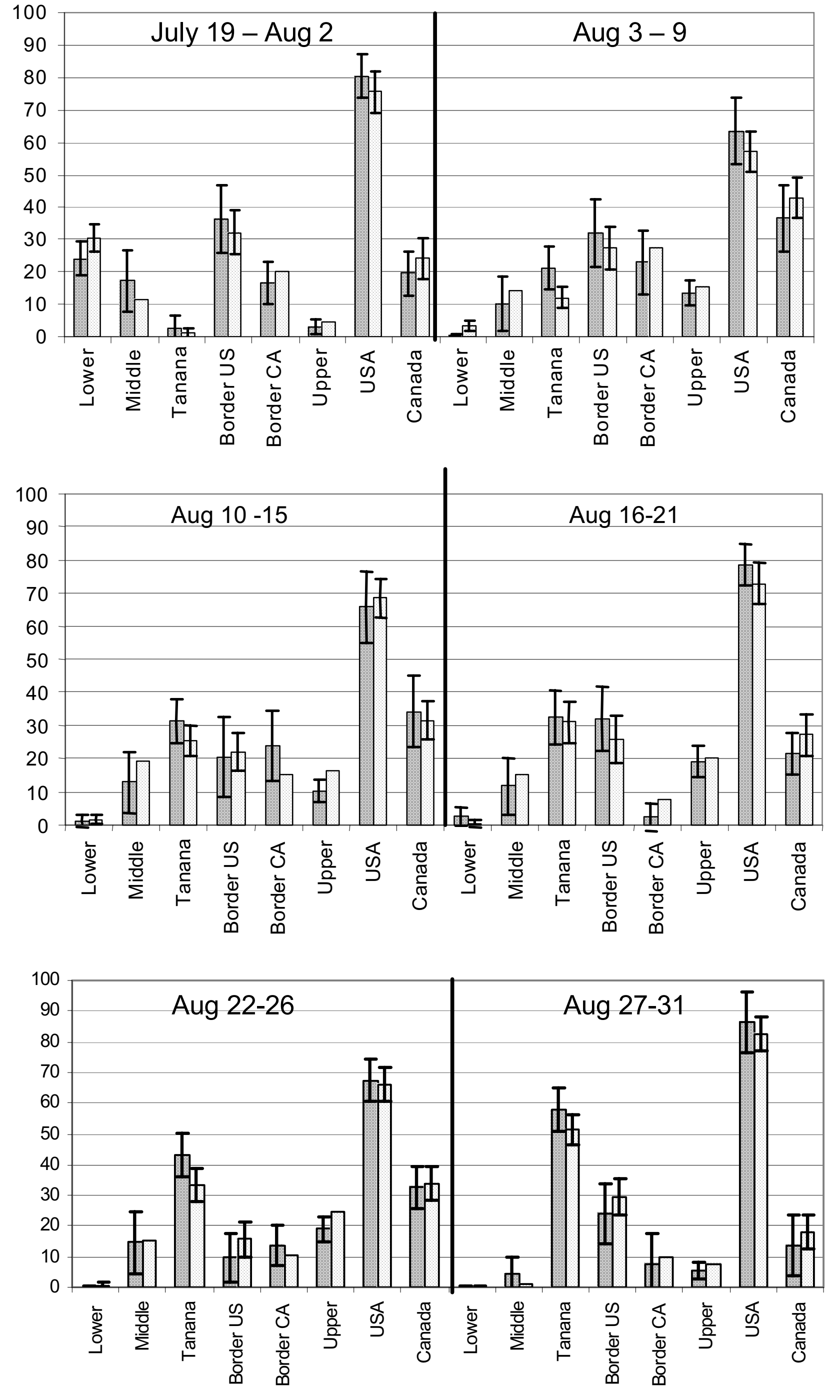


Figure 3. Average regional estimates (nine reporting regions) of accuracy and precision plotted against cumulative allele counts for USFWS (diagonal slash) and CDFO (stippled) loci. Estimates to a region were based on assuming mixture with 100% single population, where more than one population exists in a region. The average values for all runs were used for the regional estimate.

Analysis of the Pilot Station mixture sample indicated that both the USFWS baseline and the CDFO baseline produced very similar results (Figure 4). Analyses of samples indicated that summer chum salmon are still a significant contributor during the early portion of the fall management season, comprising ~40% of the Build-up stratum, but dropped precipitously in subsequent strata. Border Canada, Border US, and Upper Canada reporting groups showed an increase in the early August, presumably as headwater populations moved through the lower river. Toward the end of August the Tanana fall-run fish became the single biggest contributor.

Figure 4 – Comparison of Pilot Station mixture analysis on the same fish using the USFWS (back slash) and the CDFO (stippled) baseline.



