

Proceedings of the 21st Northeast Pacific Pink & Chum Salmon Workshop



**February 26-28, 2003
Victoria, British Columbia**

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PROCEEDINGS OF THE 21ST NORTHEAST PACIFIC PINK AND CHUM SALMON WORKSHOP

February 26-28, 2003
Fairmont Empress Hotel
Victoria, British Columbia

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FOREWORD

Pink and Chum Salmon Workshops are intended to promote the exchange of biological and other information on pink and chum salmon. These workshops bring together biologists, fishery managers and others to explore innovative approaches to understanding the biology and management of pink and chum salmon.

Sessions for the 2003 Workshop covered a wide range of topics including: conservation biology and endangered species; biology and ecology; marine survival and forecasting runs; habitat assessment and restoration; education and community involvement; genetic applications to fisheries management; enhancement issues and techniques; and poster presentations and other displays.

The manuscripts in these proceedings were compiled with minimal editorial modifications in order to provide the information to interested parties as quickly as possible.

The 22nd Northeast Pacific Pink and Chum Salmon Workshop will be held in Alaska in 2005. The contact persons for the 2005 Workshop are Alex Wertheimer (NMFS, Auke Bay), Steve Heintz (ADFG, Ketchikan), Bill Smoker (UAF, Juneau), Hal Geiger (ADFG, Juneau), Rick Focht (DIPAC, Juneau), Judy Berger (ADFG, Anchorage), and Richard Thorne (PWSSC, Cordova).

Bruce White

Greg Bonnell

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LIST OF ACRONYMS FOR CURRENT PROCEEDINGS

ADFG	Alaska Department of Fish and Game
CDFO (or DFO)	Canada Department of Fisheries and Oceans
KamchatNIRO	Kamchatka Research Institute of Fisheries and Oceanography
NMFS	National Marine Fisheries Service
PSC	Pacific Salmon Commission
PWSSC	Prince William Sound Science Center
UBC	University of British Columbia
UW	University of Washington
WDFW	Washington Department of Fish and Wildlife

PINK AND CHUM WORKSHOPS

Year	Location	Chairs	Organization
1962	Juneau, AK	T. Merrell	BCF
1964	Juneau, AK	D. Bevan	FRI
1966	Ketchikan, AK	C. Meacham	ADFG
1968	Juneau, AK	T. Merrell	BCF
1970	Prince Rupert, AK	A. Hartt	FRI
1972	Sitka, AK	R. Roys	ADFG
1974	Vancouver, BC	T. Bird	CDE
1976	Juneau, AK	J. Helle, K. Koski	NMFS
1978	Parksville, BC	J. Mason	FMS
1980	Sitka, AK	A. Kingsbury	ADFG
1983	Orcas Island, WA	K. Fresh, Schroeder	WDFW
1985	Harrison Hot Springs, BC	B. Shepherd	CDFO
1987	Anchorage, AK	P. Mundy, K. Tarbox	ADFG
1989	Port Ludlow, WA	D. Phinney	WDFW
1991	Parksville, BC	D. Bailey, J. Woodey	CDFO, PSC
1993	Juneau, AK	B. Smoker	UA-Fairbanks
1995	Bellingham, WA	G. Graves, H. Fuss	NWIFC, WDFW
1997	Parksville, BC	P. Ryall	CDFO
1999	Juneau, AK	S. Hawkins	NMFS
2001	Seattle, WA	J. Hard, O. Johnson, K. Myers	NMFS, UW
2003	Victoria, BC	B. White, G. Bonnell	PSC, CDFO

SESSION LEADERS

Session I: Conservation Biology and Endangered Species	Jim Irvine (CDFO)
Session II: Biology and Ecology	Pieter Van Will (CDFO)
Session III: Marine Survival and Forecasting Runs	Leroy Hop Wo (CDFO)
Session IV: Habitat Assessment and Restoration	Mel Sheng (CDFO)
Session V: Education and Community Involvement	Tom Rutherford (CDFO)
Session VI: Genetic Applications to Fisheries Management	Jim Shaklee (WDFW)
Session VII: Enhancement Issues and Techniques	Brian Pearce (CDFO)
Session VIII: Poster Presentations and Other Displays	Tracy Cone (CDFO)

ACKNOWLEDGEMENTS

Many individuals and companies were involved in making the 21st Pink and Chum Workshop successful. Our thanks to the following people: Sandi Wadley and Kathy Mulholland for their development of the website for the Pink and Chum Workshop; Jeff Hard and Pieter Van Will for their assistance during the early planning stages; Anne Martin for coordinating computer support services at the Workshop; Dr. Richard Thomson for his great banquet speech; Vicki Ryall and Teri Tarita for their assistance in helping to coordinate the accommodations, social events, registrations and other activities; Erin Cameron for proofreading the Workshop Proceedings; Maia Cote for formatting assistance with the Workshop Proceedings; and Jared Trevisan for his excellent artwork for the logo design for the 2003 Pink and Chum Workshop. The Fairmont Empress Hotel provided a great location and amenities for the Workshop.

We would also like to acknowledge the contributors who provided either financial support or merchandise for door prizes at the workshop.

- Fairmont Empress Hotel, Victoria, BC
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- LGL Limited Environmental Research Associates, Sidney, BC
- Pacific Salmon Commission, Vancouver, BC
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- Trotac Marine Ltd., Victoria, BC

A very special thanks to Victor Keong of the Pacific Salmon Commission for his outstanding help with all aspects of the Workshop from the planning stages through to compiling these proceedings.

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Session 1

Session Leader: Jim Irvine (CDFO)

Conservation Biology and Endangered Species

The Species at Risk Act: A DFO Perspective

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Abstract

The Canadian Species at Risk Act (SARA) is the first of its kind to provide legal protection for species designated by The Committee on the Status of Endangered Wildlife in Canada (COSEWIC). SARA aims to protect wildlife at risk from becoming extinct or lost from the wild, with the ultimate objective of helping their numbers to recover. The Act covers all wildlife species listed as being at risk nationally and their critical habitats. SARA requires protection for species and their habitat as well as recognizes the potential for compensation for landowners. SARA is a cornerstone in species protection and recovery. Canada's Strategy for protecting at risk species is three-fold: the Federal-Provincial Accord for the protection of species at risk, the Habitat Stewardship Program of Canada, and finally the Species at Risk Act. Together each element provides a part of the foundation for Canada's Strategy for protecting species at risk.

Introduction

The *Species at Risk Act* (SARA) came into force on June 5, 2003, bringing to a close a nine-year legislative process to protect Canada's species at risk and their habitat. SARA is one of three elements of the government's Strategy for the Protection of Species at Risk. Under the *Accord for the Protection of Species at Risk*, the Government of Canada works with provinces and territories on a common approach to protecting species at risk in Canada that includes complementary legislation and programs to protect habitat and species. The other key component of the federal Strategy is stewardship, a cornerstone of the Government of Canada's approach to species protection. One such initiative is the federal government's Habitat Stewardship Program for Species at Risk, which funds projects that support habitat conservation and stewardship.

The species at risk legislation ensures that species are assessed under a rigorous and independent scientific process that operates at arm's length from the federal government. It also requires the development of recovery action plans for species that are found to be most at risk, and recognizes the essential role of Aboriginal peoples in the conservation of wildlife by requiring the establishment of a National Aboriginal Council on Species at Risk and the establishment of an Aboriginal Traditional Knowledge sub-committee of COSEWIC.

Fisheries and Oceans Canada is one of the three federal departments responsible for implementing SARA and has responsibilities to protect and restore listed aquatic species and their habitats. The key responsibilities of Fisheries and Oceans Canada is to enforce the Act; provide technical support to the species assessment phase; initiate the development of recovery strategies and action plans for endangered and threatened species and develop management plans for species listed

as special concern. The department will also, in cooperation with other governments, First Nations and interested parties, carry out on-the-ground species recovery work.

The process of designating a species at risk is lengthy, but in the end provides a strategy to help achieve the ultimate goal of recovery for the species. Canada has long been waiting for such an Act to be created in order to protect the intrinsic value of our multitude of species. This paper introduces the key elements of Canada's Species at Risk Program and how species are assessed and designated as being at a particular level of risk – Endangered, Threatened, or Special Concern.

The Accord

During the spring of 1995, public workshops were held nation-wide by Environment Canada, the provinces and territories to establish key components to be included in a national approach to protecting species at risk. The importance for federal and provincial governments to work together to address the issue of species at risk in Canada was fundamental due to the multi-jurisdictional nature of the problem. Signed in October 1996, wildlife ministers agreed in principle to the Accord and committed to a national approach to protect species at risk. Outlined in the Accord are commitments to designate the risk status of species, protect their habitats and develop recovery plans. Governments agreed to play a leadership role by developing complementary legislation, regulations, policies and programs to identify and protect threatened and endangered species as well as their critical habitats.

Under the Accord, federal, provincial and territorial governments agreed to co-ordinate activities by creating the Canadian Endangered Species Conservation Council (CESCC). This multi-jurisdictional body was set up in 1996. The Council is made up of federal ministers of Environment, Fisheries and Oceans, and Heritage as well as the provincial and territorial ministers with responsibilities for wildlife species.

The Council's mandate is to provide direction on the activities of the Committee of the Status of Endangered Wildlife in Canada (COSEWIC) in the status assessment process. COSEWIC is the body responsible for designating the status of species. The Council has specific responsibilities for identifying and recovering species at risk and co-ordinating action among all parties and general responsibility for providing national leadership for the protection of species at risk. It also serves as a forum for resolving any disputes that may arise out of implementation of the Accord.

The Habitat Stewardship Program

The Federal government has recognized the important role that stewardship plays in species and habitat conservation by making stewardship a cornerstone of its three-part strategy. In the spring of 2000, the federal government announced new funding for the strategy, including \$45 million over 5 years for the Habitat Stewardship Program. This program is administered by Environment Canada and managed co-operatively with Fisheries and Oceans Canada and Parks Canada Agency and, in the Pacific region, the province of British Columbia. The goal of the Program is to contribute to the recovery and protection of habitat for priority listed species at risk, and for other species of special concern.

Table 1. HSP Funding to Aquatic Species in Pacific Region.

Year	National Allocation	Pacific & Yukon Share	Aquatic Share
2000-01	5.0 M	\$1.7 M	\$527 K
2001-02	10.0 M	\$2.6 M	\$600 K
2002-03	10.0 M	\$1.2 M	\$705.5 K
2003-04	10.0 M	\$1.7 M	\$603.6 K
Total:	45.0 M	\$7.2 M	\$2.4 M

Like many successful conservation programs, the Habitat Stewardship Program is partnership-based. In this case, federal government designs and funds the program in co-operation with non-federal government partners, who then implement projects.

Program funding is available for non-government entities including: not-for-profit organizations, First Nations, municipal/provincial, and local organizations. Project proposals must address the specific threats outlined in the aquatic priorities section of the submission guide. This year's priorities include projects that support recovery plans completed or underway, species in the Georgia Basin and other aquatic species listed as endangered and threatened. Also required, at minimum, is matched funding either in-kind or cash.

Habitat stewardship for nationally-listed species at risk must be guided by national species recovery priorities. Yet, stewardship as a conservation tool is most effective when delivered at the regional or local level. Consequently, the Habitat Stewardship Program operates through a combination of national and regional support mechanisms to achieve its goal.

The Legislation

The Act has the primary objective of preventing Canadian wildlife from becoming extirpated or extinct and provides for the recovery of these endangered or threatened species. It is also intended to manage species of special concern and to prevent them from becoming endangered or threatened. Designation of species status occurs through the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), which has now been given legal status. More importantly, the Act serves to protect species and their habitat by creating prohibitions preventing the killing or harming of the listed wildlife species.

Under the Act, compensation may be provided at the Minister's discretion for losses incurred by any extraordinary impact of protecting critical habitat – this will be subject to regulations which have yet to be developed. In addition, the SARA public registry acts as a comprehensive source of information relating to matters under the Act. The public registry serves as a key instrument in fulfilling the government's commitment to encourage public participation in environmental decision making by providing timely and comprehensive access to public documents relating to the administration of SARA. It is important, however, to understand the process that ensued allowing species to be designated as at risk.

Assessment and Legal Listing

COSEWIC is the body responsible for designating status to species according to the degree of risk they face. It has 28 members all appointed by the federal Minister of the Environment.

Membership consists of thirteen provincial/territorial representatives, four federal government (Environment Canada, Fisheries and Oceans, Parks Canada Agency, Federal Biosystematics Partnership) representatives, eight Species Specialist Sub-Committees (SSC) representatives, and 3 representatives “at large” chosen through a public nomination process. The eight SSC’s are responsible for the production and revision of status reports for plants, freshwater fish, marine fish, molluscs, terrestrial mammals, marine mammals, birds, and reptiles. DFO interacts with, at minimum, the Marine Mammal, Marine Fish, Invertebrates, Aboriginal Traditional Knowledge (ATK) and the Freshwater Fish SSG’s. The ATK sub-committee is responsible for ensuring that Aboriginal Traditional Knowledge is incorporated into COSEWIC’s assessment process.

The assessment is based on biological factors and uses rigorous assessment criteria. The COSEWIC list is published on the public registry, establishing it as the scientific list. COSEWIC usually meets twice a year (May and November) to review Status Reports, release species designation decisions and publish species status reports. Species to be assessed/re-assessed are selected from priority candidate species lists based on information from jurisdictions, non-governmental organizations (NGO’s), or from suggestions made by taxonomic specialists. These are assigned a level of priority based on the perceived degree of risk and are collated to comprise the SSC candidate species list that COSEWIC will consider at upcoming bi-annual meetings. Status Reports are commissioned by the various SSC’s or submitted after SSC approval by unsolicited authors.

Following its bi-annual meetings, COSEWIC reports on its designations to the Canadian Endangered Species Conservation Council (CESCC), and issues a press release indicating the results of decisions made at the meeting. Subsequent to the publication of the designation list, the Minister of Environment must within 90 days include in the public registry, a Response Statement for each species listed as extirpated, endangered and threatened. The Response Statement will describe the reasons for designation by COSEWIC, key threats to the species, current protection or recovery actions, jurisdictional responsibilities and document existing protection measures taken. Legal listing of species designated by COSEWIC is the responsibility of the Governor-in Council (GIC). The proposed Act lays out stringent timelines for GIC decisions. Specifically, once COSEWIC has released their list, the federal GIC, on the recommendation of the Minister of the Environment has 9 months to:

1. Accept the assessment and add the species to the *legal list* under SARA
2. Decide not to add the species to the *legal list* or
3. Refer the matter back to COSEWIC for further information or consideration.

Should GIC fail to take one of these three courses of action, within 9 months after receiving assessment status, the Minister of the Environment will be required to list the species by order, as assessed by COSEWIC. Once a species is legally listed by GIC they receive immediate protection and mandatory timelines for recovery strategy development.

Protection

Once species are legally listed as extirpated, endangered, or threatened automatic prohibitions will apply to an individual of a species, their residences, and after defined in a recovery strategy or action plan their critical habitat. Prohibitions may apply to federal lands, migratory birds and aquatic species; to provincial and territorial lands under certain conditions; and may apply to portions of federal lands for species listed by provinces or territories. The sections from the Act pertaining to protection are as follows:

“No person shall kill, harm, harass, capture or take an individual of a wildlife species that is listed as an extirpated, endangered or threatened species...” (Section 32.1)

“No person shall damage or destroy the residence of one or more individuals of a wildlife species that is listed as endangered, threatened or extirpated...” (Section 33)

“No person shall destroy any part of the critical habitat of a listed species or a listed threatened species” (Section 58.1)

There are, however, permits that exist that authorize an activity affecting listed wildlife species under certain conditions. Section 74 under SARA indicates that the Minister of Fisheries and Oceans may enter into an agreement with a person, or issue a permit authorizing an activity affecting a listed aquatic species, any part of its critical habitat or the residences of its individuals. This provision can only be used if certain conditions, as set out in Section 73.2 are satisfied.

These include:

- a) the activity is scientific research relating to the conservation of the species and conducted by qualified persons;
- b) the activity benefits the species or is necessary to enhance its chance of survival in the wild; or
- c) affecting the species is incidental to carrying out the activity.

Further, authorizations will only occur if the Minister is of the opinion that:

- a) all reasonable alternatives to the activity that would reduce the impact on the species have been considered and the best alternative has been adopted, based on scientific, technical and socio-economic considerations;
- b) all feasible measures will be taken to minimize the impact of the activity on the species or its critical habitat or the residence of its individuals; and
- c) the activity will not jeopardise the survival and recovery of the species.

There are some specific exceptions in place for prohibitions and destruction of critical habitat. Sections describing General Prohibitions (32, 33 and 36) and destruction of critical habitat (58, 60 and 61) do not apply to people engaged in activities:

- a) related to public safety, health or national security authorized under Act of Parliament;
- b) authorized by agreement, permit or license. May also include additional possession exemptions;
- c) in accordance with regulatory or conservation measures under land claims; and
- d) permitted by recovery strategy, action plan or management plan.

Incidental Harm Permits (IHP) are intended to exempt individuals from prosecution for infringing the SARA prohibitions under specific conditions. In the event of an activity accidentally harming a species in an unforeseeable situation the defence of due diligence is available. Issuance of an IHP is subject to a formal assessment to determine whether an IHP can be issued within the conditions above. Incidental harm permits for critical habitat follow the same procedures as outlined above with one notable difference. Permits and agreements allowing activities to adversely affect critical habitat would only be needed after recovery strategies and or action plans are complete and the habitat necessary for a species survival or recovery is identified and specified in a GIC order.

Recovery

Recovery planning under the SARA legislation consists of two components – a recovery strategy and an action plan. In general, a recovery team conducts recovery planning. The recovery team produces a recovery strategy, which is the first part of the two-part recovery plan. Depending on the scope of the recovery planning process, one or more recovery and action groups may be established, which aid the team in developing recovery action plans. Recovery projects identified through the strategy and action plan are implemented and results of the projects often feed back into the strategy and action plan(s). This is a continuous process – recovery plans must be updated every five years until the species is considered recovered.

The Act states that if a wildlife species is listed as extirpated, endangered or threatened, the competent minister must prepare a strategy for its recovery. This strategy includes:

- a) a description of the species and its needs that is consistent with information provided by COSEWIC;
- b) an identification of the threats to the survival of the species and threats to its habitat that is consistent with information provided by COSEWIC and a description of the broad strategy to be taken to address those threats;
- c) an identification of the species' critical habitat, to the extent possible, based on the best available information, including the information provided by COSEWIC, and examples of activities that are likely to result in its destruction; (c.1) a schedule of studies to identify critical habitat, where available information is inadequate;
- d) a statement of the population and distribution objectives that will assist the recovery and survival of the species, and a general description of the research and management activities needed to meet those objectives;
- e) any other matters that are prescribed by the regulations;
- f) a statement about whether additional information is required about the species; and
- g) a statement of when one or more action plans in relation to the recovery strategy will be completed.

Upon completion of the recovery strategy, the competent minister is required to include the proposed recovery strategy in the public registry. The public has 60 days to file written comments with the competent minister. Following the expiry of the 60 days, the competent minister has 30 days to consider any comments received, make appropriate changes and include a final copy in the public registry.

The competent minister must prepare one or more action plans based on the recovery strategy. If there is more than one competent minister with respect to the recovery strategy, they may prepare the action plan or plans together. An action plan must include, with respect to the area to which the action plan relates,

- a) an identification of the species' critical habitat, to the extent possible, based on the best available information and consistent with the recovery strategy, and examples of activities that are likely to result in its destruction;
- b) a statement of the measures that are proposed to be taken to protect the species' critical habitat, including the entering into agreements under section 11;
- c) an identification of any portions of the species' critical habitat that have not been protected;
- d) a statement of the measures that are to be taken to implement the recovery strategy, including those that address the threats to the species and those that help to achieve the population and

- distribution objectives, as well as an indication as to when these measures are to take place;
- (d.1) the methods to be used to monitor the recovery of the species and its long-term viability;
- e) an evaluation of the socio-economic costs of the action plan and the benefits to be derived from its implementation; and
- f) any other matters that are prescribed by the regulations.

As with the recovery strategy, the competent minister must include a copy of the action plan in the public registry. The public has 60 days to file comments and the competent minister has 30 days to review comments and put the final action plan onto the public registry.

Schedules and Timelines

There are 4 lists of species, each with different timelines for protection and mandatory recovery strategies. Schedule 1 lists all species for which SARA now applies. These species are subject to automatic prohibitions and recovery strategies within specified timelines. The timelines for species on Schedule 1 are:

- Endangered – Recovery Strategy completed within 3 years of proclamation
- Threatened – Recovery Strategy completed within 4 years of proclamation
- Extirpated – Recovery Strategy completed within 4 years of proclamation
- Special Concern – Management Plan completed within 5 years of proclamation

Schedule 2 includes all endangered and threatened species on the COSEWIC list that have not yet been assessed against COSEWIC criteria. Once COSEWIC reassess these species and designates a status, these species will go through normal regulatory GIC listing process. Schedule 3 contains species of special concern that are on the COSEWIC list but have yet to be reassessed. However, there is no automatic requirement for COSEWIC to reassess these species. Newly Listed Species are those newly listed or re-assessed after introduction to the House of Commons (June 2002), but before the Act came into force. Now that the Act has come into force, the normal listing process will be required under Section 27. Once legally listed, recovery strategy/ management plans will be required as follows:

- Endangered – Recovery Strategy required within 1 year of legal listing of species
- Threatened – Recovery Strategy required within 2 years of legal listing of species
- Special Concern – Management Plan required within 3 years of legal listing of species

A list of all species for each schedule can be found at the end of the Act.

Salmon Listings in BC

Currently there are three salmon populations assessed as newly listed under SARA: Interior Fraser coho, Sakinaw Lake sockeye, and Cultus Lake sockeye. Interior Fraser coho were listed as endangered in May 2002. The Sakinaw and Cultus Lake sockeye populations underwent emergency listings in October 2002 and both were confirmed as endangered in May 2003. Listing of these three populations is possible under SARA because COSEWIC considered each to be a “wildlife species”, which in SARA is defined as: *a species, subspecies, variety or geographically or genetically distinct population...*” (Section 2).

The necessary first step of identifying designatable units in Pacific salmon in Canada has now begun. The geographical extent and thus the number of designatable units differ considerably among

the species. Sockeye salmon lie at one extreme and there could be several hundred designatable units within Canada. Preliminary examinations of status within the Skeena River drainage, the southern mainland inlets, the Strait of Georgia and the Fraser River drainage are now underway. At the other extreme there may be only a dozen designatable units of pink salmon. In pink salmon there is the curious anomaly that there are two temporal “species”. Although there is considerable genetic exchange over large distances within pink salmon populations there is near total isolation between the odd- and even-year runs.

An inclusive recovery planning framework for the three salmon populations listed is underway. The identification and establishment of recovery teams to develop recovery strategies for these salmon populations has started. This will also bring together research and stewardship activities already in progress to meet the requirements of the Species at Risk Act.

Conclusion

The Species at Risk Act provides a framework for actions across Canada to ensure the survival of wildlife species and the protection of our natural heritage, which Canadians value so much. This Act represents a milestone in that it provides legal protection for species; it puts stewardship at the forefront of recovery initiatives, and establishes penalties for failure to obey the law. Together, we can work to ensure the ongoing survival of species by using the Act as a tool in our joint efforts for conservation.

A Review of the Broughton Archipelago Pink Salmon Stock Status

Blair Holtby

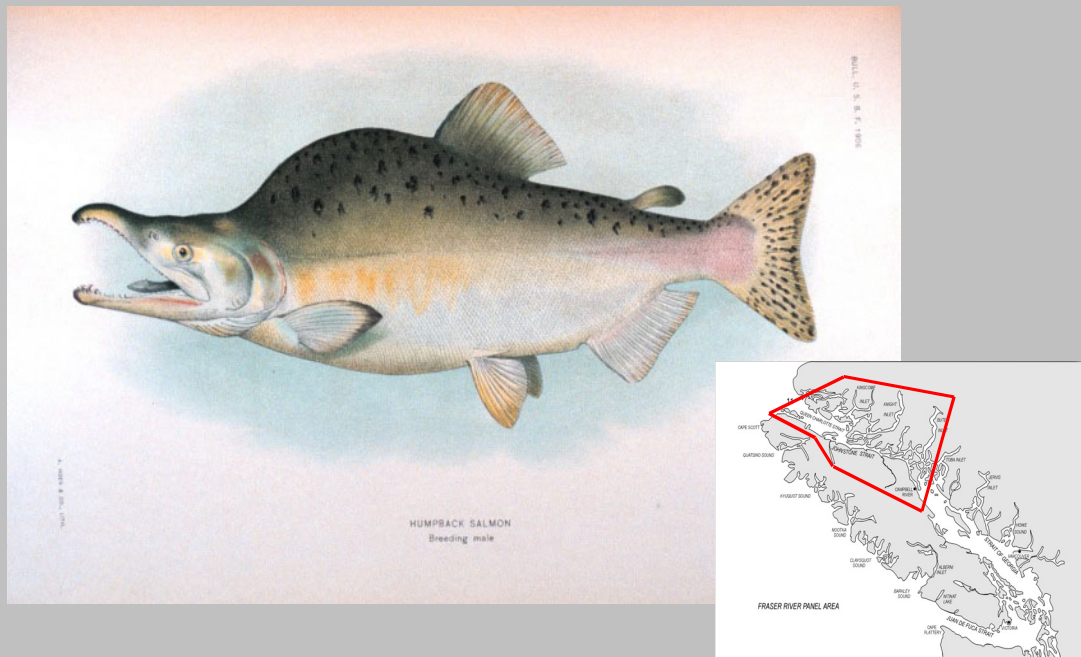
Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C., V9T 6N7

Note: this presentation is available on website www.fish.bc.ca (DFO presentation on Pink Salmon numbers).


PowerPoint Presentation

Slide 1

Returns of pink salmon to the mainland inlets of BC in 2002




Slide 2



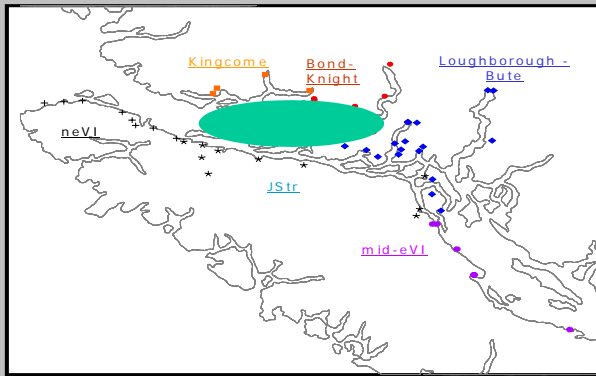
Pink life-history and other facts

- Most abundant (numerically and biomass) of the Pacific salmon
- Distributed from central CA around the Pacific Rim to Korea and Hokkaido and in the Arctic as far west as the Lena River on the East Siberian Sea and as far east as the Mackenzie River on the Beaufort Sea. Study area at 51°N is near the southern limit of current distribution.
- Have a fixed 2-year life span. Two cycles reproductively isolated.
- Some populations show cyclic dominance
- Least dependence on FW habitat of Pacific salmon
- Pink fry (~30 mm) move into the ocean soon after emergence.
- Generally occupy near-shore habitats and are surface oriented. Migratory behavior is highly variable.
- Juveniles remain in protected in-shore areas for several months before moving into the open ocean. Movement to open ocean may be size-dependent (~8 cm).


Slide 3



Study Area



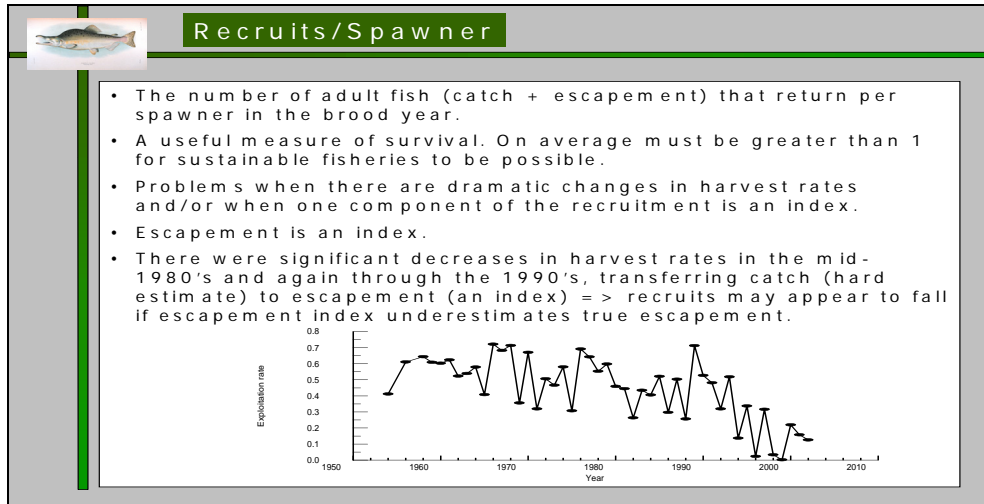
Slide 4



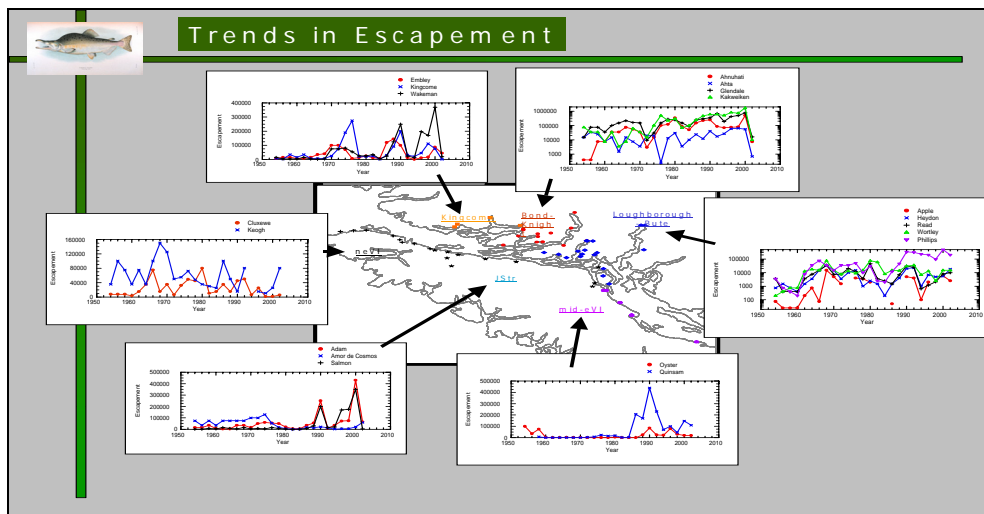
Data - Escapement and Catch

- Escapement (number of spawners) based on aerial & foot inspections, most of streams counted each year.
- Generally peak counts with several inspections.
- Due to apparent long survey life reasonable indices of abundance, although they are subject to the usual caveats that accompany most visual escapement counts
- Estimates of total catch very accurate. However, partitioning catch is problematic because no stock ID.
- Non-Fraser (even) years catch was partitioned by escapement.
- Fraser (odd) years catch was first partitioned using PSC estimates of Fraser component and then partitioned by escapement.
- Should be considered very approximate.

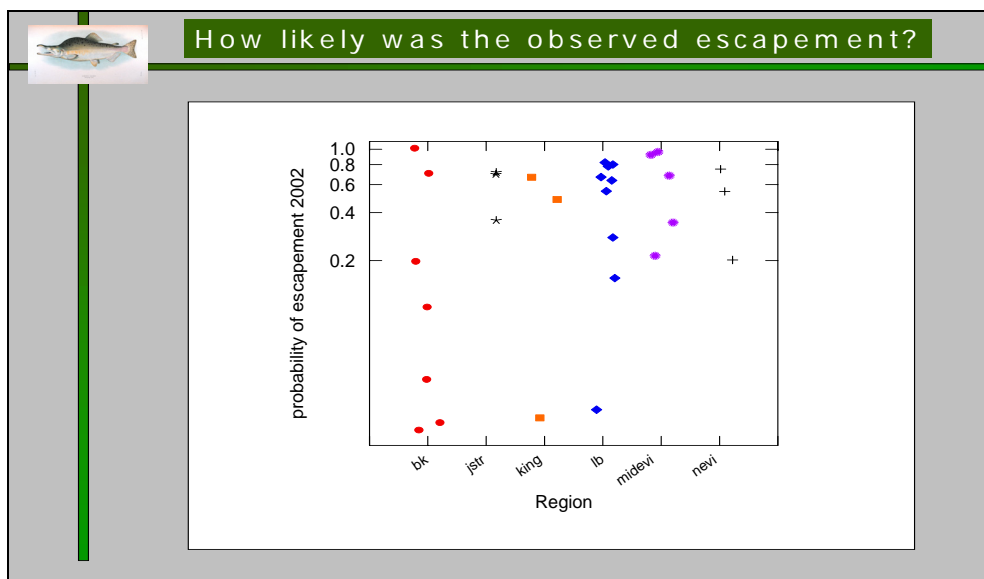
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Slide 6



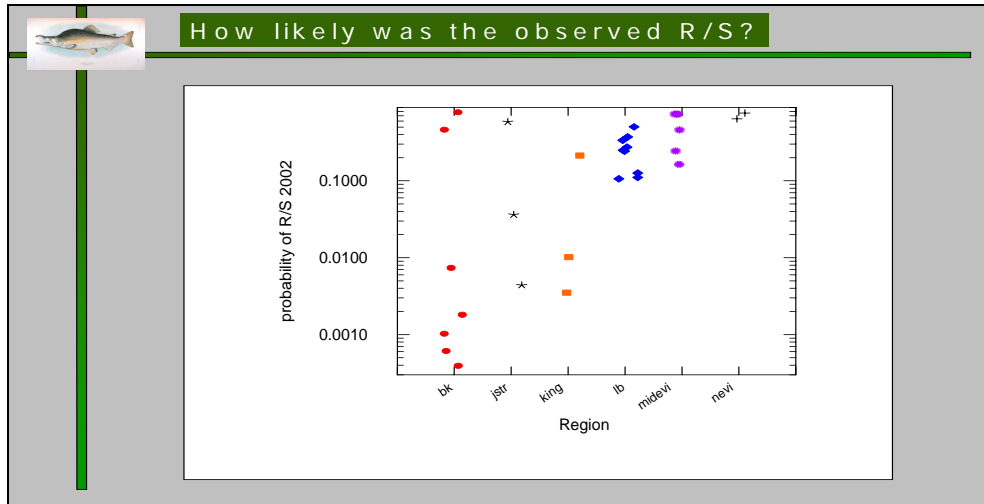
Slide 7



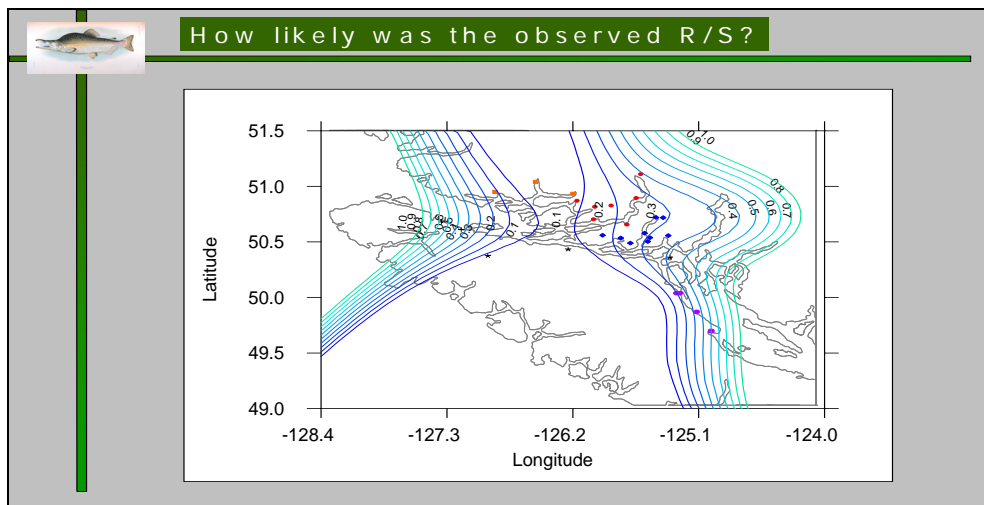


The figure displays a map of the Irish coast with arrows pointing to seven time-series plots of Recruits/Spawner (1950-2010) for various fish species. The species are: Embley, Kihgome, Wakeman, Ahnushi, Alisa, Glanville, Kowalewski, Clusnes, Keogh, Apple, Haydon, Reed, Worley, Phillips, Adam, Arter de Cosmos, Salmon, and Oyster Quorum.

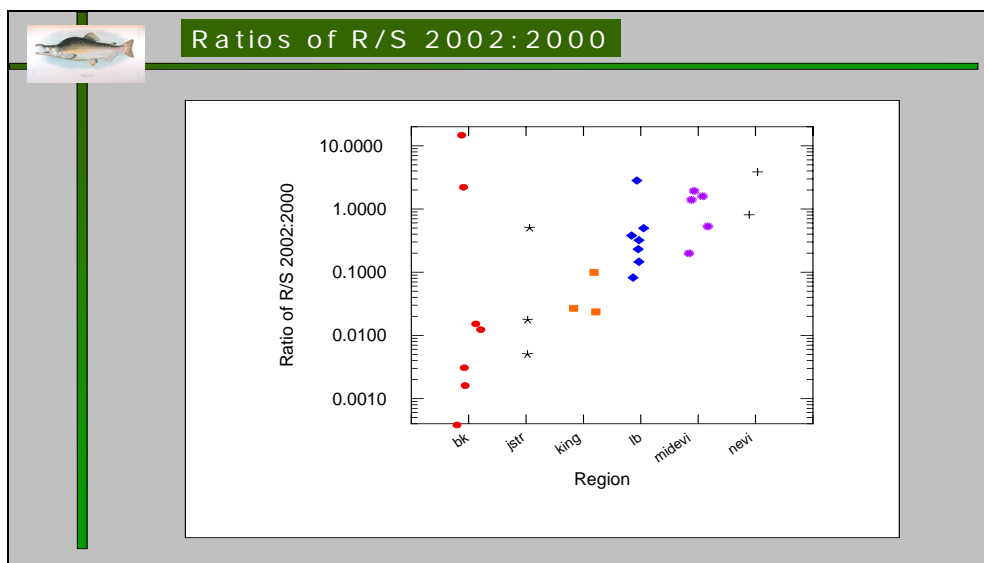
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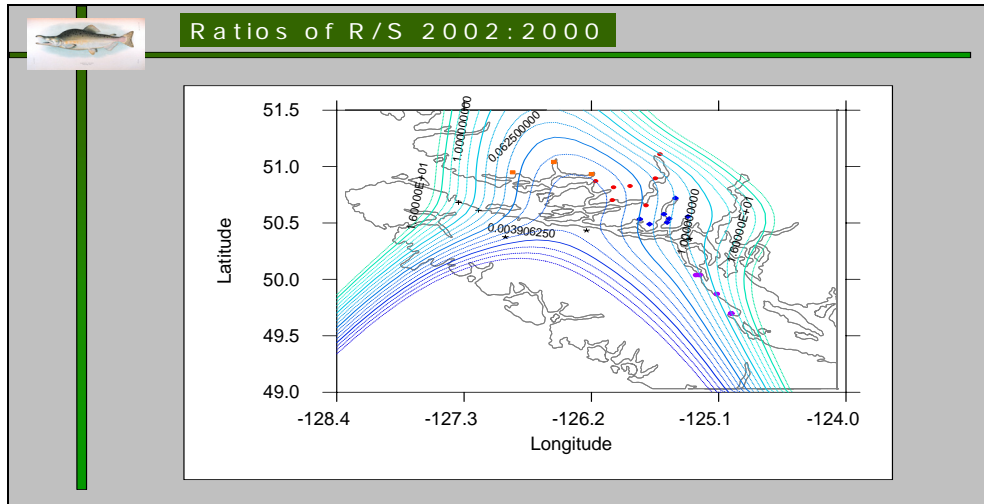
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Slide 13



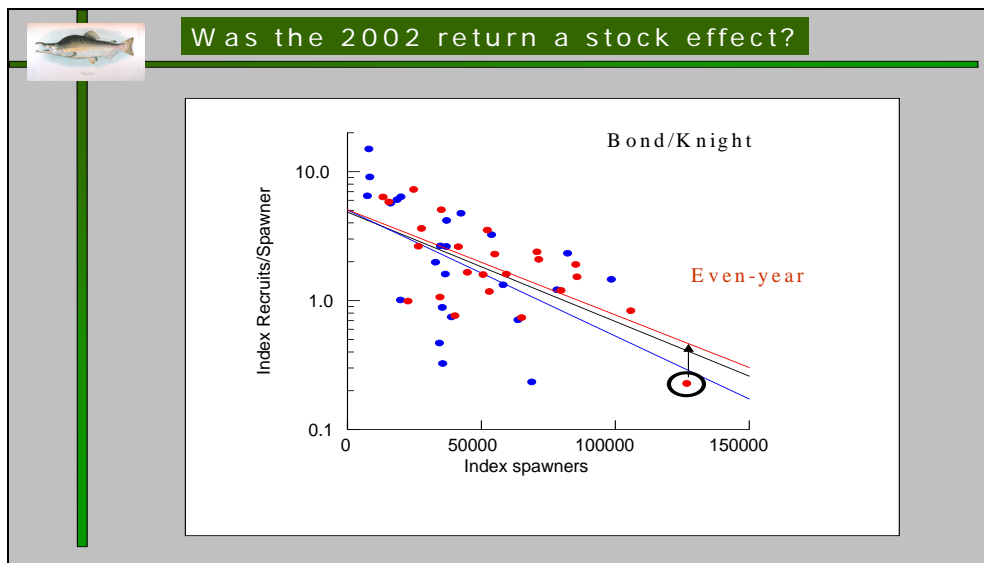
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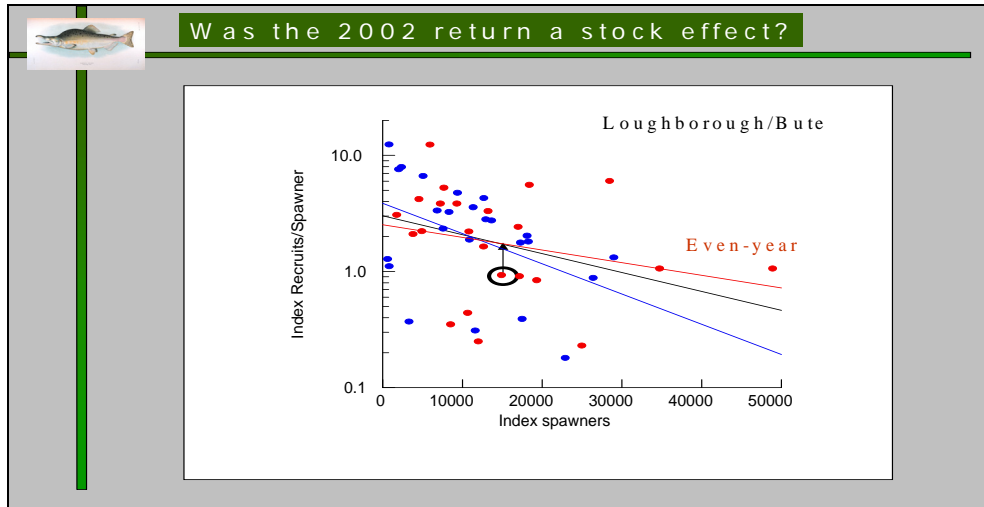
Slide 15

- 
- Some of the possible causes**
- A stock-recruitment effect – high escapement in brood year associated with poor escapement
 - Extremely poor FW survival – density independent (freezing, flooding, disease, etc.)
 - Extremely poor marine survival (first summer)
 - Extremely poor marine survival (winter/second summer)
 - Poor data – we can't tell the difference between recruitment failure and enumeration failure.

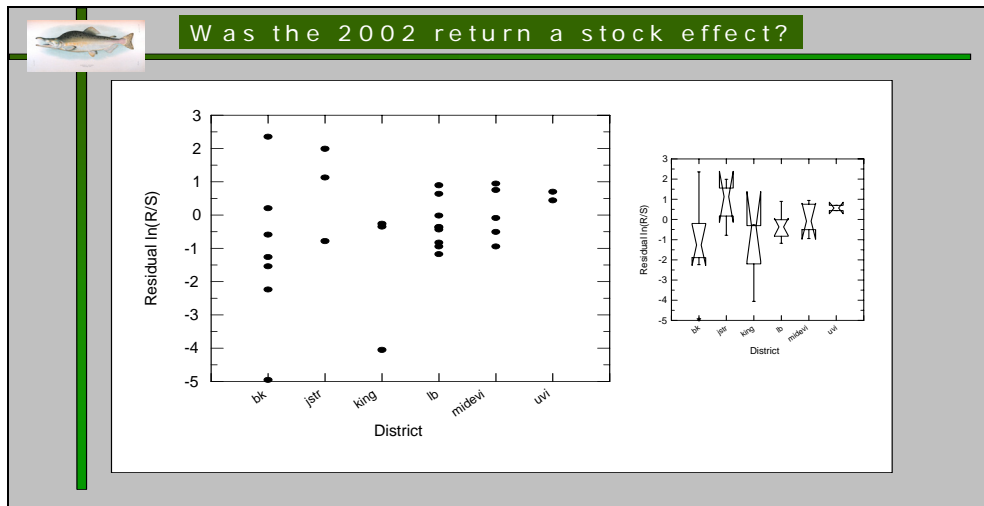
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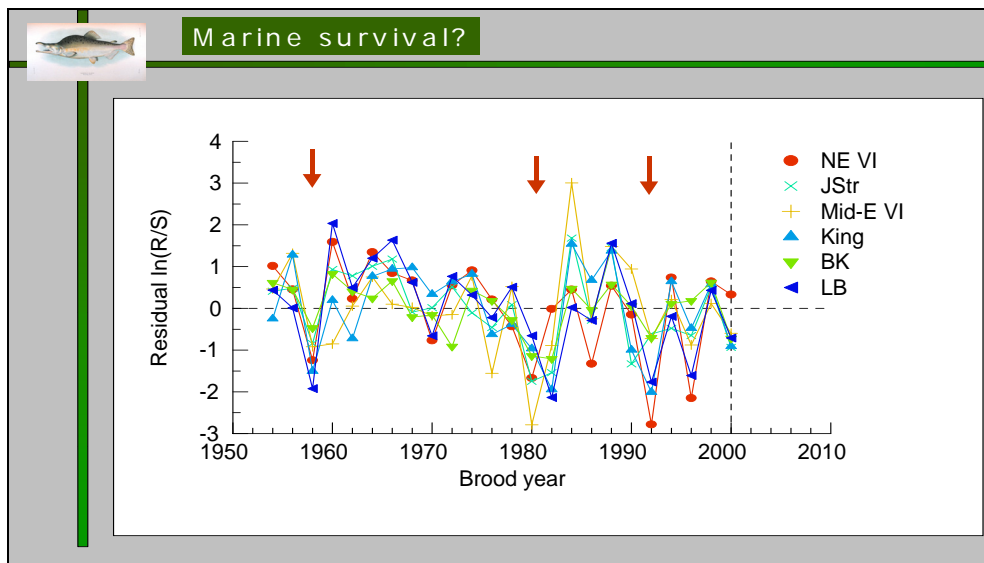
Slide 17




Slide 18



Slide 19




Slide 20



Conclusions

- Escapement, recruitment and especially R/S were depressed and in some cases severely in most of the streams of Kingcome, Bond and Knight Inlets as well as the adjacent portions of Vancouver Island bordering the Johnstone Strait.
- Streams to the north and south were not similarly affected.
- Comparisons take into account variability of pink populations.