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ESA-listed Hood Canal Summer Chum Salmon: A Brief Update on Supplementation Programs, Extinction Risk, and Recovery Goals

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Abstract

Hood Canal summer chum salmon (including the eastern Strait of Juan de Fuca) were listed as threatened under the Endangered Species Act in 1999. Recovery planning and implementation were underway prior to the listing, with harvest reductions and supplementation programs enacted in the early 1990s. Run sizes of summer chum salmon have been on the rise since the mid-1990s, with the 2004 return being the largest on record. The average harvest rate has declined from nearly 55% before recovery actions were implemented, to less than 10% in the subsequent years. Extinction risks have decreased for all stocks classified at *high* or *moderate risk* of extinction prior to implementation of recovery actions. Supplementation programs have succeeded in reducing the extinction risk of several stocks that were at critically low levels prior to supplementation, and these stocks have demonstrated strong returns of both supplementation-origin and natural-origin fish in recent years. Reintroduction programs also appear to be succeeding, with natural-origin spawners returning to two streams where summer chum salmon had been extinct for more than 10 years. Interim recovery goals for summer chum salmon have been developed by the Washington Department of Fish and Wildlife and the Point No Point Treaty Tribes based on historic population sizes and include abundance, escapement, productivity, and diversity targets. These interim goals will be reviewed and revised as more is learned about the population dynamics of Hood Canal summer chum salmon. Summer chum populations are not yet meeting the co-managers' abundance-based recovery goals, due in part to the requirement that all stocks meet recovery abundance thresholds over a period of 12 years. The outlook for summer chum salmon, however, is certainly much brighter than it was just 10 years ago.

Introduction

Hood Canal summer chum salmon (including stocks in the Strait of Juan de Fuca) experienced a severe decline in abundance in the 1980s. Abundances reached record lows in 1989 and 1990, with less than 1,000 spawners escaping to the region each year. In 1992, the state and tribal co-managers implemented harvest reductions aimed at protecting summer chum salmon, and together with the U.S. Fish and Wildlife Service and local citizen groups, initiated three hatchery supplementation programs utilizing native brood stocks. In 1999, the Hood Canal summer chum salmon Evolutionarily Significant Unit was listed as threatened under the Endangered Species Act. In 2000, the co-managers completed the Summer Chum Salmon Conservation Initiative (SCSCI; WDFW and PNPTT 2000), a recovery plan that formalized and expanded on the recovery efforts already initiated for Hood Canal summer chum salmon.

Since recovery efforts for Hood Canal summer chum salmon were initiated, six supplementation and three reintroduction programs have been undertaken. Harvest rates on summer chum salmon have been severely curtailed and these stocks are currently managed under the harvest management plan described by the SCSCI. Harvest rates dropped from an average of 54.7% during the years of decline (1980–1991) to an average of 9.8% after reductions (1992–2004). A variety of habitat restoration and protection projects have been undertaken on summer chum salmon streams and estuaries. Reports covering stock assessment, management, and supplementation activities from 2000–2002 have been completed, and the co-managers have identified interim recovery goals for summer chum salmon. This paper gives general updates on population trends, extinction risks, and supplementation programs for Hood Canal summer chum salmon, and briefly explains the co-managers' interim recovery goals. For more detailed information, consult the SCSCI report series available on the Washington Department of Fish and Wildlife (WDFW) website.

Abundance Trends and Extinction Risk

Abundances of summer chum salmon in Hood Canal declined from the late 1970s through the early 1990s (Figure 1). All stocks of summer chum salmon in Hood Canal except the Union River suffered declines in abundance during this period, with several

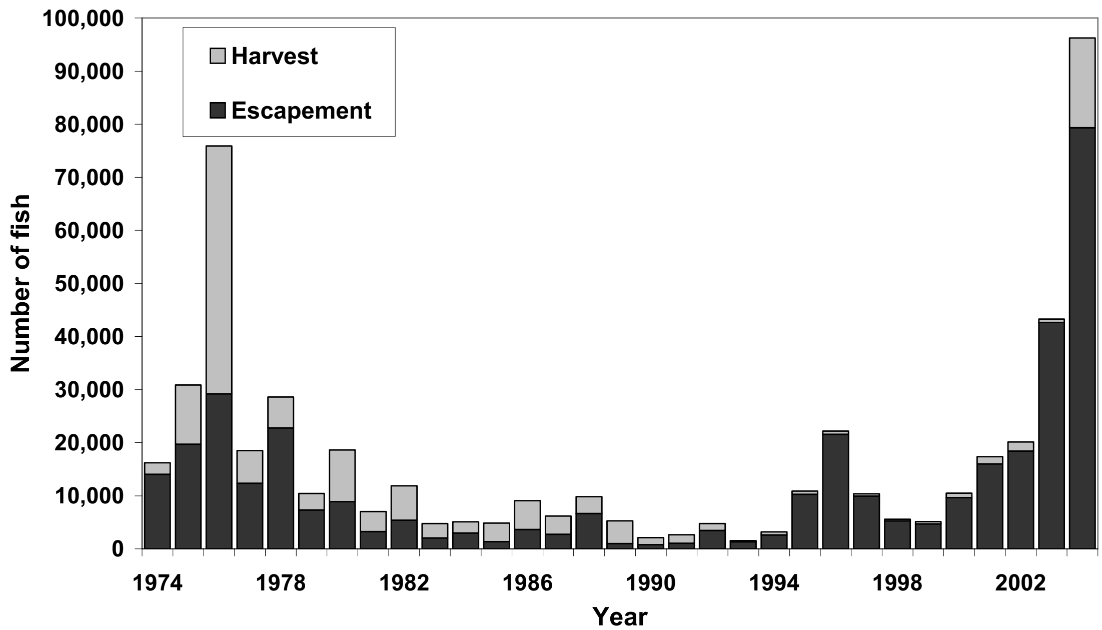

Figure 1. Total escapement and harvest of summer chum salmon returning to Hood Canal and the Strait of Juan de Fuca, 1974-2004.

stocks becoming extinct, and several others being classified at high risk of extinction (Table 1) based on methods presented by Allendorf et al. (1997). In the Strait of Juan de Fuca, the decline started approximately 10 years later, with a noticeable and lasting drop in abundance in 1989. By 1992, seven of the twelve summer chum stocks known to have inhabited Hood Canal were extinct, six were rated at *moderate* or *high risk* of extinction, and one was of unknown status.

Table 1. Mean escapement, estimated single-generation effective populations size, total population size, population trend, and extinction risk rating for Hood Canal and Strait of Juan de Fuca summer chum stocks for the 4 years proceeding onset of recovery actions, and the most recent 4 years. Extinction risk calculations are based on methodology proposed by Allendorf et al. (1997).

Stock/years	Escapement (4-year mean)	Effective Population Size (N_e)	Total Population Size (N)	Population Trend	Extinction Risk Rating
Hood Canal					
Union					
1988–1991	391	281	1,406	Stable	*Moderate*
2001–2004	5,064	3,646	18,230	Increasing	*Low*
Lilliwaup					
1988–1991	88	63	315	Chronic decline/depression	*High*
2001–2004	580	418	2,088	Increasing	*Moderate*
Hamma Hamma					
1988–1991	154	111	555	Chronic decline/depression	*High*
2001–2004	1,775	1,278	6,390	Increasing	*Low*
Duckabush					
1988–1991	175	126	631	Chronic decline/depression	*High*
2001–2004	2,995	2,156	10,780	Increasing	*Low*
Dosewallips					
1988–1991	234	168	842	Chronic decline/depression	*High*
2001–2004	5,308	3,822	19,109	Increasing	*Low*
Big/Little Quilcene					
1988–1991	89	64	319	Chronic decline/depression	*High*
2001–2004	15,437	11,115	55,572	Stable/increasing	Low
Strait of Juan de Fuca					
Snow/Salmon					
1989–1992*	283	204	1,018	Precipitous decline	*High*
2001–2004	5,303	3,818	19,091	Increasing	*Low*
Jimmycomelately					
1989–1992*	244	176	879	Precipitous decline	*High*
2001–2004	610	439	2,196	Increasing	*Moderate*
Dungeness	No data	N/A	N/A	N/A	*Special concern*

*1989–1992 escapement values used due to later onset of decline of Strait of Juan de Fuca stocks.

Populations rebounded to higher levels quickly in the mid-1990s, after the initiation of harvest reductions and several supplementation programs. Larger escapements were seen from 1995 to 1997 for the major streams entering the west side of Hood Canal, including a new record escapement for Big Quilcene in 1996, although a significant portion of the Quilcene return was thought to be of supplementation origin (see the supplementation section for details on supplementation programs and their evaluation). Abundances were down again in 1998 and 1999 (although still five times higher than abundances just prior to recovery efforts) but began to increase in 2000. The lower abundances in 1998 and 1999 were likely caused by high stream flows during the incubation periods of the 1995 and 1996 broods, and corresponding reduced survival. The 2003 and 2004 escapements were the largest on record, with a total of over 79,000 fish escaping to the region in 2004. However, 2004 is the peak return year in a strong 4-year run-size cycle, and production will likely decline in 2005 as the run cycles down from the high year. Mark data indicates that 75% of the fish returning in 2003 were of natural origin, so the success has not been limited to supplementation-origin fish. Analysis of otoliths collected in 2004 is ongoing, but a similar high contribution of natural-origin recruits is expected.

Extinction risks for all stocks have decreased since the onset of recovery activities (Table 1). The total population size has increased in each population, and in the 2001–2004 period the estimated single-generation effective population sizes per generation has been greater than 500 fish for all but two stocks (Table 1). In addition, three stocks have been introduced into watersheds where the indigenous stock was extinct, further reducing the extinction risk for the donor stocks and reinitiating natural summer chum production in these streams.

Supplementation Programs

Artificial production was identified as an important tool for use in recovery of summer chum salmon, and supplementation programs were initiated early in the recovery process. Supplementation as a salmon recovery tool has been the subject of much debate, in part due to differing application of the term *supplementation*. Supplementation, as defined by the SCSCI, is, "the use of artificial propagation to maintain or increase natural production while maintaining the long-term fitness of the target population, and keeping the ecological and genetic impacts to non-target populations within specified biological limits." Implicit in this definition is the intent to halt supplementation when the wild population has recovered.

The controversy surrounding the use of artificial production techniques to supplement depressed wild salmon populations is based on the uncertainty of whether this type of intervention would lead to irreversible losses of fitness and genetic diversity and a concern that the hatchery programs would continue indefinitely to enhance fishing opportunities. Because of past chum salmon supplementation successes (Ames and Adicks 2003), the co-managers were confident that well-founded hatchery programs would result in rapid increases in the numbers of returning fish and a corresponding reduction in extinction risk. The primary challenge facing the co-managers was to develop a set of protocols that would minimize deleterious effects on supplemented stocks.