Slide 21



Conclusions

- Causal factor(s) may have been in FW although the scale of the phenomenon is too large for most hydrologic and climatic risk factors.
- Large escapement in brood year in affected areas may have reduced survival but magnitude and commonality of the S-R residual suggests that "over-escapement" in the brood year was not the cause.
- Additional causal factor(s) should be sought in the near-shore environment during the migration of pink salmon fry out of the mainland inlets and perhaps through Johnstone Strait.
- Balance of evidence, including the observed levels of infestation, implicate sea lice .
- Returns of pink and chum in 2003 will be informative.

Sea Lice Infection on Pacific Salmon Along the Continental Shelf of British Columbia and Alaska

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Introduction

The salmon louse, (*Lepeophtheirus salmonis*), is a ubiquitous caligid copepod ectoparasitic on farmed and wild salmonids (Pike and Wadsworth 1999). Sea lice infection on large Pacific salmon (30-70 cm) has been documented in offshore waters by Nagasawa and his colleagues for the Sea of Japan, North Pacific Ocean, and Bering Sea (Nagasawa 2001; Nagasawa and Takami 1993; Nagasawa et al. 1993). These studies showed that infection rates varied among salmon hosts, regions, and years, and generally increased with host age/size.

The dynamics of sea lice infection on Pacific salmon is poorly understood. Transmission is likely to occur in open oceans since prevalence tends to increase with fish age (Nagasawa et al. 1993) and because the marine residence time of Pacific salmon generally exceeds the expected longevity of sea lice (Pike and Wadsworth 1999). However, little is known about the transmission of sea lice to juvenile Pacific salmon in coastal waters.

The general objectives of this study were to determine the extent of seasonal and spatial variation of sea lice infection on Pacific salmon in inshore waters. In particular, we tested the hypotheses that (1) juvenile salmon are infected with sea lice in coastal waters, and (2) sea lice infection rates are higher in adult than juvenile salmon.

Material and Methods

Juvenile and adult salmon were collected on the continental shelf using a mid water trawl that was hauled at the surface from the west coast of Vancouver Island (WCVI) to Southeast Alaska (SEA) in March, June, August, and October 2002, and in the Bering Sea in September 2002. The number of adult and preadult stages of sea lice were counted on juvenile and adult pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), Chinook (*O. tshawytscha*), and coho salmon (*O. kisutch*) caught off British Columbia (BC) and SEA, and on juvenile pink salmon caught in the Bering Sea. Prevalence, intensity and abundance of sea lice infections were calculated as the percentage of infected fish, the mean number of parasites per infected fish, and the mean number of parasites per fish, respectively. Further details on the methodology used in this study are presented in Trudel et al. (2003).

Results and Discussion

Sea lice were observed on all salmon species examined. The prevalence was 24.0% for pink, 12.0% for coho, 7.8% for chinook and 5.7% for chum, though none of the juvenile chum were infected. Differences in prevalence and intensity were observed between adults and juveniles. The number of

mobile sea lice observed on juvenile and adult salmon ranged from 0 to 6 lice·fish⁻¹ and from 0 to 21 lice·fish⁻¹, respectively. The prevalence of sea lice infection was higher in adult salmon, though sea lice abundance rarely exceeded 4 lice·fish⁻¹. Sea lice abundance and intensity ranged from 0.15 to 0.33 lice·fish⁻¹ and from 1.2 to 5.1 lice·infected fish⁻¹, respectively, and tended to be higher for adult fish. Sea lice infection also varied among species according to age category. In juvenile fish, pink and coho were the most infected, while chum were the least infected. In adult fish, the prevalence of sea lice infection was higher in pink, followed by chinook and chum.

The prevalence of sea lice infection on juvenile salmon varied among regions and periods. There was no consistent patterns of sea lice infection with latitude, except for juvenile chinook salmon that tended to be more infected in SEA than on the WCVI. Infected juvenile coho and chinook were also collected on the WCVI and SEA in March, indicating that there are natural reservoirs of sea lice during winter in these areas.

In conclusion, this study showed that juvenile Pacific salmon were infected with sea lice on the continental shelf of BC, Alaska, and the Bering Sea, and that sea lice infection occurred throughout the year. As there are no salmon farms in SEA and Bering Sea, these results indicate that transmission of sea lice also occurs naturally in coastal waters. The higher infection rates of adult salmon suggest that transmission of sea lice also occurs in oceanic waters. Further research is required for understanding the natural dynamics of sea lice infection on Pacific salmon.

Acknowledgements

We thank T. Zubkowski, M. Jacobs, A. Ladouceur, M. Thiess, P. Winchell, I. Wilson, J. Moss, L. Hulbert, E. Parks, as well as the crew of the *R.V. W.E. Ricker*, *F.V. Ocean Selector*, and *F.V. Sea Storm* and for their help with the collection of biological and oceanographic data, and M. Higgins for identifying sea lice. Funding was provided by Fisheries and Oceans Canada, the Bonneville Power Administration, and by the Ocean Carrying Capacity Program (National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory, Juneau, Alaska, U.S.A.).

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Infestation of the Sea Louse (*Lepeophtheirus salmonis*) on Juvenile Pink Salmon (*Oncorhynchus gorbuscha*) in British Columbia

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**Raincoast Research, Simoom Sound, British Columbia*

Abstract Only

The magnitude of sea louse (*Lepeophtheirus salmonis*) infestation on migrating juvenile pink salmon (*Oncorhynchus gorbuscha*) in a British Columbia archipelago with 27 salmon farm sites was examined from June to August 2001. Abundance ($t_{44}=11.46$, $p<0.001$) and prevalence ($t_{44}=11.46$, $p<0.001$) of lice, and mean number of lice/g host weight ($t_{424}=19.82$, $p<0.001$) were all significantly higher in juveniles directly exposed to salmon farms than juveniles that had not yet encountered a salmon farm. Chalimus I/II stage lice dominated the population throughout the study suggesting that the infection source was continuous and local. Results currently under analysis from a similar project conducted in 2002 will also be presented.

An International Perspective on the Role of Lice from Salmon Farms in Variations in Wild Salmonid Populations

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Abstract

The potential effect of salmon lice *Lepeophtheirus salmonis* from farms on the size of wild salmonid populations has become the subject of controversy in several countries, including Canada. Lice have a natural circumpolar distribution and infections are interchanged between farmed and wild salmonids. However, information is sparse on infection levels in wild fish populations before the establishment of fish farming to compare with the current situation in the same areas. It is internationally accepted that the area surrounding salmon farms is affected by infections from these, and also that lice infections are dangerous, especially to young salmonids. Although correlations have been found between some data sets, cause and effect relationships have not been established with changes in wild salmonid population levels. These correlations have become the cause of extreme polarised views in both the scientific and non-scientific communities. Often the same information is being interpreted in different ways, frequently ignoring the complexity of factors causing variations in the levels of both fish stocks and fish diseases. Knowledge of the part of the wild population of salmonids being affected in relation to recruitment to the spawning stock, is critical to an evaluation of any effect on the salmonid population by lice from farms. Lice management strategies being followed in Europe have been successful in reducing farm lice levels, but until now without obvious associated benefit to wild salmonid stocks. Caution must be exercised in making direct comparisons between different areas because of different geographical, biological, physical and climatic conditions. The determination of real hazards and their subsequent management to address the objective of protecting and improving the stock of wild salmonids should be based on the principles of risk assessment.

Introduction

Risk analysis is a structured approach used to identify and evaluate hazards affecting an area of concern and leads to the implementation of management actions that are deliverable, are likely to achieve the desired results regarding protection and are proportionate to the level of the risk. This provides a rational and defensible position for the actions taken. Risk management requires that all possible major hazards to the area of concern should be identified, and a single factor should not be taken in isolation. Recommended steps to be taken in risk analysis are:

- release assessment (level of identified hazards at origin in relation to the history of the area of concern),
- exposure assessment (biological pathways for transfer of the hazards to the area of concern),
- consequence assessment (level of potential or actual impact on the area of concern),

- qualitative and/or quantitative estimation of risk level using available data and
- implementation of appropriate management actions.

It should be noted that a weakness at any point in this logical sequence of analyses between a suspected hazard up to the risk estimation should lead to questions being asked about the real importance of a suspected hazard. Consequently, in risk management, it is firstly necessary to demonstrate that a suspect hazard is real and contributes significantly to the area of concern before actions are designed and implemented to achieve the desired protection.

In the current context of considering salmon lice, *Lepeophtheirus salmonis*, as a potential hazard, it should remain uppermost in the minds of researchers that the core objective is to achieve, where possible, some practical management over the observed variations in the size of wild salmonid stocks. This will be achieved through the identification and control of factors contributing significantly to these variations. Internationally, it is accepted that salmon lice infections are a hazard to individual salmonid fish and that there is an interchange of lice between farmed and wild fish. However, there is a continuing unresolved debate on the actual role of lice from farms in the variations in populations of wild salmonids that raises legitimate questions about whether lice control on salmon farms would achieve the desired effect of improvement in the size of wild salmonid stocks. It is of particular concern that the nature and consequences of other possible contributory factors to stock size variations have not been well investigated, as the effects of a major cause of variation could largely obscure the results of management efforts associated with salmon lice.

Salmon Lice Studies

Unfortunately, many of the investigations into the relationships between salmon farms and wild salmonid populations, including those on salmon lice, have lacked focus because they fail to clearly define their objectives in relation to variations in the wild salmonid populations. Considerable efforts have been directed into areas not contributing to a resolution of this core question and frequently into topics where there is already adequate international consensus. Without reasonable evidence that lice from salmon farms contribute significantly to variations in wild salmonid populations, there are considerable dangers in a speculative deployment of efforts into intrusive management measures, with no adequate evaluation of the probability of a successful outcome.

The current emphasis on lice from salmon farms as a possible cause of variations in wild salmonid stock size, in isolation from other possible factors, is highly unscientific. The size of a fish stock in both the freshwater and marine environments is a result of an interaction of many natural biological and physical factors, and meaningful studies into variations in fish stocks should be multidisciplinary. Similar questions can be raised about why salmon lice have been selected as the important disease of concern. *Lepeophtheirus salmonis* has a natural circumpolar distribution on salmonids and are known to be pathogenic, particularly to young fish. They are also large enough to be highly visible without specialist knowledge and equipment. However, when detailed disease studies are carried out on a species of fish, it is normal for a wide range of disease causing agents to be detected. For example with wild Atlantic salmon, over 80 infectious conditions have been recorded in the scientific literature, several of which have known pathogenic potential.

Comparative data from before, after and during periods of known changes in an area, such as the development of fish farms, enable detection of trends that are particularly useful towards achieving the study objectives. Unfortunately this type of data is sparse, even in Europe. Although this paper leans heavily on the considerable body of literature that exists on salmon lice in Europe, and particularly that from Scotland, care must be taken in extrapolating data from Europe to Pacific Canada where both the environment and salmonid hosts are considerably different.

Areas of Controversy

Extremism in views feeds on controversy. Much of the basis of the considerable controversy existing regarding the relationship between variations in wild salmonid populations and salmon lice from farms derives from a lack of good data, leading to over-interpretation and even misinterpretation of information. Associated with this, there is a concerning polarised use of available data by different individuals with an unfortunate alignment of many to sectorial positions, rather than an acknowledgement of the inadequacies of the information. Particularly in the popular press, there is a persistent use of unsubstantiated comments, dogmas and beliefs. However, the frequency of repetition of such statements does not increase their validity, but can further fuel the controversy in an unhelpful way.

Much of the controversy in this topic area centres on a naïve misunderstanding on the value and interpretation of correlations that have been found between different sets of data. In particular there is a common failure to recognise that correlation does not mean causation. Before even starting to comment on cause-effect relationships between two factors, such as variations in wild salmonid populations and lice in fish farms, there is a requirement to demonstrate that a strong association is consistently maintained over an extended period and range of circumstances.

In order to address the considerable controversy being generated internationally over at least the previous decade, the International Council for the Exploration of the Seas (ICES) commissioned a special 5 day workshop in late 1996. This examined the scientific basis behind the assertions being made on the role of salmon lice in wild salmon stock variations. A total of 31 international scientists from 6 countries, all of whom had been recently actively publishing in the topic area, attended to provide scientific justification for the conclusions being made from their research in front of their peer researchers. Disappointingly, there was a wide range of interpretation of the same data at the meeting and a lack of agreement even on basic issues. It is hardly surprising that non-specialists, the media and the public are confused about this subject. No cause-effect relationship between lice from farms and variations in wild salmonid stocks could be concluded at the meeting. Only limited final conclusions were presented in the agreed Report of the Workshop (Anon, 1997), including the fact that salmon lice are particularly dangerous to young salmonids and that there is an interchange of lice between wild and farmed salmonids. This workshop was the last major full peer review of the topic area.

A more multidisciplinary evaluation of the topic of interaction between wild and farmed salmonids was undertaken in 1997 by a joint ICES / North Atlantic Salmon Conservation Organisation (NASCO) symposium. At this meeting, the problem of interpretation of the same salmon lice data in different extreme ways was discussed, and it was pointed out that the reality was more likely to lie at variable positions lay between the extremes (McVicar, 1997). Again, this international meeting could not conclude any cause-effect relationship between lice from salmon farms and the state of wild salmonid populations (Youngson *et al*, 1998).

Correlation

It is useful to consider some of the areas of correlation between data that have led to controversy in order to put into perspective some of the more widely circulated assertions on the relationship between salmon lice and variations in wild salmonid populations.

a. Correlation between areas with salmon farms and high levels of lice in wild salmonids

It is accepted that there are higher levels of lice infection in wild salmonid populations in the general areas of salmon farming. Summary data presented at the ICES Workshop and elsewhere (e.g. MacKenzie *et al* 1998) has indicated that this correlation was related to areas down to a resolution of 25 kilometres,

rather than specifically to the presence of a farm. However, as salmon farmers in Scotland find it necessary to co-ordinate lice management measures on an area basis between farms sharing the same water, rather than by individual farms, there is clearly a local effect attributable to farms. An attempt to quantify this in Ireland demonstrated a measurable infection pressure up to one 1-2 kilometres from the farm (Costelloe *et al* 1996), but this situation may change in other localities due to differences in the local physical and biological features.

Attempts to directly compare the infection levels of salmon lice in different areas, such as farming and non-farming, is misconceived without knowledge of the natural variation in infection levels between these areas. It is a well established principle in the epizootiology of fish diseases that the deterministic factors in disease variations are multifactorial, complex and interactive. Even in closely adjacent and apparently similar sea areas, the natural variation in a wide range of fish diseases can be extensive.

From a parasitological perspective, it is an expected conclusion of natural selection that the transmission strategy of a parasite such as *Lepeophtheirus salmonis* is adapted to achieve success in finding a new host. The relatively self-contained inshore waters with a concentration of susceptible hosts will provide an ideal environment for transmission and it may be significant that this overlaps with the requirements of salmon farming for similar sheltered waters.

b. New and abnormal behaviour patterns in wild salmonids

It is being commonly claimed that sea trout *Salmo trutta* “prematurely” return to fresh water in Europe because of heavy salmon lice infections being obtained as a consequence of salmon farms in inshore waters. A suggested result is a reduced marine feeding time to the detriment of growth. This correlation implies that there is a newly acquired directional behaviour, with rational planning by these fish that recognise the lice cleansing benefits of fresh water. Such a suggestion of teleological type actions in fish is contrary to previously knowledge of fish behaviour. It is more probable that the appearance of these fish in freshwater during the summer period is a normal selective behaviour pattern, possibly linked to the elevated risk of natural levels of sea lice infection in the inshore feeding grounds being frequented by this species of fish. Personal experiences with fishing sea trout in western Scotland prior to the development of salmon farming, indicated highest inshore concentrations of sea trout in the summer, close to or within estuaries.

c. Salmon lice are dangerous, especially to young salmonids

There is a considerable body of evidence indicating the pathogenicity of salmon lice and widespread international agreement that such infections are dangerous both to farmed and wild salmonids. However, many discussions on this topic take major leaps of faith from the effects on individual fish to whole fish populations, these often ignoring basic epizootic principles. The dangers of extrapolating results from experimental disease investigations to natural situations is well known to specialists in the fish disease field, due to the absence in artificial conditions of major contributing factors to the consequences of infections. Included in these are the ability to find food and the occurrence of predation.

When it comes to interpretation of data from field studies, it is necessary that the samples obtained for disease analysis are unbiased. The general health status of fish in samples must be known, while samples must be properly representative of the salmonid population under study and properly address to core objective of the study (namely, variations in the size of the spawning stock). In particular:

- (i) care has to be taken that diseased fish are not selectively sampled. It is well known that sick fish are easiest to catch as they typically show abnormal behaviour, including surface swimming and reduced flight response.
- (ii) the “chicken and egg” scenario also has to be carefully considered, as heavy lice infections can be secondary consequences of other problems. Fish that are sick with a variety of different diseases

- (bacterial, viral and parasitic) or are otherwise compromised (e.g. through starvation or inadequate smolting status) show a strong tendency to obtaining high infections with salmon lice.
- (iii) the popular perception that every fish in each life cycle stage is important to the size of the spawning stock is not supported by classic fish stock assessment studies. Munro *et al* (1983) undertook an analysis of this topic and concluded that the majority of fish in the juvenile phase of their life cycle were “destined to die and whether disease hastens the process may not influence the outcome.” Frequently, the availability of food is the main limiting factor and the loss of a large part of the population through high levels of mortality in an early stage serves to relieve pressure on limiting resources to the remaining part of the population. It was concluded that it was not a good use of scientific effort to investigate disease in parts of the population being subjected to high levels of natural mortality. Instead the focus should be on parts of the life cycle immediately prior to and during recruitment to the adult population.

d. Status of salmonid stocks in relation to salmon farming

During the period since the establishment of salmon farming in Europe there has been a decline in wild salmonid populations and this correlation has been used by some as evidence for a cause-effect relationship. Considering the UK, salmon farming is mainly restricted to the west and north of Scotland and the main development of salmon farming did not occur until the early 1980s. However, with Atlantic salmon stocks, there is evidence of a long-term decline nation-wide over a prolonged period, possibly 100 years or more. For sea trout, the decline in stock size is most severe in the main salmon farming area of the north west of Scotland, but the general decline was again nation-wide, including in non-farming areas. Official statistics for sea trout catches are available for Scotland since 1952 (Anon, 2002a) and it is apparent that the decline of the stock has occurred over all of that period at an approximately constant rate, with around 50% of the 1952 stock having disappeared by 1980 before farms were present in most areas. It is clear that salmon farming can not be implicated in these widespread early declines in the salmonid populations in the UK and if they are having an effect in the last 20 years, this is likely to be superimposed on mortality from other factors and difficult to distinguish.

European Situation

Currently, there is no consensus in Europe regarding the potential of impact of lice from salmon farms on variations in wild salmonid stocks. Polarisation of views is prevalent, often reflecting the affiliations of the researchers and proponents of particular views. It is unfortunate that some Canadian literature suggests that consensus does exist in Europe. This stems partly from misleading reference to “Scottish Executive conclusions” (SE) when in reality, these are contained in a report produced by a consultant group (Anon, 2002b). The SE have made a clear disclaimer that “The views expressed in this report are those of the researchers and do not necessarily represent those of the Department or Scottish Ministers.” Similar inaccuracies are also contained in the emphasis being place on European Commission documentation (Anon 2002c).

It was recognised in Europe that it is in the common interests of both salmonid farmers and wild salmonid stakeholders to have as few salmon lice as possible on farmed salmon. Using this as a basis for control without determining cause-effect between farms and wild stock variation, the major salmon farming countries in Europe namely Ireland, Norway and Scotland, have taken approaches to lice management on farms. These approaches differ between these countries and even in detail within one country, reflecting the need to tailor approaches to local situations.

a. Ireland and Norway

Ireland established an official government programme in 1991, monitoring levels of lice on salmon farms and requiring chemotherapy when levels of egg producing lice per fish reached 2-3. This was later revised to 2.0 egg producing lice per farmed fish during the year and 0.5 in the spring. Norway

established an official programme in 1998 with levels of egg producing lice established at 4 per farmed fish during the year and 0.5 in the spring. However, neither of these programmes has apparently resulted in achieving the main objective, namely the recovery of local salmonid stocks. There are several possible explanations for this:

- that the maximum levels lice set for farmed fish is still too high, but it will be difficult to establish an appropriate level when this may differ from area to area,
- that programmes have not been operating sufficiently long for an effect to become apparent, despite that in Ireland having been in place for 10 years and
- that lice may have no significant effect on the wild salmonid population.

With the currently available data, it is not possible to determine which of these options, or if in fact all are contributing to the lack of recovery of wild salmonid populations.

b. Scotland

Scotland was the first to recognise the need to manage lice on an area rather than a farm by farm basis and measures including fallowing and co-ordination of treatments widely adopted in the 1980s, within and between different farm companies (Grant & Treasurer, 1993). The basis for this lice management strategy was a strong knowledge base developed through practical experiences and targeted research by the Scottish salmon farming industry, government laboratories and academia. Fallowing of all farms in an area sharing water for a short period between different generations of stock, and the synchronised treatment of farms, provided the core mechanisms for success of the agreements. This voluntary approach was extended and formalised by the Scottish Salmon Growers Association with the publication of their Code of Practice, “A National Treatment Strategy for the Control of Sea Lice on Scottish Salmon Farms” (Anon, 1998).

Concerns in non-farming agencies about the credibility of a voluntary lice control scheme by an industry were addressed with the development of a Tripartite Working Group (TWG) that comprised representatives of government, wild salmonid associations and the salmon farming industry. The remit of the TWG related to the restoration and maintenance of healthy stocks of wild and farmed fish and the initiation of measures for the regeneration of wild salmon and sea trout stocks. A disease sub-group was charged with considering the health of wild and farmed salmonids and based their discussions firmly on the risk analysis approach. Recommendations included the setting up of locally based Area Management Agreements (AMAs) under Area Management Groups comprising stakeholders with interests in the same local aquatic resource (Anon, 2000).

In establishing the framework for the establishment of AMAs, several basic principles were identified:

- the difficulty, or even the improbability of being able to establish a cause–effect relationship between lice on salmon farms and variations in levels of wild salmonid populations to a standard acceptable to all parties
- the recognition that there should be an equitable and sustainable use of the aquatic resource in Scotland
- recommended actions should build on existing knowledge and experiences (qualitative analysis)
- the recognition that salmon farms cannot achieve continual zero lice infections because of persistent re-infection from the surrounding environment but that this should remain an objective, particularly during the period immediately prior to and during the wild smolt migration period
- the initial focus of each AMA should be on practical local objectives common to different stakeholders, with their range and complexity of objectives increasing as confidence between stakeholders progressively developed

- Area Management Groups should consist of locally-based stakeholders and the business of each should remain the confidential property of each, with no official intervention
- the TWG would act as an overseeing body receiving regular reports from each Area Management Group and only acting as an official reference point by invitation wherever agreement could not be reached.

Currently, a total of 6 AMAs have been established as legally binding agreements between participants, 4 others are in the process of being developed and the ultimate objective is to have a total of approximately 25, covering the main salmon farming areas of Scotland. With regard to salmon lice management, there was a strong emphasis on early spring removal of lice from farms in a whole area. This benefits the farmers by targeting lice populations before rising water temperatures lead to increased lice reproduction rates. The consequence is that few or no treatments should be required during the remainder of that year. The timing of the treatments also addressed the concerns about the risk of lice infection from farm sources of smolts newly emerging from rivers.

The need for the availability of several different approaches to lice management was recognised, for example the benefits of alternating different chemotherapeutants, interspersing treatments with the use of single generations of farmed salmon in each area and the use of synchronised fallowing between different generations. Because of the persistent re-infection of farms from the wild, the success of a lice management strategy depends on the availability of efficacious control methods. The continual developments both in the approaches to lice management in the salmon farming industry and in the success of treatments are encouraging. An example is the recent report by Treasurer *et al* (2002) on the use of Emamectin benzoate (SLICE) where existing salmon lice infections were removed and re-infection was prevented in two Scottish salmon farms for 12 weeks after a single treatment.

Canada

In eastern Canada, the situation largely mirrors that in Europe. Concerns about the state of Atlantic salmon stocks in New Brunswick led to a DFO Regional Assessment Program workshop in 1998 considering the range of possible areas of interaction between salmon farming and the wild stocks in the area. Included in this were discussions on the possible role of disease in farmed salmon, including salmon lice. The conclusion of the workshop was that “--- with the evidence currently available, it is not possible to conclude whether sea lice from farmed salmon do have any significant impact on wild salmonid stocks” (Ritter, 1999). More recently, a similar conclusion was made by Olivier (2002) who stated that “-- there is no documented evidence to substantiate the hypothesis that wild Atlantic salmon populations are declining in the Atlantic Provinces as a result of the spread of diseases originating from farmed fish.”

In recent months, the topic area has been extensively reviewed in BC and it is not intended here to reconsider the same information. However, it is appropriate to raise some general points, based on experiences in Europe although as mentioned above, there should be considerable caution in extrapolating details from one area to another. It is evident that the causes of variation in wild salmonid populations in BC over a long period have not been clearly defined. The multidisciplinary approach should not be ignored during the enthusiasm to investigate the potential role of sea lice.

It is also particularly noticeable that the concern about salmon lice in BC increased in association with the low returns of pink salmon in 2002. Determination of the time series of fluctuations in the size of wild salmonid stocks in relation to variations in lice levels in salmon farms in the area over the years since their initial development would be informative. In particular, it would be instructive to consider what differences existed in farms in the years leading to the high returns of pink salmon in 2000 and the low returns in 2002. Such an analysis would test the rigour of any suggested correlation, at the extremes of variation of the pink salmonid population.

With the international uncertainty surrounding the possibility of a cause-effect relationship between lice on salmon farms and variations in the size of wild salmonid stocks, it is necessary to carefully consider the likelihood of the effectiveness of any remedial measures being introduced in relation to the benefits being gained. Ideally this exercise should be conducted using experiences from elsewhere, prior to the actual introduction of any resource demanding and intrusive actions. Following the introduction of any management measures, it is then necessary to introduce measurable criteria into the analyses, in order to provide a continual evaluation of the level of success, in terms of control of the variations in wild salmonid populations in the area. Ineffectual actions would not only be a waste of resources, but would also lead to a false sense of security and be a distraction away from the search for other areas where meaningful management may be possible.

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Session 2
Session Leader: Pieter Van Will (CDFO)
Biology and Ecology

Why Are They Digging? A Study About Male Digging Behavior in the *Oncorhynchus* Genus

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Note: video of spawning salmon by Manuel Esteve is available at <http://sockeye/Home.htm>
(Fisheries Data, Manu Esteve's salmon spawning videos).

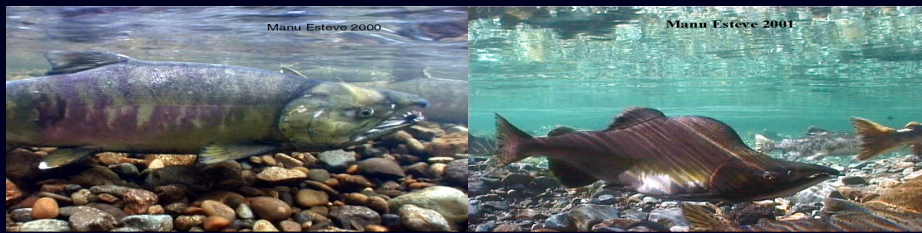
Abstract

Results from underwater video and previous research of Tinbergen (1952) are used to suggest the digging behavior of male *Oncorhynchus* salmon as a displacement reaction. Two different types of displacement diggings are derived from the observations with pink, chum and sockeye salmon: FD (fighting displacement) and SD (sexual displacement). Their proximate and ultimate causes are discussed. Additionally, the data is used to explore the two following predictions: Females should also perform displacement diggings and displacement diggings would tend to increase in frequency when fish experiments stress. Finally, speculations about the evolutionary significance of the male digging behaviour are made.

PowerPoint Presentation

Slide 1 and 17

Why are they digging?




a study about male digging behaviour
in the *Oncorhynchus* genus

Manu Esteve
University of Barcelona

Slide 2

A displacement reaction is...

a behaviour pattern with no relevance whatever to the circumstance in which the animal finds itself (Wilson 1975)



Slide 3

nest diggings



- 1. very intense*
- 2. small area*
- 3. the fish returns*

Slide 4



Slide 5

displacement diggings

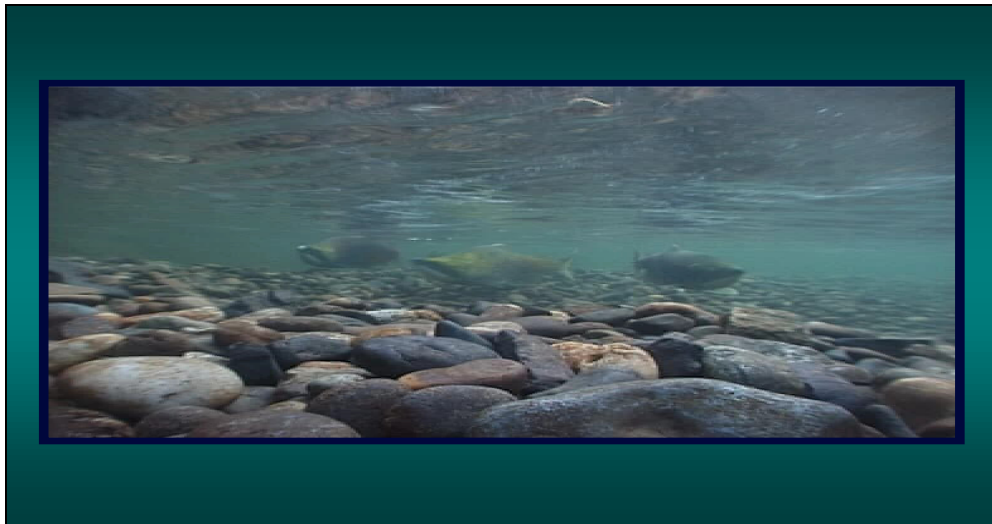


Manu Esteve 2001

*fewer tail beats
associated to fights
larger area*

This slide features a dark blue background. At the top, the title "displacement diggings" is written in a white, italicized serif font. Below the title is a rectangular inset photograph showing a fish, likely a wrasse, in a shallow, rocky underwater environment. The fish is positioned in the center, facing the viewer, with its head slightly lowered as if digging. The water is clear, and the rocks on the bottom are various shades of brown and grey. To the right of the photograph, there is a text box with a dark blue background and white italicized text that reads "fewer tail beats associated to fights larger area". Above the photograph, the name "Manu Esteve 2001" is written in a small, white, sans-serif font.

Slide 6



Slide 7

Tinbergen and the sticklebacks

Fighting displacement Simultaneous activation of
incompatible instincts



This slide has a dark blue background. At the top, the title "Tinbergen and the sticklebacks" is written in a red, italicized serif font. Below the title, there are two lines of text: "Fighting displacement" in a white, italicized serif font, followed by "Simultaneous activation of incompatible instincts" in a yellow, sans-serif font. Below the text is a rectangular inset photograph showing a stickleback fish swimming over a rocky bottom. The fish is facing the viewer, and its body is slightly curved. The water is clear, and the rocks are various shades of brown and grey.

Slide 8

Tinbergen and the sticklebacks

Sexual displacement

Strong motivation for spawning, but the external stimuli required for the release of the consummatory act is not provided by the female



Slide 9

displacement diggings

- *Should also be performed by females*




Slide 10



Slide 11

displacement diggings

2. *Should also be performed when str
conditions increased*



Slide 12

Pink salmon displacement diggings		
	fd	sd
females	11	0
males	7	0

Slide 13

chum salmon displacement diggings		
	fd	sd
females	3	0
males	28	4?

Slide 14

sockeye salm on displacement diggings		
	fd	sd
females	11	0
males	43	9

Slide 15

Male diggings	fd	sd
Sockeyes	43	9
Chums	28	4
Pinks	7	0

Slide 16

Female diggings	fd	sd
Sockeyes	11	0
Pinks	11	0
Chums	3	0

Slide 18

Proximate	Ultimate
two opposite instincts of same intensity (fd)	threat other males charm the females contribute nest building?
and instinct cannot be released because the opposite sex fails to give the necessary stimuli (sd)	charm the females? contribute nest building

Slide 19

<i>What's the evolutionary significance of male displacement digging?</i>
Why male digging is present in <i>Oncorhynchus</i> but not in <i>Salmo</i> or in <i>Salvelinus</i> ?
Why male digging is much more common in the three species we have seen today but not in coho and chinook and neither in steelhead and cutthroat?
Why is it more common in sockeye than in chum and very rare in pinks?

Slide 20

Partially funded by CSS and SFAS, UW		
Acknowledgements		
<i>In the River</i> Hans Berge Billy Ernst Mafalda Esteve Victor Ewert Gordy George Carmen Grisolia Caro Minte-Vera Jeff Shellberg Alex da Silva Mane D. de Souza Martin Lopez Brenda James Glenn Boltz Victor Esteve	<i>In the School</i> Dave Beauchamp Tom Quinn	<i>In the Workshop</i> Billy Ernst Juan Valero
<i>Additional Underwater Video</i> Barry Berejikian Washington Trout		

Effects of Fish Wheels on Fall Chum Salmon (*Oncorhynchus keta*): Non-Esterified Fatty Acids and Plasma Indices of Stress

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Abstract

I investigated the effect of tagging and capture on plasma concentrations of cortisol, glucose, lactate, chloride and non-esterified fatty acids (NEFA) in chum salmon. Adult chum salmon were captured in August and September 2000 and 2001 with a fish wheel on the lower Kantishna River, Alaska. Tagged and untagged fish were subsequently captured on the lower Toklat River (113 km upstream) and sampled for blood. Tagged fish (males and females) captured at the Toklat recovery fish wheels had significantly lower ($P < 0.04$) plasma cortisol concentrations (ng/ml) than untagged fish (tagged, 114.9 ± 17.9 ; untagged, 166.3 ± 16.7). Glucose concentrations were significantly lower ($P = 0.03$) in tagged than untagged males (tagged, 115.3 ± 5.4 ; untagged 136.1 ± 7.7) but did not significantly differ between tagged and untagged females. Lactate and chloride concentrations did not significantly differ between tagged and untagged fish (lactate, $P = 0.50$; chloride, $P = 0.82$). Tagged chum salmon captured at the Toklat River recovery wheels had significantly lower concentrations of NEFA ($P = 0.02$), (tagged $296.7 \pm SE\ 28.1$; untagged $385.1 \pm SE\ 26.0$). These results suggest capture and tagging using fish wheels causes stress in fall chum salmon and there is a metabolic cost associated with fish wheel capture and tagging.

Introduction

The Yukon River drainage is the largest in Alaska (854,700 km²), comprising nearly one-third the area of the entire state. Five species of Pacific salmon return to the Yukon River and tributaries and are utilized in subsistence, personal use, commercial and sport fisheries. The Tanana River is the largest tributary of the Yukon River. It flows northwest through a broad alluvial valley for approximately 700 km to the Yukon River at Tanana Village, draining an area of 115,250 km². The Tanana River drainage is a major producer of Yukon River fall chum salmon (*Oncorhynchus keta*) and contributes significantly to various in-river fisheries. Chum salmon return to the Yukon River in genetically distinct summer and fall runs (Crane et al. 2001). Summer chum salmon enter the Yukon River in early May, and fall chum salmon in mid July. Migration of fall chum salmon in the Tanana River drainage generally peaks around mid-September and continues into early October. Spawning takes place from mid-October through November, primarily in areas where upwelling ground water prevents freezing. The Toklat River, where part of this study was conducted, is an example of one of these areas and is one of the most productive fall chum spawning sites in the Tanana River drainage (Vania et al. 2002; JTC 2001).

Since 1981, fish wheels have been commonly used as a method of estimating run strength and timing of salmon migrations in the Yukon River drainage. In 2001, fifteen fish wheels were used to monitor salmon runs in the Yukon River drainage by the Alaska Department of Fish and Game (ADF&G), the United States Fish and Wildlife Service (USFWS), and the Canada Department of Fisheries and Oceans

(CDFO). In recent years, there has been concern that fish wheels used to assess run strength and abundance through mark-recapture studies may be causing delayed mortality of fall chum salmon (Underwood et al. 2002). Fall chum salmon migrate approximately 1,300 km from the mouth of the Yukon to the Kantishna River. During migration, Pacific salmon fast and dedicate energy to migration and gonad development. Because they are fasting, and endogenous energy resources are limited, stress from capture and tagging have the potential to decrease energy reserves and condition of these fish.

Mechanisms of Sex Ratio Regulation in Pink and Sockeye Salmon Populations

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Abstract

Sex ratio is one of the most important characteristics in Pacific Salmon populations. The aim of our investigations was to discover and to analyze the mechanisms responsible for sex ratio regulation (emerged from parental toward daughter generation) in pink and sockeye salmon from Bolshaya River (Kamchatka). It was found that sex ratio formation in daughter generations depends on parental abundance, sex ratio, the time of sex products realization (relatively to the time of ovulation), the size and hierarchical status of parents in a spawning group (of males first of all) and average egg mass. With an increasing abundance of parents the percent of males in a progeny increases, and vice versa. Parental and daughter population sex ratios correlate directly. In our opinion the abundance of parents can influence progeny sex ratio indirectly - through biological and zoosocial structures of parental spawning groups. One of the mechanisms of the influence is determined by sizes of parents. The less parental sizes - the more males in daughter generation, and vice versa. Positive asymmetry in the parental length distribution also promotes increasing number of males in the progeny, negative asymmetry – increasing number of females. Moreover, increased number of males in a daughter generation, originated from a parental abundant generation, is resulted from zoosocial situation in spawning grounds, i.e. takes place due to occurring extra number of subordinate individuals in a spawning group, causing a delay of spawning (relatively to the time of ovulation). When fishes were ready for spawning optimally, were of high hierarchical status, and their eggs were large-sized, the percent of females in the progeny increased. Ecological factors of sex ratio regulation in salmon should probably include water acidity for the time of fertilization. The tendency is revealed that the less pH the more males in progeny generated. Nevertheless, the mechanism is not supposed reliable until it is examined in further studies. A long-term forecast of sex ratio in pink and sockeye salmon populations is possible from the data complex assessed: the abundance of parents, sex, size and zoosocial structure, water pH for the time of fertilization.

Introduction

Sex ratio is one of general characteristics of fish populations, dependant on the terms of environment and influencing the abundance and biological structure of progeny. It has been found that sex ratio in parental generations of Pacific Salmon *Oncorhynchus sp.* can influence size structure and abundance of daughter generations through differentiated parental success in spawn (Chebanov, 1984; 1986). A certain, optimal, density-dependant sex ratio, providing maximum abundant progeny has been revealed for the Pacific Salmon in the study mentioned above too. These facts suggests that the

data on parental-daughter mechanisms of sex ratio determination might be useful for the purposes of rational regulation of fishery and of forecast of Pacific Salmon population structure and abundance.

Despite its undoubted actuality and important practical role sex ratio regulation has been studied poorly for both fishes and animals. V. Geodakyan and V. Kosobutsky (1969) have found in their experiments the inverse-relation mechanism of sex ratio regulation in the populations of *Lebistes reticulatus* Peters. Interesting data on human age-, body constitution- and temperament-dependant sex ratio were represented by M. Bernstein (cited from Geodakyan, Kosobutsky, 1969). K. Schaik and M. Noordwijk (1983) informed that the percent of males among the neonates and infants of non-human primates has been increased in the situations when increasing level of parental social stress (increased social tensivity, population density, food deficiency). The fact of 100% male development from the overmature oocytes of frog has been described by S. Kushakevich and R. Hertvig (cited from Geodakyan, Kosobutsky, 1969). The influence of social status, body size and relative frequency of the aggression demonstration on the sex transformation by protoandry type has been revealed in fishes (Fricke, 1983; Nemtsov, 1985; Warner, 1982). A displace of sex ratio toward the females' predominance in the progeny of *Cyprinus carpio* L. under increased amino acid concentration in and decreased pH of the water at the instant of fertilization (respectively), has been reported by I. Pluzhenko (1980). D. Rubin (1985) has found that the number of males increased under low pH (5-6), and the number of females increased under relatively high pH in the progeny of cichlids and poeciliids.

Some of the effects mentioned above can be studied in Pacific Salmon, the more so, as the data, concerning the relation between parental and daughter sex ratio on this species, are absent definitely. The only fact might be mentioned from the results of none large-scale experiment on *O. gorbuscha* (Walbaum) where the sex ratio displacement toward females took place under high water temperature and light period prolongation in early embryogenesis (Pakhomova, Khlevnaya, 1983).

The study aimed searching and analyzing the mechanisms responsible for parental-daughter sex ratio regulation in pink and sockeye salmon populations.

Pink and sockeye salmon from Bolshaya River basin have been studied. All statistical biological data on pink salmon stock, collected since 1932, have been analyzed. Stock abundance in Bolshaya River has been estimated on the every-year air observations of the spawning grounds. The data from several various experiments (some of them where definitely aimed for the purposes aside from this work) have been used.

The influence of parental sex ratio and abundance on daughter generation sex ratio in pink salmon

According to V. Geodakyan and V. Kosobutsky (1969) the "inverse relation mechanism" of sex ratio regulation implies the situation when the dominance of one sex in parental generation should determine the dominance of another sex in daughter generation. Carried out, the analysis of Bolshaya River pink salmon stock for the parental-daughter sex ratio relation gives the evidence of "direct relation mechanism" when the dominance of one sex in parental generation causes the dominance of the same sex in daughter generation. Correlation coefficient "r" is equal to +0.61 ($t_z > t_{st}$ for $P=0.01$).

Sex ratio in generations of Bolshaya River pink salmon relates rather closely to the stock abundance: $r = -0.62$ ($t_f > t_{st}$ for $P = 0.01$), for example: the higher stock abundance, the more number of males and the less number of females in generation. Similar relation is found between parental stock abundance and daughter generation sex ratio ($r = -0.53$, $t_f > t_{st}$ for $P = 0.05$). Moreover, the relation in odd years generations (they being in average more high abundant until 1983), being compared to even years generations, is more close (for odd years and even years respectively $r = -0.56$; $t_f < t_{st}$ for $P = 0.05$ and $r = -0.45$; $t_f < t_{st}$ for $P = 0.05$). Both the factors discussed bring similar effect in pink salmon daughter generation sex ratio, but there is a close relation between them; therefore, one factor could be suggested as major. That factor is parental stock abundance evidently.

The influence of this factor is indirect undoubtedly; it may be through some biological peculiarities of parents, biological and behavioral structure of spawning groups.

The influence of the time of fertilization, time period between ovulation and realization of sex products on the sex ratio in pink and sockeye salmon daughter generation

One of the most real mechanisms of the parental stock abundance influence on the daughter generation sex ratio can be the mechanism described in the work by S. Kushakevich and R. Hertvig (cited from Geodakyan, Kosobutsky, 1969). The effect of this mechanism consists in developing the 100% of males from the overmature oocytes of frog. It is known, however, that under increasing spawning density in salmon their time while on spawning grounds has been prolonged (Schroder, 1973; Chebanov, 1986, 1988), moreover the spawn itself (spawn and fertilization) often has been delayed. It is possible that some of these females have been spawning they being overmature. We decided to study how these effects might be reflected on daughter generation sex ratio in this context.

The materials of the outdoor ethological experiments with sockeye salmon, conducted in 1987, have been used for estimation of the time-factor influence on the sex ratio determination in daughter generations. Time-factor has been estimated as a relation between the times of sex products realization to the time of ovulation. These undertaken in different periods experiments implied participation of the fishes of various readiness to spawn, i.e. the fishes spent different time in spawning grounds after finishing their oogenesis and spermatogenesis. It has been found that the more late the process of fertilization is, and, hence, the longer time since optimum readiness of parents to the spawn has been, the more the progeny's sex ratio has been displaced toward predominance of males (Table 1).

Table 1. Sex ratio in daughter generations from experimental sockeye salmon breeds conducted in different time periods (at different readiness to spawn).

Date of fertilization	Number of variants	$\bar{X} \pm m_x$	σ	F
30.08	8	45.2 \pm 4.2	11.9	4.66
01.09	8	41.1 \pm 3.9	11.1	(F _f >F _{st} for P=0.05)
03.09	13	33.3 \pm 3.4	12.4	

Analysis of the materials on pink salmon breeds, carried out in various time periods with fishes, caught 2-4 days before breeding, indicates that the time period for optimum readiness to spawn did not influence daughter generation sex ratio significantly (Table 2).

It has been evident, that between two factors including the time of breeding under optimum readiness to spawn and the time period between ovulation and sex products realization, the reason factor of sex ratio changes in daughter generation in pink and sockeye salmon can be the latter only. We have suggested that the confirmation of this relation by further studies, give us the possibility to reckon this factor as one of important mechanisms of sex structure regulation in salmon populations.

The influence of parental hierarchical status within a spawning group on the daughter generation sex ratio in sockeye and pink salmon

In addition to the above, the effects of the mechanism, similar to described by K. Schaik and M. Noordwijk (Schaik, Noordwijk, 1983) for non-human primates, can possibly exist in salmon. According to observations of these authors, increased density of animals should cause sex ratio changes in favor of males in daughter generation. It was indicated, that main reason for such changes is physiological transformation in parents as a result of the stress increasing. Experimental breeds, undertaken within the behavioral studies on pink salmon in 1988, were analyzed. The results of the analysis demonstrated that the higher hierarchical status of male in a spawning group, the more number of females in its progeny, and vice versa, the lower its status, the more number of males in

progeny (Table 3). The individuals of lower hierarchical status were maximum exposed to stress in the course of spawn. Thus, the hypothesis, mentioned above, has been confirmed by the results of these experiments.

The influence of parental body size and average mass of egg on the sex ratio in daughter generation of sockeye and pink salmon

Detail analysis of ethological experiments made us pay attention to the fact that large males were dominant in most cases, and smallest males were satellites (body size almost does not influence hierarchical status of females). This fact suggests the tendency of sex ratio determination in daughter generation through the parental size structure.

The tendency suggested has been decided to test on the massive biostatistical data for the period from 1932 to recent years on Bolshaya River pink salmon. It has been revealed that increased average parental body size in both females and males, caused increased number of females in daughter generation. Correlation coefficient for both sexes is equal to $+0.47$ ($t_f > t_{st}$ for $P = 0.05$) (Table 4, 5). Moreover, average sizes the parental generations within every class of parental (females or males) have been selected by the sign of asymmetry coefficient on given parameter. Such selection provided suggestion to which size (to smaller or to bigger) the peaks in the distribution curves can be replaced in certain years. It was found that almost in all cases the replace of distribution curve peak toward smaller sizes caused relative number increase of males in daughter generations, whereas larger sizes caused relative number increase of females (Table 4, 5). Correlation coefficients for the indexes of length distribution asymmetry (for complete size series) and sex ratio in daughter generations were -0.43 ($t_f > t_{st}$ for $P = 0.05$) and -0.40 ($t_f > t_{st}$ for $P = 0.05$) in females and males respectively. Especial attention should be paid to the fact that the most close and reliable correlation was in the class of generations characterized by mediate (for a long term period) parental sizes (especially if the estimation was carried out on females).

Testing the relation, revealed from the materials of ethological experiments on pink and sockeye salmon, discussed above, indicated increased number of females in daughter generations reproduced from large parental males, it being compared to that in generations from small parental males (Table 6). The relation on parental female sizes did not take place. Thus, the influence of parental hierarchical status (mostly the status of males) in spawning groups on the sex ratio in pink and sockeye salmon daughter generation has been suggested as really provided by the length of body. The fact which might confirm the conclusion is that in some rare experiments when the length of satellite male or of subdominant male was more than the length of dominant male the percent of females in daughter generation from satellite or subdominant males was higher being compared to that in generation from dominant male.

The data by N. Vilenskaya on pink salmon breeds in 1988 (which we analyzed) revealed a quite certain relation - the higher average mass of incubating egg in particular breeds, the higher the percent of females among larvae ($r=0.48$; $t_f > t_{st}$ for $P = 0.05$). It is known, however, that the average mass of egg in Pacific Salmon is direct dependent on the size-mass characteristics of parental females. That has been confirmed by the analysis of the data from appropriate experiment (although the correlation coefficient was not reliable). Obviously, in this case the influence of the average mass of egg on the sex ratio in pink salmon daughter generation was mostly indirect as well (through the body length of parental females).

Table 2. Body length of females, average mass of egg and sex ratio in progenies from experimental breeds of pink salmon by dates (under optimum readiness to spawn) (the data by N. Vilenskaya, 1988).

The date of fertilization	Average body length of females, cm			Average mass of egg, mg			Percent of females		
	$\bar{X} \pm m_x$	σ	F	$\bar{X} \pm m_x$	σ	F	$\bar{X} \pm m_x$	σ	F
11.08	50.4±0.2	0.6		118.6±2.7	7.7		51.8±1.2	3.3	
21.08	50.5±0.5	1.2	1.77	128.4±3.2	8.4	5.95	58.4±4.5	11.9	1.30
28.08	51.4±0.5	1.3	($F_1 < F_{st}$ for $P=0.05$)	134.3±3.6	9.5	($F_1 > F_{st}$ for $P=0.01$)	52.8±2.8	7.4	($F_1 < F_{st}$ for $P=0.05$)

Table 3. Sex ratio in progenies from experimental breeds of pink and sockeye salmon of various hierarchical status, percent of females.

Species		Pink salmon				Sockeye salmon			
Sex of parent	Hierarchical status	Number of variants	$\bar{X} \pm m_x$	σ	F	Number of variants	$\bar{X} \pm m_x$	σ	F
Males	Dominant	4	54.1±2.9	5.0	5.80	7	41.0±2.5	6.1	0.02
	Subdominant	2	52.7±0.4	0.4	($F_P > F_{st}$ for $P=0.05$)	8	41.4±3.2	9.2	($F_P > F_{st}$ for $P=0.05$)
	Satellite	5	46.1±2.1	4.3		9	42.1±4.7	13.3	
	Dominant	-	-	-	-	5*	41.9±3.1	6.2	1.38
	Subdominant	-	-	-	-	6*	42.9±4.0	8.9	($F_P < F_{st}$ for $P=0.05$)
	Satellite	-	-	-	-	6*	34.9±4.4	9.8	
Females	Dominant	4	49.9±1.9	3.2	0.11	8	42.1±3.7	8.3	4.85
	Subdominant	3	49.2±4.3	6.1	($F_P > F_{st}$ for $P=0.05$)	8	46.0±2.8	5.5	($F_P > F_{st}$ for $P=0.05$)
	Satellite	4	51.2±4.0	6.7		9	32.3±3.5	7.7	

Note. * - Estimated without the data from the experiment №1, where satellite male was larger than dominance male.

Table 4. Sex ratio in Bolshaya River pink salmon in relation to female size structure in parental generation.

Average size of parental females, cm	Year of spawn of daughter generation	As length of parental females		The percent of females in daughter generation	
		Variants	In average	Variants	In average
43.5 - 46.4	1977	+0.46	+0.09 ± 0.09 (σ = 0.23)	46.0	46.05 ± 2.1 (σ = 5.5)
	1954	+0.31		50.0	
	1953	+0.22		51.9	
	1981	+0.16		50.0	
	1979	+0.03		40.0	
	1951	- 0.11		50.0	
	1932	- 0.13		44.4	
	1937	- 0.20		36.1	
	1983	+0.35		42.0	
	1959	+0.20		48.5	
46.5 - 49.4	1980	+0.12	- 0.04 ± 0.08 (σ = 0.24)	51.0	49.3 ± 1.1 (σ = 3.2)
	1958	+0.03		50.0	
	1982	+0.03		48.0	
	1984	-0.08		49.2	
	1975	-0.16		47.3	
	1952	-0.26		50.0	
	1978	-0.28		53.0	
	1956	-0.36		53.6	
	1977	+0.78		53.0	
	1964	+0.59		59.5	
49.5 - 54.5	1965	+0.03	- 0.14 ± 0.12 (σ = 0.42)	62.8	59.7 ± 2.7 (σ = 9.4)
	1960	0		52.9	
	1962	- 0.08		48.5	
	1967	- 0.15		62.6	
	1966	- 0.20		62.8	
	1973	- 0.25		54.5	
	1961	- 0.34		49.7	
	1968	- 0.40		51.5	
	1974	- 0.51		72.5	
	1969	- 0.54		79.0	
	1976	- 0.69		67.1	

Note. Correlation coefficients for:

The size of parental females – daughter generations sex ratio = +0.47 ($t_{t>t_{st}}$ for $P = 0.05$). As length of parental females – daughter generations sex ratio:
In average = -0.40 ($t_{t>t_{st}}$ for $P = 0.05$). Parental females size in the range 43.5 - 46.4 cm = +0.52 ($t_{t<t_{st}}$ for $P = 0.05$), 46.5 - 49.4 cm = -0.72 ($t_{t>t_{st}}$ for $P = 0.05$) and 49.5 - 54.5 cm = -0.42 ($t_{t<t_{st}}$ for $P = 0.05$).

Table 5. Sex ratio in Bolshaya River pink salmon in relation to male size structure in parental generation.

Average size of parental males, cm	Year of spawn of daughter generation	As length of parental males		The percent of females in daughter generation	
		Variants	In average	Variants	In average
43.0 - 46.5	1979	+0.40	+0.09 ± 0.14 (σ = 0.25)	40.0	43.0 ± 4.2 (σ = 4.2)
	1977	+0.26		46.0	
	1981	-0.04		50.0	
	1932	-0.05		44.4	
47.0 - 51.5	1937	+0.56	+0.04 ± 0.09 (σ = 0.35)	36.1	48.1 ± 1.5 (σ = 4.9)
	1978	+0.41		53.0	
	1959	+0.26		48.5	
	1975	+0.24		47.3	
	1953	+0.22		51.9	
	1954	+0.17		50.0	
	1983	+0.11		42.0	
	1984	+0.11		49.2	
	1980	+0.09		51.0	
	1952	+0.02		50.0	
	1958	0.00		50.0	
	1956	-0.02		53.6	
	1982	-0.23		48.0	
	1974	-0.64		72.5	
	1951	-0.74		50.0	
	1968	+0.40		51.5	
	1962	+0.34		48.5	
52.0-57.0	1969	+0.32	-0.10 ± 0.10 (σ = 0.35)	58.4 ± 8.2 (σ = 14.2)	58.7 ± 2.7 (σ = 8.9)
	1973	+0.23		79.0	
	1965	0.00		54.5	
	1960	-0.19		62.8	
	1971	-0.29		52.9	
	1964	-0.34		53.0	
	1967	-0.34		59.5	
	1976	-0.34		58.8 ± 2.4 (σ = 6.2)	
	1961	-0.35		62.6	
	1966	-0.62		67.1	
				49.7	
				62.8	

Note. Correlation coefficients for:

The size of parental males – daughter generations sex ratio = +0.47 ($t_{\text{f}} > t_{\text{st}}$ for $P = 0.05$).

As length of parental males – daughter generations sex ratio: In average = -0.43 ($t_{\text{f}} > t_{\text{st}}$ for $P = 0.05$). Parental males size in the range 43.0 - 46.5 cm = -0.68 ($t_{\text{f}} < t_{\text{st}}$ for $P = 0.05$), 47.0 – 51.5 cm = -0.60 ($t_{\text{f}} > t_{\text{st}}$ for $P = 0.05$) and 52.0 - 57.0 cm = -0.05 ($t_{\text{f}} < t_{\text{st}}$ for $P = 0.05$).

Table 6. Sex ratio in generations from experimental broods of different sizes pink and sockeye salmon*, percent of females.

Species	Pink salmon					Sockeye salmon				
Parental sex	Size class, cm	Number of variants	$\bar{X} \pm m_x$	σ	F	Size class, cm	Number of variants	$\bar{X} \pm m_x$	σ	F
Males	50.0-53.0	6	47.2±2.1	4.7	5.41	65.0-68.0	14	37.3±2.5	8.9	5.66
	54.0-60.0	5	53.7±2.3	4.6	(F _r >F _{st} for P=0.05)	68.5±74.0	11	46.9±2.9	9.3	(F _r >F _{st} for P=0.05)
Females	48.0-50.5	6	50.5±2.5	5.6	0.03	60.0-62.5	13	44.7±2.9	9.9	2.85
	51.0-53.0	5	49.9±2.8	5.6	(F _r >F _{st} for P=0.05)	63.0-66.0	12	38.1±2.9	9.5	(F _r >F _{st} for P=0.05)

Note. * - Materials from etological experiments on sockeye salmon (3 males per 1 female) in 1989 have been used

The facts mentioned above make us suggest that the predominance of males or females in number in daughter generations is determined quite clear by the average parental body sizes (small or large respectively). At that, influence of the sign and the value of the asymmetry coefficient in this characteristic are rather significant for the average body size class in parental generation. To make more clear the gist of the above, we have to remind about the phenomenon of positive assortative mating, determined by body sizes (when breeding the individuals of similar sizes) in pink salmon spawning ground (Chebanov, 1984). Therefore, under the positive asymmetry, implying the predominance of small-size fishes in stock, the breeds between small-size fishes have been more frequent compared to the breeds between the fishes of another size. Hence displacement in sex ratio toward male's predominance in daughter generation has got. Otherwise, under the negative asymmetry, the breeds between larger fishes have been more frequent; hence displacement in sex ratio toward female's predominance in daughter generation has got.

Thus, if to take into account the fact that the abundance of pink salmon generations relates closely to averaged spawners' body sizes in stock ($r = -0.68$, $t_{\text{f}} > t_{\text{st}}$ for $P = 0.001$), it could be affirmed that one of the mechanisms to determine sex ratio in daughter generation should consist in scheme: parental stock abundance – parental generation size structure - daughter generation sex ratio.

The influence of water pH at the instant of fertilization on the sex ratio in sockeye salmon daughter generations

To the number of ecological factors regulating the sex ratio in salmons probably the factor of water pH at the instant of fertilization should be reckoned. In 1989 we had carried out a special experiment in order to estimate the influence of this factor on the sex ratio in sockeye salmon generation. For the purposes of this experiment 5 parental pairs were used. Water pH was changed using sodium phosphate monosubstituted. Prepared solutions bore the pH values as: 1) 6.5 (control); 2) 6.25; 3) 6.03; 4) ≤ 6.00 . Four portions of eggs (300 eggs each) were taken from every female; the portions were fertilized with sperm from single male respectively under four different water pHs. As a result the tendency has been revealed according to which the lower pH at the instance of fertilization, the higher the number of males in progeny (Table 7). These data are well coordinated to the data by D. Rubin (1985). Nevertheless, because of low survival of progeny in the course of the carried out experiment we cannot claim how real the mechanism is until its confirmation or no confirmation in further experiments. It is expected that in the case of confirmation, the forecast of sex ratio in salmon populations by the pHs in home rivers would be possible.

Table 7. Sex ratio in generations from sockeye salmon experimental breeds, carried out under different water pH conditions.

Water pH	Parental pair No	Sex ratio in generation				F
		Number of males	Number of females	Percent of females		
				By variants	In average	
6.50	4	4	7	63.6	56.8	0.72
	5	1	1	50.0		
6.25	-	-	-	-	-	
6.03	3	29	22	43.1	51.5	
	4	2	3	60.0		
6.00	3	20	19	48.7	45.8	
	5	8	6	42.9		

Conclusion

The analysis, carried out, makes us suppose that among internal population mechanisms responsible for the sex ratio formation in generations of pink and sockeye salmon the most important ones are those where the factors of parental stock abundance and sex ratio in spawning ground, the period between ovulation and realization of sex products, the average mass of egg, parental body size (male size first of all) and hierarchical status in spawning group are included. Male predominance in daughter generation is provided by the males' predominance in parental generation, high parental stock abundance, delayed spawning (relatively to ovulation time), small body sizes and low hierarchical status of parents in spawning group, low average mass of egg in particular females. Positive asymmetry in parental length distribution as well provides a displacement toward males' predominance in daughter generation (negative asymmetry – a displacement toward female predominance). This relation is most clear for parental generations characterized by mediate average size for a long-term period of observations. An increase of the number of females in daughter generation goes under female predominance in parental generation, under low parental abundance in spawning ground and optimum parental readiness for spawn, when parents have got high hierarchical status, large body size, and high average mass of egg.

In the number of ecological factors of sex ratio regulation in salmon the factor of water pH at instant of fertilization should be included perhaps. According to the revealed tendency, the less water pH, the more males in progeny generated. Nevertheless, the mechanism is not considered reliable until it is examined in further studies.

Thus, a long-term forecast of sex ratio in pink and sockeye salmon populations is possible on the basis of the data complex assessed: the abundance of parents, parental sex-, size- and zoosocial structures and water pH at the instant of fertilization.

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Pink and Chum Salmon Stock Status in Southeast Alaska

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Abstract

The Alaska Department of Fish and Game annually monitors, via aerial surveys, 718 pink salmon spawning streams in Southeast Alaska. We divided these streams into 45 stock groups in three sub-regions (Southern Southeast, Northern Southeast Inside, and Northern Southeast Outside). All 45 stock groups were stable or increasing over the past 21 years. We used a “tabular approach” to establish new pink salmon escapement goals for each of three sub-regions of Southeast Alaska. We developed an index of 82 chum salmon streams in the region that have extensive, 21-year time-series of peak escapement survey estimates: 71 streams (87%) exhibited stable or increasing trends (27 streams showed a significant increase), while 11 streams (13%) exhibited declines. Harvests of wild chum salmon in the commercial fisheries have also trended upwards over the past two decades, and have averaged about 3 times the catches of the 1970s. We did not establish formal escapement goals for chum salmon in Southeast Alaska, due to a lack of sufficient information. Although some fall-run chum salmon stocks appear to have declined recently, the overall status of pink and chum salmon in the region remains biologically favorable, particularly for pink salmon.

Introduction

Pink salmon (*Oncorhynchus gorbuscha*) spawn in approximately 2,500 short, coastal streams throughout Southeast Alaska, while chum salmon *O. keta* are known to spawn in approximately 1,500 streams in Southeast Alaska. Annual commercial harvests of both species in Southeast Alaska were historically at high levels in the early to mid-1900s, then gradually declined to their lowest levels in the 1960s and 1970s (at which time fishing was fairly restricted). Catches of pink salmon have risen tremendously since then, reaching nearly 60 million in 1989, and fluctuating between 20 million and a historical high of 78 million fish (1999) since 1990 (Figure 1). Nearly all (>97%) of the pink salmon harvest in Southeast Alaska is of wild origin. As noted by Van Alen (2000), the great increase in chum salmon harvests beginning in the 1990s is due largely to the production and release of hatchery fish, which have accounted for an average of 69% of the commercial harvest of chum salmon over the past 10 years (Figure 1).

A 1996 American Fisheries Society sponsored study of salmon stocks at risk found pink salmon populations to be increasing or stable in over 96% of the spawning aggregations they examined in Southeast Alaska (Baker et al. 1996). Baker et al. (1996) also reported that only 45 chum salmon spawning locations (out of 1,516) in Southeast Alaska possessed enough information for formal evaluation using their methods. Of the 45 locations, they evaluated, 8 (18%) were classified as increasing, 27 (60%) as stable, 9 (20%) as declining, and 1 (2%) in precipitous decline. They noted that “little is known about the actual abundance and escapement of the vast majority of spawning aggregations

in Southeast Alaska.” Van Alen (2000) also noted a general upward trend in pink salmon abundance (only one of the 652 streams he examined showed a downward trend between 1960 and 1996), and the lack of stock-specific information for chum salmon. His analysis of 180 streams that had “peak” aerial survey estimates for at least 10 years, between 1960 and 1996, showed that counts of chum salmon tended to be higher in the 1960s and early 1970s, and he identified significant declines in 12 of those streams.

Here we provide a summary of two stock status reports recently completed to meet the reporting requirements of the Sustainable Salmon Fisheries and Escapement Goal policies. Those policies, adopted into regulation by the State of Alaska Board of Fisheries in 2000, requires the Alaska Department of Fish & Game (ADF&G) to conduct regular, formal assessments of the status of salmon stocks, and to establish escapement goals when the department can reliably estimate escapement levels. We looked at trends in the harvest and escapements of pink and chum salmon in Southeast Alaska over the past 21 years, 1982-2002, and revised regional escapement goals for pink salmon. More detailed analyses can be found in Zadina et al. (2003), and Heintz et al. (2003).

Methods

Estimates of the annual harvest of pink and chum salmon through 1997 were taken from Byerly et al. (1999). More recent harvests were obtained from the ADF&G Integrated Fisheries Database. The annual estimated contributions of hatchery fish to the commercial fisheries were obtained from the hatchery operators, as reported to ADF&G (McNair 2002, and previous reports in that series).

Pink Salmon Escapement

Area management biologists annually estimate salmon spawning stock size for 718 pink salmon index streams via aerial surveys, conducted at intervals, during most of the migration period. Fish counts are divided into four categories: mouth, intertidal, stream live, and stream dead. Since 1997, each survey has additionally been qualified based on visibility and timing as: 1) not useful for indexing or estimating escapement; 2) potentially useful for indexing or estimating escapement; and 3) potentially useful as a peak escapement count.

Individual observers tend to count at their own rate, or “bias” (Dangel and Jones 1988, Jones et al. 1998). Beginning in 1995, raw stream survey counts were standardized to remove as much “observer bias” as possible – not by removing bias, but rather by adjusting all observer counts within a management area to the same bias level (Hofmeister 1998, Van Alen 2000). Each individual observer’s counts are converted to the counting rate of a major observer using the following method:

- 1) We identified every instance where that individual observer and the major observer from the same management area surveyed the same stream within three days of one another, and each paired observation was expressed as a ratio of the count of that individual observer to the count of the major observer (the major observer’s rate is set at 1.0).
- 2) The median of the ratios of all such paired observations was used as a “bias adjustment” for that individual observer.
- 3) All surveys by that individual observer were then multiplied by that individual observer’s bias adjustment.

Peak survey counts for each stream are identified at the end of the season. If a particular index stream is missing a peak escapement count for any given year, an iterative EM algorithm (McLachlan and Krishnan 1997) is used to interpolate a peak count. Southeast Alaska index streams were further divided into 45 management “stock groups.” Stock groups are organized into four management areas (Juneau, Petersburg, Sitka, and Ketchikan) that correspond to department area offices in charge of managing

commercial fisheries on these stocks. We divided the stock groups into three subregions throughout SE AK: Northern Southeast Inside waters (Districts 109-112, District 113-inside, Districts 114-115), Northern Southeast Outside waters (District 113-outside), and Southern Southeast (Districts 101-108). Numerous tagging studies (e.g., Nakatani et al. 1975, and Hoffman et al. 1984) have shown that the commercial fisheries in each subregion generally target pink salmon that ultimately spawn in that subregion. Stock-specific harvests cannot be identified on any finer level than this.

Chum Salmon Escapement

Chum salmon in Southeast Alaska are generally divided into two runs based on migration timing: summer-run fish peak from mid-July to mid-August, and fall-run fish peak in September or later. We developed an index that included 82 streams (76 summer-run chum salmon streams and 6 fall-run chum salmon streams) based on the following criteria:

- 1) Streams that had peak survey estimates for at least 16 of the most recent 21 years, 1982-2002; i.e., there were useful survey counts available for 75% of the most recent 21 years.
- 2) Only one type of survey data was used for the entire series for a given stream; i.e., we did not mix aerial and foot surveys for any one stream (we used peak aerial survey estimates for 78 streams, and peak foot survey estimates for 4 streams).
- 3) Survey estimates had to be obtained in a fairly consistent timing and method year after year. Ideally, there would be at least several years with multiple surveys over the course of the season that established good timing for a peak survey for a given stream.

The index was simply the annual sum of the peak survey estimates for all 82 streams. We did not find it necessary to interpolate for missing peak survey counts, because we used only streams with a fairly complete time series. Chum salmon escapement data were used “as is”; we did not attempt to standardize the data in any way.

Trend Analysis

We used a nonparametric approach, described by Geiger and Zhang (2002), to evaluate the most recent 21 years of escapement index values. This method provides a robust estimate of a stock’s increase or decline over a given time series, by fitting a resistant regression trend line to the data. The regression line is then used to back-cast to an estimate of an escapement at year zero, which we call the *year-zero reference point*, and the slope of the line is a robust estimate of the stock’s decline (or increase). We would conclude that an escapement decline was *biologically meaningful* when the estimated underlying annual decline was more than 3% of the year-zero escapement, based on the recommendation of Geiger and Zhang. A sustained 21-year, overall decline that is 3% of the back-cast year-zero reference point would result in the stock declining by more than 60% (Geiger and Zhang 2002).

Results and Discussion

For all of Southeast Alaska, 8 of the top 10 pink salmon index escapements have occurred within the last 10 years. In over 100 years of commercial exploitation, the pink salmon catches in Southeast Alaska are recently at the highest levels observed, yet the number of fish escaping the fishery to breed is also at very high levels – at the highest level since statehood, when record-keeping began (Figure 2). Taken as a whole, the escapement index exhibited an annual increase that was 7% of the year-zero reference point per year, over the past 21 years. Escapements of pink salmon are well distributed throughout Southeast Alaska. Of the 45 stock groups we examined, 42 showed clear increases in peak aerial escapement survey estimates over the last 21 years, and three showed declines so small that we interpreted the escapements to these stock groups to be functionally stable.

Taken as a whole, the chum salmon stocks that we chose as index streams showed an annual increase that was 5% of the year-zero reference point per year, over the 21-year series (Figure 3). Using the same Geiger and Zhang (2002) analysis of the annual catch of wild chum salmon, we see that the increase in peak escapement estimates has paralleled, to a similar degree, the 3% of the year-zero reference point per year increase in the estimated harvest of wild chum salmon since 1982 (Figure 3). Annual commercial harvests of wild chum salmon have tripled, on average, since the 1970s.

A total of 71 of the 82 (87%) chum salmon index streams that we examined were stable or exhibited increasing trends in peak survey estimates over the past 21 years, and 27 (33%) of those streams showed a statistically significant increasing trend (Spearman's rank: $P < 0.05$; $n = 21$). Increasing trends were particularly pronounced for many streams in northern areas of the region. The remaining 11 streams showed a robust estimate of decline in peak escapement surveys over the last 21 years, and six of those streams showed declines of 3 to 5% of the reference point per year, which we considered biologically meaningful under Geiger and Zhang's criteria: Hidden Inlet (ADF&G Stream No. 101-11-101), Tombstone (ADF&G Stream No. 101-15-019), Tyee Head East (ADF&G Stream No. 109-30-016), Sample Creek (ADF&G Stream No. 109-62-014), St. James Bay NW Side (ADF&G Stream No. 115-10-042), Clear River-Kelp Bay (ADF&G Stream No. 112-21-005), Port Camden S Head (ADF&G Stream No. 109-43-006), and Port Camden W Head (ADF&G Stream No. 109-43-008). The last two streams were the only ones that showed a statistically significant decline in peak survey counts over the past 21 years (Spearman's rank: $P < 0.05$; $n = 21$).

Peak survey estimates are used to index escapement, but they are in units that are very different from our estimates of catch. The "peak" escapement estimates that we use here underestimate the true escapement, and should only be considered a relative indicator of escapement magnitude (Van Alen 2000). The majority of aerial surveys have been conducted to monitor inseason development of salmon escapements for management purposes, not to estimate total escapements. For this reason, a Ricker analysis is not possible without making some unproven and possibly ill-advised assumptions. Hilborn and Walters (1992) suggest what they call a rough and ready "tabular method" for setting escapement goals when the form of the stock-recruit relationship is not known, and when there might be errors that would complicate traditional statistical approaches. They do caution that this approach requires large sample sizes, which we have. Therefore, we used a tabular approach to expand the escapement index to varying levels to estimate total return, and to update escapement goals for each of the three sub-regions of Southeast Alaska. We recommend a biological escapement goal of 4 to 9 index spawners (millions of summed peak counts) in the Southern Southeast sub-region, 2.5 to 5.5 in the Northern Inside sub-region, and 0.75 to 1.75 in the Northern Outside sub-region (Zadina et al. 2003). Although odd- and even-year lines of pink salmon are genetically isolated (Gharrett and Smoker 1990) and biologically separate populations, data from both lines were pooled for our analysis of escapement trends because they are managed as if they were a single population. Escapement goals in Southeast Alaska are the same for both brood lines.

We do not recommend any formal escapement goals for chum salmon in Southeast Alaska at this time. The quality of existing escapement and stock-specific production measures would need to be significantly improved to develop meaningful and technically supportable escapement goals for specific streams or areas. Chum salmon are most easily observed early in the season when there are few pink salmon in the streams. As the season progresses, and large numbers of pink salmon enter streams, it frequently becomes much more difficult to see and count chum salmon. Peak annual counts of chum salmon for many streams have been limited to the period before pink salmon become abundant in the streams (e.g., July to mid-August), and high pink salmon escapements may have masked high chum salmon escapements in many areas (Van Alen 2000).

In addition to the chum salmon streams in our index, we also examined several stocks for which we do not have reliable escapement measures, but for which harvest information has clearly demonstrated recent declines: Chilkat River fall chum, Taku River fall chum, and East Alsek River fall chum. Those streams are discussed at length by Heinl et al. (2003). Briefly, possible reasons for declines of fall-run chum salmon in those streams may include over harvest, changes in spawning habitat (natural changes due to glacial river dynamics), interactions with other species, or interactions with hatchery-reared fish. ADF&G has taken measures to limit harvest on those runs until more can be learned as to the causes of declines, and until reliable measures of escapement can be established for those streams. It is of interest to note, that while runs of fall chum in the Taku and Chilkat Rivers declined in the late 1980s, runs to many other chum salmon streams in northern Southeast Alaska actually increased. For example, peak escapement estimates of summer chum salmon to 8 streams in Tenakee Inlet, Chichagof Island, have increased significantly over the past 21 years, while also supporting an early-season purse seine fishery that is directed at summer chum returns to the inlet.

In summary, although some fall-run chum salmon stocks appear to have declined recently, the overall status of pink and chum salmon in the region remains biologically favorable, particularly for pink salmon. Our goals for improving escapement monitoring of pink and chum salmon in Southeast Alaska over the next few years include: 1) refine our escapement data for pink salmon, and establish escapement goals based on a more technical analysis than the simple approach we used; 2) standardize our chum salmon escapement data; and 3) establish escapement goals for the chum salmon systems that we have monitored more intensely, particularly the Chilkat and Taku rivers in northern Southeast Alaska.

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Figures

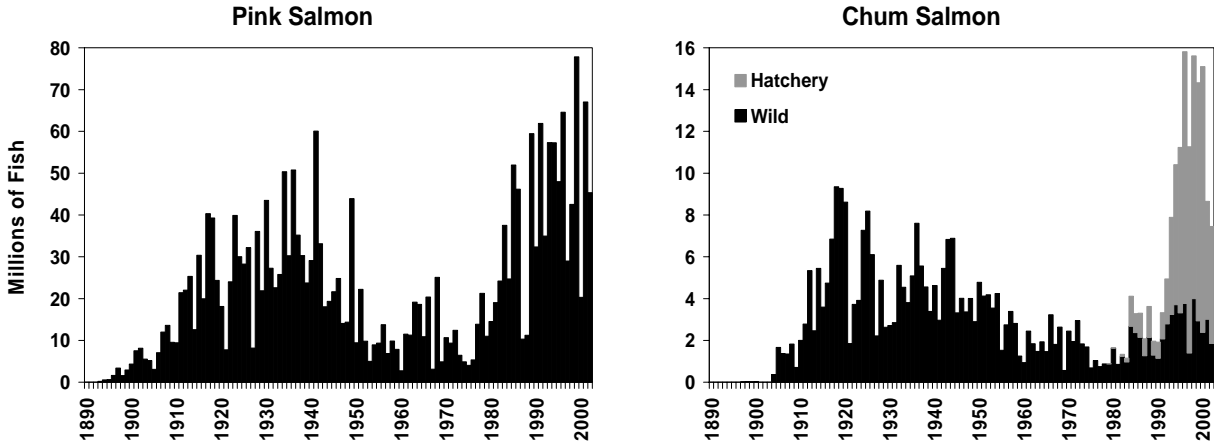


Figure 1. Annual harvest of pink and chum salmon in Southeast Alaska, 1890-2001.

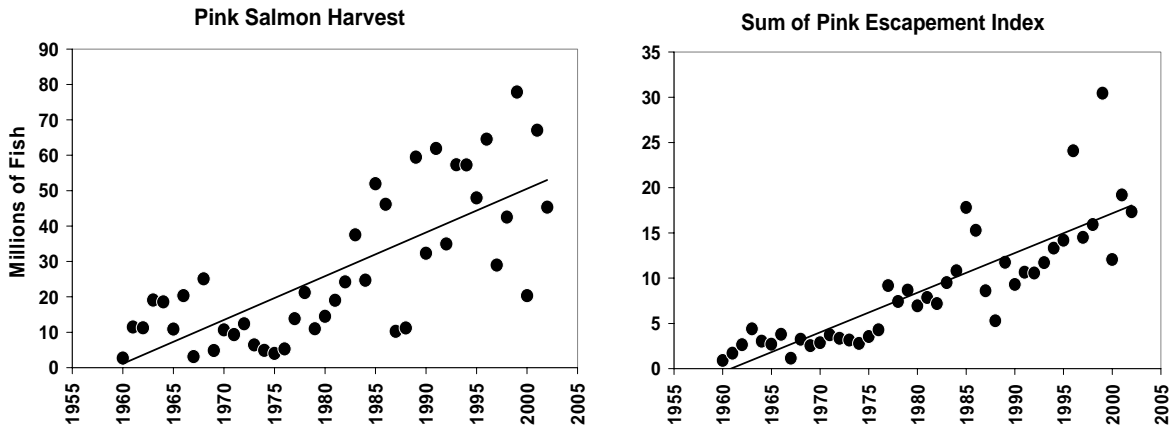


Figure 2. Annual commercial harvest and overall escapement index, of pink salmon in Southeast Alaska, 1981-2002. The index is not total spawning stock size; it is the sum of the observed peak abundance (in millions of fish) in 718 index streams.

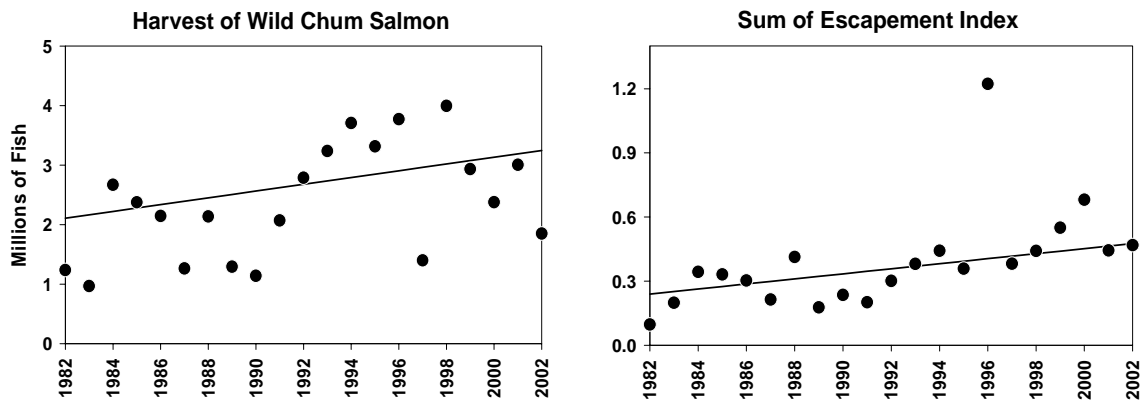


Figure 3. Annual estimated commercial harvest and overall escapement index, of wild chum salmon in Southeast Alaska, 1981-2002. The index is not total spawning stock size; it is the sum of the observed peak abundance (in millions of fish) in 82 index streams. The line is found by the “resistant regression,” and the slope of the line is a robust estimate of increase or decline relative to the size of the harvest at the beginning of the series; in this case an annual increase of 3.0% in the harvest, and 5.2% in the escapement, over the 21-year series.

Pink Salmon Migratory Energetics: Response to Migratory Difficulty and Comparisons With Sockeye

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Abstract Only

Pink salmon (*Oncorhynchus gorbuscha*) are generally considered weak upriver migrants when compared to sockeye (*O. nerka*), though this assertion is largely anecdotal. To assess the energy-use patterns of migrating pinks, we collected salmon from two major Fraser River stocks (Weaver and Seton) in 1999 at the: start of freshwater migration, end of migration before spawning, and immediately after spawning. We calculated energy content of somatic and reproductive tissues, recorded several body measurements, and conducted both intra-specific (between pink stocks), and inter-specific analyses with Fraser River sockeye collected during the same migration season. We found that between stocks, pink salmon showed no distinct energetic or morphological differences at either river-entry or upon arrival at spawning areas, regardless of stock and the level of migratory difficulty encountered. When compared to sockeye however, we found that pink salmon began upriver migration with significantly smaller somatic energy reserves, but made up for this deficiency by minimizing absolute transport/activity costs relative to sockeye, presumably by seeking out migratory paths of least resistance. This energetic efficiency comes as a cost reproductive output: relative to sockeye, pinks diverted less absolute energy to ovarian development and produced smaller ovaries and fewer eggs. We present evidence that pinks are much stronger migrants than previously suspected, and speculate that fundamental differences in life-history, specifically juvenile life-history, drive the migratory and energetic strategies employed by pinks.

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Session 3

Session Leader: Leroy Hop Wo (CDFO)

Marine Survival and Forecasting Runs

Multi-Stock Kalman Filter Models for Estimating Trends in Stock-Recruitment Dynamics of Salmon

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Extended Abstract

Growing evidence suggests that environmental fluctuations can create trends in productivity (e.g., recruits produced per spawner) of pink and chum salmon that are shared among nearby populations (Pyper et al. 2001; Pyper et al. 2002). Adkison et al. (1996) accounted for such spatial and temporal structure in stock-recruitment models for Bristol Bay sockeye salmon. They found the best model was one in which environmental influences were modeled via shifts in parameters of the Ricker model, in particular, the a parameter. Peterman et al. (2000) subsequently developed a Kalman filter (KF) formulation of the Ricker model in which a time-varying a was used to estimate productivity trends. Using simulations, they found that the KF model provided better estimates of parameters and optimal escapements than the standard Ricker model under various scenarios of climatic fluctuations.

In this study, we extend this KF model to include multiple stocks and use simulations to examine the potential benefits of this multi-stock approach. A key assumption of the model is that nearby stocks share similar trends in productivity. The goal therefore is to estimate the shared-trend component amid stock-specific variation. By using multiple stocks, more precise estimates of parameters and management targets may be obtained.

One possible KF formulation of the Ricker model that depicts shared productivity trends via a time-varying a parameter has the following two equations. First, the “observation equation” relates observations of recruits R and spawners S of the i th stock to the state variable a_t :

$$(1) \quad \ln(R_{i,t} / S_{i,t}) = \tilde{a}_i + a_t - b_i S_{i,t} + v_{i,t} \quad v_{i,t} \sim N(0, \sigma_i^2).$$

In this formulation, there is a time-varying component of a that is shared across stocks (a_t). However, the i th stock may exhibit unique differences in productivity via a stock-specific deviation in mean a (i.e., \tilde{a}_i), a stock-specific b parameter (b_i), and a stock-specific observation-error variance (σ_i^2). The stock-specific deviations in mean (\tilde{a}_i) are assumed to be constrained about zero such that $\sum_{i=1}^n \tilde{a}_i = 0$. Second, the “state equation” describes the time dynamics of a_t , which are modeled here using a random walk:

$$(2) \quad a_t = a_{t-1} + w_t \quad w_t \sim N(0, \sigma_w^2).$$

All error terms ($v_{i,t}$ and w_t) are assumed to be serially uncorrelated. The observation-error terms ($v_{i,t}$) may be correlated with each other across stocks; however, they are assumed to be uncorrelated with the state error (w_t). The KF algorithm is used to recursively estimate the time series of a_t conditional on maximum likelihood estimates of the other time-invariant parameters (Peterman et al. 2000).

To examine this multi-stock approach, we simulated 40 yrs of stock and recruitment data for four pink salmon stocks that shared identical trends in their a parameters (i.e., $\tilde{a}_i = 0$ for each stock). The dynamics of a_t followed a sine wave, with additional random stock-specific variation modeled via $v_{i,t}$ ($\sigma_i = 0.7$ for all stocks) (e.g., Figure 1). The b parameter for each stock was equal to one (arbitrary units). Recruits were harvested at a fixed rate of 50% in all years. Three models were used to estimate parameters at each of three times ($t = 20, 30$, and 40). The first was the multi-stock KF model (denoted M-KF) defined by equations (1) and (2) with the assumption that there may be differences in stock-specific means for a (i.e., parameters \tilde{a}_i were estimated even though no differences existed). The second was a single-stock KF model (S-KF) with a time-varying a parameter that also followed a random walk (Peterman et al. 2000). The last model was the standard (single-stock) Ricker model (RK). Parameter estimates at each of the three estimation times were used to estimate optimal (MSY) escapements that would be applied the following year. These estimates were compared to the true optimal escapement at those times to determine expected losses in catch.

At each time period, the multi-stock model (M-KF) yielded more precise estimates of a_t than did the single-stock Kalman filter model (S-KF) (Figure 2A). Although parameter estimates of the Ricker model (RK) were precise, they were often very biased in comparison to M-KF and S-KF (e.g., Figure 2A). Estimates of b for RK, on the other hand, were much less precise than for either M-KF and S-KF (results not shown). The higher precision of M-KF parameter estimates resulted in more accurate and precise estimates of optimal escapement for this model with 20 or 30 years of data (Figure 2B). In turn, this translated into greater expected catch for the M-KF model, in particular at $t = 20$. For example, at $t = 20$ the expected catch of M-KF was 23% and 167% greater than that of S-KF and RK, respectively, but only 3% and 12% greater at $t = 40$.

In summary, the simulations indicate that the multi-stock formulation can provide superior parameter estimates and management performance, in particular for short data sets (e.g., 20 years). Of course, the potential advantages of the multi-stock model depend critically on the assumption that trends in productivity are similar among stocks.

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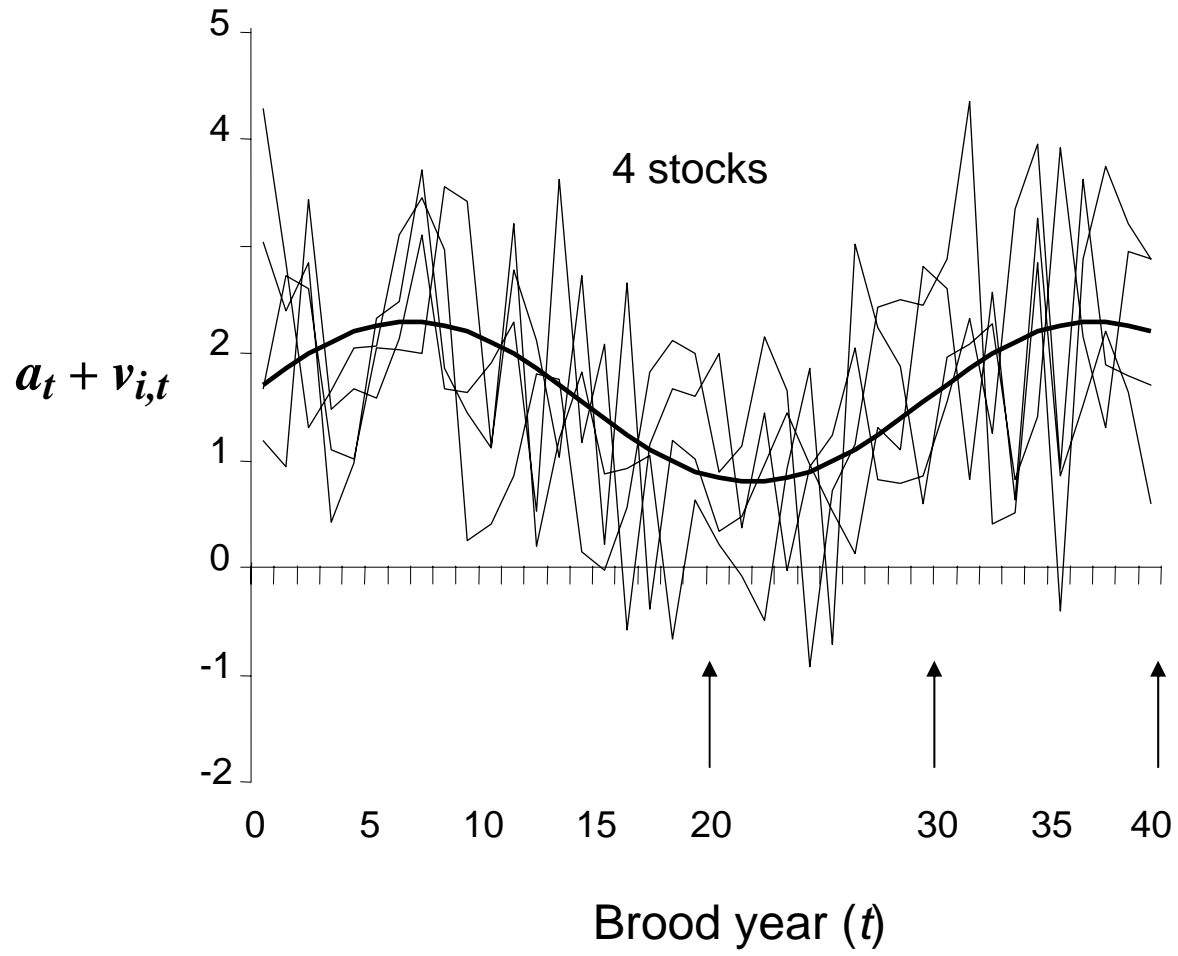


Figure 1. The assumed "true" time series for one simulation trial of a_t (bold line; sine wave) and stock-specific variation $v_{i,t}$ for four stocks superimposed on this trend in a_t . Arrows denote years ($t = 20, 30,$ and 40) in which parameters were estimated for each model.

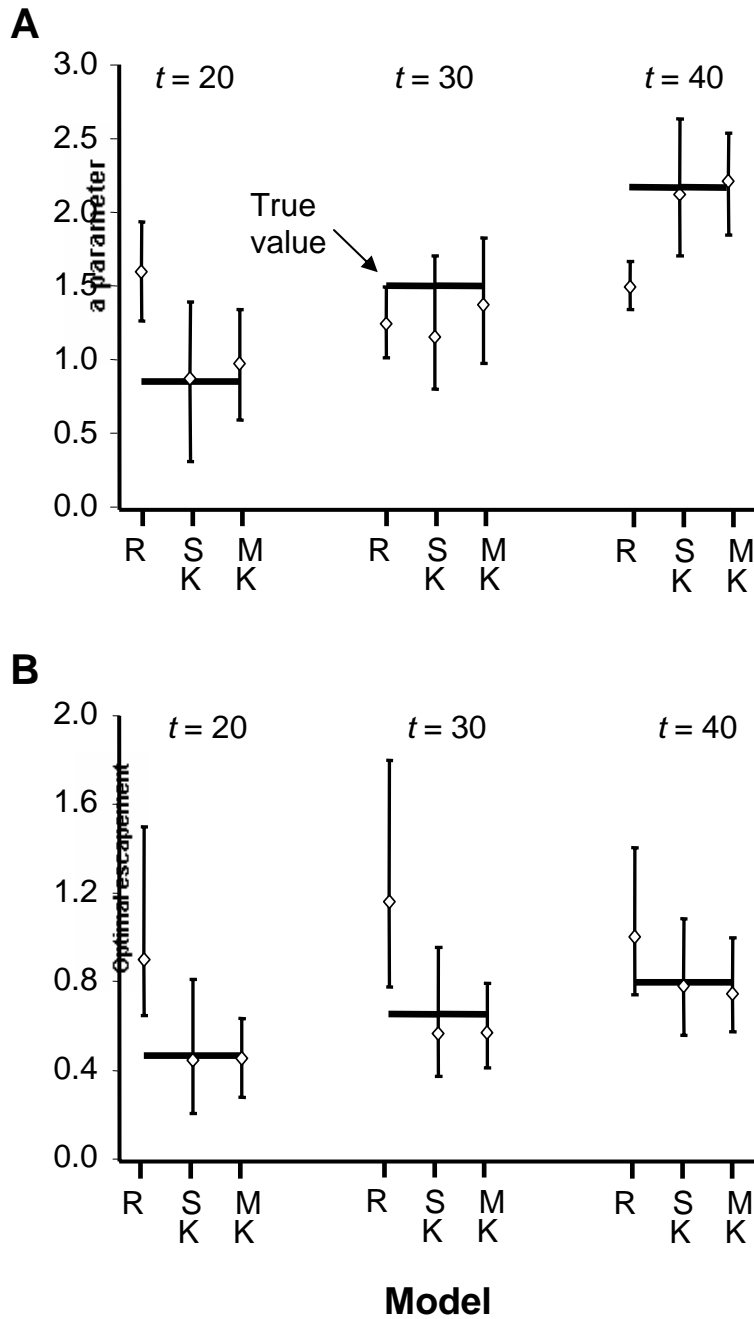


Figure 2. Averages and 80% intervals (from the 10th and 90th percentiles) of estimates of (A) the a parameter, and (B) optimal (MSY) escapement. Solid horizontal bars indicate the true value for a given year ($t = 20, 30$, or 40). RK is the standard Ricker model, S-KF is the single-stock Kalman filter mode and M-KF is the multi-stock Kalman filter.