The definition of supplementation used in the SCSCI is central to the strict criteria and standards used for selecting and conducting supplementation programs for Hood Canal summer chum salmon. Supplementation is to be used only when a summer chum stock is at risk of extinction or to develop a broodstock in support of a program to reintroduce summer chum salmon to previously occupied habitats. Tynan et al. (2003) summarized the strict standards guiding supplementation programs set forth by the SCSCI. These standards included strategies for minimizing potential deleterious effects of supplementation and requirements for monitoring and evaluation of supplementation programs. Schroder and Ames (2004) further detailed specific protocols to be followed during artificial production to insure the SCSCI standards are met. Early results of monitoring and evaluation of supplementation programs are presented in WDFW and PNPTT (2001, 2003). A brief overview and some specifics on two of the programs are presented here.

Table 2 lists the supplementation (and reintroduction) programs undertaken to date for Hood Canal summer chum salmon. Four of the programs have been terminated after reaching adult-return targets (Quilcene, Salmon, Chimacum, and Union); two of those were terminated before the 3-generation (12-year) maximum duration was reached, due to success in meeting adult-return targets (Chimacum and Union).

Table 2. Brood years that summer chum salmon supplementation or reintroduction programs and mass marking of fry releases (otolith marking or adipose clipping) were initiated and terminated in Hood Canal and eastern Strait of Juan de Fuca streams and the first year marked adults from the programs are/were expected to return.

Supplementation/ reintroduction program	Brood year program initiated	Brood year mass marking initiated	First year marked adults to return[1]	Brood year program terminated
Salmon Creek	1992	1993	1996	2003
Big Quilcene River[2]	1992	1997	2000	2003
Lilliwaup Creek[3]	1998	1997	2000	
Chimacum Creek (reintro.)	1996	1999	2002	2003
Big Beef Creek (reintro.)	1996	1998	2001	
Hamma Hamma Creek	1997	1997	2000	
Jimmycomelately Creek	1999	1999	2002	
Union River	2000	2000	2003	2003
Tahuya River (reintro.)	2003	2003	2006	

[1] First year of returning age-3 fish is shown. Most adults return at ages 3 and 4, with perhaps a few at ages 2 and 5.
[2] Adipose clip.
[3] Attempts to initiate supplementation efforts at Lilliwaup began in 1992, but broodstock collection efforts were largely unsuccessful until the 1998 brood, when a functional trap was first installed on the creek.

Since 1997, all supplementation fish have been mass marked, with adipose clips used for Quilcene, and program-unique otolith marks for all other programs. Beginning with the 2001 return, all supplementation origin recruits were identifiable as supplementation fish and also could be identified to program of origin. Reintroduction fish were not necessarily marked for the first few years of the program, since the streams selected for reintroduction did not have extant summer chum populations, and all returns were assumed to be of supplementation origin.

Summer chum salmon adults returning to Hood Canal streams are sampled for marks as a part of broodstock collection and on the spawning grounds. This allows estimation of the proportions of natural-origin and supplementation-origin returns, and the evaluation of return rates and straying of supplementation-origin fish. Scales were also sampled, allowing analysis of age structure and productivity for natural-origin fish and analysis of contributions of supplementation-origin fish, by brood year. Sampling effort has increased each year, with over 4,100 fish sampled for scales and 3,500 for otoliths in 2004. From 2001 to 2003, percentages of supplementation-origin recruits declined each year, accounting for 45%, 37%, and 26% of annual summer chum returns. Those percentages will decrease even further as programs are terminated, and summer chum salmon populations return to unsupplemented production.

Big Quilcene River

The Quilcene summer chum salmon supplementation program was one of the original programs undertaken in 1992 and was the largest program undertaken in terms of numbers of fry produced. The program was operated by the U.S. Fish and Wildlife Service at the Quilcene National Fish Hatchery. In addition to rebuilding the Quilcene stock (in the Big and Little Quilcene rivers), the program was intended to supply fry for the reintroduction of summer chum salmon to Big Beef Creek. Since 1995 (the first year of returns from the supplementation program) combined escapement to the Big and Little Quilcene has exceeded the pre-decline mean escapement; this led to a reduction in the target fry release number for the program in its last two years of operation (2002 and 2003). Because mass marking of fry did not begin until the 1997 brood, it is not possible to separate supplementation-origin returns from natural-origin returns until 2001. Data from 2001 through 2004 show supplementation returns ranging from 1,258 to 3,354 fish. Perhaps the most interesting development has been the number of natural-origin recruits returning to Quilcene in those years, with total escapement increasing from 3,229 in 2001 to 35,775 in 2004 (Figure 1). This is a very encouraging sign, as it indicates that the Quilcene stock can produce large numbers of summer chum salmon without the aid of supplementation.