A Spatial Hierarchical Bayesian Model for Multi-Stock Stock-Recruitment Analysis of Pacific Salmon

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Abstract Only

We developed a spatial Bayesian hierarchical model (SBHM) for a multi-stock analysis of salmon stock-recruitment relationships and the effects of environmental factors on salmon survival rates. The SBHM explicitly models spatial correlation in productivity among salmon stocks by applying a spatially correlated prior distribution to the stock-specific parameters. We applied the SBHM to analyze the environment and recruitment data of pink salmon stocks. We found that the SBHM produces more consistent and reliable estimates of early summer coastal sea-surface temperature (SST) effects than a single-stock approach that estimates each stock separately. In addition, the multi-stock approach substantially reduces uncertainty in the estimates of SST effects compared to the single-stock approach. Similar to earlier results using mixed-effects models on the same data, we found significant positive effects of SST on survival rates of pink salmon of northern stocks, but weaker negative effects of SST on survival rates of pink salmon of southern stocks.

Factors Governing Pink Salmon Survival in Prince William Sound, Alaska

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Abstract

The survival of pink salmon fry (*Oncorhynchus gorbuscha*) in Prince William Sound (PWS) is known to depend on the zooplankton food availability and predator abundance. We used a multi-frequency acoustic system, supported by net tows, to make synoptic measures of zooplankton and fish predators during the spring bloom periods of 2000, 2001 and 2002. The zooplankton biomass during the spring bloom is dominated by large-bodied calanoid copepods, primarily genus *Neocalanus*. Net catches of these large copepods showed excellent correlation with the high-frequency backscatter. We were able to document many features of the zooplankton population distribution and abundance. Overall abundance of large copepods was much higher in 2000. That difference was reflected in substantially higher adult returns in 2001 than 2002. The two most abundant fishes in PWS, walleye pollock (*Theragra chalcogramma*) and Pacific herring (*Clupea pallasii*), are known to exhibit prey switching behavior between zooplankton and small fish, including juvenile salmon. These fishes undergo post-spawning migrations into areas where the juvenile salmon are located. In 2000, the predators were widely distributed. In 2001 and 2002, with much lower zooplankton abundance, the fish showed pronounced near-shore orientation, reflecting piscivorous feeding behavior in response to the lower zooplankton abundance.

Introduction

Several hatcheries annually release hundreds of millions of juvenile pink salmon (*Oncorhynchus gorbuscha*) into the waters of Prince William Sound (PWS), Alaska (Thomas and Mathisen 1993). Previous research has documented two critical factors in the juvenile salmon survival (1) the availability of large calanoid copepods (genus *Neocalanus*), and (2) the abundance of walleye pollock (*Theragra chalcogramma*). The large calanoid copepods reproduce at depth in late winter. Their progeny migrate to the surface layer to graze for a brief period in late April and May. They are an especially valuable source of food for many fishes because of their relatively large size and high energy content (Cooney 1986). The timing of natural pink salmon fry entry into salt water is adapted to match that of the *Neocalanus* spring bloom (Cooney et al. 1995, 2001a). Willette et al. (2001) showed that both survival and early growth rates of pink salmon were correlated with the duration of the *Neocalanus* spring bloom. Survival of juvenile pink salmon is also negatively correlated with abundance of walleye pollock. Adult pollock feed on *Neocalanus*, thus are competitors of juvenile pink salmon for this food source. However, when *Neocalanus* abundance is low, pollock become piscivorous and are the dominant pelagic predator of pink salmon fry (Willette 2001). Pacific herring (*Clupea pallasii*) exhibit a similar prey switching behavior. Most pink salmon fry rearing in PWS are consumed by predators during their initial 45-60 days of early marine residence (Cooney et al. 2001b).

Based on these findings, the Oil Spill Recovery Institute (OSRI) initiated a program in spring 2000 to monitor the abundance of zooplankton and predators. The program has completed three years of fieldwork, associated with two subsequent years of pink salmon returns. This paper presents some initial results of these investigations.

Materials and Methods

The survey coverage evolved slightly during the three years. Coverage in 2002 consisted of eight clusters of three transects each. Three of the clusters extended along the main basin of PWS from Bligh Island to the Hinchinbrook Entrance, and three other clusters extended from Perry Island Passage out through Knight Island Passage (Figure 1). These locations were surveyed all three years. Two additional locations were added after the initial year, one above the deep basin adjacent to Naked Island and the second in Montague Strait. Surveys were conducted three times during the spring. Three types of data were collected: acoustic, plankton tows and CTDs. The routine survey procedure was to continually acquire acoustic data along each cluster, then backtrack to sample at selected locations for zooplankton composition, salinity and temperature measurements.

The acoustic data acquisition consisted of volume backscatter measurements from three acoustic frequencies, 420, 120 and 38 kHz. The 38 kHz is the most widely used frequency in fisheries acoustics (MacLennan and Simmonds 1992). The 120 kHz is probably the second most used, and is also the primary frequency used in euphausiid assessments. The 420 kHz frequency is well matched to the large copepod size and is commonly used in zooplankton research (Benfield et al 1998; Kirsch et al. 2000). The zooplankton sampling was a 50 m vertical tow using a 0.335-mm 0.5 m-ring net, following procedures of Cooney et al. (1995). At least one zooplankton tow was made within every cluster, every cruise. Temperature and salinity data were acquired using a SeaBird Electronics Model 19.03 CTD. Typically, 6-7 CTD stations were taken each cruise. Data collection was limited to daytime hours for consistency.

The acoustic data were analyzed using standard echo integration techniques (Thorne 1983a,b; MacLennan and Simmonds 1992). Separate analyses were conducted on the backscatter from fishes, which was then subtracted from the total backscatter to obtain the backscatter from zooplankton. Typically, volume backscattering measurements were made in 2-m intervals every 30 seconds of transect. Zooplankton biomass estimates were calculated from the upper 50 m, while fish biomass was estimated for the upper 150 m. Kirsch et al. (2000) determined the acoustic scattering characteristics of large-bodied copepods, pteropods and euphausiids in PWS. Values for the remaining components were estimated by a forward problem analysis (Wiebe et al. 1997) from the 2000 data. The plankton samples were analyzed to determine both size and frequency of the major components following procedures detailed in Kirsch et al. (2000). Numerical abundance was converted to estimates of biomass using average wet weights by category following Cooney et al. (2001b).

Results

Copepods dominated the zooplankton net catches both numerically and in biomass during all three years. Small copepods numerically dominated the catch all three years, but large copepods were the dominant biomass in 2000 (68%) and in 2002 (51%), while small copepods were the largest biomass component in 2001 at 44% compared to 39% for large copepods. There were substantial differences in large copepod abundance among the three years (Figure 2). In particular, abundance in 2000 was appreciably higher than the other two years. Springs 2001 and 2002 were similar in overall magnitude. However, the last cruise in 2002 was characterized by an unusually high measurement at the

Hinchinbrook Entrance location. Temperature and salinity characteristics at the location showed an intrusion of water from the Northern Gulf of Alaska.

Fish abundance generally declined in the main basin of PWS and increased in the more protected areas of Knight and Perry Island Passages as spring progressed. Overall abundance was highest in 2002 and lowest in 2000. However, there was a major change in inshore/offshore trends during the three years. Fish distributions in 2001 and 2002 were strongly oriented toward shorelines (Figure 3), where pink salmon fry and other juvenile fishes are known to be concentrated. In contrast, the fish distribution in 2000 was more widespread and showed no detectable inshore/offshore trends.

Adult pink salmon returns for 2001, corresponding to 2000 fry, were appreciably higher than those in 2002, and appeared to reflect the difference in the large copepod abundance (Figure 4). The difference between years was considerably greater for wild fish stocks than hatchery stocks.

Discussion

The capability of acoustic techniques to accurately measure zooplankton abundance is well documented (Wiebe et al. 1997; Kirsch et al. 2000; Thomas and Kirsch 2000). An important factor in the success of acoustic applications, whether for fish or zooplankton, is dominance of the target organism (Thorne 1983a,b). In this study, the primary goal was to measure the abundance of large copepods. The dominance by these organisms simplified the estimation of the absolute biomass and was expected from previous observations (Cooney et al. 1995, 2001a; Kirsch et al. 2000). The target strength characteristics of the large-bodied copepods were well established at both 420 and 120 kHz from previous studies.

Willette et al. (2001) indicated that herring and adult pollock switch to alternate prey (nekton) when large copepod densities fall below 0.2 g/m^3 . This value corresponds to 10 g/m^2 as the data were obtained from 50 m vertical tows. The actual value is probably slightly higher as the net sampling is unlikely to be 100% efficient. The value implies that the large copepod densities observed in 2000 were adequate for herring and adult pollock, while those observed in 2001 and 2002 were low or marginal (Figure 2). That difference may be reflected in the contrasting fish distributions. The pronounced near-shore orientation that we observed in 2001 and 2002, when zooplankton densities were low, most likely reflects piscivorous feeding.

The large differences in both zooplankton abundance and fish orientation relative to shore that was observed between 2000 and 2001 appeared to be reflected in the subsequent adult returns. However, while overall differences in large copepod abundance between years are undoubtedly important, the impacts of temporal and spatial variability in concert with wild stock fry distributions and hatchery release operations are complex. The intense temporal and spatial coverage that can be obtained with acoustic technology is critical in this regard. Ultimately, a more complete understanding of the complex environmental conditions that govern juvenile salmon survival will only be obtained through long-term acquisition of this type of information.

Acknowledgements

This study was primarily supported by funds from the Oil Spill Recovery Institute. Additional funds were provided by the Exxon Valdez Oil Spill Trustee Council. The Ship Escort/Response Vessel System (SERVS) provided the services of the M/V Valdez Star for these cruises. Gary Thomas and Shelton Gay, colleagues at PWSSC, provided valuable inputs to this study.

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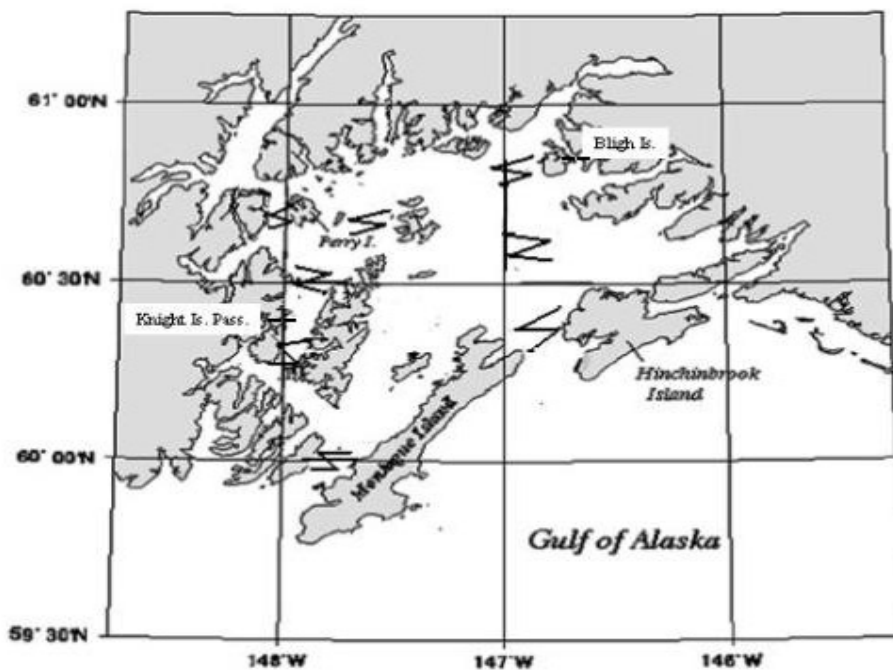


Figure 1. Location of transects for 2002 surveys.

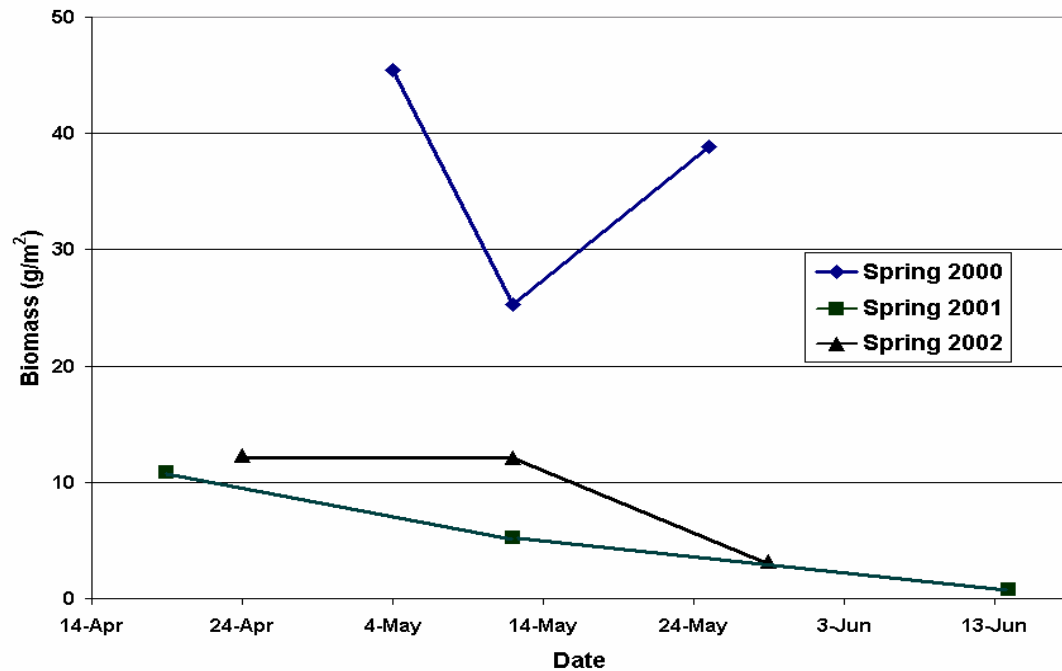


Figure 2. Comparison of estimates of large copepod biomass for various cruises, spring 2000-2002. Values are averages for the six locations in common all three years.

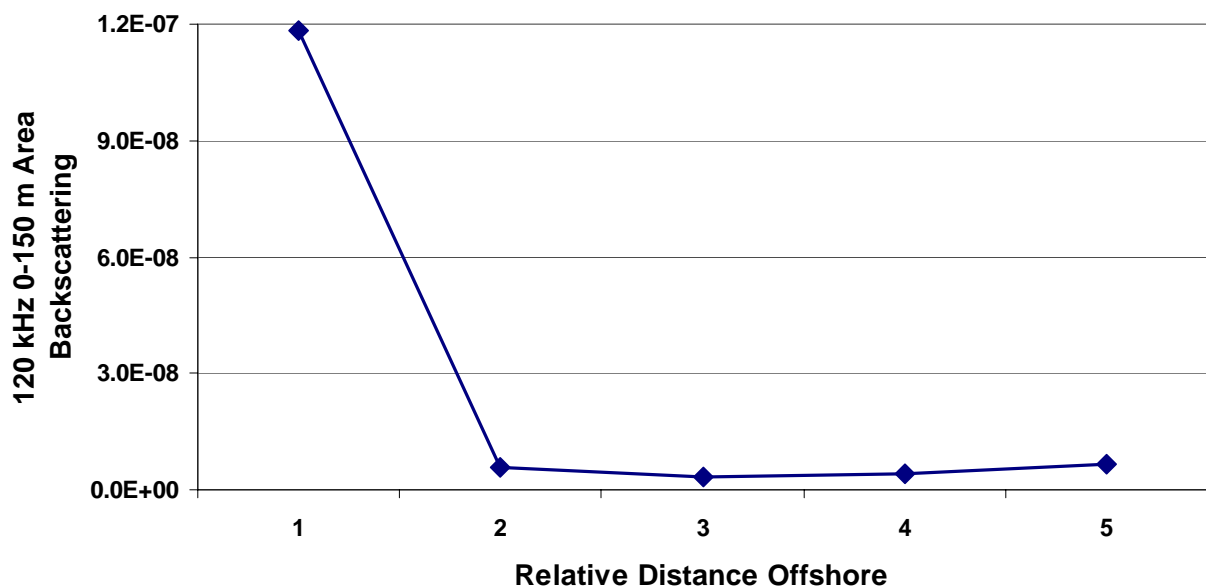


Figure 3. Distribution of fish relative to transect distance offshore during cruise 2 as seen in the 0-150 m 120 kHz area backscatter. Results are typical of observations during 2001 and 2002.

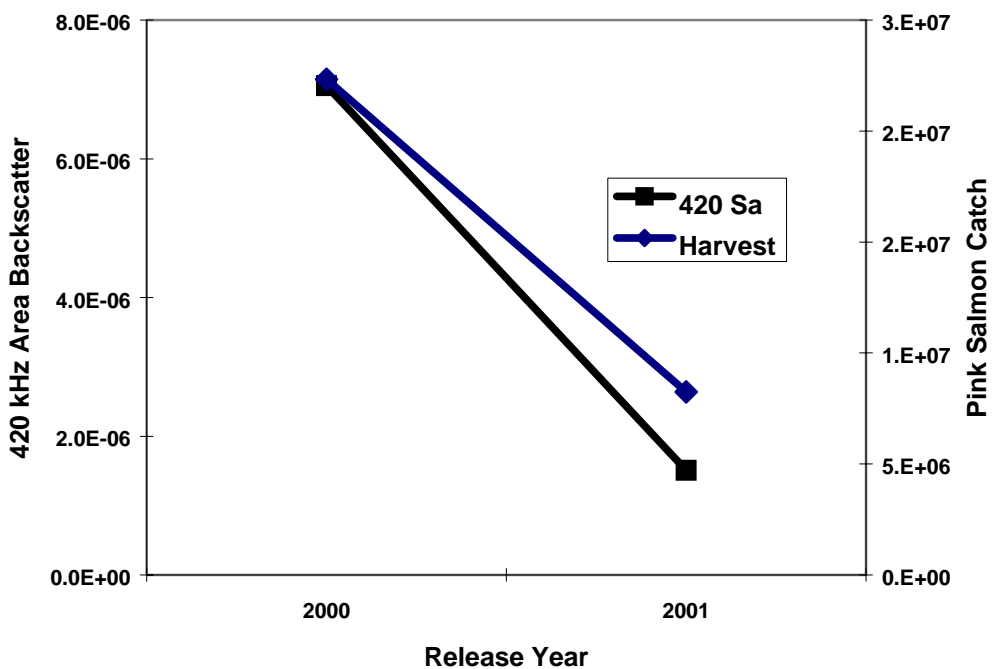


Figure 4. Comparison of 420 kHz backscattering from zooplankton and subsequent common property fishery harvest of pink salmon in Prince William Sound for release years 2000 and 2001.

Short Term Tagging of Chum Salmon as a Harvest Management Tool

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Abstract Only

In an effort to assess the purse seine harvest rate of the Johnstone Strait mixed stock chum fishery, the CDFO has operated a pre-fishery tagging project for 3 consecutive years. This chum fishery has undergone significant changes because of: fleet reduction, cessation of an early assessment fishery based on coho by-catch concerns, and a complete reworking of the management - which relied heavily on imprecise in-season run size estimation. The effective fishing capacity of the fleet is now less certain. The new management approach is harvest rate driven, by coordinating openings with the run timing curve. Part of the new management requires an understanding of the fleet efficiency relative to numbers of fish available. The tagging project has allowed us to assess fleet efficiency during different parts of the run timing curve and different run sizes.

Comparison of Alternative Measures of Salmon Productivity for Quantifying Spatial and Temporal Scales of Climate-Induced Variation

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Abstract Only

Identifying the spatial and temporal scales over which environmental processes affect fish recruitment is critical for generating and testing appropriate hypotheses regarding mechanisms. It is therefore important that inferences concerning scales of climate-induced variation be based on measures of fish productivity that best reflect these scales. Recent comparisons of trends in climatic conditions and aggregate catches of salmon provide evidence that broad, decadal-scale processes are a key determinant of salmon production in the Northeast Pacific. In contrast, however, analyses of survival rates across numerous stocks suggest that salmon productivity is primarily driven by more regional-scale processes that exhibit greater modes of interannual variation. Both catch and survival-rate data are potentially confounded by factors such as measurement error and changes in spawner abundance. Which is a better measure of productivity? Under what circumstances? To address these questions, we compared catch and survival indices using empirically-based simulations that explored numerous scenarios of climate-induced variation in salmon productivity. We also examined novel state-space formulations of stock-recruit relationships that provide promising models for simultaneously estimating low-frequency (e.g., decadal-scale) and high-frequency (e.g., interannual) modes of variation. We found that for a typical stock of pink or chum salmon, survival-rate data provide a better index of environmental influences than do catch data. We discuss the implications of our results for interpreting past studies and understanding mechanisms regulating marine survival of pink and chum salmon.

Session 4
Session Leader: Mel Sheng (CDFO)
Habitat Assessment and Restoration

Puntledge River High Temperature Study: Influence of High Water Temperatures on Adult Pink Salmon Mortality, Maturation, and Gamete Viability

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Abstract

Adult pink salmon (*Oncorhynchus gorbuscha*) were exposed to three declining water temperature regimes prior to spawning. The mean (range) test temperatures for the chilled, ambient, and heated regimes were 15.1°C (11.6°C-19.4°C), 18.4°C (15.0°C-21.8°C), and 21.3°C (16.6°C-24.0°C), respectively, from August 28 to Sept. 17, 2002. During that period, the adult mortality was 2, 10, and 82 %, respectively. Maturation rates also were affected with 53, 7, and 0 % of females ripe by October 1, 2002, respectively. Thirdly, mean egg mortality was 14, 41, and 60 %, respectively. Hence, the adverse influence of high water temperature during the latter phase of maturation was demonstrated to significantly ($P < 0.05$) increase adult mortality, delay maturation rate, and reduce gamete viability.

Introduction

Returning adult salmon are exposed to high water temperatures in many BC rivers including the Puntledge River. The water temperatures in the Puntledge River have been recorded since the early 1950's and the daily means and extremes (i.e. averaged minima and maxima) are illustrated in Figure 1.

Although studies on the acute lethal effects of high temperatures on adult salmon have been reported (Berman, 1990; Servizi and Jensen, 1977), the effect of temperature on latter stages of egg maturation, fertilization success and egg development is complex and poorly understood. The high water temperatures recorded for the Puntledge River in the summer and early fall likely affect the productivity of summer chinook (*Oncorhynchus tshawytscha*) and pink (*O. gorbuscha*) salmon returning to the Puntledge River. The purpose of this study was to capture returning adult pink salmon and to expose them to different temperature regimes for the latter part of maturation and spawning in order to determine the potential impact on maturation rate, adult mortality, and subsequent gamete viability.

Materials and Methods

The Puntledge River is located on the east side of Vancouver Island, British Columbia, Canada (Figure 2). On August 28, 2002, adult pink salmon were captured using a beach seine downstream of the Puntledge hatchery diversion fence (Figure 3). Additional fish were also obtained from a holding area, by using a dipnet, at the outflow from the hatchery adult raceway (Figure 4). The fish, totalling 148 (68 females and 80 males), were then randomly distributed among six 3-m diameter circular tanks (Figure 5) at the Puntledge hatchery.

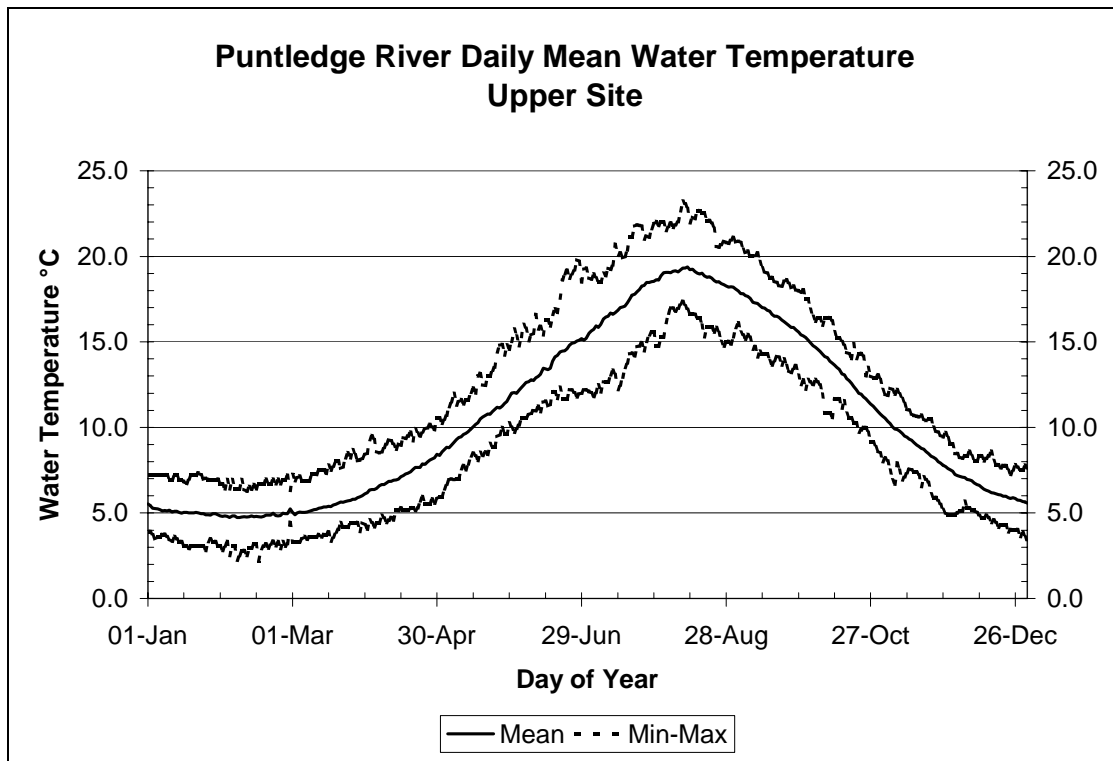


Figure 1. Puntledge River daily temperature means, minima, and maxima from 1955 to 2002. Note this is not a continuous data set, but consists of about 30 years of data.

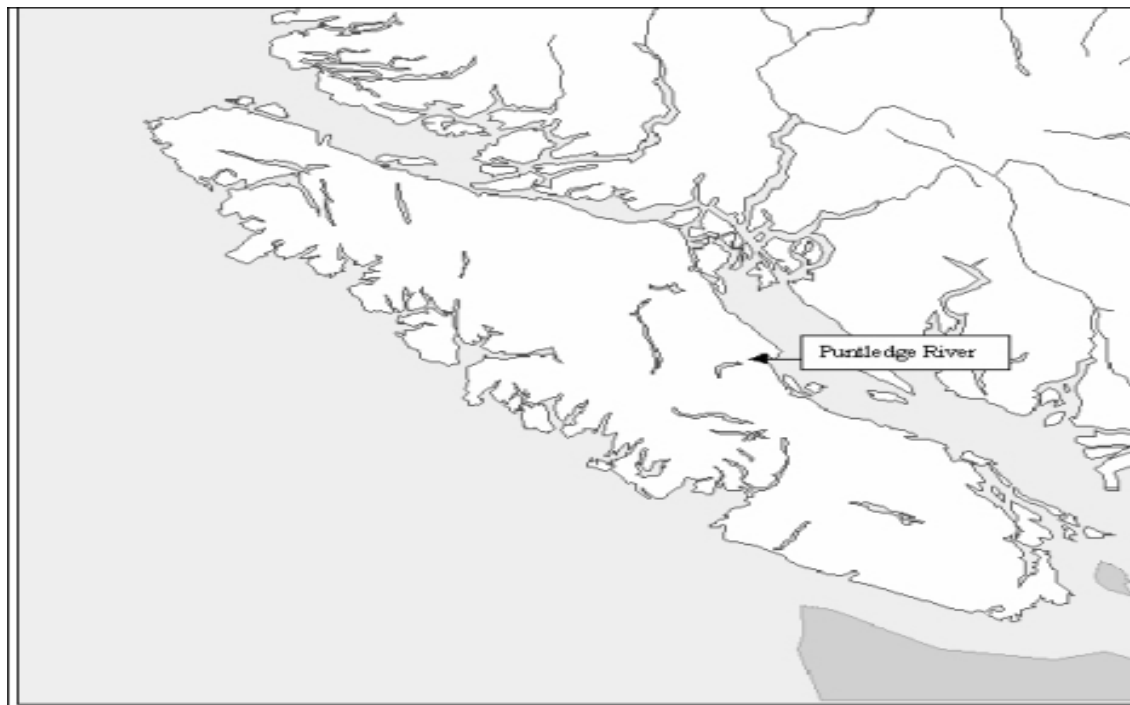


Figure 2. Map of Vancouver Island indicating the location of the Puntledge River.



Figure 3. Transportation tanks waiting for adult pink salmon captured downstream of the diversion fence, indicated by arrow.



Figure 4. Capturing fish by crowding and then using a dipnet.



Figure 5. Circular tanks used for holding adult pink salmon at different temperatures at the Puntledge hatchery.

The volume of each tank was 6.7 m^3 with flows nominally set at 40 litres per minute (LPM). Flow was checked regularly by timed volume measurements and re-set if found to be 5 LPM too low or too high. Supplemental oxygen was also plumbed to each pond in case the fish lowered the dissolved oxygen (DO) below 6 mg/L. DO measurements showed that this system was not required and it was turned off on August 30.

The temperature treatments for adult fish exposure consisted of 3 temperature regimes. The chilled treatment was achieved by running ambient temperature river-water through a refrigeration system, powered by a 25-horsepower motor operated at full capacity, with planned nominal cooling of 2°C below ambient. The chiller performed poorly until Sept.4, when repairs were made, increasing chilling capacity dramatically. The second temperature regime was achieved by using ambient temperature river-water. The third temperature regime was achieved by running ambient temperature river-water through a 6-element 180 KW heater with a planned nominal heating of 2°C above ambient. Gas supersaturation caused by heating was removed by the use of aeration columns. Each temperature regime exhibited a natural daily fluctuation due to solar heating.

Temperatures in each holding tank were recorded using Onset TidbiT temperature loggers, set to record at 15-minute intervals. Flow rates and dissolved oxygen levels were monitored regularly. The fish were visually inspected daily for signs of maturation and mortalities were recorded, removed, and measured for length and weight. Weights and post-orbital hypural lengths (POHL) were taken before removal of gametes.

Typical hatchery spawning procedures were employed. The water level in each tank was lowered and fish were carefully captured, using a dipnet, and placed in an anaesthetic bath (50 ppm tricaine methanesulfonate). Mature females were dispatched by clubbing. Milt was expressed from mature males, which were then returned to the holding tanks. Three replicate subsamples of about 100 eggs per female were fertilised with 0.3 ml of pooled (i.e. pooled from all ripe males in a temperature treatment) milt from mature fish for each temperature treatment; the only exception occurred on the last day of spawning where milt from males exposed to ambient temperature was used to fertilise eggs from females exposed to heated temperature, since no males exposed to heated temperature had survived. Chilled water was used for incubation to ensure the best potential for egg survival, since anticipated ambient temperatures were expected to cause increased egg mortality (Velsen, 1987). Egg mortality was monitored to just prior to hatch to assess gamete viability.

Adult mortality, maturation rate, and gamete viability data were analysed by ANOVA and Tukey's or Dunn's multiple comparison testing, using Sigmasat software, to assess the impact of adult exposure to the three temperature regimes.

Results

The initial number of fish distributed to the 6 tanks on August 28th is shown in Table 1.

Table 1. Number of adult pink salmon captured and distributed to the 6 tanks on August 28, 2002.

	Chilled Treatment		Ambient Treatment		Heated Treatment		
	Tank 1	Tank 3	Tank 2	Tank 4	Tank 5	Tank 6	Total
Female	10	13	11	14	9	11	68
Male	13	15	13	14	15	10	80
Total	23	28	24	28	24	21	148

During the 56-day period of testing, 66 fish (i.e., 48 females and 18 males) were measured for weight (gm) and length (POHL, cm). The data are summarised in Table 2.

Table 2. Mean lengths (POHL; cm) and weights (gm) of pink salmon tested.

	N	Length (cm)	Weight (gm)
Female	48	36.3	949.0
Male	18	35.5	938.9
Total	66	36.1	946.2

The water flow rates and dissolved oxygen measurements for the 6 test tanks are summarised in Table 3 along with initial calculated load rates, based on the mean total weight presented in Table 2.

Table 3. Water flow rates (LPM), dissolved oxygen (%), number of fish per tank, mean biomass per tank (kg), and load rates (Kg/LPM and Kg/m³) for the 6 tanks. Note, numbers in brackets indicate number of measurements.

	Chilled Treatment			Ambient Treatment			Heated Treatment		
	Tank 1	Tank 3	Mean	Tank 2	Tank 4	Mean	Tank 5	Tank 6	Mean
Flow (LPM)	42.3 (17)	43.0 (17)	42.6	41.8 (18)	41.9 (20)	41.9	44.9 (15)	41.3 (17)	42.8
DO (%)	87.4 (20)	83.6 (19)	85.6	87.6 (19)	86.2 (20)	86.9	96.6 (19)	96.7 (19)	96.7
No. of fish	23	28	26	24	28	26	24	21	23
kg	21.76	26.49	24.13	22.71	26.49	24.60	22.71	19.87	21.29
kg/LPM	0.51	0.62	0.57	0.54	0.63	0.59	0.51	0.48	0.49
kg/m³	3.26	3.97	3.62	3.40	3.97	3.69	3.40	2.98	3.19

Water temperature regimes for the chilled, ambient, and heated treatments from August 28 to October 22 are shown in Figure 6 superimposed on the means, minima, and maxima from 1955 to 2002. Note that the minima and maxima shown in Figure 6 are the lowest and highest temperatures recorded on a particular calendar day.

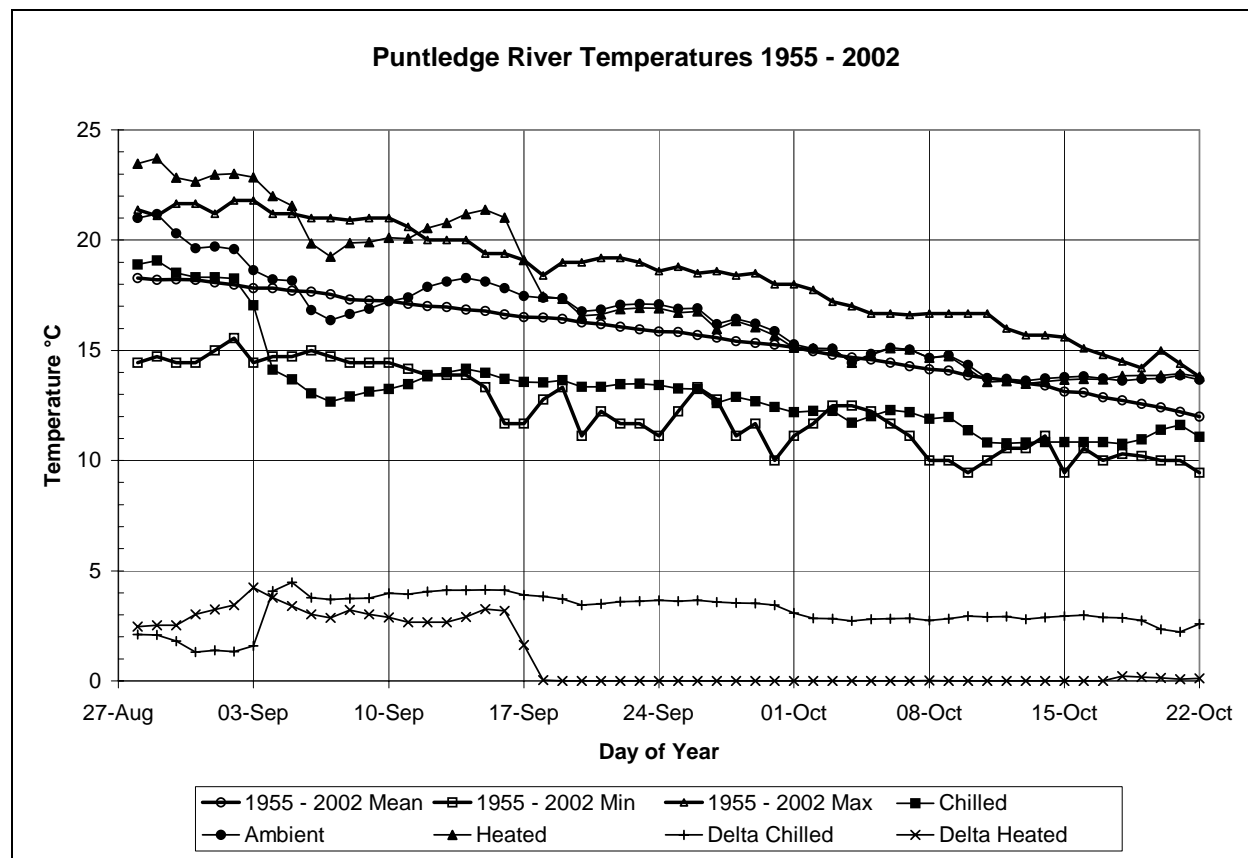


Figure 6. Daily mean, minimum, and maximum temperatures for the 3 experimental temperature regimes are superimposed on the 1955-2002 daily mean, minimum, and maximum Puntledge River temperatures. The difference between ambient and heated or chilled treatments is also shown (i.e. delta heated and delta chilled).

Figure 6 shows that the fish were exposed to temperatures that generally fall within the extreme temperatures recorded for the Puntledge River since 1955, with the exception of the heated treatment that was above the maximum temperatures for the first week of exposure. The heated treatment was maintained for 21 days; after which heating was terminated mid-day on September 17th due to other water demands in the hatchery. The rate of temperature decline, determined by linear regression, and mean temperatures for this 21-day period are listed in Table 4.

Table 4. Linear regression equations, total temperature decline (based on linear equation), and mean (range) temperatures for the 21-day period from Aug. 28 to Sept. 17, 2002.

Treatment	Linear Regression (R^2) $Y = \text{temperature } (^{\circ}\text{C})$ $X = \text{time (days from Aug. 28)}$	Total temperature ($^{\circ}\text{C}$) decline over 21 days	Mean temperature ($^{\circ}\text{C}$) (range)
Chilled	$Y = -0.3027X + 18.469$ (0.6230)	6.4	15.1 (11.6 – 19.4)
Ambient	$Y = -0.1573X + 20.085$ (0.4902)	3.3	18.4 (15.0 – 21.8)
Heated	$Y = -0.1760X + 23.275$ (0.5825)	3.7	21.3 (17.6 – 24.0)

Adult mortality was averaged for the 2 test tanks per treatment and is summarised in Figure 7.

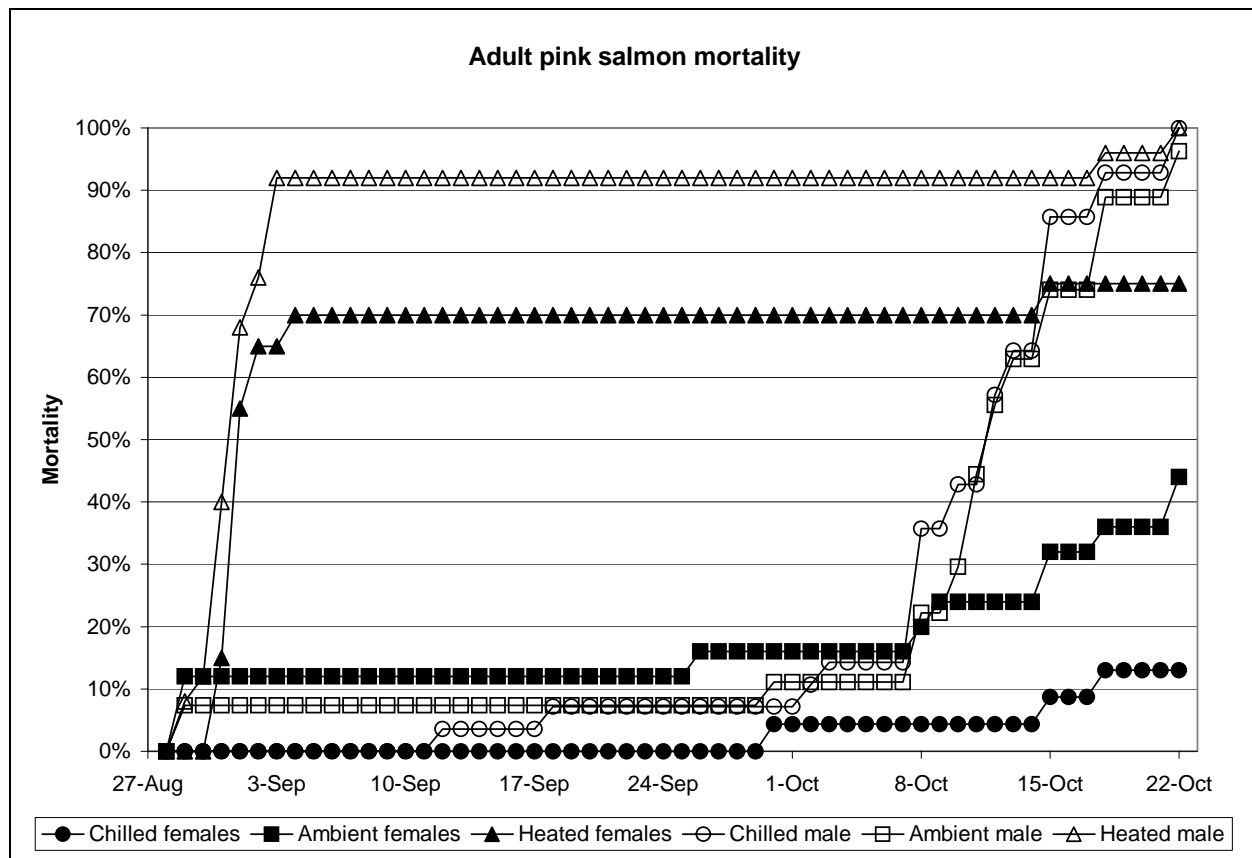


Figure 7. Mean adult mortality of pink salmon exposed to the chilled, ambient, and heated temperature regimes.

Notice that the majority of mortality in the heated treatment occurred within the first week of exposure. Recall also that the heated treatment was terminated mid-day on Sept. 17, after which the temperature treatment was the same as the ambient treatment. The total (i.e. both male and female) adult mortality as of Sept. 17 was 2, 10, and 82 % for the chilled, ambient, and heated treatments, respectively. A two way ANOVA, with mortality averaged weekly for each temperature treatment, and Tukey's multiple comparison showed that female mortality increased significantly ($P < 0.05$) when exposed to chilled, ambient, and heated temperature regimes, respectively (Table 5). In addition, pairwise comparison of adult mortality averaged over weeks of exposure showed significant differences ($P < 0.05$) for week 8 versus week 4 and earlier. Similarly, a two way ANOVA of male mortality also showed a

significant ($P<0.05$) increase in mortality when fish were exposed to the heated temperature regime, while differences were not significant between chilled and ambient treatments (Table 6). The pairwise comparison of male mortality averaged over weeks of exposure was similar to the female mortality with significant differences ($P<0.05$) in mortality for week 8 versus week 4 and earlier.

Table 5. Comparison of mean female adult mortality proportions indicating significant ($P<0.05$) differences between each treatment.

Comparison	Diff of means	P	P<0.05
Heated vs Chilled	0.668	<0.001	Yes
Heated vs Ambient	0.506	<0.001	Yes
Ambient vs Chilled	0.162	<0.001	Yes

Table 6. Comparison of mean male adult mortality proportions indicating significant ($P<0.05$) differences between each treatment.

Comparison	Diff of means	P	P<0.05
Heated vs Chilled	0.807	<0.001	Yes
Heated vs Ambient	0.735	<0.001	Yes
Ambient vs Chilled	0.072	0.240	No

Spawning commenced on October 1, 2002 and continued for 3 weeks, ending on October 22, 2002. It was apparent on the first day of spawning that the 3 temperature treatments had influenced maturation, with 53%, 7%, and 0% of females ripe by October 1, 2002, in chilled, ambient, and heated treatments, respectively. The complete maturation response of female pink salmon (i.e. the percent of the initial number of females) is illustrated in Figure 8.

A two-way ANOVA indicated that the percent of female spawners was significantly ($P<0.05$) affected by both spawning time and temperature regimes.

Mean egg mortality from fish held in chilled, ambient, and heated temperature regimes was 14, 41, and 60 %, respectively. ANOVA showed that egg mortality from fish exposed to the chilled temperature regime was significantly ($P<0.05$) lower than egg mortality from fish exposed to both ambient and heated temperature regimes. However, egg mortality was not significantly ($P<0.05$) different between ambient and heated treatments, likely because of the small number of spawners (i.e. 5), with subsequently greater variance, surviving in the heated treatment.

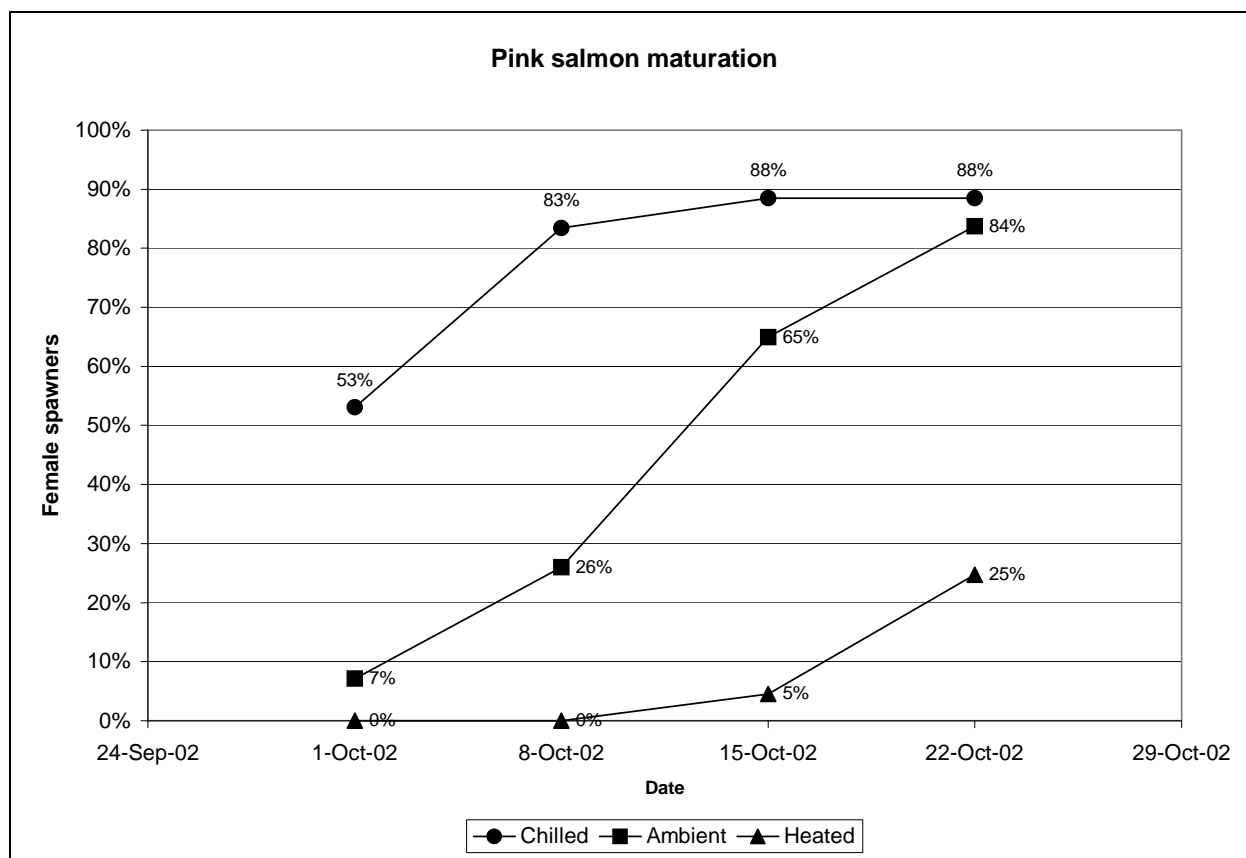


Figure 8. Mean pink salmon female maturation (i.e. female spawners, %) over a 21-day period in chilled, ambient, and heated temperature regimes.

Discussion

Controlling the chilled and heated temperature treatments proved more difficult than anticipated. Initially, the refrigeration system did not provide enough cooling. This was resolved after 1 week. Similarly, the heated treatment approached acutely lethal levels during the first few days of exposure. In spite of these initial problems, the chilled and heated treatments generally were close to historical Puntledge River temperatures, falling within the minima and maxima recorded since 1955 (Figure 6). Since all the temperature treatments were affected by normal seasonal cooling, each temperature regime gradually declined during the adult pink salmon exposure period. This decline was modelled for the initial 21 days of exposure using linear regression (Table 4). The mean temperatures (range) for this period for the chilled, ambient, and heated treatments were 15.1°C (11.6°C-19.4°C), 18.4°C (15.0°C-21.8°C), and 21.3°C (16.6°C-24.0°C), respectively. It must be emphasised from this study that we do not know the minimum exposure time that will influence adult mortality, maturation rate, and gamete viability. The total exposure time for the high temperature treatment was 21 days and 56 days for the ambient and chilled treatments.

Excluding the effect of temperature, the holding conditions, as indicated by water flow, DO, and initial loading densities (Table 3), are considered to have been very good, since the fish that survived to spawn were generally in very good condition. Of particular note was the lack of external fungal lesions that are often observed when maturing adult salmon are handled and kept in captivity in artificial containers.

Adult holding temperature had a significant detrimental ($P<0.05$) effect on adult mortality (Figure 7, Tables 5 and 6), maturation rate (Figure 8), and egg mortality. As expected, the high temperature groups had the highest adult mortality and egg mortality rates and the lowest maturation rate (Figure 7). More surprising were the significant differences between the ambient and chilled groups. Total female mortality in the chilled treatment (13%) was significantly ($P<0.05$) lower than in the ambient treatment (44%). Maturation rate in the chilled treatment occurred significantly ($P<0.05$) earlier than either ambient or heated treatments (Figure 8). Finally, egg mortality in the chilled treatment (15%) was significantly ($P<0.05$) lower than ambient (37%) and heated (67%) treatments. These effects are all indicative of the adverse effect of high temperatures on the final stages of maturation. Therefore, even in a year with moderate temperatures similar to the mean Puntledge temperatures from 1955 to 2002 (Figure 1), pink salmon will be significantly affected, resulting in increased adult mortality, delayed spawning, and increased egg mortality.

This conclusion was further substantiated by observations made during production egg takes at Puntledge River and Quinsam River hatcheries in 2002. The Quinsam water temperatures are colder than the Puntledge temperatures (Figures, 9 and 10).

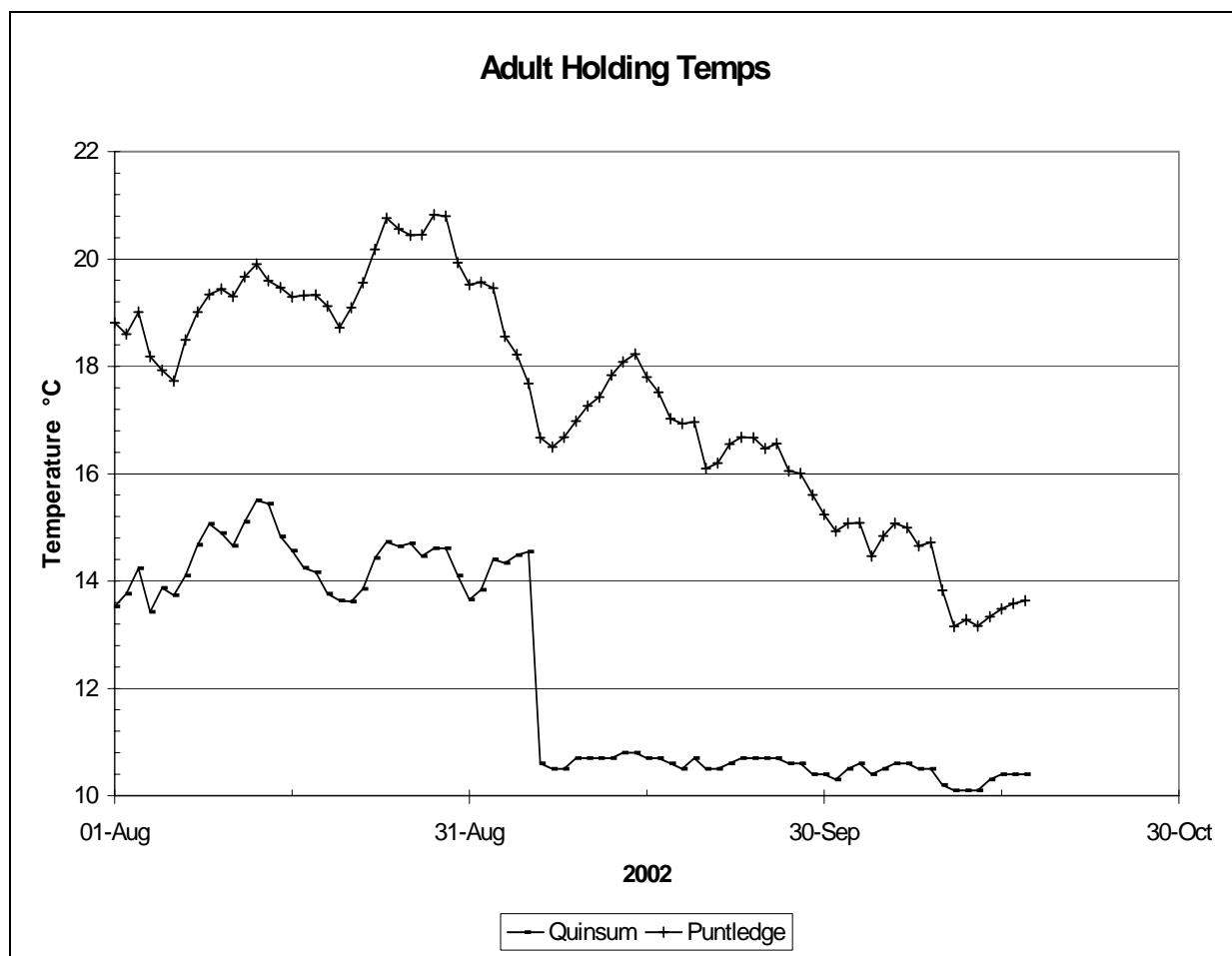


Figure 9. Mean daily adult holding temperatures for pink salmon at the Quinsam River and Puntledge River hatcheries in 2002.

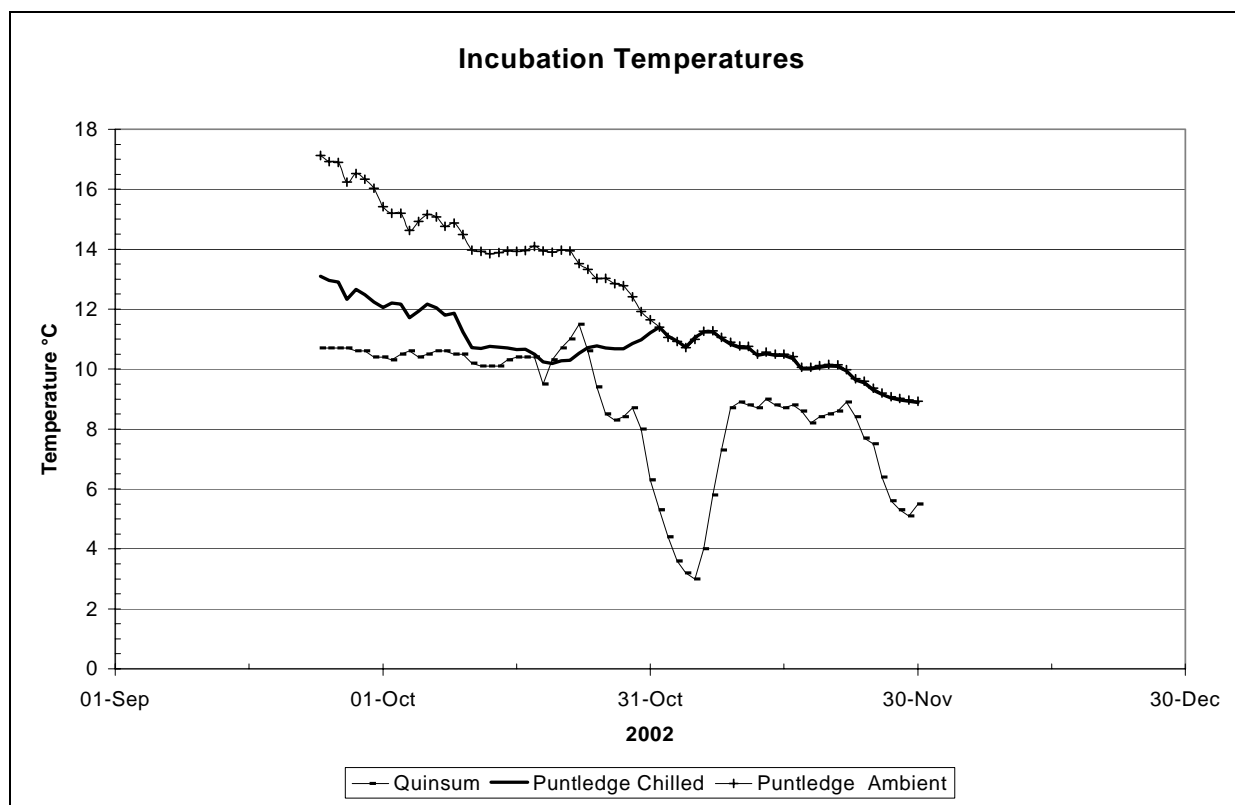


Figure 10. Pink salmon incubation temperatures at the Quinsam River and Puntledge River (chilled and ambient) hatcheries.

In 2002, gametes were collected at the Quinsam hatchery and divided into two groups. One group was kept at Quinsam and the other was transported to the Puntledge hatchery for incubation. The eyed egg mortalities of these groups of eggs, as well as mean production eyed egg mortalities, are summarised in Table 7.

Table 7 . Mean adult holding and incubation temperatures (°C) at Quinsam and Puntledge River hatcheries and subsequent eyed egg mortality (%) in 2002.

Source	Incubation Site	30-day adult mean temperature (°C)	60-day incubation mean temperature (°C)	Eyed mortality (%)
Quinsam	Quinsam	12.6	8.8	3.5
Quinsam	Quinsam	12.4	8.7	3.5
Quinsam	Quinsam	12.1	8.5	3.5
Quinsam	Puntledge	12.9	10.9	8.9
Quinsam	Puntledge	12.8	10.8	8.9
Puntledge	Puntledge	17.0	11.1	28.0
Puntledge	Puntledge	16.8	11.0	27.8
Quinsam	Puntledge	11.0	10.3	9.3

Two way ANOVA indicated that both high adult holding temperature and high incubation temperatures resulted in significantly ($P < 0.05$) higher eyed egg mortality.

This study has shown that typical water temperatures occurring during late August and early September in the Puntledge River adversely affect the final stages of pink salmon maturation. The consequence is increased adult mortality, delayed maturation rate, and reduced gamete viability.

Acknowledgements

We gratefully acknowledge the funding by BC Hydro for this study. We also thank the staff at the Puntledge hatchery; especially Lorne Frisson and Bob Addy for capturing the fish, and Christine Berg and Cheryl Burroughs for monitoring and tabulating egg mortality. We are grateful to Joan Bennett and Lorne Frisson for providing the hatchery pink salmon production data used in the discussion. Finally, we thank Mel Sheng for securing funding for this research.

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Rebuilding the Salmon Runs to the Stave River: A Co-operative Effort of Harvest Reduction, Enhancement, Habitat Restoration, and Flow Control

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(Note: paper was presented by Roberta Cook, CDFO)

Introduction

Rebuilding of stocks can be accomplished in many ways, depending on the mechanisms that depressed the stocks. Some of these mechanisms include over harvesting, habitat degradation and water removal affecting freshwater survival, and estuary and ocean conditions affecting ocean survival. Enhancement via hatchery releases is only one tool for rebuilding stocks. Reductions in harvesting and habitat restoration are also needed. Enhancement has the ability to rebuild the stocks more quickly than by harvest reduction and habitat restoration alone, especially if ocean survival is not also depressed. Once the stock has been rebuilt, enhancement can cease. Continued assessment of the stock is needed to determine if the stock can maintain itself without enhancement.

The flow of the Stave River is affected by a complex of three dams and associated hydroelectric facilities on the Alouette and Stave Rivers that were constructed between 1910 and 1930. The Ruskin dam at the lower end of Stave River removed about 1.5 km of spawning area and limits salmon spawning to 1.5 km between the dam and tidal influence. Water diversion to the Alouette River, flow fluctuations from the peaking hydroelectric facilities and the destruction of habitat during gravel removal operations during the 1950's severely limited fisheries productivity of the Stave River.

Enhancement of chum salmon on the Stave was recommended by Palmer (1972), but was limited by the wide fluctuation in flows to a possible small spawning channel on the right bank and to incubation boxes or ponds supplied by a flow of clean gravity fed water from the dam. The initial success of Japanese-style chum hatcheries by the Salmon Enhancement Program (SEP) allowed for a new option for enhancement of Stave River chum. This technique involved using groundwater to incubate eggs in bulk upwelling incubators and alevins in gravel lined keeper channels, and rearing fry in concrete raceways to approximately 1.5 grams or about five times their ponding size while still releasing the fry at normal wild fry migration timing.

In 1980, the Fisheries & Oceans (DFO), Canada Fraser River Geographical Working Group developed a plan to increase the returns of Fraser chinook, coho, chum, and steelhead by use of enhancement and harvest reductions (MacKinlay, 1985). This plan included enhancement of Stave River chum and coho at Inch Creek Hatchery. The goal was to produce 122,000 Stave chum adults from about 8.5 million eggs. Stave coho was added to the plan in 1987 to enhance the small run of coho.

Increased chum escapements as a result of enhancement and harvest reduction would be of little benefit for long term stock rebuilding unless the Stave water flow regime was changed to improve salmon spawning and incubation survival and habitat restoration was undertaken to increase and improve the degraded spawning areas. An interim water use plan and habitat restoration program began in 1990.

Enhancement

Inch Creek Hatchery had an initial target of 4.0 million Stave chum eggs starting with the 1982 brood. This was expected to produce 57,600 chum adults annually (90% egg-to-fry, 80% fry-to-fed fry, 2% fed fry-to-adult survival). Between 1983 and 1998 Inch Hatchery released an average of 4.2 (2.1-5.5) million fed fry at 1.48 (1.0-1.9) gm. annually into the Stave River. Between 1985 and 2000, enhancement has produced an estimated average of 68,800 (5,500-1,069,500) adults annually, exceeding the expectation by 19%. This has been the result of better than expected survivals at all stages. Highly variable chum survival is responsible for the wide range in annual returns. This includes an average marine catch of 20,800 (500-332,200) and an average exploitation rate of 27.1% (1.0-52.9).

Exploitation Rate Reduction

From 1953-1979 Fraser chum exploitation rates averaged 53.6% (11.3-92.1). As part of a strategy to increase escapements, rebuild stocks, and probe the optimum sustainable yield of Fraser chum, Fraser chum exploitation rates have been reduced to a 1980-1997 average of 27.6% (3.9-65.1).

Flow Agreement

Flow fluctuations from the peaking hydroelectric facilities severely affected spawning salmon. The highly variable flows disrupted spawning behaviour, stranded adults, and often left redds without flow. A provisional water use agreement was established between B.C. Hydro and DFO in 1990 to increase survival of salmon eggs by maintaining minimum flows for the river downstream of the dam during the salmon spawning and incubation periods (Lamont & Foy, 1996). These including weekly block loading (no peaking) i.e. flows were maintained at a constant level for at least a week at a time without variation, and constraints were implemented on minimum and maximum flows. Further refinements to the flow regime to improve fisheries productivity occurred in 1995 and 1999 (Failing, 1999). Issues affecting spawning, incubation, egg stranding, fry migration, rearing, total gas pressure, and reservoir productivity were addressed as well as non-fish issues such as heritage, recreation, industry, wildlife, and power values.

The new 1995 agreement consisted of the following fish productivity elements:

- Weekly block loading during the fall spawning period.
- Daily block loading during fry emergence.
- A 1999 amendment allows for peaking above 130 cms and limited block loading that allows peaking above 100 cms during spring and fall. This would detrimentally affect spawning but would reduce egg and fry stranding so that overall salmon productivity should improve or at least remain the same.
- Minimum water levels year around.
- A monitoring plan would be put in place and funds made available to maintain restored habitat.

Habitat Restoration

The benefits of increased returns from enhancement and reductions in harvest would have been wasted without the habitat restoration initiatives on the Stave River to increase the spawning ground capacity. Prior to these initiatives, the estimated chum spawning capacity of the Stave River was about 92,000 adults and the real capacity was likely less because of the effects of hydro-electric peaking operations on fish stranding and redd de-watering.

The 1990 flow agreement between the Department of Fisheries and Oceans and B.C. Hydro also allowed for co-operative stream restoration work to be undertaken to maximize the benefits of the improved flow regime as well as provide increased habitat for the progeny of enhanced releases (Lamont & Foy, 1996). During 1990-1994 several re-contouring and construction projects funded jointly by the Department of Fisheries and Oceans and B.C. Hydro increased the chum spawning capacity of the lower Stave River.

These projects included:

- In 1990, re-contouring of the 360-metre centre channel so that it remained wetted during spawning and incubation flows.
- In 1991-92, the construction of a 400 m spawning channel on the left bank bringing water from the Ruskin dam tailrace through this channel to an improved 1,000 m. former overflow spawning and rearing channel adjacent to the road.
- In 1993, the restoration work continued with gravel additions to upstream areas, re-grading selected river bars, and providing flow to cut-off side channels as well as construction of a 1225 sq. m. spawning beach and 600 sq. m. spawning channel and major re-contouring of gravel along the right bank.
- In 1994, a 2,600 sq. m. spawning beach downstream of the tail-water pool and a side channel immediately west of the centre channel were constructed as well as re-grading of an 3,600 sq. m. of existing spawning beach adjacent to the main left bank channel.

The summation of the work added 118,000 sq. m. of improved spawning area to the existing 84,000 sq. m. of natural area for a total of 202,000 sq. m. which is estimated to support 220,000 spawning chum.

Results of Enhancement, Harvest Reduction, and Habitat Restoration

The combined effect of enhancement, harvest reductions, and habitat restoration to rebuild Stave escapements can be seen in Figure 1. The chart shows 5 year moving averages of escapement estimates in order to smooth out the effect of variable annual survival.

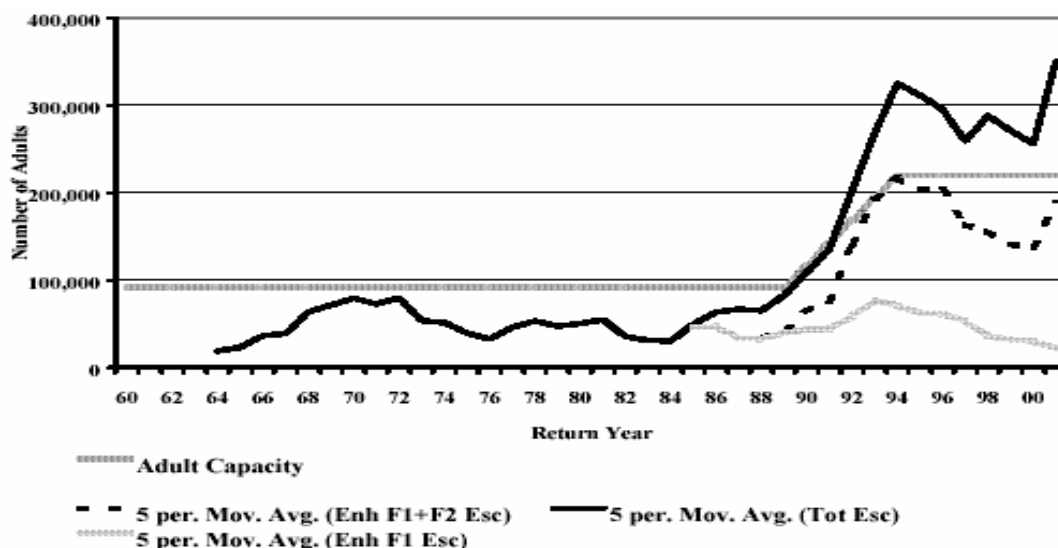


Figure 1. Stave chum escapements-enhanced F1 & F2 & Total.

The solid dark top line shows total Stave chum escapements between 1960 and 2001. Escapements from 1960-69 were based on a tag and recovery enumeration program on all Fraser stocks. Between 1970-1988, Fishery officer visual estimates, which in later years were conducted by helicopter, were used. Between 1989-1994, Inch Hatchery staff conducted tag and recovery programs to estimate escapements. Since then, Inch Hatchery staff conducted weekly helicopter flights and Area Under the Curve (AUC) is used to estimate the escapement. The lower solid grey line shows enhanced first generation (F1) returns of enhanced chum releases from Inch Hatchery. This number was calculated from sampling adults on the spawning grounds for adipose codedwire tags applied to between 50,000 and 150,000 Stave chum fry in each year except the 1983 and 1984 brood years. The middle dark dashed line is the F1 returns plus the estimated second generation F2 returns of the progeny of enhanced F1 returns spawning naturally. This number was calculated by apportioning the returning escapement (less estimated F1 returns) into F2 and wild returns based on the numbers of F1 and wild spawners in the brood year. This assumes that hatchery F1 spawners have the same spawning success and survival to adult as wild spawners. The middle grey solid line shows the spawner capacity before and after habitat restoration.

Total escapements increased gradually after 1985 when enhanced first generation (F1) chum began to return. A dramatic increase in total escapement began in 1990 when (F2) chums began to return. These dramatic increases were also aided by ocean survivals about 50% above average and reduced exploitation rates. The increased return peaked at 400,000 in 1994 and has been more variable since then averaging 297,800 (105,000-625,000) from 1995-2001. Returns have also been reduced by reduced hatchery fry production to 3.1 million in the 1996 brood, 2.1 million in the 1997 brood and no hatchery production since then.

The habitat restoration from 1990-1994 occurred just in time to take advantage of the dramatic increase in escapements starting in 1990.

The average total Stave escapement from 1990 to 2001 has increased to 309,000 a 7-fold increase in just three generations from the pre-enhancement 1960 to 1984 average of 44,000. This is a prime example of how enhancement, harvest reductions, and habitat restoration can be used to rebuild a stock. This is a biological example of the benefits of compound interest, which can show dramatic results when survivals are good and prudent management is undertaken.

Other Benefits

Prior to enhancement, there was a limited sport fishery for cutthroat in the Stave River. Since 1983, the hatchery has released approximately 10,000 adipose clipped cutthroat smolts annually into the Stave River to provide a mark only recreational fishery which will help maintain the naturally spawning cutthroat stocks by diverting effort onto marked hatchery fish.

A plan was developed to rebuild Stave coho stocks and provide an urban recreational fishing opportunity for coho in addition to the cutthroat fishery.

Between 1990 and 1994, Inch Hatchery released 40,000-50,000 Stave coho smolts annually into the Stave River. Since 1994, the hatchery has released an average of 212,000 coho smolts into the Stave River. As a result, coho escapements have increased from about 200 to an estimated 2-4,000 even in the current regime of poor marine survivals of coho. All hatchery coho are adipose fin-clipped and only marked fish are allowed to be retained in the recreational fishery. This allows a recreational fishing opportunity as well as accelerated rebuilding of the naturally spawning coho.

Prior to hydroelectric development, there were reports of chinook salmon in the Stave River but only one report of any chinook since 1969. In order to reestablish chinook in the Stave River and provide a

further recreational fishing opportunity, 373,000 Chilliwack white (originally the close by Harrison white stock) chinook smolts were transplanted into the Stave River between 1995 and 1997. In 1997, Inch Hatchery began collecting chinook eggs from the progeny of the transplants to the Stave River and released an average of 196,000 smolts into the Stave River in the last three years.

As part of the rebuilding of Stave coho and cutthroat, habitat restoration was also aimed at increasing rearing benefits for these and other species. The overflow side channel on the left bank, which now has sufficient flow for year round rearing, was deepened and filled with water-laden cedar stumps salvaged from Stave Lake during a drawn-down period. This added 8,000 sq. m. of ideal coho rearing habitat. Other constructed spawning channels and improved side channels also added additional coho rearing habitat. The flow agreement also substantially improved the spawning and rearing habitat in the Stave River.

The addition of angling pools during habitat restoration, the presence of a B.C. Hydro recreation site, parking lot, and boat ramp, and the increased escapements from hatchery returns of cutthroat, coho, and chinook has significantly improved the recreational angling opportunities on the Stave River. The fall sport fishery for coho is expanding rapidly, and the year round cutthroat trout fishery has improved. In addition, with the returns of hatchery chinook in 1997, a fall sport fishery for chinook has also developed.

Additional benefits to wildlife and recreation have also accrued. The large chum salmon escapements provide an abundant food source for bald eagles wintering on the Stave River and the nutrients from the carcasses likely produce an abundant food supply for rearing chinook, coho, steelhead, and cutthroat. The B.C. Hydro recreation site provides access to the left bank spawning channel, which has become a popular viewing area for salmon spawning.

The Future

With the rebuilding of the natural run of Stave chum to spawning capacity, there was no longer a need for hatchery releases. As a result, Inch Hatchery ceased releases of chum to the Stave River after the 1997 brood. The chum escapements will continue to be monitored to evaluate whether the stock can maintain itself at the current estimated capacity of 220,000 adults. The spawning grounds will be monitored to ensure that the habitat improvements are maintained and further restoration will be performed as required.

The Stave is not the only Fraser chum stock that was enhanced; all major Fraser chum stocks including the Harrison, Chehalis, Chilliwack, Inch, and Alouette stocks have been enhanced. Releases of fed fry from these stocks averaged 21 million between the 1982-1997 broods. In addition, extensive habitat restoration occurred on the Chilliwack, Harrison, and Alouette. Enhancement, habitat restoration, and harvest reduction have resulted in the rebuilding of all the major Fraser chum stocks. As a result, the hatcheries have reduced their releases to about 5 million as a buffer against catastrophic freshwater mortalities in streams. Fraser chum escapements will be monitored in the future to assess whether these stocks can maintain themselves at the current high levels.

Conclusion

Stave River chum rebuilding was accomplished by releases of hatchery chum and reductions in exploitation rate to put the returns from this production on the spawning grounds. Extensive habitat restoration and a flow agreement was undertaken so that spawning and incubation conditions were improved for production of fry from these adults. The result is a 7-fold increase in chum escapements from 44,000 to 309,000. Hatchery releases of coho, chinook, and cutthroat trout have also increased the returns of these species and habitat restoration should substantially increase the natural production of

these species. Additional benefits of this enhancement and habitat restoration include sport angling, food for other wildlife, and viewing of spawning. As the salmon life cycle is very dynamic and rivers are always changing, the Department of Fisheries and Oceans and B.C. Hydro will have to be vigilant to ensure that the conditions on the Stave River remain optimal for spawning, incubation, and rearing success.

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Planning Stream Habitat Enhancement Projects Using Two-Dimensional River Modeling: Examples of River_2D Applications

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Abstract

Two-dimensional flow modeling on regulated and unregulated rivers provides opportunities for quantifying benefits of habitat enhancements and flow changes for target species and life histories. The River_2D hydrodynamic model application developed in partnership with DFO integrates hydraulic modeling and physical habitat simulation modeling (PHABSIM) techniques to quantify flow-habitat relationships. During BC Hydro's Water Use Planning processes on the Campbell and Shuswap Rivers, River_2D simulations provided the basis for making operating decisions by modeling the incremental benefits of flow change. An important component of these models is the ability to integrate habitat changes, and pre-scope operational alternatives available. The tools available in these models allow the proponent to alter target habitats and identify benefits of changes in gravel condition, channel morphology and flow. Flow models can be developed using simple cross-sectional baseline data or more complex elevation models, depending on the planning requirements. In all cases, however, models represent estimates to be field validated once operational alternatives are reduced. The accuracy of these models is based primarily on the precision of the survey data and the HSI (habitat suitability) relationships integrated into the usable area calculations. By reducing the scope of the project and focusing on index areas rather than whole river habitats, modeling can be a cost-effective approach to planning enhancement initiatives.

Introduction

Planning fisheries habitat enhancement initiatives in streams requires careful consideration of several factors to ensure long-term and effective use of target species. Once a mitigable impact to a watercourse has been identified, the project proposed will be developed in consideration of the following:

- Target species life history requirements: depth, velocity, substrate size, and cover;
- Watershed characteristics: typical hydrology, flood-event frequency, native substrate condition;
- Cost: project size, amount of gravel, instream structures, etc.; and
- Maintenance: gravel cleaning/addition, stream access, and timing.

The more planning and information that can be gathered prior to project implementation, the more successful the project is likely to be, both in terms of functionality and stability. In many circumstances, analysis of all factors is not possible given limited budget and time. It is therefore practical to use predictive tools to estimate the impacts of variable factors involved in a proposed project, and create an optimal design of the enhancement. Depth averaged, two-dimensional models have become a practical

solution to these types of problems, due to the combination of improved numerical procedures and faster personal computers. The following contribute the effective application of stream modeling:

- bed topography for the proposed site: required for the extent of the site and locally adjacent portions of the stream only;
- habitat use relationships for the target species life histories; and
- watershed characteristics as above.

The Water Use Planning (WUP) process undertaken in British Columbia is directed at optimizing the use of water in consideration of power, fish, recreation, industry, consumptive use, and First Nations' values (B.C., 1998). A significant proportion of this effort is spent trying to understand instream flow relationships with fish habitat. Due to the relatively short duration of each WUP project, direct instream trials were often not possible, and modeling techniques were implemented where warranted. On the Cheakamus, Shuswap and Campbell Rivers, and Big Falls Creek (all British Columbia streams), flow models were used to predict the habitat responses to flow changes being discussed at the table. The models proved to be useful in several ways:

- providing cost effective evaluations of a large range of operations;
- informing consultative decision making;
- setting habitat targets for future monitoring and performance;
- providing visual aids for lay discussions; and
- providing the basis for scientific debate of habitat needs.

Planning Stream Restoration Projects Using 2D-Flow Modeling

Once a prescriptive approach has been identified for a target stream section, and a model has been created for the area, the proponent will conduct a weighted usable area (WUA) sensitivity analysis for the factors that are expected to affect the site. Flow, substrate and topography are all factors that can be manipulated in a flow model. Prior to completing the sensitivity analysis, proponents will have quantified aspects of the stream to satisfy model requirements. Stream hydrograph, event frequency analysis and target species life history requirements are critical requirements for appropriate application to planning projects.

Habitat Suitability Criteria

Proponents will have already followed the procedures laid out by their funding source for planning enhancement projects. Fundamental in any plan is setting project objectives. Johnston and Moore (1995) provide an example of planning procedures for watershed restoration, which are applicable to enhancement projects. Once project objectives have been set, with habitat use objectives within, a prescription for habitat enhancement can be developed. Habitat use will dictate the design criteria and will be the driver for performance monitoring of the habitat after construction. The habitat suitability criteria for spawning chum salmon present an example of what planners would incorporate into their design specifications (see Figure 1).

Stream Analysis

Flow model runs should be performed across the range of flows most likely to be seen at the site, in particular for critical period stream flow, and high frequency flood events (1:2 to 1:5 year events). Newbury and Gaboury (1993) outline several techniques for estimating stream discharges during critical periods and flood events. Knowing the general hydrograph only, planners can use mean annual discharge (MAD) to set critical flow targets, such as those developed by Tennant (1996).

Table 1. List of Tennant flow targets (expressed as percentages of mean annual discharge) which optimize stream and riparian biotas.

Habitat Condition	<i>October-March</i>		<i>April-September</i>	
	<i>Lower</i>	<i>Upper</i>	<i>Lower</i>	<i>Upper</i>
Flushing or Maximum	200%		200%	
Optimum Range	60%	100%	60%	100%
Outstanding	40%		60%	
Excellent	30%		50%	
Good	20%		40%	
Fair or Degrading	10%		30%	
Poor or Minimum	10%		10%	
Severe Degradation	0%	10%	0%	10%

Habitat values for the range of flows modeled will likely vary according to the maxima function:

$$y = Ax \bullet e^{nx} \quad \text{Equation 1}$$

where:

y = amount of habitat units;

x = amount of flow units;

A = scalar for magnitude; and

n = scalar for the rate of incline/decline of the relationship.

Equation 1 and Figure 2 illustrate the relationship describing the generally accepted habitat-flow relationship for all salmonids.

Application Example: Enhancing Spawning Opportunities in the Campbell River

Using data collected for the Campbell River Water Use Plan WUP, the Second Island sidechannel study and the tailrace gravel placement plan, we developed a River_2D model for the entire reach as shown in Figure 3. We evaluated the existing digital elevation model, with integrated substrate composition, to determine where habitat improvements for chum spawning could be made. The WUP process used the River_2D flow modeling to distinguish habitat values between differing operations on the Campbell River. We expanded on this analysis to demonstrate the other functions of planning river modeling can achieve.

Setting:

The Campbell River and tributaries (most notably the Quinsam River) support several salmonid species, including steelhead and four species of Pacific salmon: chum, chinook, coho and small numbers

of pink. The anadromous length of the Campbell River mainstem is 3.7km, with an additional 1.2km of canyonized habitat accessible between the John Hart powerhouse and dam (Elk Falls Canyon). MAD in the mainstem below the powerhouse is $98\text{m}^3\text{s}^{-1}$, but has historically (pre-impoundment) seen flows as low as $12\text{m}^3\text{s}^{-1}$ in September and October and as high as $335\text{m}^3\text{s}^{-1}$ in November and December (Hamilton and Buell, 1976). Because the system is regulated, the range of flows for review was within the range of available operations (including spill scenarios).

The John Hart powerhouse can release up to $122\text{m}^3\text{s}^{-1}$ during normal operations, and during a high inflow period, John Hart dam may spill greater than $350\text{m}^3\text{s}^{-1}$, with total mainstem flows exceeding $500\text{m}^3\text{s}^{-1}$ in worst case (1:30year) scenarios (see Figure 4).

The historic significance of the Campbell River fishery has been diminished in recent decades due to the habitat pressures caused by impoundment, industrial development, urban encroachment and overfishing. The Campbell River has been assessed as having poor quality spawning habitat, resulting in a low spawning capacity (Burt and Burns, 1995). Comparing assessments between 1973-74 (Hamilton and Buell, 1976) and 1993 (Burt and Burns, 1995) gives the strong indication that there is a net loss of spawning gravel from historically utilized sections.

In recent years, Fisheries and Oceans Canada (DFO), British Columbia Hydro (BCH) and local stakeholders have attempted to compensate for lost habitat by enhancing existing sidechannels, creating new sidechannel habitats, installing spawning platforms and restoring estuary habitat. Flow models have been used on the river in the past to develop design criteria (Hay and Co., 1996), evaluate habitat benefits (Burt and Burns, 1995) and determine impacts of operational changes.

Examples of two projects in particular are the Second Island Sidechannel improvements and tailrace spawning platform initiatives that have been undertaken by DFO and BCH. The study by Hay and Co. (1996) used the Shallow Water Numerical Analysis (S.W.A.N.) to develop design criteria for weir and spawning platforms in the second island sidechannel.

Developing the Flow Model in River2D

Developing a flow model in River2D is a three stage process:

- (1) Create a bed file: Using existing information from DFO surveys for their second island reconstruction and tailrace spawning plans, and collecting additional bed topography for the mainstem and floodplain areas of the reach, we were able to develop a comprehensive bed elevation model using R2D_Bed, the bed topography editing package included with River2D. We created two bed files: one depicting current conditions, the second incorporating changes we would want to see in the river.
- (2) Create a mesh file: R2D_Mesh is the mesh generating software that we used to create the elevation model that River2D imports into its final modeling package. In it, we set the inflow and outflow boundaries and made final improvements to the bed topography model. Figure 6 illustrates the three steps taken to generate a mesh file from a bed file.
- (3) Run a flow file: We ran several discharge scenarios for the reach through the River2D flow editor. The editor also has a weighted usable area utility we used to calculate the habitat values for each flow scenario ran. We ran enough scenarios to develop a comprehensive flow-habitat relationship under each model condition.

Changing Flows

Evaluating several flow scenarios, we defined a flow-habitat relationship for chum spawning which defined peak habitat conditions for reach 2 of the Campbell River. The relationship (see Figure 5) shows a peak in habitat at $20\text{m}^3\text{s}^{-1}$, well below the mean annual discharge of $98\text{m}^3\text{s}^{-1}$, but expected given the constrained channel and lack of floodplain relief. Channel constraints result in depths and velocities outside of the range of suitable spawning conditions for chum spawning. The relationship does provide insights that speak to the importance of sidechannel habitats. At $50\text{m}^3\text{s}^{-1}$, the Second Island sidechannel starts to provide habitat benefits, up to $100\text{-}110\text{m}^3\text{s}^{-1}$.

Investigating Erosion Impacts

Upstream gravel recruitment sites in natural rivers replace materials lost through the erosive processes of high flows. The erosive power of these events is dictated by Shields' relationship of shear and velocity. This relationship can be calculated for cross sections, and we generalized the relationships for the entire river reach of interest so that we could determine where erosion forces were most pervasive at moderate flows (see Figure 7). The analysis showed that in shallow depths, spawning gravel would be lost at 1.5ms^{-1} . Typically, the gravel of interest is susceptible to erosion at velocities $> 2.0\text{ms}^{-1}$. We developed criteria relationships so that we could cross-reference the flow data in the model to see where areas of erosion would be likely for each gravel size class. We then reviewed information from Burt and Burns (1993) and Hamilton and Buell (1976). Comparing the results of the historic habitat review and the model outputs, we were then able to target areas in the river that required gravel replenishing. Figure 8 shows the three areas where entrainment of spawning gravel is currently occurring, but where successful spawning has been observed in the past: downstream of the John Hart GS tailrace, and in the mainstem adjacent to the second island spawning channel.

Changing Habitat Conditions

We then went back to the bed topography model and for those areas identified for enhancement, changed the substrate category to the desired gravel quality, including changing the bed elevation for the tailrace area to that specified by DFO in their original plan. The mesh and flow files were regenerated and a new flow-habitat relationship was developed for the reach. As Figure 9 illustrates, the "enhanced model" showed a dramatic increase in mainstem habitat area over the current model for moderate flow levels.

The model demonstrated again the limitations of enhancement opportunities on a constrained floodplain, as our enhancement sites are unsuitable for spawning at higher flows due to velocity and depth increases.

Conclusions

There are several tools available today to help planners evaluate proposed enhancements and focus limited resources effectively. The exercise we undertook was helpful in demonstrating the limited opportunities available for enhancement in constrained river channels. Water Use Planning at BC Hydro is using these tools to promote the release of flows for downstream benefits, targeting fisheries, recreation, First Nations and industrial resources. River2D has the additional benefit of providing modeled flows and their habitat values to fish, and as we demonstrated, to gravel recruitment. As our desktop computing capacity increases, flow modeling will become a standard method for predicting flow change impacts, integrating geographic information systems (GIS), properties mapping, and riparian habitat models.

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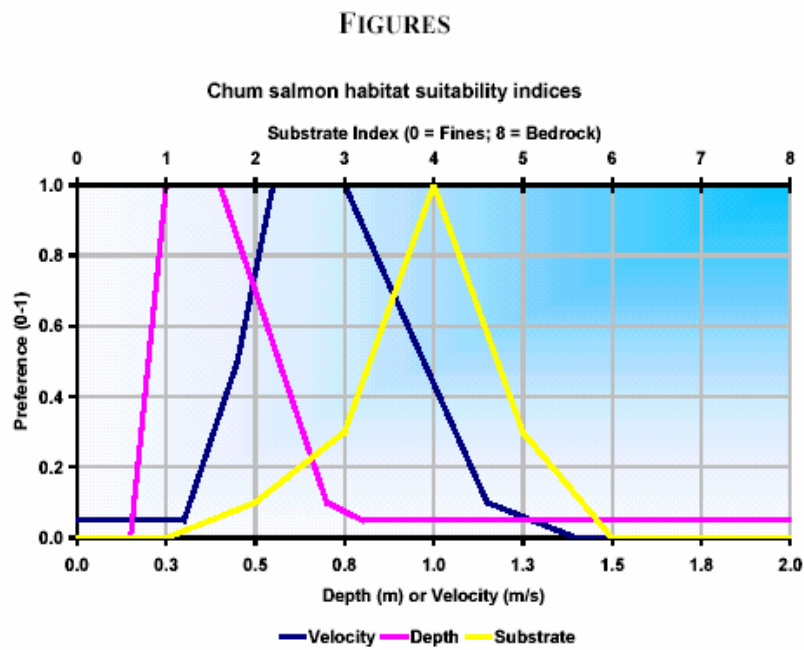


Figure 1. Habitat suitability criteria for spawning chum salmon (MWLAP, 2001).

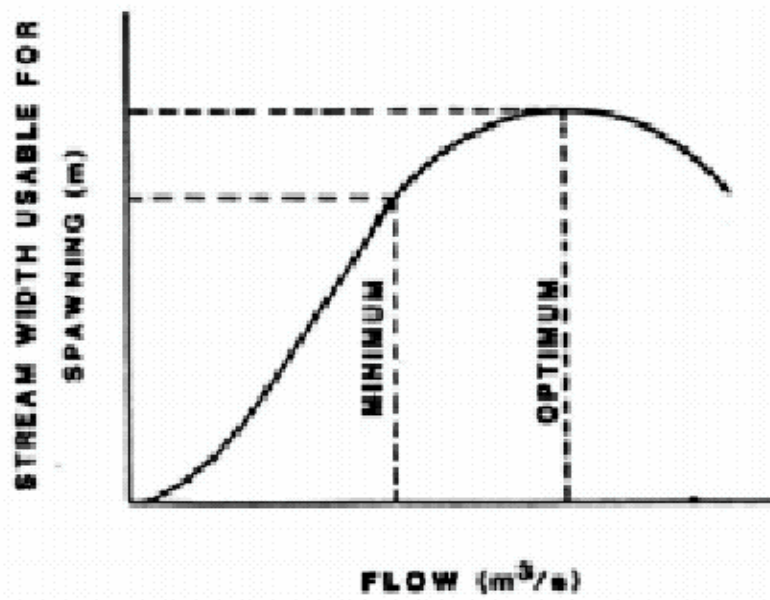


Figure 2. Typical habitat use relationship described by Equation 1 (Bjornn and Reisser, 1991).

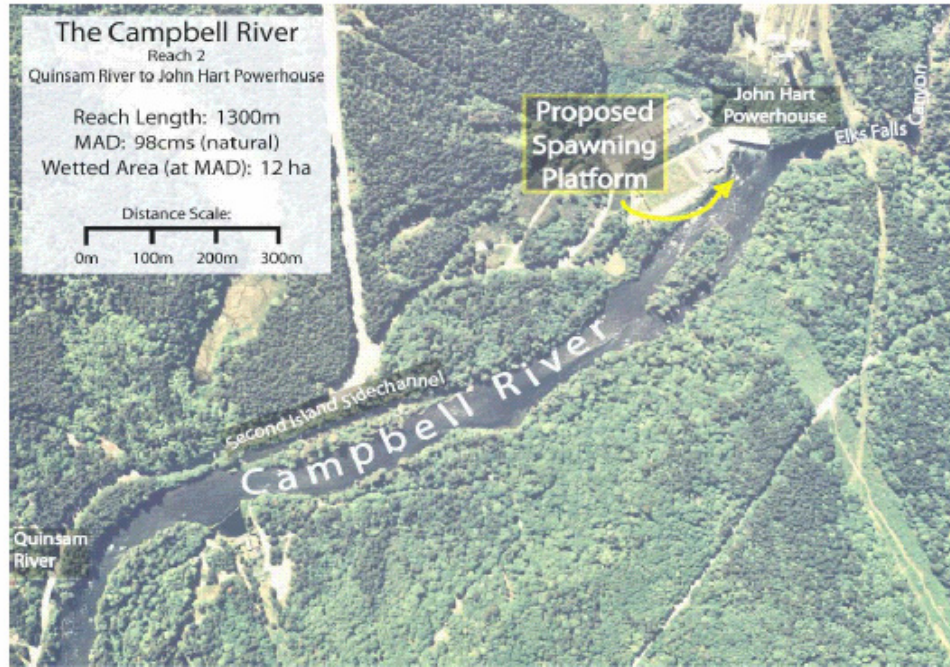


Figure 3. The Campbell River – reach 2 upstream of the Quinsam River. Points of reference include the Second Island Sidechannel, tailrace spawning platform (proposed), and the Elk Falls canyon.