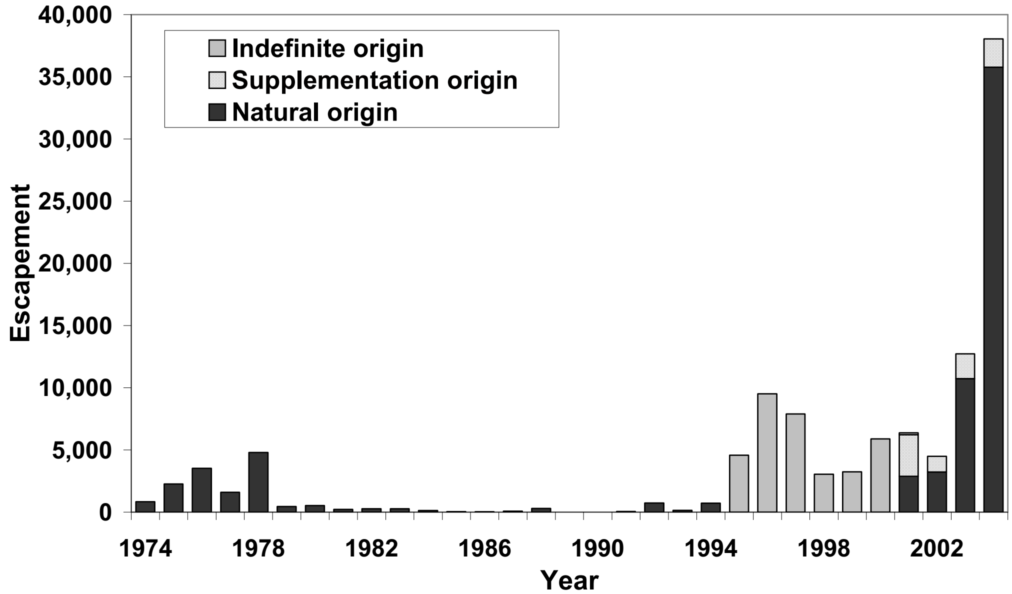

Figure 1. Escapement of summer chum salmon to Big and Little Quilcene rivers, 1974-2004.

Chimacum Creek.

Chimacum Creek supported an indigenous summer chum salmon population until the mid-1980s, when a combination of habitat degradation and poaching evidently led to its extinction (WDFW and PNPTT 2000). A supplementation program aimed at boosting numbers of summer chum salmon in Salmon Creek was initiated in 1992 by Wild Olympic Salmon, with the goal of using the Salmon Creek stock as the donor for reintroduction to Chimacum. Beginning in 1996, eyed eggs were transferred from Salmon Creek for incubation, rearing, and release as fed fry in the Chimacum watershed. Adult summer chum salmon returned to Chimacum Creek in 1999, with the first resulting natural-origin recruits returning in 2002 (Figure 2). Initial estimates show that the first two broods of natural spawners after reintroduction have resulted in return rates greater than four recruits per spawner. Due to the number of fish returning from 2001–2003, and due to the success of natural-origin spawners, Chimacum Creek hatchery releases were terminated after the 2003 brood, only eight years after the first fry release.

It is important to note that although Chimacum Creek is now supporting its own summer chum run, the Chimacum stock is still considered to be extinct. For the present time, summer chum salmon returning to Chimacum Creek are considered to be a range extension of the donor stock, Salmon Creek. The same idea applies to Big Beef Creek, whose summer chum salmon are considered a range extension of the Quilcene stock. The same principle will apply to Tahuya River, when reintroduced chum salmon of Union River origin begin returning there.

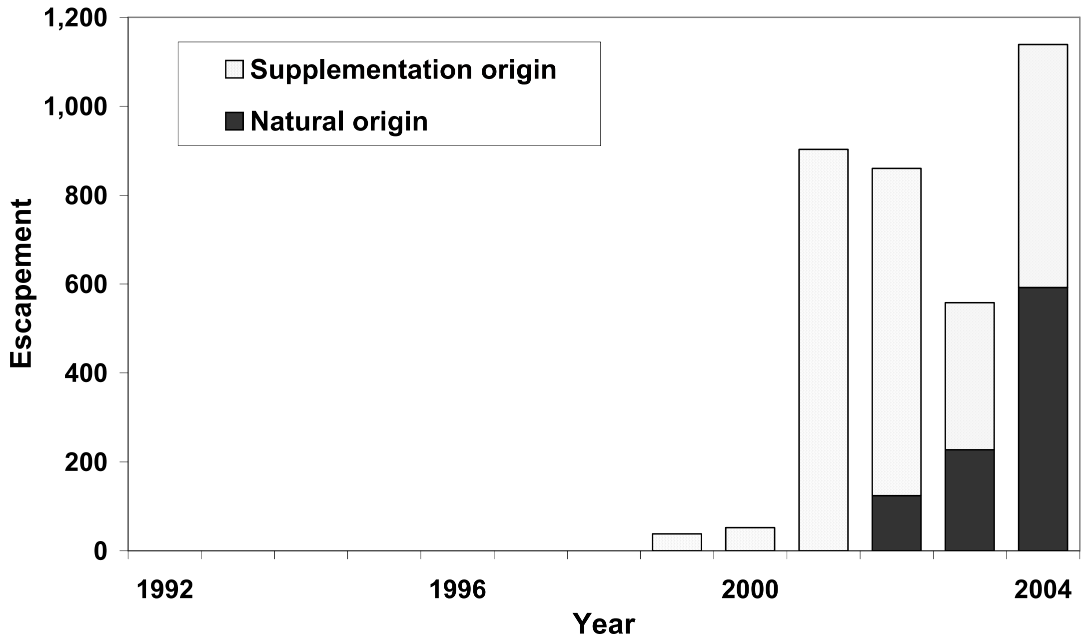

Figure 2. Escapement of summer chum salmon to Chimacum Creek, 1992-2004.