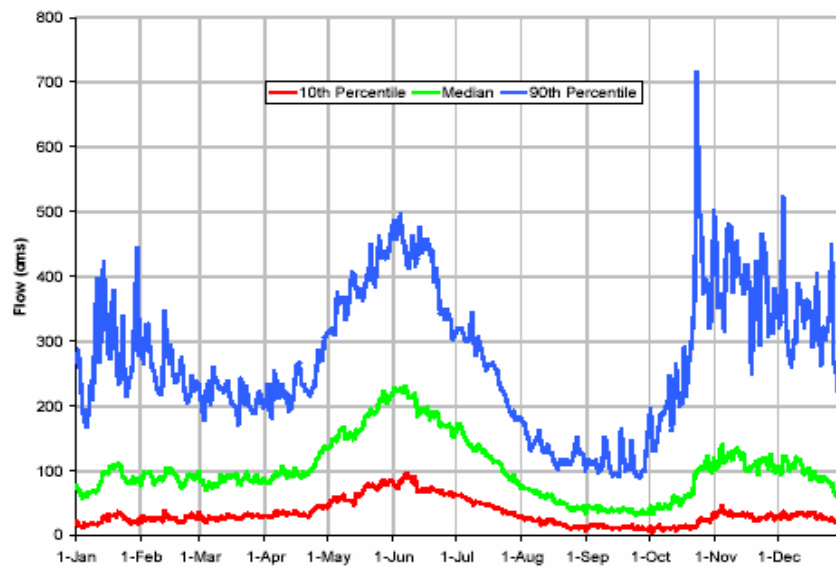


Figure 4. Modeled natural Campbell River inflows as measured at John Hart generating station (1963-1999) (BC Hydro, 2001).

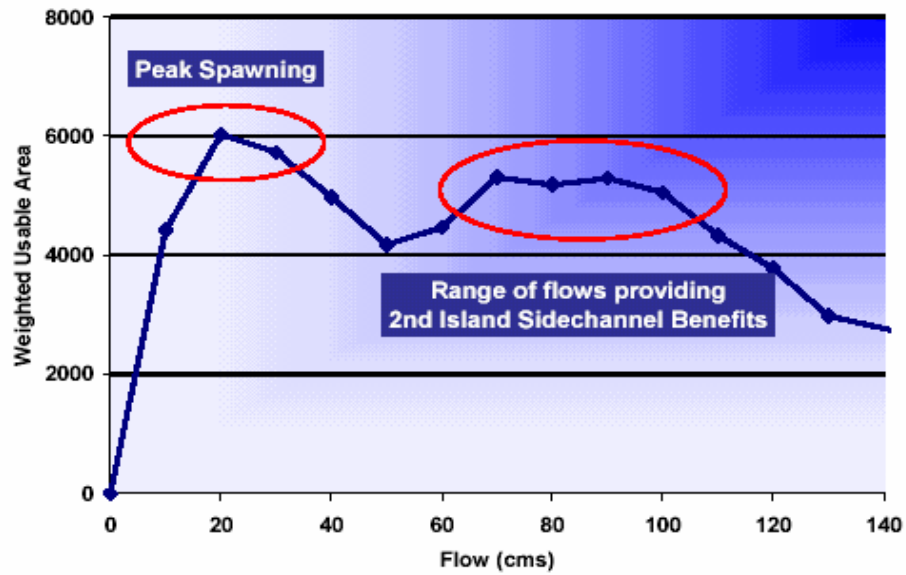


Figure 5. Flow-habitat relationship for spawning chum salmon in Reach 2 of the Campbell River. Illustrates peak habitat flow and the benefits provided by the Second Island enhancements.

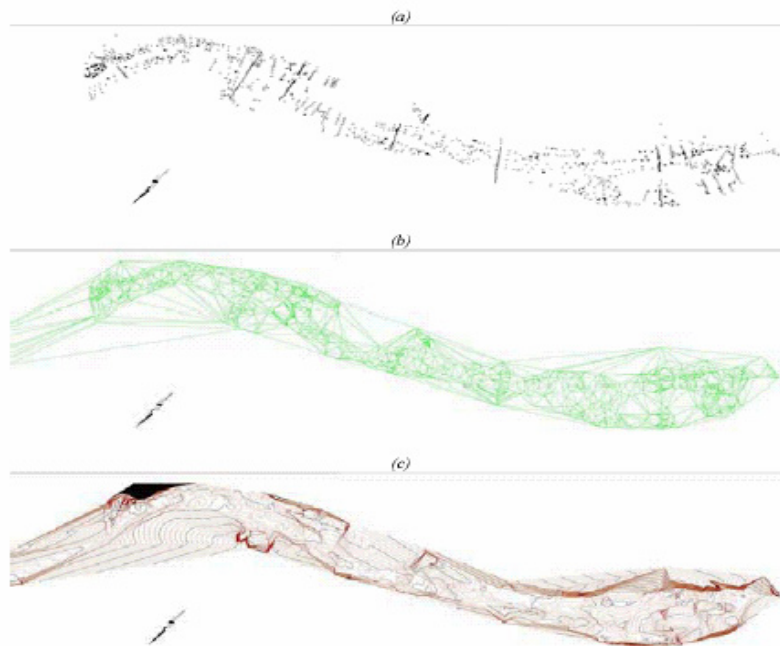


Figure 6. Three steps to develop a mesh for the study area (Campbell River) – (a) collate available raw data; (b) develop triangulated network (TIN) model; (c) define a contour interval for topographic representation.

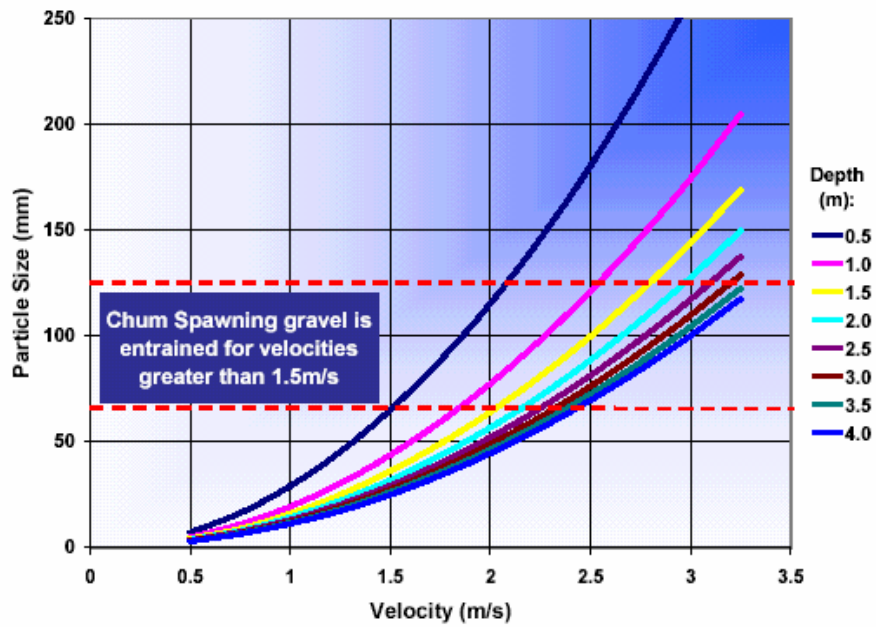


Figure 7. Shields relationship for standard stream velocity at which a particle is entrained (erosion).

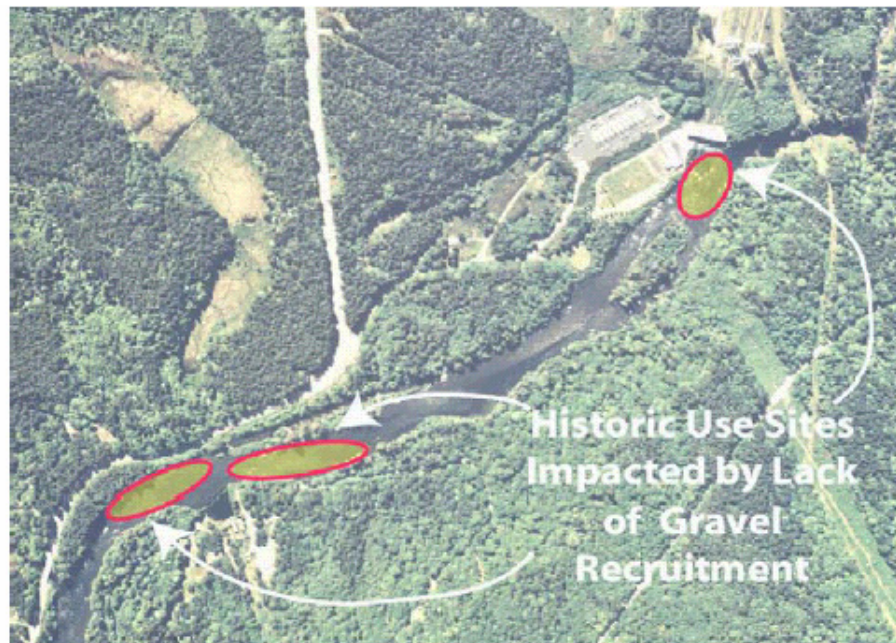


Figure 8. Reach 2 gravel erosion areas determined by habitat assessment (Burt and Burns, 1995) and River_2D modeling.

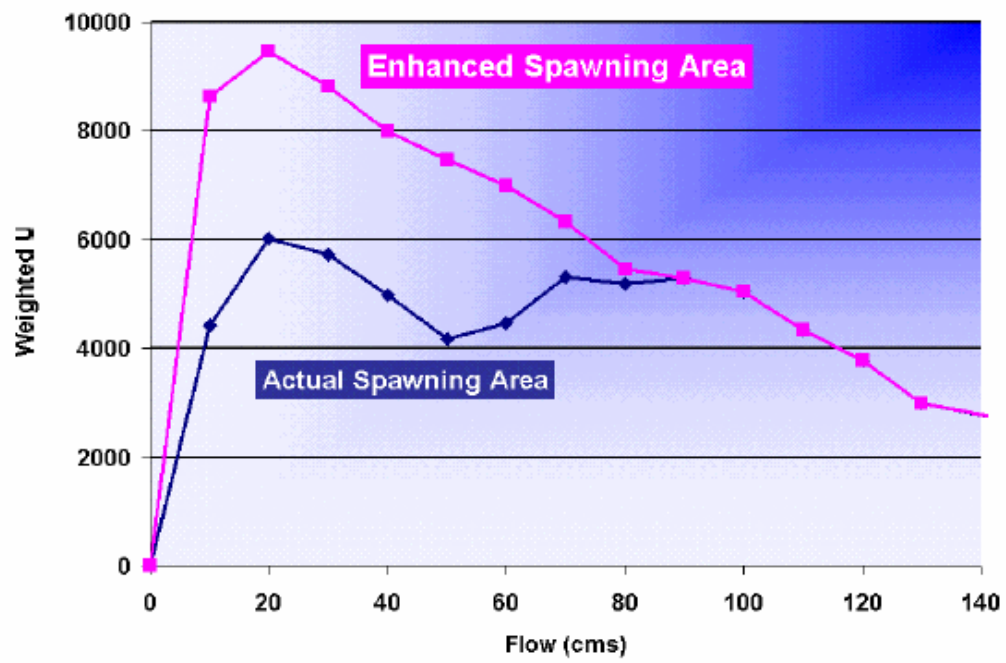


Figure 9. Comparing current and enhanced chum spawning habitat relationships developed using River_2D modeling.

Effective Spawning Performance Measure: Modelling Spawning and Incubation Success in Regulated River Planning

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Abstract

Of recurring concern across multiple hydroelectric projects in British Columbia is the influence of discharges on salmon and trout spawning success. For many regulated rivers, flow changes below hydroelectric projects may facilitate spawning in areas that are not subsequently watered or oxygenated during incubation. In addition, regulated flow changes can influence redd density subsequently affecting incubation survival. To address these impact hypotheses, an Effective Spawning Performance Measure (ESpwn PM) was developed and applied to projects on the Shuswap, Campbell, and Cheakamus Rivers in British Columbia in 2002 for the Water Use Plan (WUP) process. The objective of the PM was to differentiate between spawning distribution and subsequent incubation success of salmon and trout under different operational alternatives on rivers regulated by hydroelectric facilities. This paper describes the development of an Effective Spawning Performance Measure, its model components, and application in the BC Hydro Water Use Plan process.

Introduction

WATER USE PLANNING

In 1996 the Water Use Plan (WUP) process was jointly initiated by British Columbia Hydro (BCH), the provincial Ministry of Environment, Lands and Parks (MELP), and the federal Department of Fisheries and Oceans Canada (DFO). The objective was to ensure that regulated river and reservoir management operations at BCH hydroelectric projects reflected current public values and environmental priorities. To achieve water use optimisation for a variety of interests, current operations and proposals for new operations were considered for each BCH project through a mediated stakeholder process. Investigation of effects and impacts of each operation proposal was accomplished by modelling different alternatives based on incremental changes to reservoir storage and the timing, magnitude, and rate of downstream discharges (Figure 1).

For each WUP, the merits and impacts of proposed operation alternatives and current operations were assessed by a suite of performance measures (PMs). The breadth and number of performance measures reflected issues specific to that hydroelectric project. General examples included measures of annual revenue, flood protection, recreation river flows, maintaining a reservoir littoral zone, and rearing habitat for riverine fish. If the absolute value of the PM was significant and differences in the PM between alternatives was significant, the PM was subsequently used in a multi-attribute trade off with all other PMs to determine the optimum project operation.

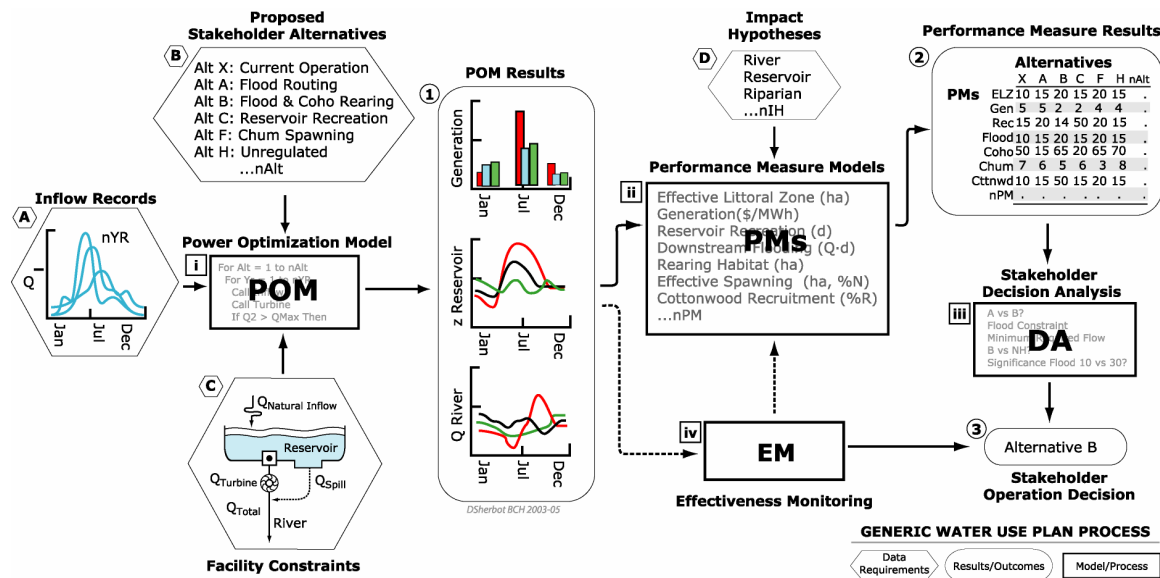


Figure 1. Schematic of generalised Water Use Plan (WUP) process. Core data requirements include a historical inflow record set (A), a set of proposed operational alternatives (B), hydroelectric facility constraints (C), and impact hypotheses (D) that link operations to environmental, social, and economic impacts. Governing the plan are models that relate plant operation alternatives (i, 1) and performance measures (ii, 2) defined for specific impact hypotheses and a structured decision analysis process (iii) where decisions (3) are subsequently audited through an effectiveness monitoring program (iv).

Of recurring concern across multiple hydroelectric projects on Vancouver Island and on the mainland of British Columbia was the influence of discharges on salmon spawning success. For many projects, it is observed that regulated changes in flows below hydroelectric projects may facilitate spawning in areas that are not subsequently watered or oxygenated during incubation (Reiser and White 1981; Gibbons and Acornley 2000). In addition, regulated flow changes can influence redd density subsequently affecting incubation survival. To address these impact hypotheses, an Effective Spawning Performance Measure (ESpwn PM) was developed and applied to projects on the Shuswap, Campbell, and Cheakamus Rivers in British Columbia in 2002.

Method

PERFORMANCE MEASURES

The intent of each Performance Measure (PM) was to quantify the absolute and relative differences between operational alternatives or physical work scenarios for a hydroelectric project on a desired objective (e.g. increase spawning habitat for pink). For the WUP process, any objective and subsequent PM development first had to be linked to impact hypotheses that related incremental flow changes in facility operation to the desired objective (e.g. H_0 : Unseasonably high discharges provide chum spawning habitat that will subsequently be dewatered).

Development and application of PMs in each WUP had one of four outcomes. (1) The PM was ineffective in linking operation changes (discharge magnitude, timing, rate of change, reservoir levels, etc...) to the outcome it was trying to measure. This indicated that the PM needed to be revised or discarded from the planning process. (2) The PM was sensitive to linking operation changes to an outcome, but outcomes between different operation scenarios were inconsequential. Consider comparing

two operation alternatives that result in downstream salmon spawning habitat of 5 and 50 m², respectively. Both outcomes are trivial when the objective is a target > 1000 m². (3) The PM was sensitive to linking operation changes to outcomes, but outcomes between different operation scenarios had no significant difference. Consider comparing two operation alternatives that result in net downstream spawning habitat of 1000 and 1010 m². Neither outcome is significantly different for planning purposes. (4) The PM was sensitive to linking operation changes to outcomes and outcomes had significant differences between scenarios. Consider comparing two operation alternatives that result in downstream spawning habitat of 5000 and 1000 m². The first alternative may be significant enough to influence decisions for planning purposes.

A performance measure model, ESpwn PM, was developed to predict spawning and incubation success from redd placement through swim-up. For decision analysis between multiple operation alternatives, four metrics were typically produced by the ESpwn PM: mean area available for spawning over the spawning period (ASpwn), the total area that was available for spawning and is effectively watered during incubation (EASpwn), the percent redds that are effectively watered during incubation (%EIncb), and mean density of effectively incubated redds (pEIncb). Both spawning and subsequent incubation success have temporal components. The aforementioned indicators consider life stage periodicity, run density distribution, and dynamic habitat characteristics related to regulated river discharges. Consequently, solving for percent redd survival is not as simple as %EIncb = EASpwn/ASpwn unless flows and spawning run density are constant during the spawning interval.

MODEL COMPONENTS

The ESpwn PM is based on four discrete components. A Power Optimisation Model (POM) for the hydroelectric facility, a hydraulic model for computing depth averaged velocities in river channels (River 2D), a physical habitat simulation model (PHABSIM) for calculating spawning and incubation habitat suitability as a function of river discharge, and a Dynamic Spatial Spawning Model (DSSM) to compute spawning metrics as a function of spawning distribution and changing river discharges over spawning and incubation life stages (Figure 2). The first and last models were independently developed by BCH for the WUP process, with the DSSM integrating information from all three other components to permit performance measure calculation. Each component and its data requirements are detailed individually below. For simplicity, all future references to a hydroelectric facility refer to a generic project with one storage reservoir and a downstream release facility consisting of a single turbine and spillway. For the WUP process, hydroelectric facilities where ESpwn PM was applied were more complex, characterised by multiple storage reservoirs, diversions, generation facilities, and changing river morphology.

POWER OPTIMIZATION MODEL (POM)

For each project, the POM (Figure 2 A) simulated daily reservoir level and downstream discharge over a collection of proposed operating alternatives and across different hydraulic inflow conditions. Principle requirements of the POM include hard hydroelectric facility constraints based on physical limits (e.g. turbine capacity, reservoir capacity, spillway rating, etc...), licensing, integrated electrical system requirements, and/or treaty obligations. Within the hard constraints, soft changes governing daily operational use of water (timing, magnitude, rate, etc...) could be made to meet the different or combined needs of various interests. Each proposed package of soft operational constraints represented a unique operation alternative within the bounds of the hard constraints. For example, an alternative could be created to target high releases of downstream discharge for fall spawning at the expense of winter reservoir storage. Conversely, a different alternative that favours flood control could be crafted to drain the reservoir rapidly, year round, indifferent to the downstream flow regime. When possible, however, alternatives were designed to reflect multiple interests rather than mutually exclusive objectives.

Driving the POM was an inflow record set. In most WUPs, the inflow was based on historical inflows over a ~30 year data series ($dt = 1$ d). Variation in snowpack levels, freshet timing, and precipitation events resulted in different reservoir levels and facility discharges between years. Subsequently, this variation was reflected in different intra and inter annual discharge regimes within a given alternative as the POM attempted to optimise for power production. Furthermore, if reservoir storage capacity is sufficient to influence the following year, operations from the previous year affect operations in the subsequent year. Two successive drought years, for example, may have large implications on how the hydroelectric project behaves in the 3rd year based on soft and hard operating constraints.

The objective functions (both hard and soft constraints, defined with penalty functions for tolerance) were solved using a linear optimisation scheme, where inflow forecasting was generally limited to 7 days. The objective functions were coded in AMPL and solved using CPLEX. Operational output from the POM simulations included reservoir levels, downstream discharge, spill discharge, and diversion flows (BCH 2002). Computation of ES_{pwn} PM metrics using the DSSM incorporated mean daily discharge (the sum of turbine and spill discharges) and associated tributary inflow. Ancillary information based on turbine discharge permitted simultaneous calculation of generation (MWh) and annual revenue based on MWh weighted by monthly and peak Value of Electricity (VOE) demand profiles.

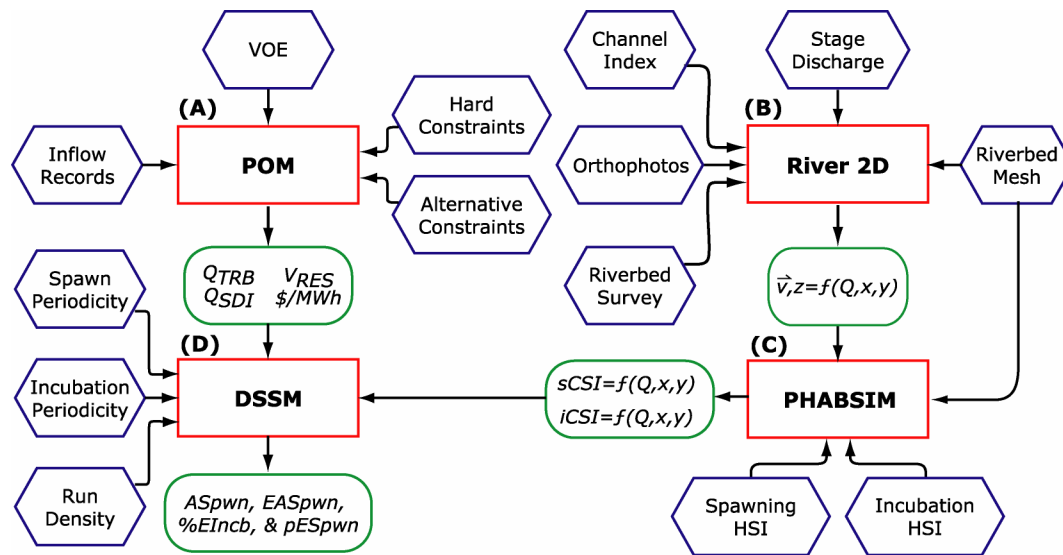


Figure 2. Effective Spawning Performance Measure (ES_{pwn} PM) model components. Data requirements and results for the (A) Power Optimisation Model (POM), (B) River 2D, (C) Physical Habitat Simulation (PHABSIM), and the (D) Dynamic Spatial Spawning Model (DSSM). Turbine discharge (Q_{TRB}), spill discharge (Q_{SDI}), reservoir storage (V_{STO}), value of electricity (VOE), generation (\$/MWh), combined spawning (sCSI) and incubation (iCSI) suitability indices, and habitat suitability indices (HSI). DSSM permits calculation of spawning area (AS_{pwn}), effective spawning area (EAS_{pwn}), percent of effective redd incubation ($\%EInc$), and density of effectively incubated redds (pES_{pwn}).

RIVER 2D

The river channel hydrology is solved using a depth averaged velocity model (River 2D: Steffler and Blackburn 2001). River 2D is based on a finite element scheme solved using Petrov-Galerkin formulation. For a series of defined flows, River 2D provides a spatial plan of water depth and depth

averaged velocity vectors for the river channel. The computation engine can resolve subcritical and supercritical flows and is capable of dealing with variable wetted areas. The model is capable of solving transient solutions, however, for application within the ESpwn PM, only the hydraulics associated with discrete incremental steady state solutions were used.

Channel index characteristics (topography and bed roughness) were required for each river reach to be analysed in the DSSM. These data were subsequently used to generate a computational node mesh to solve channel hydrodynamics. In practice, representative reaches < 500 m in length were used. To improve model accuracy, upstream and downstream water surface elevations from stage discharge relations (SDR) were collected in the field over the range of flows expected under project operations. In addition, orthophotos, when available, could validate that the simulated wetted perimeters in the mesh mirrored actual channel behaviour. Within the framework of the ESpwn PM, River 2D was used to generate a series of hydrodynamic plans across the range of possible flows downstream the project (Figure 2 B). Subsequent generation of habitat suitability indices using PHABSIM required the spatial velocity and depth characteristics at each flow increment modelled (e.g. $Q = 1, 2, 5, 10, 15 \dots 200$ cms) and the distribution of wetted substrate. Hydrodynamic solutions were typically set at intervals <5% the maximum expected project discharge: $dQ = 0.05 Q_{Max}$ and increased in resolution over flows of particular biological significance.

PHYSICAL HABITAT SIMULATION (PHABSIM)

For each flow increment, a series of Weighted Usable Area (WUA) indices (Bovee 1982) were generated (Figure 2 C). River 2D has a physical habitat simulation routine integrated in the model and was used to generate WUA indices in parallel with solving for river hydraulics. PHABSIM routines were run discretely for spawning preference and incubation preference.

Generation of combined suitability indices (CSI) for each possible spawning flow (Figure 3 RIGHT) were based on the geometric mean of velocity habitat suitability indices ($vHSI$), depth ($zHSI$), and substrate ($sHSI$). Each index provided a preference, 0 (none) -1 (ideal), as a function of the parameter. For velocity and depth, these curves were continuous (Figure 3 LEFT). For substrate, the preference is based on discrete substrate classes. The combined index for incubation success was based on minimum required wetted depth and velocity requirements. This is solved as a binary function 0 (unsuccessful) and 1 (successful) based on meeting or exceeding the minimum requirements. HSI data is defined for each salmon species investigated. Information for the WUP is taken from meta data describing generic preferences for a species across multiple systems with the same channel configuration (BCH 2002 A) and biogeoclimatic zone or, when available, from *in situ* observations.

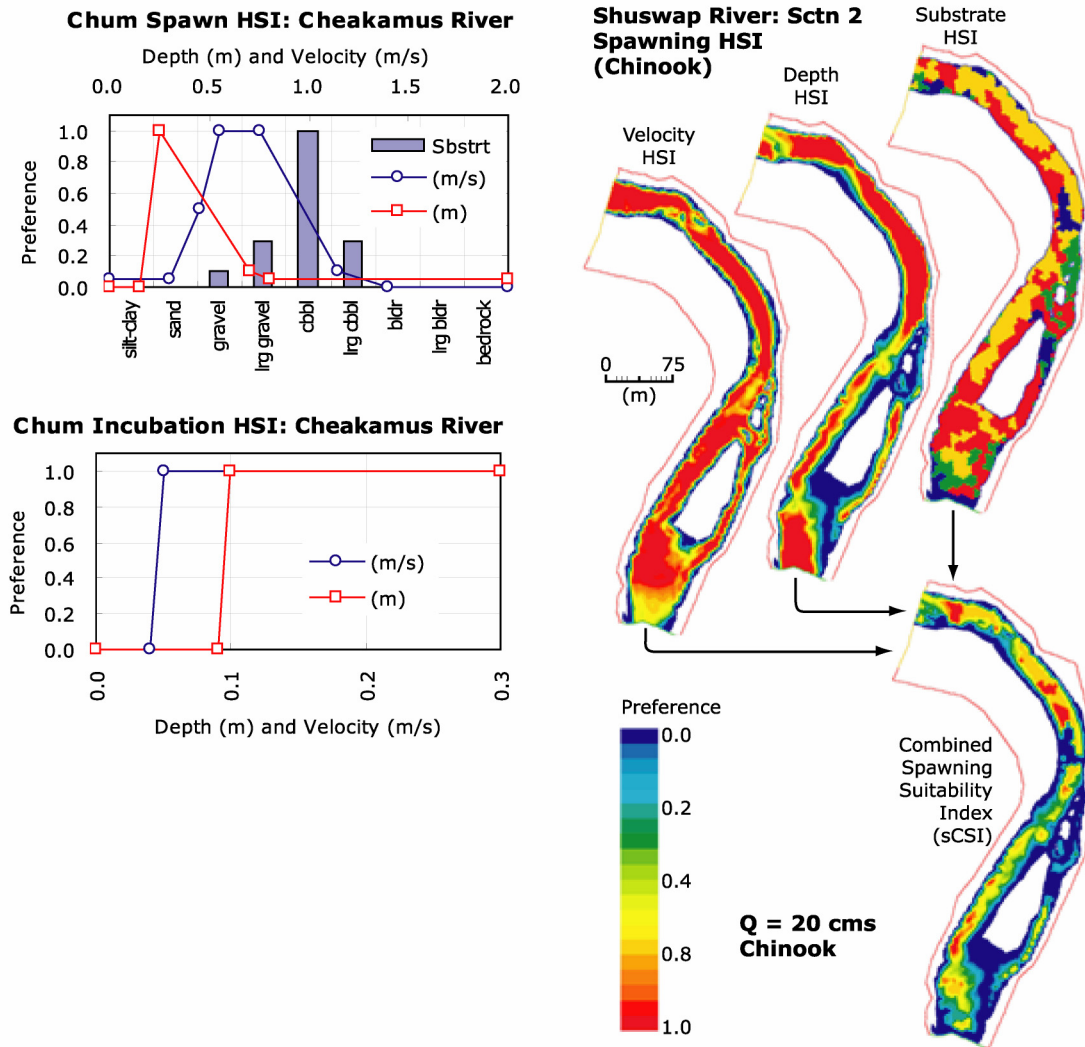


Figure 3. Generation of Combined Spawning Suitability Indices (CSI) spatial data. Habitat suitability indices (HSI) was required for each river system and species for the ESown PM. Example (LEFT) HSI data presented for Cheakamus River chum. HSI data were required to generate CSI data for the river sections modelled at each flow increment. Example (RIGHT) of chinook spawning CSI data generated for section 2 of the Shuswap River at 20 cms. Note that weighted useable area associated with the sCSI plan is much less than any of the three individual HSI plans. $sCSI(Q,x,y) = vHSI(Q,x,y) \cdot zHSI(Q,x,y) \cdot sHSI(Q,x,y)$.

DYNAMIC SPATIAL SPAWNING MODEL (DSSM)

The DSSM integrated information from the previous three components with the temporal distribution of project discharges, spawning periodicity, run density, and incubation periodicity for each year in the inflow record set available for the POM (Figure 2 D). The model and user interface for the DSSM were coded in VB 6.0. Results from the POM, River 2D and the PHABSIM results from River 2D and output from the DSSM were managed using MS Access. Spawning periodicity data describe the start and end dates of the spawning period. Run density describes the proportion of total spawner pairs expected each day between the start and end spawning dates. These data were typically obtained from historical run

records for the specific river system. Incubation periodicity describes the start and end dates of emergence. Emergence distribution between these dates was proportioned in the same weight as the spawning distribution. Incubation timing, like spawning information, were defined for each specific river system. Results associated with spawning distribution and incubation success were both calculated on a daily time step (Figure 4).

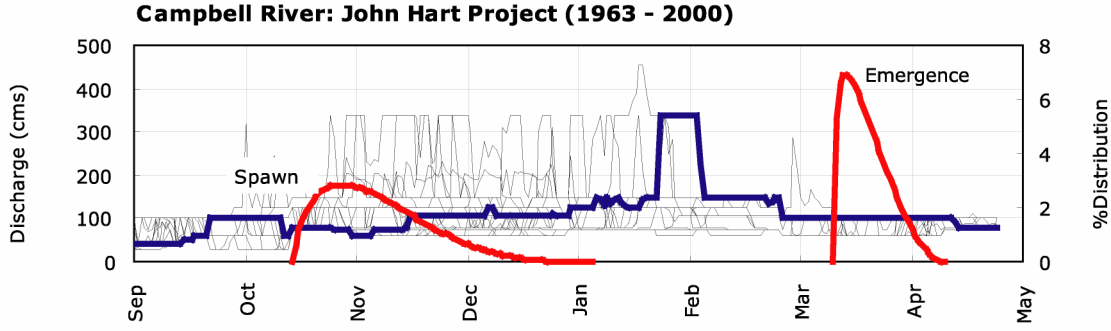


Figure 4. Annual discharge profiles (1963-2000) for Campbell River WUP downstream of JHT powerhouse (Alternative T). Year 1994 highlighted. Sample periodicity data for chum spawning and incubation timing is superimposed with run distribution density.

For each inflow year available for the POM, 365 days of discharge data were generated starting with the first spawning day. For each spawning day, area weighted by the spawning CSI, $f(Q)$, and run proportion, $f(t)$, was determined. Project discharge varied day to day according to energy demands, inflows and specific alternative constraints. Consequently, the magnitude of usable spawning area and the spatial location changed daily. Furthermore, as run distribution is not constant (e.g. peaking during the middle of the spawning interval) redd density was dependent both on run proportion and the associated spawning area for that discharge day. After redd creation and through until the end of incubation, incubation success was determined by the minimum depth and velocities the channel was exposed to under subsequent project discharges for that spawning year.

For each operation alternative (Alt), species (Sp) and river section ($Sctn$), mean spawning area ($ASpwn$) is calculated over all simulation inflow years (nYR) as:

$$(1) \quad \overline{ASpwn}_{(Alt, Sp, Sctn)} = \frac{1}{nYR \cdot nDY} \cdot \sum_{YR=1}^{nYR} \sum_{DY=1}^{eSpwn} \sum_{i=1}^{nNode} A_{(YR, DY, i)} \cdot sCSI_{(YR, DY, i)}$$

$$A_{(YR, DY, i)} = f(Q_{(YR, DY, i)}) \quad sCSI_{(YR, DY, i)} = f(Q_{(YR, DY, i)})$$

where $nNode$ is the total number of nodes used in the mesh model for each river section and area (A) is estimated daily between the start ($oSpwn$) and end of spawning ($eSpwn$) and weighted by the combined suitability indices for spawning ($sCSI$) for the target species based on project discharge flows (Q) for each day. Estimation of mean Effective Spawning Area ($EASpwn$) is estimated as:

$$\overline{EASpwn}_{(Alt, Sp, Scm)} = \frac{1}{nYR \cdot nDY} \cdot \sum_{YR=1}^{nYR} \sum_{DY=1}^{eSpwn} \sum_{i=1}^{nNode} \left(\frac{A_{(YR, DY, i)} \cdot sCSI_{(YR, DY, i)} \cdot iCSI_{(YR, DY, i)}}{A_{(YR, DY, i)} \cdot sCSI_{(YR, DY, i)}} \right) \quad (2)$$

$$iCSI_{(YR, DY, i)} = f(QMIN_{(YR, i)} |_{oInc}^{eInc})$$

where the combined incubation suitability index (*iCSI*) is calculated based on minimum flow observed between the start (*oInc*) and end of incubation (*eInc*). Incubation survival (*%EInc*) associated with each spatial area is thus a measure of initial area available for spawning weighted by the run that was available to spawn that day (*iSpwn*) and the subsequent portion of the area that remained effectively watered during incubation:

$$\%EInc_{(Alt, Sp, Scm)} = \frac{\sum_{YR=1}^{nYR} \sum_{DY=1}^{eSpwn} \cdot iSpwn_{(DY)} \sum_{i=1}^{nNode} \left(\frac{A_{(YR, DY, i)} \cdot sCSI_{(YR, DY, i)} \cdot iCSI_{(YR, DY, i)}}{A_{(YR, DY, i)} \cdot sCSI_{(YR, DY, i)}} \right)}{nYR \cdot nDY \cdot nSpwn} \quad (3)$$

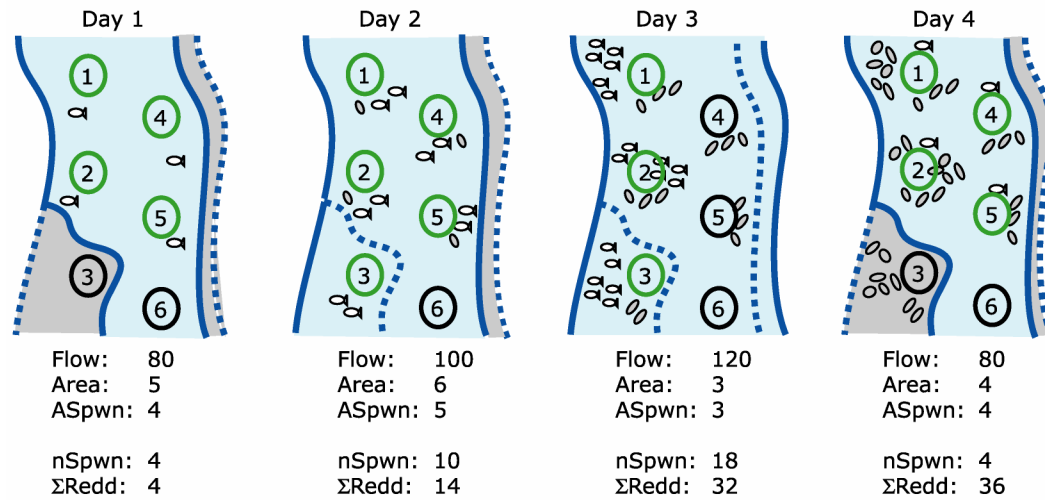
Application of the accounting methods in Equations 1, 2, and 3 for a single simulation year are illustrated in Figure 5. The examples assumes a 4 day spawning interval with a critical incubation flow for all redds on day 150 and all emergence completed by day 160. Each model node represents an area with unique hydrodynamic properties and habitat suitability indices. Investigation of the simulation demonstrates effective incubation was highly sensitive to exposing vulnerable habitat on day 3 simultaneously with peak run distribution.

Results & Discussion

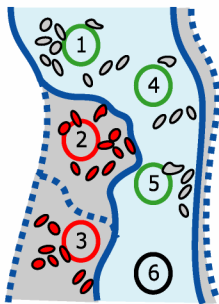
APPLICATION & FUTURE DEVELOPMENT

For hydroelectric operation planning purposes, the ESpwn PM was used to compare outcomes across a set of proposed operation alternatives, species, and river reaches. For any given operation alternative, the metrics were calculated across multiple inflow years with different hydraulic conditions. This permitted calculation of a collection of summary statistics. For most decision analyses in the WUP, mean values (e.g. mean *ASpwn*) and maximum impact scenarios (e.g. minimum *%EInc* {YR = 1 to nYR}) were used to distinguish between different alternatives. In many cases, inter and intra flow optimisation for fish could be antagonistic. Subsequent decision analysis and trade off between scenarios, particularly those involving different species, proved to be the most difficult part of the planning process (BCH 2002 A; BCH 2002 B; BCH 2003). An example of intra species trade-offs is illustrated in Figure 6.

Spawning Flows



Critical Incubation Flow: Day 150



ASpwn (ha): 5
 QMin (cms): 40
 EASpwn (ha): 3

 Total Redds: 36
 Effective Redd: 18
 %EInc: 50%
 pInc: $6 = 18/3$
 pEInc: $9 = 36/3$

LEGEND

1	R2D Model Node
①	Suitable Spawning Site
⑥	Unsuitable Spawning Site
	Spawner
	Wetted Area
	Dewatered Area
	Redd
	Dewatered Redd

Figure 5. Simplified illustration of Effective Spawning Performance Measure calculation. D1: 5 nodes are wetted, however, only 4 are suitable for spawning (N1, 2, 4, & 5). D1 represents the start of spawning run and only 4 spawner pairs are available for the suitable areas. D2: project discharge increased to 100 cms and additional spawning area becomes available. 10 spawning pairs arrive that day and distribute homogeneously between all suitable nodes. D3: project discharge increases to 120 cms. All nodes are wetted, but increased velocity eliminates suitability for N4 and 5. Peak spawner distribution (18 spawner pairs) occurs this day and the new redds distribute between remaining nodes (N1, 2, and 3). Day 4: project discharges decreased to 80 cms. Remaining spawner pairs (4) distribute between N1, 2, 4, and 5. All spawning pairs associated with D3 at N3 are dewatered. D150: low inflows and limited reservoir storage reduce project discharge to 40 cms. Both N2 and N3 are dewatered. D180: end of all possible redd emergence. Effective incubation observed at N1, N4, and N5. Mean spawning area over the simulation is 5 ha. Mean effective spawning area is 3 ha. Effective incubation is 50%. Spawning area (ASpwn), spawning area effectively incubated (EASpwn), percent of redds effectively incubated (%EInc), number of spawning pairs (nSpwn), and cumulative redd numbers (ΣRedd).

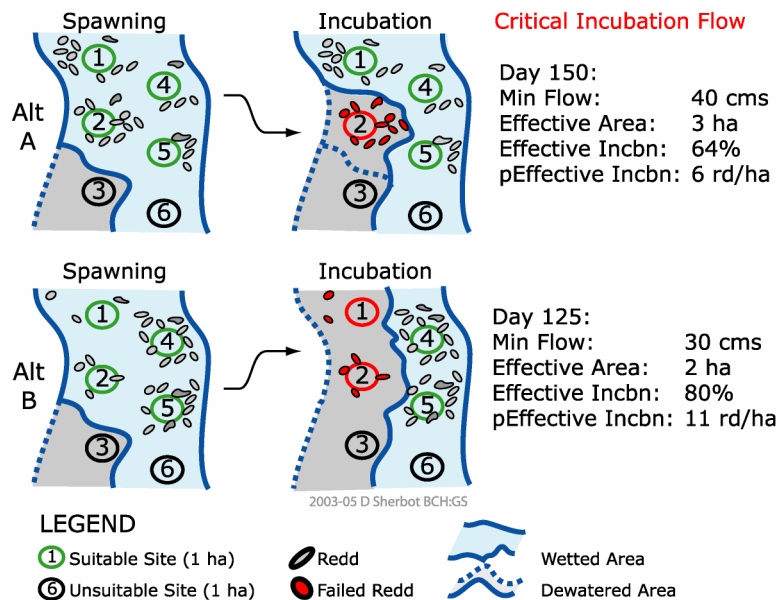


Figure 6. Example: Using the ESpm PM to compare two operation alternatives. Different soft constraints in hydroelectric discharges result in differences between percent redd survival and redd density.

Three regulated river planning scenarios were characteristically addressed in each WUP. (1) Soft constraints were contrived to eliminate suitable spawning habitat in areas that would likely be dewatered during incubation. A hydroelectric facility that peaks between 20 – 100 cms, could be restricted to 20 cms during spawning to ensure that spawners did not take advantage of ephemeral habitat > 20 cms. (2) Soft constraints were contrived to maximise incubation success of target salmon species. This usually involved optimisation between providing spawning flows and subsequent incubation flows with reservoir storage and seasonal inflows. (3) Physical works solutions were contrived to maximum effective spawning for a predetermined alternative. For example, spawning gravel could be strategically placed to supplement existing flow conditions under a regulated river discharge (Leake 2003). All the scenarios involved intra and inter species trade offs between redd density and percent successful incubation in addition to other interests addressed in the WUP.

The ESpm PM was developed as a planning tool, in the absence of empirical data, to assess the relative merits of different operation alternatives on spawning and incubation success. Model accuracy under the proposed flow regimes, however, remains to be validated. To address this, post WUP implementation for each project includes plans to assess the accuracy of spatial spawning distribution and subsequent incubation survival in river sections modelled once the new operating regimes are implemented. The subsequent iterative process of validating the model should demonstrate areas of key sensitivity and uncertainty in the model mechanisms. Examples of areas already flagged for investigation include variable spawning and incubation timing based on flow dependent temperature regimes rather than fixed calendar windows, the ability to dynamically change bed substrate associated with scouring flows, and increasing certainty associated with river specific HSI data.

Acknowledgements

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Leake and J. Bruce (BCH), M Sheng, and B Chilibeck (DFO), and P Steffler for his initial help in applying the River 2D model.

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Session 5

Session Leader: Tom Rutherford (CDFO)

Education and Community Involvement

Attitude Enhancement – How Classroom Incubation of Chum Salmon Can Foster a Stewardship Ethic

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Overview

Classroom observation of a chicken developing from the egg stage offers students a temporal dimension to life. Watching salmonids develop over a four-month period offers this same dimension.

Releasing fry into a local stream goes a step further. This personal investment – this visceral connection to the stream - can instill a more complex sense of place within students.

It's easy to throw garbage out the car window if a child does not feel spiritually connected to that particular piece of highway. It's much more difficult for a child to watch someone pour used paint thinner down a storm drain, or to throw rocks at spawning chum, or to see litter on the beach, if that child has a personal investment in that watershed.

That investment enriches one's sense of place beyond where one lives, works or goes to school. It gives the child a watershed address, the precursor of a mature environmental ethic. This is attitude enhancement.

As the child grows, connections can be made to other organisms sharing salmonid habitat. Beach studies complete a simple understanding of the geography of a watershed. The study of other life cycles can teach the student an appreciation of the cycle of life and the interconnectedness of all living things.

Introduction to Presentation

My purpose is to present you with ideas about the concept of stewardship and the resources we need and possess to instill this ethic in others. I will give you an overview of Fisheries and Oceans Canada's *Classroom Incubation Program* as a method of teaching stewardship, and end with some information about the Program's current scope and impact.

What is Stewardship?

- An ethic being a code that guides our behavior
- Golden rule (Immanuel Kant) intended for application to humans. Did not address Nature.

Quote re reverence for life (Albert Schweitzer)

“Let a man once begin to think about the mystery of his life and the links which connect him with the life that fills the world, and he cannot but bring to bear upon his own life and all other life that comes within his reach the principle of reverence for life....”

Quote re interdependence of living things (Chief Seattle)

“This we know: The earth does not belong to man; man belongs to the earth. This we know. All things are connected like the blood that unites one family. All things are connected.... Man did not weave the web of life; he is merely a strand in it. Whatever he does to the web, he does to himself...”

- To understand or demonstrate stewardship requires a paradigm shift away from the notion that the earth is my sandbox to shape as I wish, that there is a meaningful separation between me and Nature, and that the rules of life can be altered to my “advantage”. (example of David Collenette, Canada’s Transport Minister, assertion that the new federal initiative on new infrastructures is “good for the environment and good for us”).
- Toward the notion that the earth sustains us according to laws that are beyond our ability to manipulate. Perhaps learning to live within those laws is the path to becoming a good steward.