Other Supplementation Programs
Similar information is available for the other summer chum salmon supplementation and reintroduction programs. For more information, refer to WDFW and PNPTT (2000, 2001, and 2003). Additional reports with updated data will be published on a regular basis in the future.

Recovery Goals

While the original SCSCI report provided the basis for protection and recovery of Hood Canal summer chum salmon, it did not describe specific recovery goals for summer chum salmon. Supplemental Report No. 5 to the SCSCI (PNPTT and WDFW 2003) presents the co-managers' interim recovery goals for summer chum salmon. The goals were developed with the information available at that time, with the expectation that the recovery standards will be reviewed and revised as more is learned about the population dynamics of Hood Canal summer chum salmon.

The recovery goals were based on historic (pre-decline) population sizes, and include abundance, escapement, productivity, and diversity targets. While sporadic spawner escapement data for Hood Canal summer chum salmon date back to the 1940s, reliable escapement and abundance data are available from 1974 to present. Because population declines for many stocks had begun by the late 1970s, there is limited data available representing pre-decline population sizes. Table 3 shows the period of time considered to represent pre-decline population sizes, and the average pre-decline population size values were adopted as the abundance recovery thresholds.

Table 3. Recovery escapement and abundance thresholds as established by co-managers (PNPTT and WDFW 2003), and pre-decline time periods used for determining recovery abundance thresholds.

Hood Canal Stocks	Pre-decline period	Escapement threshold	Abundance threshold
Quilcene	1974–1978	2,860	4,570
Dosewallips	1974–1980	1,930	3,080
Duckabush	1974–1980	2,060	3,290
Hamma Hamma	1974–1979	3,790	6,060
Lilliwaup	1974–1978	1,960	3,130
Union	1974–2000	340	550
Strait of Juan de Fuca Stocks			
Salmon/Snow	1974–1989	970	1,560
Jimmycomelately	1974–1989	330	520

Unfortunately, historic age data were inadequate to estimate brood-specific returns, meaning that recruit-per-spawner values cannot be calculated. However, annual escapement and abundance data could be used to estimate overall productivity of summer chum salmon during that period. For the purposes of recovery, the co-managers selected a productivity threshold of 1.6 recruits per spawner. This goal was close to historic productivity estimates for Hood Canal summer chum salmon and within the range of productivities observed for other chum salmon populations. It was believed that meeting this productivity goal, along with abundance targets, would ensure sustainability and could accommodate lessening some of the restrictions on fisheries. Targets for escapement were set by dividing the abundance targets by the productivity targets (Table 3), meaning that these three targets are interlinked.

In addition to setting these escapement, abundance, and productivity thresholds, the recovery goals specify criteria for meeting the thresholds. For each stock, the mean natural-origin abundance and spawning escapement must exceed the thresholds over the most recent 12 years. In addition, the natural-origin abundance and escapement of each stock cannot be lower than the stock's critical thresholds (as described in the SCSCI) in more than two of the most recent eight years or more than once in the most recent for years. Finally, the return-per-spawner rate for natural-origin spawners must average at least 1.6 over the most recent eight brood years for which estimates exist, and no more than two years of eight shall fall below 1.2 returns per spawner.

To address diversity, the recovery goals also specify that the eight extant stocks of Hood Canal summer chum salmon must all meet their individual stock criteria. This means that as a whole, the regional escapement and abundance must exceed the sum of the individual stock thresholds. The decision to require recovery of all extant stocks was based in part on the fact that nearly half of the summer chum stocks recognized to have existed historically are now extinct. In addition to this regional abundance requirement, the harvest, habitat, and supplementation approaches outlined by the SCSCI were all designed to be supportive of population diversity.

Despite recent abundant returns of Hood Canal summer chum salmon, it will be some time before stocks can meet recovery thresholds over the period of twelve years required by the recovery goals. In addition, only a few observations of return-per-spawner data have been collected, while eight full broods are required for stocks to meet the productivity requirement. These interim goals will be revisited as more is learned about summer chum salmon population dynamics and productivity. One important issue remaining involves how to include reintroduced summer chum salmon populations in recovery goal setting.

Conclusions

Again, the overall goal of the SCSCI is, "to protect, restore and enhance the productivity, production, and diversity of Hood Canal summer chum salmon and their ecosystems to provide surplus production sufficient to allow future directed and incidental harvests of summer chum salmon." The SCSCI acknowledged that both short-term and long-term measures would be necessary to meet that goal. Recent returns of summer chum salmon to Hood Canal indicate that the short-term measures have been highly successful. Harvest reductions and supplementation programs, along with favorable freshwater and marine conditions, have all contributed to recent success. The total abundance and escapement of summer chum salmon in 2004 were the largest on record for Hood Canal. Although summer chum salmon stocks are not yet meeting the co-managers' recovery targets, recent returns are a positive sign that the goals can be met.

The true test of success will be in the longterm, as supplementation programs are discontinued, and as summer chum salmon potentially face less favorable freshwater and marine survival regimes. There is good reason to be optimistic that summer chum salmon can remain at abundances higher than pre-supplementation levels even after supplementation is stopped, as has happened with past chum salmon supplementation programs (Ames and Adicks 2003). Continued monitoring of escapement and abundances, careful management of harvest rates, and commensurate protection and restoration of habitat critical to Hood Canal summer chum salmon are all imperative if the goal of the SCSCI is to be met. On-going data collection will contribute to better understanding of the population dynamics of Hood Canal summer chum salmon, and will help to focus long-term management actions to maximize benefits to summer chum salmon.

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Post-Glacial Colonization of Pink Salmon in Glacier Bay

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The recent deglaciation of Glacier Bay in Southeast Alaska was followed by development of numerous watersheds that in turn provide habitat for new populations of salmon. Pink salmon, *Oncorhynchus gorbuscha*, are the most widespread and numerically abundant species of salmon that spawn in Glacier Bay streams; however, beyond a few sporadic escapement surveys, little is known about these populations. Our study evaluates colonization mechanisms of pink salmon from populations among streams of different ages within and adjacent to Glacier Bay. Using a population genetic approach, we examined genetic variation from eight populations using protein electrophoresis of allozyme loci, restriction site analysis of mitochondrial DNA, and genotyping of nuclear microsatellite loci. With this information, we address the questions of whether colonization is a one-time event or a lengthy process with re-current straying, and whether the initial colonization events involved large numbers of fish or sustained founder effects.

Developing a Pacific Rim Baseline for Chum Salmon: The Need for Standardized Genetic Markers

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Chum salmon (*Oncorhynchus keta*) are widely distributed and an important component of fisheries throughout the North Pacific. In addition to spawning in several nations, maturing chum salmon migrate across international and management boundaries before returning to their natal streams. Genetic stock identification has proven to be a useful tool for estimating the stock components of mixtures from throughout their range. The collaborative development of a Pacific Rim baseline made this possible on the high seas. A multinational, multi-agency effort in the 1980s and 1990s developed a baseline of 20 allozyme loci in 356 populations from throughout the species' range. Recent efforts to apply new DNA-based genetic marks (mainly microsatellites) has led to the development of regional markers sets in as many different laboratories, but at this time there is no consensus set that can be applied across the species range. Standardization of microsatellites is not a trivial task, requiring considerable time and expense to design, implement, and confirm in every participating laboratory. We report the characterization of single nucleotide polymorphism (SNP) markers in chum salmon. Unlike microsatellites, these markers can be easily transported and combined across laboratories and platforms with no standardization required. SNPs and similar markers like them will reduce the time and expense required to develop a Pacific Rim baseline of DNA-based markers.

Poster Session

Prince William Sound Pink and Chum Salmon Commercial Fisheries Management

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The mission of the Alaska Department of Fish and Game, Division of Commercial Fisheries is to manage, protect, and develop fisheries consistent with the sustained yield principle. The Sustainable Escapement Goal (SEG) midpoint for Prince William Sound (PWS) is 2 million pink salmon and 175 thousand chum salmon. Large-scale hatchery production of pink and chum salmon represent a high percentage of hatchery-produced fish in the current returns to PWS. The management objective is the achievement of escapement goals while allowing for the orderly harvest of all fish surplus to spawning requirements. In addition, the fishery managers must follow regulatory plans that allow hatcheries to achieve cost recovery and broodstock objectives. The PWS salmon management area is divided into eleven districts that correspond to local geography and distribution of salmon. Commercial fishing management is primarily based on escapement monitoring. Escapement of pink and chum salmon is monitored through the season by weekly aerial surveys of 209 index streams. Escapement estimates are compared to weekly and seasonal escapement goals to track inseason progress of salmon runs. As escapement requirements are met, commercial fisheries harvest surplus fish. Management is further guided by stock-contribution estimates derived from recovery of thermally marked otolith and from pink salmon sex ratios. Hatchery corporate escapement goals are achieved by opening and closing subdistricts near the hatcheries. Subdistrict openings are also used to target hatchery stocks when wild salmon escapement is weak.