Quote Gloria Snively’s 2001 definition of stewardship, Junior Shorekeepers Handbook (draft) page 47:

“The concept of responsible caretaking; based on the premise that we do not own resources, but are managers of resources and responsible to future generations for their condition”

How Can We Teach This Ethic?

- Our teachers cannot instruct us to be good stewards, but they can demonstrate stewardship, and they can expose us to experiences that create this reverence for life. Those experiences are especially effective when they involve a personal investment. More on that later.

What Tools Do We Have? (with slides)

- Rivers, snow and mountains
- Insects
- Oceans
- Sunsets
- Images of unsullied natural beauty (chum spawner, head shot)
- Teachers – they come in many shapes and sizes.

Classroom Incubation

- Fisheries and Oceans Canada began to support classroom incubation activities in the early 1980’s. Some teachers put a petri dish with eggs in the staff fridge. Old restaurant juice coolers were used to cool classroom tanks.
- Today’s program design brings 100 liters of a local stream into the classroom, and brings the classroom to the stream. Tanks are cooled using the kind of equipment found in most refrigerators, and stand on custom-made carts.

- Fall – most students in this program participate in a field trip to see spawners, and many teachers present classroom salmon dissections.
- Hatchery staff are busy capturing broodstock and conducting egg takes, and they sometimes offer on-site programs like egg take demonstrations for schools. Hatchery staff maintain the eggs to the eyed stage
- Winter – Teachers set up incubators in early January, then receive up to 200 eyed eggs.
- In the CRD, over 80% of the participating schools (72 of 88) receive chum eggs from the Goldstream River.
- Students attend the tanks with daily monitoring, water changes, ATU charting and feed the fry for a short time before they are released. Teachers use this program for all subject areas.
- Spring (April or May) – Classes release all or most fry into a designated nearby stream. Every effort is made to ensure that the recipient stream is within the child's own concept of his or her neighbourhood. This is where classroom incubation differs qualitatively from many other kinds of classroom critter custody.
- The difference is the fry release experience – the letting go of a personal investment into Nature's care. I believe that it facilitates the incorporation of this stream, and its inhabitants, into the child's own sense of place. This sense of place – this watershed address - is an important prerequisite for a stewardship lifestyle.

Quote (Allen Gussow)

“There is a great deal of talk these days about saving the environment. We must, for the environment sustains our bodies. But as humans we also require support for our spirits, and this is what certain kinds of places provide. The catalyst that converts any physical location – any environment if you will – is the process of experiencing deeply.

A place is a piece of the whole environment that has been claimed by feelings. Viewed simply as a life support system, the earth is an environment. Viewed as a resource that sustains our humanity, the earth is a collection of places.”

- The experience of watching the release of chum fry from a child's custodial care is enough to make a parent weep on-site. Is it a powerful experience for the child? Does it change the child's sense of place? I think it does. I'd love to have \$50K to prove it.

Partnerships

A complex partnership supports the Classroom Incubation Program.

- Stock – volunteers with support from DFO
- Materials – Grants from DFO and Pacific Salmon Foundation, contributions from schools, school districts, industry, community groups, Parent Advisory Councils and school hot dog funds.
- Support (administrative, technical) – School districts, volunteer hatcheries and DFO

- Teachers – volunteers, classroom educators, education coordinators from DFO, Wild BC and local NGO's

Results

- Over 1 million BC citizens have now been exposed to the Department's Salmonids in the Classroom Program, including activities like storm drain marking, Gently Down the Stream, classroom incubation or instruction from DFO curriculum. Probably 80% of the above exposure included classroom incubation.
- *Stream Team* – Developed from the enthusiasm that secondary students expressed for continued involvement in freshwater habitat studies and restoration activities. It is basically the Streamkeeper Program adapted for use in secondary schools. Currently, 60 students in 5 schools are now engaged in Stream Team activities in the Capital Regional District, and there is a growing Team based on the Sunshine Coast.
- I don't have \$50K to prove my point, but I have plenty of anecdotal evidence that we are making a difference. The following is a letter to Al Gould, South Coast Area Chief of Oceans and Community Stewardship:

From: BeckmannS@pac.dfo-mpo.gc.ca
Sent: Thursday, November 08, 2001 10:13 AM
To: GouldAl@pac.dfo-mpo.gc.ca
Cc: h2oship@islandnet.com
Subject: Applause from the troops

Al,

I wanted to pass on to you a discussion we had recently amongst our officers.

We had all worked in the Victoria District for many years, patrolling the local rivers from poachers and vandals in the fall.

We were all in agreement that the level of illegal fishing by juveniles had dropped substantially in the last few years. Many actually had read the fishing regulations and were not only informed about the rules but had a good understanding about salmon lifecycles and their needs for good habitat including water quality.

This new change did make an impression on us. We are certain that Don Lowen's classroom educational programs are showing its dividends as well as the work done through the Oceans and Community Stewardship Program.

The change in attitude by our youth reminds me of my favourite quote: "A mind touched by a new experience will never return to its old dimension." by Wendall Oliver Jones.

Thanks for delivering such a worthwhile program.

Stefan Beckmann
Field Supervisor
Conservation & Protection, Victoria
Ph: (250) 363 3252
Fax: (250) 363 0191

The Importance of Restoration of Chum Populations in Urban Streams

Tom Rutherford

Fisheries and Oceans Canada, P.O. Box 241, 5653 Club Rd., Duncan, B.C., V9L 3X3

Extended Abstract

Background/Introduction

As a community advisor for Fisheries and Oceans Canada, my role is to facilitate the realization of the aspirations of community partners to engage in projects that benefit freshwater and marine fish and fish habitat. These projects include a wide spectrum of initiatives including habitat assessment, habitat mapping and inventory, stock assessment, stock enhancement, and education and awareness programs. Likewise, I work with a very eclectic group of partners including volunteers, First Nations, industry, educational institutions, local governments, and non-governmental organizations. As a community advisor, I often say I don't know very much about anything. I always follow with the caveat that I know a little bit about a lot of things. One of the things that I know a little bit about is the success that local area community groups are having restoring chum populations in urban streams. More importantly, I see how these accomplishments can engage and inspire not only the people working on the projects directly, but also those living in the watershed. This type of project helps to foster a stewardship ethic and can change the way people live their lives. This talk will show how these successes are achieved, and more importantly, how they change the way that people interact with their environment and, ultimately, can change the world.

Craigflower Creek

Volunteer and community groups have re-established sustainable runs of chum salmon in several streams in the Victoria area whose original populations had been extirpated. These streams include Ganges, Tsyecum, Mancell, and Craigflower. I have chosen to talk about Craigflower Creek as it lies in the greater Victoria area, not far from where we are meeting today. The Craigflower watershed is approximately 25 square kilometres with a mainstem length of just over 6 Km. The system is fed by 5 small lakes or large ponds, depending on your perspective. Over 20,000 people live in the watershed. Land use in the lower part of the watershed is primarily residential, with linear development (roads, highways, railways), light service industries, and institutions (Victoria General Hospital, correctional institutions, etc.) The upper watershed is relatively intact with hobby farms, 10 acre zoned residential areas and some forest and parkland. The Craigflower supported a wild run of chum salmon up until the early 1950's.

The Project

Local area volunteers from Goldstream Volunteer Salmon Enhancement Association (GVSEA) and Esquimalt Anglers approached Fisheries and Oceans Canada in 1992 with aspirations to restore a sustainable run of Chum salmon in Craigflower Creek.

My approach to this type of initiative is to encourage the community partner to do a bit of “homework” before implementing such a program. The goals of this “homework” include:

- Getting a good picture of the existing habitat, fish presence/distribution, benthic invertebrate populations
- Trying to get a handle on limiting factors to fish production
- Coming up with some possible interventions to address the limiting factors
- Developing a strategy to assess the effect of the interventions

Most of this work is not rocket science and is achievable by a motivated and informed community stewardship group. The work carried out in this case included:

- A basic stream survey to identify the quantity/quality of available habitat, barriers to passage and other potential concerns
- Presence/absence sampling to identify fish species and distributions in the system
- Water quality and quantity sampling including such parameters as Dissolved Oxygen, pH, Temperature, and Turbidity
- Benthic invertebrate survey
- A search of historical records pertaining to fish populations in Craigflower creek

The Results of the Watershed Assessment Work

The work carried out by the volunteers in 1992 yielded the following results:

- Although the watercourse had been straightened and channelized in the lower reaches, there existed plenty of available spawning habitat with good substrate associated with complexed pools and cutbanks to allow for spawner cover.
- Good water quality.
- Significant % of impervious surface in lower watershed resulting in increased winter freshets and lower summer water flows. Adequate water flows to sustain population of chum salmon.
- Healthy Benthic invertebrate populations including several pollution intolerant taxa.
- BC16 records documenting chum escapements of several hundred regularly to 1951.
- Records of highway upgrading in 1951.
- A “smoking gun” – adult fish migration barrier associated with highway crossing in area of tidal influence.

Project Implementation and Results

Members of GVSEA engaged in a major boulder rolling extravaganza to construct a low tech fish access structure to allow chum salmon passage over the barrier and into the system. It should be noted that this access was further improved as part of the Vancouver Island Highway Project in 1995. The necessary work was done to obtain a stock transplant permit to use Goldstream Chum stock in the attempt to re-establish a sustainable Chum population in Craigflower Creek. (In British Columbia, and joint Federal/Provincial committee consisting of veterinarians, disease specialists, fisheries managers etc. oversees all stock transplants to ensure no negative impacts).

Volunteers took 50,000 brood 1992 Goldstream Chum eggs with close to 50,000 fed fry being outplanted into Craigflower creek in the spring of 1993. This program was repeated 8 years (2 cycles) and then the stocking program was terminated.

To assess the program, volunteers operate an adult enumeration fence and downstream juvenile trap.

In 1995 15 three year old chum salmon were counted into Craigflower creek. The majority (80%+) of Goldstream chum salmon return as four year olds, the remainder as threes and fives). This represented the first escapement of Chum salmon into the system in 44 years. The average escapement over the last 3 years has been 500 adults, roughly the same as historic levels.

Making a Difference in the Watershed

The fact that there are now chum salmon in Craigflower creek is very significant, both in terms of the ecology of the watershed and the lives of the people who live there.

With respect to the ecology of the Craigflower watershed, the effects of chum salmon are well documented. Each fall between two and three tons of biomass are injected into the Craigflower system with little or no sign of carcasses remaining a few months after spawning. This infusion of organic material, best demonstrated by chum and pink salmon is responsible for the richness of our coastal ecosystems here on the West Coast of North America. It is an almost incredible phenomenon – ridiculous numbers of large fish charging up relatively small streams and dying within a matter of a few weeks every fall. Without a doubt, the watershed is benefiting from the restoration of this annual occurrence.

But, perhaps as importantly, the returning chum salmon have affected the people who live in the watershed as well.

The one hundred and fifty or so volunteers involved in this project over the last 14 years have given the residents of the Craigflower watershed a tremendous gift – the gift of living in a watershed that supports a significant run of salmon – and this gift has been noticed.

This past fall my office received countless phone calls from concerned residents inquiring about the effects of the unusually low water on the ability of the salmon to migrate upstream. These are people who previously saw the Craigflower as an open storm drain, a nuisance, and a hindrance. These are people who are now thinking twice about their impact on the watershed in which they live.

These are people who are conserving water. People who are not pouring left over paint down storm drains. People who are using environmentally friendly cleaning products. There is even a Salmon Friendly Lawn Care program sponsored by NGO City Green that supplies signage to households that use water conservatively and no longer rely on pesticides and herbicides in their gardens.

It should also be noted that we are talking about Chum salmon here. Not furtive little cutthroat trout or elusive Coho but “in your face” big, ugly, obvious Chum salmon – it’s hard to miss them!

I would suggest to you that the fact that there are now salmon in Craigflower Creek is changing the way that people in the watershed are living their lives. I would go even further. It’s my opinion that the fact that there are chum salmon in Craigflower creek, and other urban streams like it, is changing the world.

Making a Difference Globally

Most of us attending this conference work for government agencies. As you are aware, the really big decisions about resource management and the research associated with it are not made by professionals, but by politicians. Politicians, for the most part, are driven by the desires and aspirations of their constituency.

My colleagues often ask me why I spend my time working on these little urban streams. Why don't I dedicate all my time to the larger systems in my area –the Cowichan, the San Juan, the Sooke, and the Goldstream? Although I do spend a fair amount of time working in larger watersheds, I have no problem justifying my time spent in urban watersheds – these are the watersheds that support large numbers of people as opposed to fish.

Salmon are an icon on the West Coast of North America and the presence of Salmon in an urban stream inspires and educates local residents and, more importantly, turns them into advocates. It turns them into advocates for Salmon and the habitats that support them. It turns them into advocates who are active politically on a local, regional, and national level. It turns them into advocates who voice concerns over salmon and salmon habitat in a different way and in a different forum than you can as professionals.

I would suggest to you that without an enlightened and involved public, your jobs as technical people, as managers, and as research scientists will become more and more difficult in the future, if not impossible.

Conclusion

Community Stewardship groups have the skills and resources to successfully restore salmon populations in many urban streams in British Columbia and the Pacific Northwest. As Resource Agency representatives, we should be supporting them in their aspirations to do so.

The fact that we now have Chum salmon in Craigflower creek and other urban streams is important. This importance is about more than the 500 chum that now spawn annually in the creek. It's about the people that worked so hard to restore them and the people with whom they now share the watershed.

The fact that Craigflower creek now supports a sustainable run of Chum salmon has changed the way that watershed residents live their lives and has turned them into politically active advocates for salmon and salmon habitat. This process of fostering a stewardship ethic can result in pressure through advocacy that leads to changes in the way that local and senior levels of government deal with, and fund, fisheries related issues. The work that you do as fisheries managers and research scientists is inexorably linked to the work that volunteer watershed stewards do. As community advisor, my role in the future will include forging partnerships between the two – partnerships that, I am convinced, will lead to real benefits to the resource that we all care so much about.

Pinks for the Pier

Dave Ewart

Quinsam River Hatchery, Fisheries and Oceans Canada, 4217 Argonaut Road, Campbell River, B.C., V9H 1P3

Abstract

This power point presentation will review an ongoing community project that is aimed at creating a Pink Salmon sportfishery near a popular fishing pier in Campbell River, B.C. This is a co-operative project between a community group and Fisheries and Oceans Canada (Quinsam River Hatchery). A history and purpose of the project, rearing and release strategy, results, and pro's and con's will be presented with slides and narrative.

PowerPoint Presentation (Abbreviated Version)

"PINKS FOR THE PIER"

**FISHERIES & OCEANS CANADA
QUINSAM RIVER HATCHERY**

David Ewart



HISTORY

- Pink fry rearing for a short time in ocean net-pens is a proven technique to:
 - a) *Increase survival for catch & escapement.*
 - b) *Return adults to a designated area where they were released as fry.*
- Pink rearing was done by Quinsam Hatchery throughout the 1980's with excellent results, but discontinued in the 90's due to lack of funding.

HISTORY

- Fishing pier was built in the early 80's in downtown Campbell River. Very popular fishing area for locals and tourists.



HISTORY

- Low salmon numbers and reduced fishing opportunities in the 90's affected angling success on the pier.
- Community Fisheries Committee was formed to try and resolve conflicts between recreational and commercial fishers.
- Quinsam Hatchery was asked to help in creating local recreational fishing opportunities.



PROJECT GOALS

- 1) Provide a predictable and productive Pink salmon sport fishing opportunity in the Fishing Pier area during the summer months.
- 2) Increase survival rates for Pink Salmon to maintain & improve spawning escapements to the Campbell & Quinsam Rivers.

WHY PINKS???



- Quick return (2 years).
- Short rearing duration.
- Low cost to rear large number of small fry in ocean pens.
- Adult return timing is mid-July to September - Matches most active fishing period.
- Pinks are very good “homers” to release site.

PROJECT DESCRIPTION

- First year was spring of 2000.
- Two rearing locations were chosen: Hidden Harbours & Fisherman's wharf.
- Target of 1,000,000 fry to be reared for 3 weeks and released near the fishing pier (500,000 at each site).
- Potential return of 30,000 adults (based on 3% survival).

RESULTS

- Summer of 2001 saw the first return of thousands of adult Pinks to the release area.
- Overnight, the area became a very popular fishing location for shore-based anglers.



RESULTS

- Pinks showed up in the release sites in mid-August, and moved around in the area until early September.
- Estimated that most returned to the Quinsam River, but some strayed to 2 small creeks in the local area of the pens, where they had been absent for 50 years.



PRO'S

- PRO'S: It worked! Created fishing opportunity in the target area.
- Allowed anglers of all ages, abilities, and income level to fish.
- Rejuvenated the fishing spirit in Campbell River, creating more local activity for business and more awareness of the resource.
- Community inspired, funded, and directed, in partnership with government (Fisheries & Oceans Canada, Quinsam Hatchery).

CON'S

- Fish returned too well; Homed in to the Harbour area where the pens had been located.
- Problems with anglers and boat owners.
- Large number of anglers with some unethical fishing practices which caused enforcement issues.



- Some public perception that fish did not return to river to spawn.

CURRENT STATUS

- With continued community support, the project has continued annually, (2003 will be the 4th year).
- Returns during the summer of 2002 were good, and Pink catch at the fishing pier was excellent. Not as many returns into the Harbour because of very dry summer.
- Harbour authority has supported project by building cleaning tables, installed signage, and hired summer students to monitor the fishing activity in the area to reduce conflicts.

The Restoration of Douglas Creek

Robert Bridgeman

Friends of Mount Douglas Park Society, Victoria, B.C.

Extended Abstract

Our Organization / Our Watershed

- **FOMDPS**

The Friends of Mount Douglas Park Society was formed as a registered non-profit Society 14 years ago. The Society promotes the conservation of the natural environment in Mount Douglas Park for the education and pleasure of the public.

- **Douglas Creek**

Douglas Creek is an urban stream that flows through Mount Douglas Park. Formerly an order two stream Douglas creek is now reduced to an order one 1.1-kilometer long stream that flows through a mixed deciduous/coniferous coastal Douglas-fir riparian ecosystem. As a project the society is restoring the Creek to a natural functioning state.

For us that means a Creek that supports self sustaining stocks of salmonids—coho and chum.

Five thousand people live on the 5.2 km², 34% total impervious area, Douglas Creek watershed.

The Restoration of Douglas Creek

- **Streamkeepers**

The Streamkeepers Program was developed in response to the concerns of many volunteers working on stream enhancement projects. The objectives of the Streamkeepers Program are:

- To provide volunteers with the training and support required to protect and to restore local aquatic habitats.
- To educate the public about the importance of watershed resources.
- To encourage communication and cooperation in watershed management.

To begin to understand the complex aquatic issues two members of the Society took the Streamkeeper's training and completed the practicum in 1995.

- **Mapping**

As part of the initial assessment of the Creek we completed a detailed map of the channel including features from the right bank, left bank and the substrate. Benchmarks were created at convenient locations.

- **Water Quality**

We sampled three water quality stations (upper, mid and lower) for four parameters (dissolved oxygen, temperature, pH and turbidity) once per week over the course of one year. We used Streamkeepers protocols. According to what we saw the Creek had outstanding water quality.

- Invertebrate/vertebrate assessment

Using Streamkeeper's protocol we have completed several benthic invertebrate assessments. Students from local colleges and universities have also conducted benthic invertebrate assessments using several protocols. Combined results document a population composed of predominantly pollution tolerant taxa.

So the long-term indicators showed water quality problems.

To assess vertebrate populations we have both g-trapped and electroshocked.

- Hydrology

We have created a registered hydrometric station on the creek. A certified Hydrometric Technician has created a stage discharge table and a hydrograph from the collected data.

- Habitat Restoration

We have worked with the federal Department of Fisheries and Oceans, the provincial Ministry of Land, Air and Water Protection, and the municipal District of Saanich to see large woody debris introduced into the creek as habitat complexes.

- Salmon

Initial assessments proved that salmonids had been extirpated from the system.

However, habitat conditions seemed surprisingly good when we considered the urban watershed that set the stage for conditions in the Creek.

Salmon in Douglas Creek Again

- How....

Initially a fisheries challenge was carried out. The coho fry survived 48 hours in the Creek.

Over the course of several years we have transplanted coho fry into the creek. We started with fall transplants and then transplanted in the spring. Finally we transplanted eyed eggs. The different life stage transplants were used to probe for bottlenecks to fish production. Fry were stocked at densities of less than $1/M^2$.

In the spring of 2002 we transplanted 20,000 chum fry into the Creek. We penned them in the creek for 48 hours and then allowed them to migrate downstream into Cordova Bay.

Both the chum and coho came to us from the volunteers at the Howard English hatchery on the adjacent Goldstream river system.

The Community Advisor For Salmon Enhancement for Southern Vancouver Island, Tom Rutherford, did the work to get the fry transplant permits in place. He also brought us the brilliant strategy of probing a stream ecosystem for limiting factors by transplanting salmonids at different life stages. An excellent restoration tool.

- Monitoring

We carry out gee trapping throughout the year and visually monitor.

- Results

Gee trapping has shown time and again that members of an age class increase in size while decreasing in number through time.

Trapping is not a reliable indicator of numbers of fry in the Creek.

We have numbers of fry killed during summer spates especially after long dry periods.

We lost very few chum fry after the 2002 transplant.

- A Natural System....

There are few if any unimpacted streams or watersheds of any size on southern Vancouver Island. We have tried to piece together a healthy stream paradigm from advice given by local experts and by a search of the literature.

Since the Society and our Community partners have limited resources we are committed to restoration by returning the missing natural system components that are accessible, from time to time, to community groups.

An Innovative Approach

- Putting the Pieces Back...

Watershed conditions control downstream biotic response. Modifying conditions on an urban watershed is a long-term proposition.

However, there is a body of work that can be done in the short term to prepare for changing conditions at the watershed scale. This body of work consists, in part, of returning missing ecosystem components.

- Marine Derived Nutrients...

There is a growing body of research that documents the decline of the input of marine derived nutrients into aquatic systems in the Pacific Northwest.

A portion of this literature documents the importance of these nutrients in the development and maintenance of stream health.

Chum Carcasses for Douglas Creek

- Regulatory Hurdles

There are very strict regulations for transplanting live fry from one system to another. These same regulations apply to transplanting carcasses. The Community Advisor worked through the regulatory process for eighteen months to allow the chum carcass transplant to go forward.

This is a transplant of carcasses from one system to another.

- How Many?

Fisheries and Oceans Canada specifies 100 as the optimum number of carcasses per kilometer of stream for healthy streams. This number depends on species and several other variables related to stream health.

- Source?

The Howard English Hatchery provided 100 chum carcasses in the 5 to 6 kilogram range. The carcasses were the result of an egg take for the hatchery. These were fresh, one day dead, unfrozen carcasses.

- Handling and Transport

The hatchery volunteers placed the carcasses in untreated burlap bags—two to a bag. The community advisor delivered the carcasses to the site.

- Methods of Placement

About one third of the fish were left inside the untreated burlap bags. These were pushed into woody debris jams or put under large cobble.

Two thirds of the fish were put singly under large cobble, jammed under woody debris, or tied through the gills to stable woody debris piles.

- Results....

The carcasses did not migrate downstream during spates as was expected.

Some carcasses were pulled up on the streambank and eaten by animals (possibly raccoons).

Some carcasses were washed up on the streambanks and stranded during spates.

The carcasses were introduced November 24, 2002. By January 18th 2003 virtually all traces of the carcasses were gone: (7 to 8 weeks).

Challenges....

- Monitoring the Effects

It may ultimately prove very difficult to tease the direct effects of transplanted carcasses out of the overall effects of dubious water quality and an unnatural hydrologic regime.

- Financial Constraints

The restoration is run on \$600.00 a year cash, donated staff time by agency professionals, and time given by volunteers. There is no budget to analyze samples for nitrogen and phosphorous and carbon.

- Existing Baseline Data

We have baseline data showing the community of benthic invertebrate taxons in the Creek excepting winter months.

- Partnerships

Through our community partners we recently have had the good fortune to have four students from Royal Roads University undertake an 8-month major project to sample and analyze aquatic invertebrates in Douglas Creek

- Benthic Invertebrate Response

We are interested in seeing if transplanted carcasses can shift the aquatic invertebrate community to something that looks like communities found in healthy streams.

We would also like a way to monitor the effects of changes on the watershed.

Why Bother??

- It's Not Just The Fish

Mount Douglas Park is a 200 hectare fragment of a landscape that was typical of southern Vancouver Island pre development. As such it is a living piece of what was. It is important for us, as local residents who have made the commitment to see that place preserved in its natural state, to see that ecosystems inside the park can be sustained into the future.

- Making A Difference On A Local Level

As citizens living and working in the neighborhood how can we buck the global trend to marginalized natural systems? What can we do to ensure that these remaining fragments can function as natural systems?

- Community Empowerment

We can begin by taking responsibility for our own actions.

We need to be vocal about our commitments to our neighborhoods and to the watersheds we live on.

We can stop the marginalization of ecosystems and promote the restoration ecology that must take place to roll back the clock; we can mitigate the poor judgment and the abuses.

We can **demonstrate** that we can live in healthy functioning natural ecosystems.

We can impact landscape scale land use decisions.

We can make a difference by empowering our community and our watershed.

The Pink Salmon Festival – Take a Kid Fishing

Laurie McBride

Victoria, B.C.

Note: Mr. McBride was not able to present at the workshop but provided this abstract.

Abstract Only

This event runs biennially and is organized and hosted by local area volunteers from a variety of backgrounds and occupations. It provides an opportunity for the sport fishing community to introduce children and parents to the joys of sport fishing and provide some exposure to the marine environment and stewardship ethics. An all volunteer event, in 2001, 40 boat owner/guides were involved, providing 75 children the opportunity to spend a half day on the water. Over 200 children, families and volunteers enjoyed food and prizes following the fishing experience. In 2003 plans are to recruit 100 volunteer boat owner guide hosts to allow us to introduce 200 children and parents to the joy of fishing for pink salmon. By introducing our youth to sport fishing we are helping to create another generation of stewards who will be aware of issues involving salmon and salmon habitat and act as advocates for this important resource. The volunteers involved in this event have found that the personal satisfaction associated with its organization and implementation is tremendous and the long-term benefits to the participants and the salmon resource will likely be very significant.

Session 6

Session Leader: Jim Shaklee (WDFW)

Genetic Applications to Fisheries Management

Origin of Juvenile Chum Salmon From Gulf of Alaska Coastal Waters, 2000 and 2001

Christine M. Kondzela, Edward V. Farley, Jr., and Richard L. Wilmot

*U.S. Dept. of Commerce, NOAA, NMFS, Alaska Fisheries Science Center, Auke Bay Laboratory,
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Abstract

Summer surveys (July–August) of juvenile salmon ecology along the continental shelf of the Gulf of Alaska are conducted annually by scientists from the Ocean Carrying Capacity program of the National Marine Fisheries Service's Auke Bay Laboratory. These surveys are an effort to link changes in salmon production to biological and physical factors in the ocean environment. An improved understanding of salmon distribution is one objective of this research. We identified the origin of juvenile chum salmon collected in transects from around the Gulf of Alaska in 2000 and 2001, using the presence of thermal marks in hatchery fish and the divergence of genetic characteristics among regional groups of populations. In both years, 36% of the juvenile chum salmon caught during the survey had been thermal marked from three Alaskan hatcheries, the Macaulay and Hidden Falls facilities in Southeast Alaska, and the Wally Noerenberg facility in Prince William Sound. By transect, the proportion of thermal-marked fish ranged from 0 to 85%. The majority of thermal-marked fish were captured just beyond the nearest coastal exit corridor; few thermal-marked fish were recovered from Shelikof Strait or south of Kodiak Island. Identification analyses based on genetic characteristics revealed similar regional estimates across the Gulf of Alaska between the two years. Overall, the contribution of southern North American populations was low; significant, but limited contribution was only found in the transects off the Kenai Peninsula. The contribution of Southeast Alaska–northern British Columbia populations was greatest in collections east of Prince William Sound, and the Prince William Sound contribution was concentrated just west of Prince William Sound. Fish from northern Cook Inlet (Susitna and Yentna rivers), and the Alaska Peninsula–Kodiak Island regions made up a large proportion of fish caught in the Shelikof Strait transects. These results provide the most detailed view yet on the distribution of juvenile chum salmon migrating through this coastal corridor.

Introduction

Migration models for juvenile chum salmon (*Oncorhynchus keta*) in the Gulf of Alaska, developed from previous, limited surveys and tagging, indicate a counter-clockwise movement pattern along the continental shelf (Hartt and Dell 1986). Little is known about many of the specific aspects of this migration such as migration rates, abundance and distribution of specific stock-groupings along this corridor, and movement from coastal to offshore waters.

Summer surveys of juvenile salmon ecology along the continental shelf of the Gulf of Alaska are

conducted annually by the Ocean Carrying Capacity program, part of the National Marine Fisheries Service's Auke Bay Laboratory. These surveys are an effort to link changes in salmon production to biological and physical factors in the ocean environment. An improved understanding of salmon distribution and migration is one objective of this research. We identified the origin of juvenile chum salmon collected in transects from around the Gulf of Alaska in 2000 and 2001, using the presence of thermal marks in hatchery fish and analysis of genetic characters that exhibit regional geographic divergence.

Methods

Juvenile chum salmon were collected in Gulf of Alaska coastal waters using a midwater rope trawl towed 3.5–5 knots at the surface for 30 minutes by the chartered F/V *Great Pacific* between 11–17 August 2000, and between 17 July and 6 August 2001 (for details, see Farley et al. 2000, 2001). In 2000, sampling occurred at 31 stations along five transects that extended perpendicularly from nearshore sites, across the continental shelf to oceanic waters between the Kenai Peninsula and Kodiak Island. In 2001, sampling occurred in a larger geographic area at 75 stations along 11 transects between northern Southeast Alaska and Kodiak Island (Figure 1). Whole juvenile chum salmon were stored in ultra-cold freezers onboard and then shipped to the Auke Bay Laboratory for processing.

Otoliths were extracted and analyzed by the Alaska Department of Fish and Game's Mark, Tag and Age Laboratory in Juneau, Alaska (Farley and Munk 1997). Otoliths with thermal marks were compared with voucher specimens to identify hatchery of origin. Heart, liver, muscle, and eye tissues were extracted and then analyzed with protein electrophoresis to identify genotypes for 20 allozyme loci (Kondzela et al. 1994). Regional origin estimates were made for each mixture collection using a Bayesian method of mixture analysis (Pella and Masuda 2001). The total dataset for each year was analyzed with the full 356–population genetic baseline for chum salmon (Kondzela et al. 2002) to estimate Asian and North American proportions. A reduced baseline with 238 North American populations, from the Alaska Peninsula to Washington, was used for subsequent analysis of each transect collection or pooled collections.

Results

In both 2000 and 2001, 36% of the juvenile chum salmon examined (280 of 777 fish in 2000, and 377 of 1039 fish in 2001) were thermal marked at one of three Alaskan hatcheries, the Wally Noerenberg Hatchery in western Prince William Sound (PWS), and the Macaulay Hatchery and the Hidden Falls Hatchery in Southeast Alaska (Tables 1 and 2). The fraction of thermal-marked fish in each collection ranged from 0–85%. The majority of thermal-marked fish were captured just beyond the nearest coastal exit corridor; few thermal-marked fish were recovered from Shelikof Strait or south of Kodiak Island. The highest concentration of thermal-marked fish (primarily Wally Noerenberg fish) occurred in the collections just beyond the western exit corridor of PWS. In 2001, most of the juvenile chum salmon from Southeast Alaska hatcheries were caught east of PWS. The distribution of Macaulay Hatchery fish extended farther west than that of Hidden Falls Hatchery fish.

Regional estimates of origin for each collection or group of collections, using six North American regions, are provided in Tables 3 and 4. Identification analyses based on genetic characters revealed similar regional estimates across the Gulf of Alaska between the two years. Overall, the contribution of southern North American populations was low. Significant, but limited contribution from the Washington and southern British Columbia region was only found in the transects off the Kenai Peninsula—this region comprised 18% of the fish from Gore Point in 2000 and 20% of the very small collection from Cape Cleare in 2001. Queen Charlotte Island populations are genetically distinct from

nearby populations in Southeast Alaska and northern British Columbia (Kondzela et al. 1994). The highest contribution from this region, 11%, occurred in the Yakutaga–Cape St. Elias collection in 2001, but was statistically insignificant, probably due to the small collection size. The contribution of Southeast Alaska and northern British Columbia populations was greatest in collections east of PWS (2001 only); in 2000 the only significant contribution from the Southeast Alaska and northern British Columbia region occurred in the Seward Line collection, the easternmost transect surveyed that year. Fish from the PWS region were concentrated on the Seward Line and Gore Point transects, with lesser contributions in the small Cape Chiniak and Cape Cleare collections in 2000 and 2001, respectively. The genetically distinct Susitna and Yentna river populations in northern Cook Inlet, and in the Alaska Peninsula–Kodiak Island region made up a large proportion of fish caught in the Shelikof Strait transects. Few fish were caught in the transects on the south side of Kodiak Island—more than 80% of the juvenile chum salmon recovered from the small collection at Cape Chiniak in 2000 were estimated to be from the Alaska Peninsula–Kodiak Island region.

Discussion

Our results present the most detailed view yet on the distribution of juvenile chum salmon migrating through the Gulf of Alaska coastal corridor. Genetic and thermal mark analyses used to identify the origin of juvenile chum salmon provided congruous results that were similar between years. The distribution of thermal-marked fish and estimates of regional origin from genetic analyses indicated that most of the fish had migrated just beyond nearby coastal exit corridors. As observed in previous surveys (1996–98), juvenile chum salmon preferentially migrated through Shelikof Strait rather than south of Kodiak Island in the Alaskan Stream. Fish from all four Alaskan regions were detected in Shelikof Strait from either genetic or thermal mark information. However, most of the fish were caught early in their coastal oceanic migration, and it is unknown whether the majority of fish from PWS and eastward enter oceanic water before reaching Kodiak Island, seaward of Kodiak Island, or after a southwestward transit through Shelikof Strait. Surveys in late summer/early fall might resolve this question.

Some of the fish assigned to the Macaulay Hatchery in 2001 may actually be from the Nitinat River Hatchery on southwestern Vancouver Island, British Columbia; chum salmon released from these two facilities shared the same otolith mark patterns (Peter Hagen, ADF&G personal communication). Juvenile chum salmon from the Nitinat River Hatchery have been recovered in past surveys from transects along Southeast Alaska and as far north and west as northern Shelikof Strait (Farley and Munk 1997; Farley et al. 1999). Their presence in previous surveys supports the concept that at least some of the more southern populations of chum salmon migrate to sea early in the summer, mix with later migrating northern populations, and extensively migrate around the coastal continental shelf corridor to the northern Gulf of Alaska by mid-to-late summer.

Estimates of regional origin using the Bayesian method were very similar to those calculated using a conditional-maximum likelihood (CML) method (and a slightly different version of the baseline) (Kondzela and Wilmot 2002). The primary difference in the results of the two methods typically was lower estimates for regions of small or zero contribution and higher estimates for regions with large contribution by the Bayesian method.

The results of our identification analyses will eventually be used in conjunction with oceanographic information, and growth and diet data to more fully understand the factors that affect distribution, abundance, and survival of chum salmon in the Gulf of Alaska.

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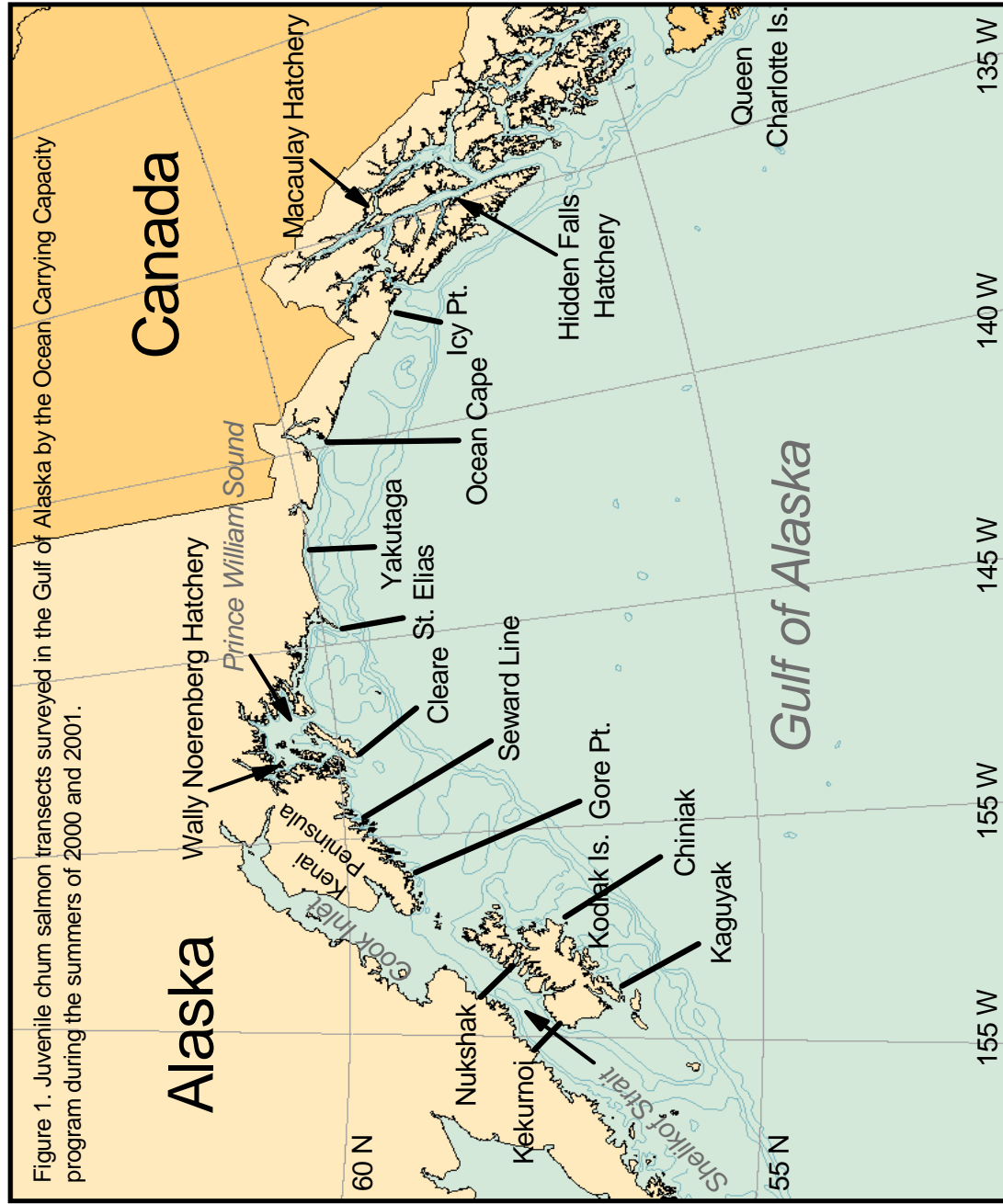


Table 1. Number of thermal-marked hatchery and unmarked (hatchery and wild) juvenile chum salmon collected in August 2000 in the Gulf of Alaska. Release sites are given under hatchery names. N/A = fish released were not thermal marked

Location	Date	Macaulay Hatchery				Hidden Falls Hatchery			Wally Noerenberg Hatchery						
		Limestone	Macaulay	Amalga	Boat Harbor	Total	Hidden	Takatuz	Deep Inlet	Total	Wally N.	Port Chalmers	Total	Unmarked	Total
West of Prince William Sound															
Seward Line	Aug 12	1	6	11	0	18	0	N/A	0	0	78	11	89	66	173
Gore Point	Aug 13-14	0	0	2	0	2	1	N/A	0	1	135	20	155	129	287
Shelikof Strait															
Cape Nukshak	Aug 16	0	0	0	0	0	0	N/A	0	0	2	4	6	148	154
Cape Kekumoi	Aug 16-17	0	0	0	1	1	0	N/A	0	0	4	1	5	113	119
South of Kodiak Island															
Cape Chiniak	Aug 15	0	0	0	0	0	0	N/A	0	0	1	2	3	41	44
Total		1	6	13	1	21	1		0	1	220	38	258	497	777

Table 2. Number of thermal-marked hatchery and unmarked (hatchery and wild) juvenile chum salmon collected in July--August 2001 in the Gulf of Alaska. Release sites are given under hatchery names.

Location	Date	Macaulay Hatchery				Total	Hidden Falls Hatchery			Wally Noerenberg Hatchery					
		Limestone	Macaulay	Amalga	Boat Harbor		Hidden	Takatuz	Deep Inlet	Wally N.	Port Chalmers	Total	Unmarked	Total	
East of Prince William Sound															
Icy Point	Jul 17	4	3	9	7	23	12	19	7	38	0	1	1	110	172
Ocean Cape	Jul 18-19	1	4	21	6	32	2	4	12	18	0	0	0	85	135
Cape Yakutaga	Jul 22	0	5	11	3	19	1	0	1	2	0	0	0	17	38
Cape St. Elias	Jul 23	0	1	8	4	13	0	0	1	1	2	0	2	7	23
West of Prince William Sound															
Cape Cleare	Jul 24	0	9	16	8	33	0	0	0	0	14	4	18	9	60
Seward Line	Jul 25-27	1	9	9	4	23	0	0	0	0	81	11	92	28	143
Gore Point	Jul 29-31	0	0	1	0	1	0	0	0	0	50	6	56	15	72
Shelikof Strait															
Cape Nukshak	Aug 3	0	0	0	0	0	0	0	0	0	5	0	5	281	286
Cape Kekumoi	Aug 4	0	0	0	0	0	0	0	0	0	0	0	0	104	104
South of Kodiak Island															
Cape Chiniak	Aug 1-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cape Kaguyak	Aug 5-6	0	0	0	0	0	0	0	0	0	0	0	0	6	6
Total		6	31	75	32	144	15	23	21	59	152	22	174	662	1039

Table 3. Regional estimates (mean \pm one std. deviation) of juvenile chum caught August 2000 in the Gulf of Alaska using a Bayesian method. Below each point estimate is the 95% probability interval for the true estimate. Estimates significantly greater than zero are in bold font.

Mixture Sample	N	Regional Allocation					
		AK Peninsula/Kodiak Is.	Susitna	Prince William Sound	SE Alaska/N. BC	Queen Charlotte Is.	Washington/S. BC
West of Prince William Sound							
Seward Line	178	0.023 ± 0.034 (0 - 0.122)	0 ± 0.001 (0)	0.703 ± 0.091 (0.523 - 0.873)	0.239 ± 0.094 (0.056 - 0.423)	0.002 ± 0.009 (0 - 0.028)	0.033 ± 0.036 (0 - 0.128)
Gore Point	295	0.099 ± 0.023 (0.059 - 0.150)	0 (0)	0.700 ± 0.046 (0.606 - 0.785)	0.017 ± 0.026 (0 - 0.093)	0.003 ± 0.008 (0 - 0.026)	0.181 ± 0.040 (0.108 - 0.264)
Seward/Gore Pt. combined	473	0.072 ± 0.021 (0.039 - 0.122)	0 (0)	0.700 ± 0.051 (0.597 - 0.796)	0.099 ± 0.057 (0.001 - 0.217)	0.002 ± 0.006 (0 - 0.020)	0.128 ± 0.036 (0.063 - 0.201)
Shelikof Strait							
Nukshak	163	0.308 ± 0.072 (0.124 - 0.429)	0.640 ± 0.051 (0.538 - 0.735)	0.001 ± 0.006 (0 - 0.012)	0.030 ± 0.057 (0 - 0.225)	0.004 ± 0.014 (0 - 0.042)	0.018 ± 0.019 (0 - 0.067)
Kekurnoi	125	0.488 ± 0.087 (0.316 - 0.654)	0.392 ± 0.058 (0.280 - 0.505)	0.022 ± 0.042 (0 - 0.143)	0.073 ± 0.072 (0 - 0.236)	0.011 ± 0.032 (0 - 0.121)	0.014 ± 0.018 (0 - 0.065)
Nukshak/Kekurnoi combined	288	0.403 ± 0.053 (0.295 - 0.502)	0.531 ± 0.039 (0.454 - 0.607)	0.018 ± 0.028 (0 - 0.090)	0.029 ± 0.036 (0 - 0.125)	0.003 ± 0.012 (0 - 0.039)	0.016 ± 0.016 (0 - 0.055)
South of Kodiak Island							
Chiniak	46	0.821 ± 0.061 (0.689 - 0.924)	0 ± 0.002 (0 - 0.001)	0.139 ± 0.059 (0.035 - 0.267)	0.017 ± 0.028 (0 - 0.099)	0.007 ± 0.025 (0 - 0.080)	0.016 ± 0.024 (0 - 0.084)

Table 4. Regional estimates (mean \pm one std. deviation) of juvenile chum caught July--August 2001 in the Gulf of Alaska using a Bayesian method. Below each point estimate is the 95% probability interval for the true estimate. Estimates significantly greater than zero are in bold font.