Southeast Alaska Coastal Monitoring Project

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The Southeast Alaska Coastal Monitoring (SECM) project, a long-term sampling program, was initiated in the spring of 1997 to enhance understanding of the relationships between environmental conditions and salmon production and survival. The SECM research is conducted on an annual basis by the National Marine Fisheries Service, Auke Bay Laboratory, and addresses objectives defined by the North Pacific Anadromous Fish Commission and the Gulf of Alaska Global Ocean Ecosystem Dynamics Program. A primary goal of the SECM research is to build and maintain an annual time series of biophysical oceanographic indices related to the seasonal early marine growth, distribution, abundance, and habitat utilization of juvenile salmon (*Oncorhynchus* sp.) stocks. Other goals are to examine zooplankton dynamics, salmon stock composition, marine carrying capacity, and trophic relationships between juvenile salmon and ecologically-related species. Sampling for juvenile salmon, ecologically-related fish species, and their associated biophysical parameters is conducted using the NOAA ship *John N. Cobb*. The SECM sampling is focused in the northern region of Southeast Alaska in Icy Strait, the principal seaward corridor utilized by juvenile salmon migrating from inside waters to the Gulf of Alaska. Each year, sampling occurs four to six times between May and October, at up to 24 stations (covering inshore, strait, and coastal habitats), in an area that spans 250 km and culminates 65 km offshore in the Gulf of Alaska. Ongoing SECM research emphasizes process studies that focus on bioenergetics and interactions of hatchery and wild stocks of juvenile salmon.

Zooplankton Dynamics in Northern Southeast Alaska

M.V. Sturdevant, E.A. Fergusson, J.A. Orsi, W. Park, A.C. Wertheimer, and B.L Wing

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The Southeast Coastal Monitoring (SECM) project has collected monthly samples of zooplankton and associated biophysical oceanographic data in northern Southeast Alaska annually since 1997. This long-term monitoring is conducted along 250 km of the principal migration corridor in the region for juvenile salmon migrating to the Gulf of Alaska. The zooplankton studies are designed to index essential habitat conditions and prey fields available to planktivores, including juvenile salmon, and to improve understanding of carrying capacity. Here, we present preliminary analyses of zooplankton abundance and composition on several temporal and spatial scales. Sampling is conducted by Auke Bay Laboratory biologists monthly from the NOAA ship *John N. Cobb* at stations in inshore, strait and coastal habitats, from May to September-October annually. At each station, fish, zooplankton, and surface water samples as well as temperature and salinity-profile data are collected. Core zooplankton sampling in each habitat utilizes vertical 20-m Norpac (243 µm mesh) and ≤ 200-m double oblique Bongo (333- and 505-µm mesh) net hauls. Displacement or settled volumes are measured for every sample, while abundance and composition estimates are completed for sample subsets. Spatial patterns in zooplankton were examined from three mesh sizes collected over the five-month season in 2000, from inshore (Auke Bay and Taku Inlet areas), strait (Icy Strait and Upper Chatham Strait), and coastal (Cross Sound and Icy Point) transects. Interannual patterns were examined from deep (≤ 200 m), 333-µm mesh collections along the Icy Strait transect. Monthly day-night (13:00 vs. 01:00 hrs) patterns by shallow-deep (20 m vs. 200 m) strata were collected at station ISC in 2004. Monthly diel patterns were examined from a shallow (20 m) sample series taken every 3 hr over 24 hr at ISC in 2001. Sample and data analysis are ongoing. This research has been partially supported by the U.S. Global Oceans Ecosystems Dynamics (GLOBEC) program.

Guest Speakers

Tom Quinn

Some Things I'd Like to Know About Salmon and Trout

Tom Quinn did his graduate work at the University of Washington and received his Ph.D. in 1981 for work on the use of the earth's magnetic field for orientation by sockeye salmon. He then worked for the Canadian Department of Fisheries and Oceans at the Pacific Biological Station in Nanaimo, studying various aspects of salmon migratory behavior, and then joined the faculty of the University of Washington in 1986. Since then he has conducted research on diverse aspects of the behavior, ecology, and evolution of salmon and trout, including the evolution of Chinook salmon in New Zealand, the mechanisms and patterns of homing and straying, spawning behavior, bear predation, and interactions between wild and hatchery fish. He recently completed a book on "The Behavior and Ecology of Pacific Salmon and Trout," co-published by the University of Washington Press and the American Fisheries Society.

Mary Kapsner

Banquet Speaker

Representative Mary Kapsner is a Yup'ik Eskimo from Bethel, Alaska. She is a member of the Alaska State Legislature, representing House District 38 in the Yukon-Kuskokwim Delta. Her mother, Lizann, is from Kwethluk. Her father, Ward, came to Alaska as a teacher and commercial pilot. He raised his family in Kwethluk, Tuntutuliak, Platinum, and Bethel. She has two sons, Conrad Qugpak and Van Mutaq.

Mary grew up fishing for subsistence and commercial salmon. During college she worked summers for the Alaska Department of Fish and Game as a herring and salmon technician. Previously she was an executive with Coastal Village Seafoods and she commercially fished in the late 1980s. Every year she works to put up fish for the coming year.

Mary started college with an eye toward an elementary education degree. After working one legislative session in Juneau as a legislative intern, she re-focused her energies on political issues facing rural Alaska. In 1998 she was elected to the State House of Representatives.

In the Alaska Legislature Mary has served on the House Resources Committee, Special Committee on Fisheries, Health, Education, and Social Services Committee, Special Committee on Education, Transportation Committee, and the Legislative Ethics Committee. She has been a member of the budget subcommittees for the Departments of Corrections and Public Safety. She chairs the House Bush Caucus and serves on the Governor's Task Force on Rural Sanitation, the Statewide Suicide Prevention Council, and the Kuskokwim Economic Development Council.