Mixture Sample	Regional Allocation					
	N	AK Peninsula/Kodiak Is.	Susitna	Prince William Sound	SE Alaska/N. BC	Queen Charlotte Is.
East of Prince William Sound						
Icy Point	180	0.028 ± 0.063 (0 - 0.238)	0 ± 0.001 (0)	0.004 ± 0.018 (0 - 0.057)	0.941 ± 0.072 (0.730 - 1)	0.004 ± 0.016 (0 - 0.053)
Ocean Cape	136	0.131 ± 0.157 (0 - 0.489)	0 ± 0.003 (0 - 0.001)	0.007 ± 0.027 (0 - 0.098)	0.815 ± 0.166 (0.450 - 0.999)	0.033 ± 0.060 (0 - 0.203)
Icy/Ocean combined	316	0.028 (0 - 0.223)	0 (0)	0.023 (0 - 0.169)	0.931 (0.731 - 1)	0.007 (0 - 0.068)
Yakutaga/Cape St. Elias combined	64	0.028 ± 0.057 (0 - 0.204)	0 ± 0.002 (0 - 0.001)	0.002 ± 0.011 (0 - 0.018)	0.759 ± 0.176 (0.364 - 0.996)	0.113 ± 0.147 (0 - 0.473)
Icy/Ocean/Yakutaga/St. Elias combined	380	0.025 ± 0.054 (0 - 0.200)	0 (0)	0.013 ± 0.035 (0 - 0.130)	0.920 ± 0.079 (0.717 - 0.999)	0.026 ± 0.045 (0 - 0.152)
West of Prince William Sound						
Cape Cleare	61	0.027 ± .061 (0 - 0.225)	0 ± 0.002 (0 - 0.001)	0.342 ± 0.107 (0.149 - 0.564)	0.410 ± 0.161 (0.067 - 0.710)	0.021 ± 0.053 (0 - 0.187)
Seward Line	144	0.051 ± 0.056 (0 - 0.179)	0 ± 0.002 (0 - 0.001)	0.800 ± 0.063 (0.666 - 0.909)	0.118 ± 0.087 (0 - 0.293)	0.003 ± 0.014 (0 - 0.043)
Gore Point	75	0.050 ± 0.060 (0 - 0.204)	0.003 ± 0.015 (0 - 0.204)	0.794 ± 0.074 (0.639 - 0.925)	0.102 ± 0.078 (0 - 0.273)	0.005 ± 0.016 (0 - 0.057)
Cleare/Seward/Gore Pt. combined	280	0.018 ± 0.033 (0 - 0.119)	0 ± 0.001 (0 - 0.001)	0.705 ± 0.049 (0.607 - 0.797)	0.192 ± 0.066 (0.048 - 0.315)	0.021 ± 0.033 (0 - 0.112)
Shellkof Strait						
Nukshak	317	0.515 ± 0.083 (0.264 - 0.625)	0.432 ± 0.039 (0.356 - 0.507)	0.005 ± 0.014 (0 - 0.049)	0.040 ± 0.069 (0 - 0.270)	0.001 ± 0.005 (0 - 0.012)
Kekurnoi	87	0.749 ± 0.146 (0.373 - 0.969)	0.001 ± 0.004 (0 - 0.002)	0.011 ± 0.037 (0 - 0.146)	0.150 ± 0.156 (0 - 0.551)	0.069 ± 0.087 (0 - 0.288)
Nukshak/Kekurnoi combined	404	0.554 ± 0.074 (0.407 - 0.684)	0.341 ± 0.033 (0.277 - 0.407)	0.003 ± 0.012 (0 - 0.043)	0.087 ± 0.068 (0 - 0.229)	0.006 ± 0.016 (0 - 0.056)

Toward a Coast-Wide Baseline for Chum Salmon

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Abstract

Recently we have started building a coast-wide chum salmon baseline using 15 microsatellite DNA markers. At present this baseline consists of 5,000 individuals from ~60 populations from Japan to southern British Columbia (including the Peel River, Mackenzie Drainage). Two mixture analysis examples, Yukon River chum and east coast of Vancouver Island chum illustrate the utility of the present baseline. In contrast, the sockeye and chinook salmon microsatellite/MHC baselines are much more extensive, both with >40,000 fish and ~300 populations covering the geographic range of these species. The sockeye and chinook salmon baselines allow us to accurately estimate stock compositions from SE Alaska to Washington State. Using a Bayesian cluster analysis, we compared the level of discrimination displayed by chum populations with that of sockeye and chinook, and noted that there may be less genetic differentiation among chum salmon populations compared with chinook and sockeye salmon.

Introduction

Historically, allozyme data have been used to determine stock composition in commercial fisheries and stock structure for chum salmon populations in southern British Columbia (Beacham et al. 1985, Beacham et al. 1987). Coast-wide microsatellite DNA baselines are becoming more useful to fisheries managers by providing increased accuracy and precision of stock composition estimates in mixed stock fisheries analysis (MSA) combined with reduced cost of sampling and ease of tissue collection. Extensive baselines now exist for sockeye, chinook, and coho salmon where each species has baselines consisting of >40,000 individuals from between 250-350 populations, making it possible to estimate stock compositions from SE Alaska to Washington State. The chum salmon baseline is still much smaller, consisting of only ~5000 individuals from 60 populations (Table 1).

In this paper we outline the current extent of the chum salmon microsatellite baseline. We look at two specific examples where this baseline has been used for MSA, and compare the discriminant ability of the present suite of loci for chum salmon with those used for chinook and sockeye.

Methods

Genetic Sampling

A total of 57 baseline populations consisting of ~5000 individuals has been analyzed for 15 microsatellite markers. The selectively neutral microsatellite markers chosen for chum salmon are *Oke3*, *Oki100*, *Oki2*, *One101*, *One102*, *One104*, *One106*, *One108*, *One109*, *One111*, *One114*, *Ots103*, *Ots3*, *Otag68*, and *Ssa419*. Potentially many markers are available, but these markers show variability between populations, are easier to amplify and size, provide genotypic frequencies in Hardy-Weinberg

equilibrium, and form multiplexing suites. The methods used for DNA extraction, PCR reaction, electrophoresis, and allele scoring are outlined in Beacham et al. (2003). A summary of the DNA processing-analysis at the Pacific Biological Station can be seen in Figure 1. Mixture samples of 100 fish each were collected from the 1998-1999 test chum salmon seine fishery. One sample was collected in 1998 from DFO Statistical Area 19-8 and in 1999 two samples were collected from DFO Statistical Area 19-8 and 19-11. These chum salmon were assumed to be of Cowichan River or Goldstream River origin.

Analysis

Population genetic structure was analyzed using chord distance (Cavalli-Sforza and Edwards 1967) and neighbour-joining phenograms (Felsenstein 1993). Mixed stock analysis from fisheries were analyzed using the maximum likelihood estimation (MLE) method. The Statistical Package for the Analysis of Mixtures software program (SPAM) (Debevec et al. 2000) was used to determine stock composition of the mixture samples. SPAM uses the expectation-maximization and convergent-gradient algorithms for MLE procedures (Pella et al. 1996). Each baseline population and fishery sample was sampled with replacement in order to simulate the random variation involved in the collection of baseline and fisheries samples. To test the capability of the baseline to correctly estimate a population, we used SPAM in simulation mode where assignment of mixture was determined for a mixture containing 100% of a population. Yukon chum data was analyzed with GSI Sim (beta version, Steve Kalinowski, skalinowski@montana.edu) using Rannala and Mountain adjustment for small sample size. For cluster analysis comparing different species, we used a Bayesian model which employs multilocus genotypes to assign probabilities to individuals belonging to the inferred populations (Pritchard et al 2000). To test the discriminant power of the loci, we chose three populations for each species from SE Alaska/Yukon, Central Coast, and Vancouver Island. Multilocus genotypes were screened to include only those individuals with greater than 10 loci present.

Results and Discussion

Stock structure

The phenogram shows clustering of populations, indicating regional groupings (Figure 2). The regional grouping of populations in the dendrogram is indicative of the regional differentiation of allelic frequencies. Populations closer together geographically tend to be more similar genetically, reflective of an “isolation by distance” distribution of genetic variation. Allozyme data show similar stock groupings to microsatellite data, however not all of the stock groupings determined by the allozyme data come from geographically proximate populations (Beacham et al. 1987). Less discrete geographically based clustering of populations with the allozyme data will lead to poorer MSA estimates compared to those generated with the microsatellite data.

Mixture Applications

Cowichan/Goldstream Chum

Although Cowichan and Goldstream group together on the dendrogram (Figure 2.), simulations of the Cowichan-Goldstream baseline indicate that sufficient genetic separation occurs between the two populations to be useful in MSA. A mixture of 100% Goldstream will estimate 96.1% Goldstream and a mixture of 100% Cowichan will estimate 94.2% Cowichan (Table 2). Simulated estimates of over 90% assuming 100% true should provide reasonable estimates of stock composition in mixed stock fisheries. Estimates of stock composition indicate that the Area19-11 sample has a higher proportion of Goldstream than the other two samples which were taken farther away from the Goldstream

River in Satellite Channel (Area19-8, Figure 3). Comparison between the 1998 and 1999 stock compositions indicate the stock composition between the two years is quite similar.

Yukon River chums

Variation in microsatellite loci have been surveyed for 11 populations in the Yukon River drainage (Figure 4). Scribner et al. (1998) reported that Yukon chum populations from the U.S. – Canada border regions were not clearly distinguishable based on a combination of allozyme, microsatellite, and mtDNA loci. Although some microsatellite loci with fewer alleles may provide equivalent discriminant power to allozymes (Scribner et al. 2002), highly polymorphic loci provide higher levels of precision and accuracy in the estimate of stock compositions (Beacham et al. 1998). Simulations would suggest that our suite of multilocus allele frequencies should be able to provide reasonable resolution of these border region populations (Table 3).

Comparison among species

Inferred population structure determined by the Bayesian cluster approach correctly assigned the highest probabilities of most individuals to the three population groups for all three species (Figure 5). Most scattering of individual assignment occurred between Vancouver Island and Central Coast for the chum salmon populations. Mean F_{st} values were calculated for each inferred cluster (Table 4). Overall, highest F_{st} values occurred for the sockeye populations and lowest F_{st} values occurred for the chum salmon populations with the clustering of the chinook populations intermediate. These results are dependent on the populations chosen for this analysis but this may indicate that the discriminant power for chum salmon may be less than the other two species.

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Tables

Table 1. Summary statistics for Pacific Salmon DNA baselines at the Pacific Biological Station.

Species	#loci	#populations	#individuals	Geographic range
Sockeye	14msats/2MHC	250	42,222	Japan-Columbia R
Chinook	13 msats	298	41,689	Russia-California
Coho	13msats/2MHC	321	40,786	Russia-California
Chum	15 msats	57	4,331	Japan-South B.C.

Table 2. Simulated (standard deviation in brackets) stock compositions for 150 Goldstream and Cowichan chum salmon. True values for simulations in bold. Applications to actual fishery samples are listed for Area 19-8 and 19-11.

Population	Simulations									Estimations					
										Area19-8		Area19-8		Area19-11	
										1998		1999		1999	
N	150			150			150			86		92		98	
Cowichan	100	94.2	(4.3)	50	49.3	(6.8)	0	3.9	(3.6)	22.7	(18.5)	20.1	(14.8)	3.6	(9.7)
Goldstream	0	5.8	(4.3)	50	50.7	(6.8)	100	96.1	(3.6)	77.3	(18.5)	79.9	(14.8)	96.4	(9.7)

Table 3. Simulations (values for True, Estimated, and Standard Deviations) for 100% by population for Yukon River chum salmon for simulated mixtures of 150 chum salmon from each population using Rannala and Mountain correction for small sample size.

	TRUE	Est	SD	TRU	Est	SD	T	Est	SD	T	Est	SD	T	Est	SD	T	Est	SD	T	Est	SD	T	Est	SD	T								
Tachun	100	81.3	(5.3)	0	0.0	(0.1)	0	0.2	(0.4)	0	0.3	(0.5)	0	0.3	(0.5)	0	0.0	(0.1)	0	0.1	(0.2)	0	1.4	(1.2)	0	0.4	(0.5)	0	2.1	(1.5)	0	0.2	(0.3)
Kluane	0	0.2	(0.4)	100	99.4	(0.7)	0	0.1	(0.2)	0	0.0	(0.1)	0	0.1	(0.3)	0	0.3	(0.5)	0	0.3	(0.4)	0	0.3	(0.4)	0	0.0	(0.0)	0	0.1	(0.2)	0	0.0	(0.1)
Andreafsky	0	0.1	(0.2)	0	0.0	(0.0)	100	97.8	(1.3)	0	0.1	(0.2)	0	0.0	(0.1)	0	0.0	(0.0)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.1	(0.2)	0	0.1	(0.1)
Sheenjek	0	0.6	(0.7)	0	0.0	(0.1)	0	0.4	(0.5)	0	0.4	(0.5)	0	0.1	(0.1)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.6	(0.7)	0	0.1	(0.2)	0	0.2	(0.4)	0	0.2	(0.4)
Fishing_Br	0	8.9	(3.6)	0	0.1	(0.2)	0	0.9	(0.8)	0	7.8	(3.1)	100	97.6	(1.4)	0	0.8	(0.9)	0	0.2	(0.3)	0	10.3	(3.5)	0	0.5	(0.7)	0	7.2	(3.0)	0	3.2	(2.1)
Pelly	0	0.0	(0.1)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.0	(0.1)	100	98.6	(1.2)	0	0.0	(0.0)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.0	(0.0)	0	0.0	(0.0)	0	0.0	(0.0)
Donjek	0	0.1	(0.2)	0	0.4	(0.6)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.0	(0.1)	100	82.2	(5.6)	0	0.1	(0.1)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.0	(0.0)
Big_Creek	0	3.4	(2.3)	0	0.1	(0.1)	0	0.3	(0.4)	0	0.8	(0.9)	0	0.7	(0.8)	0	0.1	(0.2)	0	0.1	(0.2)	100	80.9	(4.7)	0	0.6	(0.8)	0	6.3	(3.0)	0	0.5	(0.8)
Teslin	0	0.3	(0.4)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.1	(0.2)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.3	(0.4)	0	0.0	(0.1)	100	97.3	(1.6)	0	0.4	(0.5)
Minto	0	5.1	(2.5)	0	0.0	(0.1)	0	0.3	(0.5)	0	0.7	(0.8)	0	0.1	(0.2)	0	0.1	(0.2)	0	0.0	(0.1)	0	6.3	(2.9)	0	1.1	(1.0)	100	83.6	(4.7)	0	1.0	(1.0)
Chandindu	0	0.0	(0.1)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.0	(0.0)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.0	(0.1)	100	94.7	(2.8)
Yukon(main)	100	90.0	(0.9)	0	0.1	(0.3)	0	0.8	(1.2)	0	1.4	(3.3)	0	1.7	(0.6)	100	98.8	(0.5)	0	0.1	(0.2)	100	88.5	(0.9)	0	2.2	(1.6)	100	92.0	(0.7)	100	96.4	(0.5)
Fishing Branch	0	8.9	(3.6)	0	0.1	(0.2)	0	0.9	(0.8)	0	7.8	(3.1)	100	97.6	(1.4)	0	0.8	(0.9)	0	0.2	(0.3)	0	10.3	(3.5)	0	0.5	(0.2)	0	7.2	(3.0)	0	3.2	(2.1)
White	0	0.3	(0.4)	100	99.8	(0.3)	0	0.1	(0.2)	0	0.1	(0.1)	0	0.1	(0.3)	0	0.4	(0.5)	100	99.7	(0.4)	0	0.3	(0.4)	0	0.0	(0.1)	0	0.1	(0.3)	0	0.0	(0.1)
Yukon(US)	0	0.7	(0.8)	0	0.0	(0.1)	100	98.2	(1.2)	100	90.7	(3.3)	0	0.5	(0.5)	0	0.1	(0.2)	0	0.0	(0.1)	0	0.6	(0.7)	0	0.1	(0.2)	0	0.3	(0.4)	0	0.3	(0.4)
Teslin	0	0.3	(0.4)	0	0.0	(0.0)	0	0.0	(0.1)	0	0.0	(0.1)	0	0.1	(0.2)	0	0.0	(0.0)	0	0.0	(0.1)	100	97.3	(1.6)	0	0.4	(0.5)	0	0.1	(0.2)	0	0.1	(0.2)

Table 4. Mean Fst values for inferred population groups determined by Bayesian cluster analysis.

Species	Regional Group	Population	N	Mean Fst value
Sockeye	Vancouver Island	Great Central Lake	291	0.0727
Sockeye	Central Coast	Long Lake	368	0.0739
Sockeye	SE Alaska	Karta	189	0.0669
Chinook	Vancouver Island	Sarita	319	0.0477
Chinook	Central Coast	Kildala	366	0.0308
Chinook	Yukon	Mayo	115	0.0540
Chum	Vancouver Island	Cowichan	227	0.0145
Chum	Central Coast	Bella Bella	138	0.0154
Chum	Yukon	Fishing Branch	274	0.0549

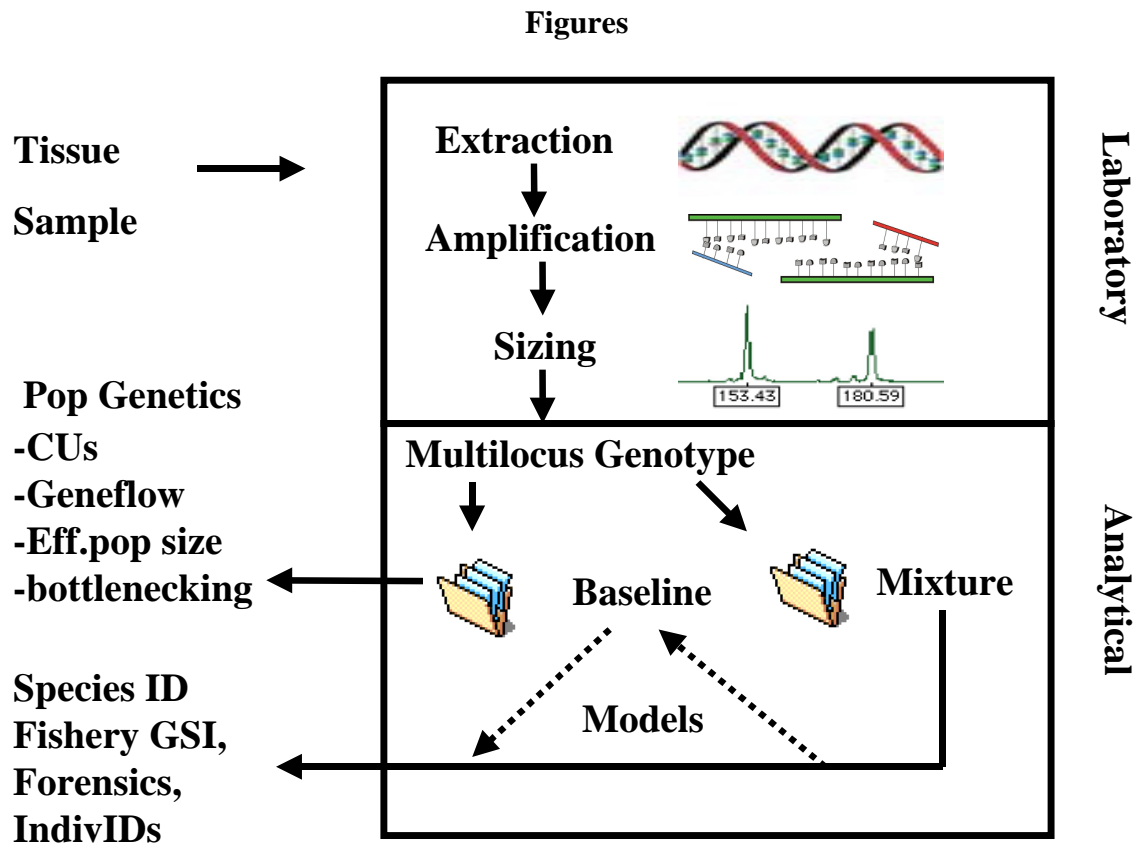


Figure 1. Steps used to analyze DNA. The first process involves the laboratory work where the DNA is extracted, amplified, and sized. The second process involves assigning size fragments to alleles, bringing together all the data for that individual to produce a multilocus genotype. Depending on the source of the tissue the multilocus genotype become part of the baseline dataset if the tissue is from spawning ground samples or part of the mixture dataset if it is from unknown populations. The baseline data can be used for population genetics work. The mixture data is compared to baseline data using mathematical models to determine stock-of-origin for the unknown samples.

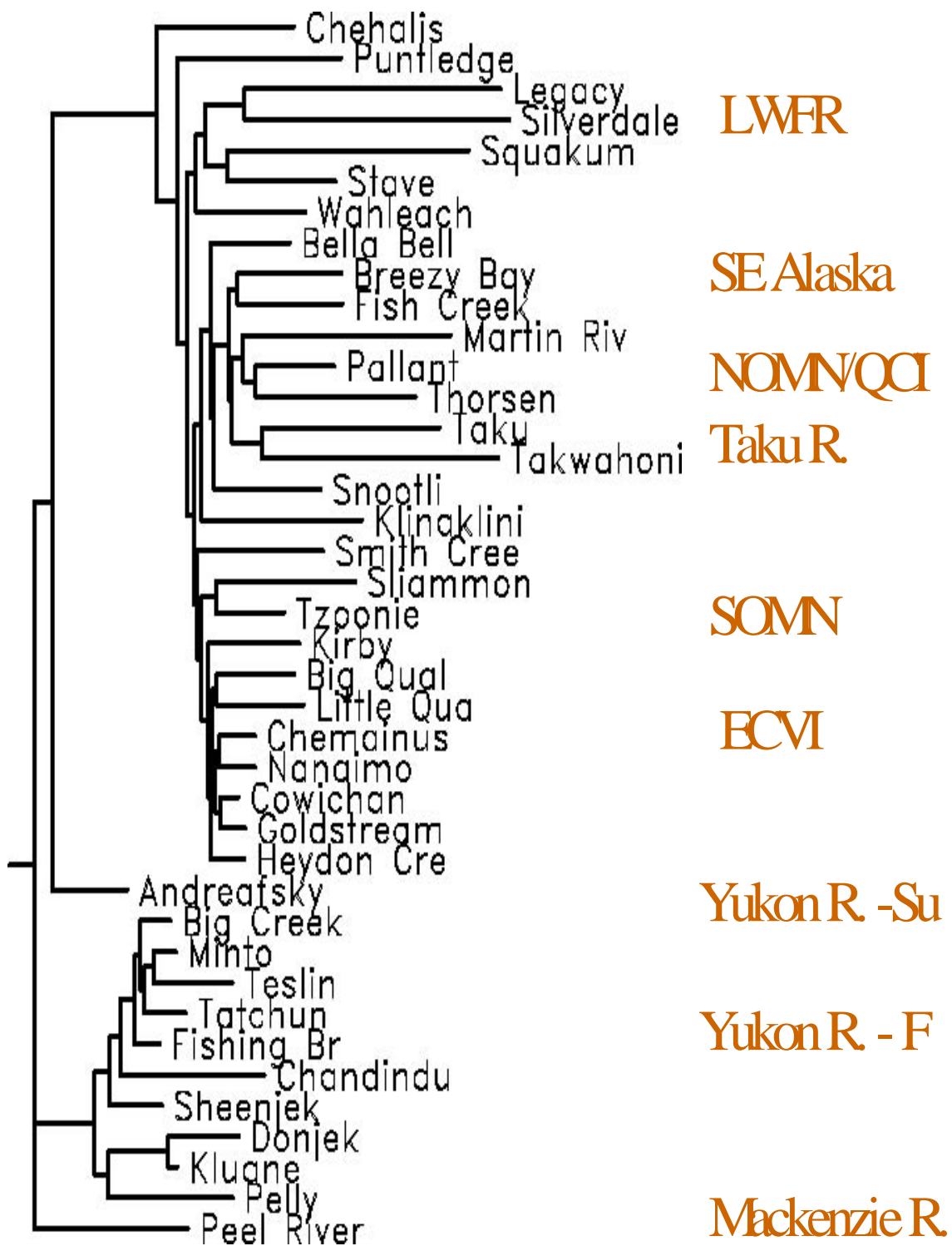


Figure 2. Neighbour joining dendrogram of Cavalli-Sforza and Edwards (1967) chord distances (15 loci) among 40 chum salmon populations.

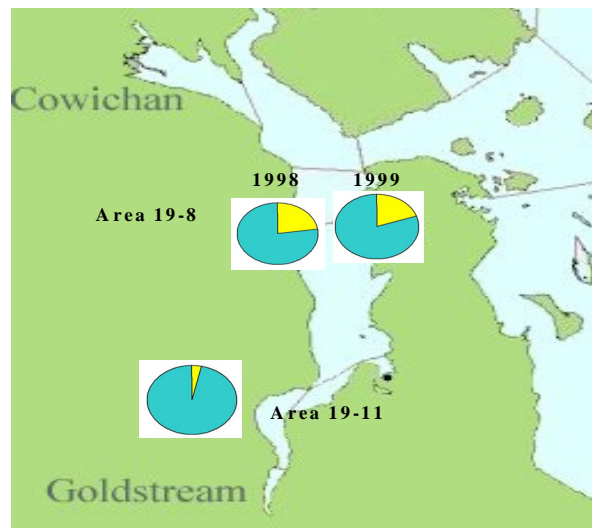


Figure 3. Estimated stock compositions for Cowichan (Yellow) and Goldstream (Blue) populations for fishery samples from Areas 19-8 and 19-11, 1998-1999.

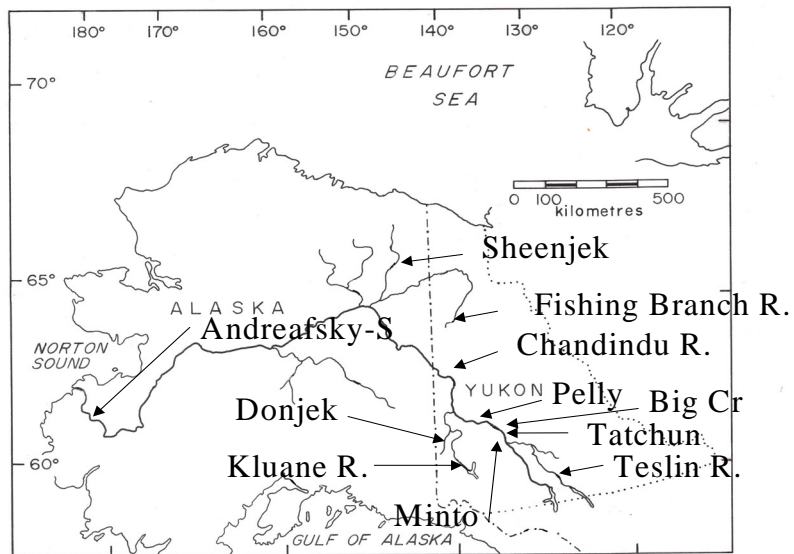


Figure 4. Yukon River chum salmon populations in the baseline.

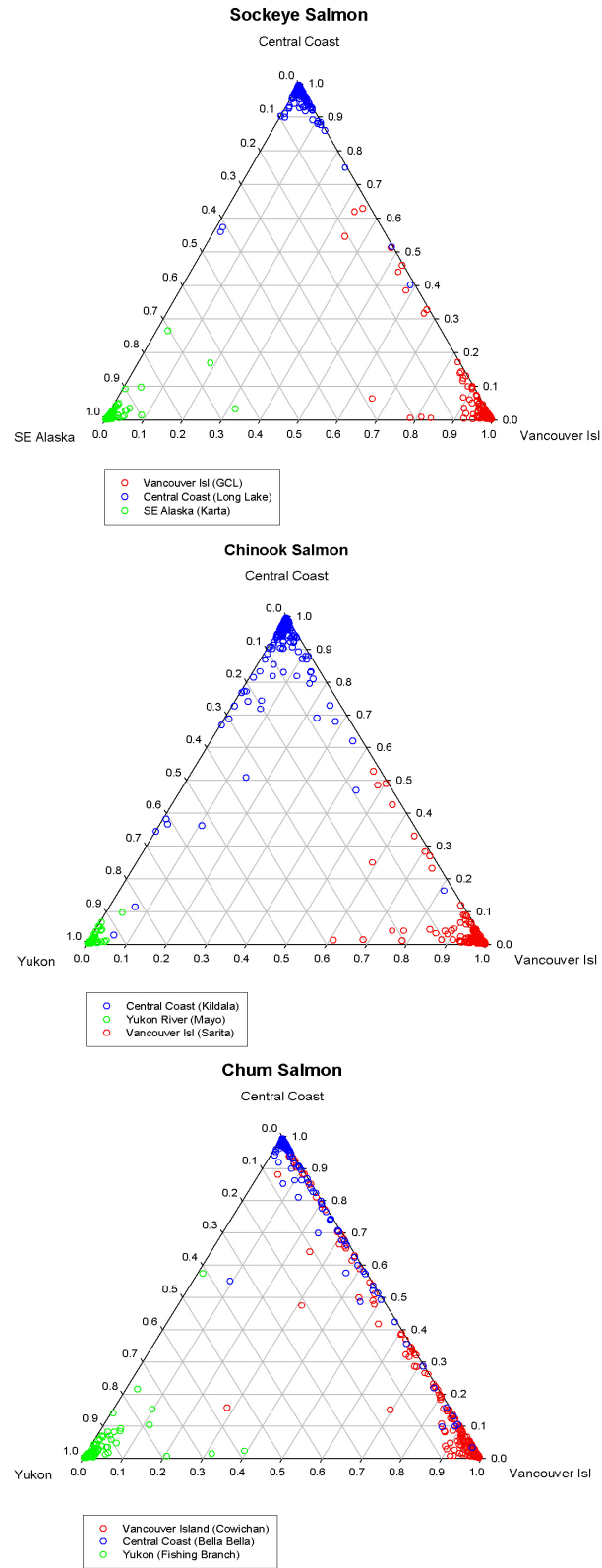


Figure 5. Inferred population structure (given $k=3$) and probabilities associated with individuals assignment to the inferred populations for a) sockeye, b) chinook, c) chum, using three geographically separated populations for each species.

Chum Salmon (*Oncorhynchus keta*) Genetics, Morphology, and Life History in the Southern Portion of the Species Range (Columbia River, Oregon, and California)

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Abstract Only

There is very little genetic and other biological information available on chum salmon in the southern portion of the species range (Columbia River, Oregon coast and California), even though some of these fish (Columbia River) were listed under the ESA in the late 1990s. Beginning in 2004, this information will be critical as recovery programs approved by NMFS technical recovery teams begin to be implemented for these depleted listed populations. Even less information is available for chum salmon on the Oregon and California coasts. Although spawning adults and out migrating smolts are reported each year, it is not even known if these are sustainable populations or strays from other regions. To support recovery efforts, we propose to collect tissue samples from spawning chum salmon in these regions and develop genetic data (only two locations in the Columbia Basin and one on the Oregon coast were analyzed for the 1997 status review) and other life history and morphological information that could be used for management and risk analysis. Information developed and analyzed will include 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. A critical portion of this proposal is to examine chum salmon collections using both allozyme and DNA-based microsatellite data being developed by WDFW and our NWFSC DNA lab. Allozyme data can be compared to the extensive allozyme database already developed for northern populations and used to develop information for ESU identification in our status reviews. However, microsatellite data may 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.

A Genetic Analysis of Summer and Early Fall Chum Salmon Populations in Hood Canal, Strait of Juan de Fuca, and South Puget Sound Using Microsatellite DNA

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Abstract Only

Chum salmon are notable among Pacific salmonids for their limited residence in fresh water. Since year classes overlap in this species, geographic proximity and run-timing serve as barriers to gene flow. In this study, we compare genetic relationships among chum salmon populations in three geographic areas, Hood Canal, Strait of Juan de Fuca and South Puget Sound with either summer or fall run-timing. Allele frequencies at 13 microsatellite loci indicate that chum salmon populations in this study separate into four groups based upon geography and run-timing. Hood Canal summer-run populations form a group distinct from but associated with Strait of Juan de Fuca summer-run populations, these summer-run populations are distinct from Hood Canal fall-run populations and from South Puget Sound summer-run populations.

Session 7

Session Leader: Brian Pearce (CDFO)

Enhancement Issues and Techniques

Relationship of Size at Return with Environmental Variation, Large-Scale Enhancement, and Productivity of Pink Salmon in Prince William Sound, Alaska: Does Size Matter?

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Abstract

Pink salmon returning to Prince William Sound (PWS), Alaska, have increased to historically high levels of abundance in recent years, but average size at return has declined. We examined the relationship of size at return of PWS pink salmon to ten biophysical factors, including the scale of hatchery production. We also examined the effect of size at return on productivity of wild pink salmon in PWS. For the 1975-1999 brood years, we found that an index of total abundance of pink salmon in the Gulf of Alaska and sea surface temperature during the year of return best explained the variation in pink salmon size over time. Size at return was also negatively correlated with productivity of wild pink salmon. We used stepwise-regression to fit a generalized linear version of the Ricker spawner-recruit model to determine if size would explain significant variation in productivity in context with other environmental variation, including hatchery production. The results indicated that variability in wild-stock productivity was primarily driven by density-independent factors in the marine environment, but that size of spawners also significantly affects productivity of PWS pink salmon. We conclude the success of large-scale enhancement increasing the total run in PWS may have contributed to the decline in body-size because of density-dependent growth in the Gulf of Alaska. We used a simulation model to estimate the impact of hatchery-induced size changes on wild-stock production in PWS. We estimated an annual loss of a half million wild-stock pink salmon associated with the annual production of 24.3 million hatchery pink salmon for brood years 1990-1999.

Introduction

Pink salmon returning to Prince William Sound (PWS), Alaska, have increased to historically high levels of abundance in recent decades (Wertheimer *et al.* 2001). Total pink salmon returns to PWS have averaged 31 million fish annually from 1990-2000 (Johnson *et al.* 2002). Many of these fish have been produced from a system of four large hatcheries. The numbers of juveniles released by the hatcheries increased rapidly until the mid-1980's (Figure 1); 500-600 million juvenile pink salmon have been released annually since then (Johnson *et al.* 2002). Hatchery returns from these releases have averaged

25.3 million fish annually from 1990-2000 (Johnson *et al.* 2002), providing large benefits to the region (Pinkerton 1994; Smoker & Linley 1997).

Concurrent with increasing hatchery production, however, the run of wild pink salmon (Figure 1) in PWS has declined from record high levels for brood years 1977-1983, and productivity (returns per spawner) of wild pink salmon has generally declined. The role of hatcheries relative to wild-stock decline is controversial. Hilborn and Eggers (2000) have attributed the decline in wild-stock abundance to interactions with hatchery production; they concluded that hatchery fish had largely replaced wild fish, and estimated a net annual benefit from hatcheries of 2 million fish. Wertheimer *et al.* (2003), however, found that conditions in the marine environment, rather than number of hatchery juveniles released, best explained the variability in wild-stock productivity. They concluded that pink salmon productivity in PWS was driven primarily by density-independent marine conditions, and that the hatchery releases provided an annual net benefit of 20.6 million – 25.3 million pink salmon annually, for the 1990-2000 returns.

None of the prior analyses investigating the interaction of large-scale enhancement and wild-stock productivity have considered the effect of size at return. In recent decades, while abundance of Pacific salmon in the North Pacific has increased, body size of adult fish has generally decreased (Ishida *et al.* 1993; Bigler *et al.* 1996; Pyper and Peterman 1999). Ricker (1995) noted that low adult growth rates and small body size of pink salmon have been associated with unusually high abundance in local regions. Bigler *et al.* (1996) found that average size of pink salmon in commercial fisheries throughout Alaska had declined from 1970-1993, including PWS. Average size of pink salmon in PWS has declined substantially since the inception of the hatchery program; average size for returns from 1965-1975 was 1.86 kg, 26% larger than the 1.48 kg average for returns from 1990-2000.

In this paper, our objectives were (1) to examine factors, including the scale of hatchery releases, affecting the size at return of PWS pink salmon; (2) examine the effect of size of return on the productivity of PWS pink salmon in conjunction with the scale of hatchery releases and other sources of environmental variation; and (3) develop simulation models incorporating factors identified as significant to estimate the degree of impact on large scale enhancement on size and productivity.

Methods

DATA SOURCES

Productivity (returns per spawner) of wild pink salmon and size at return of pink salmon in PWS since the inception of the hatchery program (1975 brood) through the 1999 brood was evaluated in relation to the size of the spawning population and 10 measures or indexes of environmental conditions over time. The indexes reflect 1) temperature experienced by pink salmon at different stages of their lives; a direct physiological determinant of growth and size over the range of temperatures experienced by the salmon; 2) the abundance (density) of pink salmon, a putative depressor of growth, size and survival; and 3) the aggregated effect of the biophysical environment on survival of pink salmon in the ocean. The variables used and data sources are listed below.

Wild-stock Spawners and Returns by Brood Year: (Johnson *et al.* 2002).

Size at return: Average size of pink salmon in the commercial fisheries in PWS (ADFG 2003). Size at return was used both as a response variable, and as an index of parent size (ParentSize, Table 1) for a brood year.

Spring Air Temperatures: Spring air temperatures (SpringAir, Table 1) in Cordova, Alaska, (www.wrcc.dri.edu/summary/climsmak.html) were used as an index of sea surface temperature (SST) conditions affecting initial marine rearing of juvenile pink salmon in PWS. Annual spring temperatures were computed as the average of the monthly averages for April, May, and June in a given year.

Gulf of Alaska Summer SST: Summer seasurface temperatures (SST) in an area of the Gulf of Alaska (GOA) adjacent to PWS were used as an index of temperature conditions affecting PWS pink salmon (1) as juveniles after they migrated from PWS into the GOA (GOASST-0, Table 1); and (2) as adults as they migrated from the GOA into PWS (GOASST-1, Table 1). Temperature records for the area lying between 58° and 60° north latitude and 146° and 149° east longitude were extracted from the Comprehensive Ocean-Atmosphere Data Set (COADS; Mendelssohn & Roy 1996) for 1961-1997 (affecting brood years 1960-1996); and from the Global Telecommunication System Data Base (www.pfeg.noaa.gov) for 1998-2000 (affecting brood years 1997-1999). Annual summer temperature was computed as the average of the temperature records for July, August, and September in a given year.

Pacific Decadal Oscillation (PDO): The PDO is an index of temperature changes in the North Pacific Ocean that has been related to basin-scale changes in the abundance and productivity of fishes in the North Pacific and GOA, including Pacific salmon (Mantua *et al.* 1997). Because the average PDO during winter is thought to affect growth and survival conditions influencing salmon populations in the subsequent spring and summer (Mantua *et al.* 1997), the annual PDO index was calculated as the average winter PDO, the monthly averages for November of a given year through March of the following year. Monthly PDO index values were extracted from data maintained at (ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest) by N. J. Mantua. The winter PDO index was used as a measure of basin-scale temperatures affecting juvenile pink salmon in year $y+1$ (PDO-0, Table 1) and adult pink salmon in year $y+2$, where y is the brood year (PDO-1, Table 1).

Hatchery Releases and Returns: Release (HatFry, Table 1) and return numbers (HatRun, Table 1) for hatchery pink salmon were from Johnson *et al.* (2002).

GOA pink salmon abundance: The average annual catch of pink salmon in regions of Alaska adjacent to the GOA was used as an index of pink salmon abundance in the GOA (GOARun, Table 1) to examine potential density-dependent interactions in the GOA (primarily in year $y+1$). Catch data was compiled from Byerly *et al.* (1999) and from ADFG (2003).

Marine Survival Index: Average annual survival rate of hatchery juveniles released in PWS (Johnson *et al.* 2002) were used as an index of marine survival conditions (MSI, Table 1) affecting wild-stock survival and productivity.

ANALYTIC APPROACH

The association of wild-stock productivity and average size at return to the factors in Table 1 was examined using simple correlation analysis and stepwise regression. Wild-stock productivity was defined as $\text{Ln}(R_{y+2}/S_y)$, where R is the return, S is the spawning escapement, and y is the brood year.

We used a multiple linear regression model to determine which factors best explain the variability in size at return:

$$\text{Size} = a + b_1X_1 + \dots + b_nX_n + \varepsilon_1 \quad (\text{Equation 1}),$$

where a is the intercept, b is the coefficient for variable X , and ε_1 is the residual error for the fit of equation 1.

We used the generalized linear version of the Ricker model (Quinn & Deriso 1999) to determine which factors best explain the variability in productivity:

$$\text{Ln}(R/S) = a + \beta S + \gamma_1 X_1 + \dots + \gamma_n X_n + \varepsilon_2 \quad (\text{Equation 2}),$$

where a is the natural log of the Ricker productivity parameter α , β is the Ricker density-dependence parameter, γ is the coefficient for variable X , and ε_2 is the residual error for the fit of Equation 2.

We used forward-backward stepwise regression (Minitab 2000) to identify significant variables in these models. A variable could enter a regression model at each step only if its coefficient was significantly different from zero at $P < 0.1$ (forward step); a variable already in the regression model would be dropped if its coefficient was not significantly different from zero at $P < 0.1$ after the addition of a new variable (backward step). The exception to this decision rule was that annual numbers of spawners, S , was kept in the regression model regardless of the P value for β .

SIMULATION OF HATCHERY EFFECTS

The models fit to Equations 1 and 2 were used to simulate the impact of hatchery production on size at return and productivity of PWS pink salmon. Hatchery releases or returns per se were not identified as significant parameters in either model. For Equation 1, however, GOARun and GulfSST-1 were identified as significant. Because HatRun is a component of GOARun, we simulated the annual effect on size at return in each year i in the absence of hatchery production by:

$$\text{Size}_i = a + b_1(\text{GOARun}_i - \text{HatRun}_i) + b_2\text{GOASST-1} + \varepsilon_{1i} \quad (\text{Equation 3}),$$

where b_1 and b_2 are the coefficients estimated for GOARun and GOASST-1 by Equation 1, and ε_{1i} are the residuals from Equation 1. In turn, parent size was identified as a significant parameter affecting productivity. We used the results from Equation 3 to simulate the annual effect of parent size on the productivity of brood year y by:

$$\text{Ln}(R_{y+2}/S_y) = a + \beta S_y + \gamma_1 \text{MSI}_y + \gamma_2 \text{ParentSize}_y + \varepsilon_{y2} \quad (\text{Equation 4}),$$

using the estimated average annual size from Equation 3 for parent size rather than the observed parent size, and the parameter coefficients and residuals as estimated by Equation 2. Confidence intervals for the deterministic estimates from Equations 3 and 4 were generated by non-parametric bootstrapping of the regression equations (Efron and Tibshirani 1993) by selecting ε randomly from the vector of residuals for all years. This process was repeated 1000 times. Average values of size for each of the 1000 permutations were computed, and the lowest and highest 50 values were truncated to identify the bootstrap 95% confidence interval.

Results

FACTORS AFFECTING SIZE

Five of the 10 variables tested were significantly correlated with size at return (Table 1). The two measures of temperature conditions affecting the adult ocean period, GOASST-1 and PDO-1, were positively associated with size, while measures of temperature conditions affecting the juvenile marine period were not significantly correlated with size. The three measures of pink salmon abundance, HatFry, HatRun, and GOARun, were negatively associated with size at return. The coefficient of variation was greater for GOARun ($r = -0.589$), a basin-scale measure index of pink salmon density, than for HatFry or

HatRun ($r = -0.479$ and -0.491 , respectively), which are more indicative of regional, PWS-scale pink salmon density (Table 1).

There was substantial cross-correlation among variables significantly associated with size at return. The PDO-1 was inversely and significantly correlated with the three measures of pink salmon abundance. This inverse relationship of the PDO-1 to pink salmon abundance is reflective of the declining trend for the PDO over this time series ($r = -0.340$, $P = 0.096$), a period that hatchery releases and adult pink salmon abundance were generally increasing. The three measures of pink salmon abundance were highly correlated; larger hatchery releases were positively correlated with larger hatchery runs, which were positively correlated with greater abundance of pink salmon in the GOA.

The stepwise regression fit for the linear model for size at return (Equation 1) identified two variables as explaining statistically significant variability in size at return: GOARun and GOASST-1 (Table 2). The GOARun index was the first variable to enter the model, and explained 31.9% of the variation in size at return. The addition of GOASST-1 increased the R^2 to 38.5%. With these parameters in the model, no other variable of the 10 considered could be added at the $P = 0.1$ significance criterion.

SIZE AND PRODUCTIVITY

Four of the 10 variables tested were significantly correlated with wild-stock productivity ($\ln(R/S)$), including Parent Size (Table 1). Three of these variables were positively associated with productivity: MSI ($r = 0.602$), the index of hatchery marine survivals; ParentSize ($r = 0.543$); and GOASST-0 ($r = 0.505$), an index of regional-scale temperatures affecting the juvenile ocean period. The number of hatchery fry released, HatFry, was negatively associated with productivity ($r = -0.394$).

There was limited cross-correlation among the variables identified as significantly associated with productivity. ParentSize was inversely and significantly correlated with HatFry and GOARun, demonstrative of the same trends identified for size at return. The correlation of MSI with HatFry was negative, but not significant ($r = -0.150$, $P = 0.475$), indicating that MSI was generally independent of the density of hatchery fry in PWS.

The stepwise regression fit of the generalized linear Ricker model (Equation 2) identified four variables as explaining statistically significant variability in size at return: MSI, ParentSize, GOASST-0, and the index number of spawners (Table 3). Because the spawners index was arbitrarily kept in the model, this variable entered the model at the first step, although it was not statistically significant ($P = 0.261$) as the only predictive parameter. When MSI entered the model at step 2, the adjusted R^2 increased from 1.4% to 43.5% (Table 3). ParentSize increased the R^2 to 64.0%, and GOASST-0 to 69.2%. With these parameters in the model, no other variable of the 10 considered could be added at the $P = 0.1$ significance criterion.

IMPACT OF HATCHERY PROGRAM ON SIZE AND PRODUCTIVITY

As hatchery runs increased, the predicted size diverged positively from the observed size. The predicted average size at return from brood years 1990-1999 (return years 1992-2001) was 1.61 kg, 5% larger than the observed size of 1.53 kg (Table 4). The bootstrap predicted average for these years, 1.56 kg, was biased low relative to the deterministic estimate. The bootstrap 95% confidence interval was 1.50-1.64 kg; thus, the predicted hatchery effect on average size was not significantly different from the observed average size.

The estimated size effects in the absence of hatcheries result in higher predicted productivity from wild-stocks. The predicted average $\ln(R/S)$ in the absence of hatchery fish from Equation 4 for brood

years 1990-1999 was 1.26, 11% higher than the observed (Table 4). The bootstrap predicted average $\ln(R/S)$, 1.39, was biased high relative to the deterministic estimate. The bootstrap 95% confidence interval was 1.19 -1.62 kg; thus the predicted size effect on productivity was significantly different from the observed. The exponents of the productivity values were calculated to estimate R/S , and applied to the average escapement for the 1990 -1999 brood years to estimate average run size at the different productivity levels (Table 4). The difference between the estimated runs at observed and predicted productivities are estimates of yield loss from wild stocks due to the hatchery production. We estimated a yield loss of 0.52 million fish, with a 95% confidence interval based on the bootstrap estimates of 0.21 – 2.70 million fish. The asymmetrical confidence interval is a result of the transformation from $\ln(R/S)$ to R/S .

Discussion

Size at return of PWS pink salmon was significantly affected by the density of pink salmon in the Gulf of Alaska, and by environmental conditions during their adult growing season at sea. These results are consistent with the paradigm that growth of salmon during their ocean life history is density-dependent, and is affected by both regional and basin-scale abundance of conspecifics (Ishida et al. 1993; Ricker 1995; Bigler et al. 1996; Pyper and Peterman 1999).

Our analyses indicated no direct effect of the number of hatchery fry released on either return size or wild-stock productivity when other biophysical variables are considered. However, releases of hatchery fry were negatively correlated with size at return and productivity. Releases of hatchery fry were also positively correlated with the Gulf of Alaska abundance of pink salmon. Catches from PWS hatcheries comprised 24% of the GOARun index. We infer from these relationships that the scope of hatchery production is indirectly contributing to the effect of pink salmon abundance on size at return.

We also conclude that size does matter for the productivity of PWS pink salmon. Variations in parent size explained a significant portion of the variation in productivity over time in a model that took into account other biophysical factors. To our knowledge this is the first time that smaller body size of pink salmon has been shown to have directly reduced realized productivity. Both egg size and fecundity of pink salmon have been shown to decline with decreased body size (Heard 1991; Malecha 2002). At a fixed escapement level, changes in fecundity directly affects the number of eggs transported into the spawning habitat. The impact of reduced fecundity on potential egg deposition in a spawning stream could be mitigated by modifying annual escapement goals in response to inseason measures of size at return.

Smaller eggs result in smaller fry, which may reduce fitness of pink salmon (Bams 1970; Parker 1971). However, Malecha (2002) found that the relationship between egg size, fecundity, and body size was non-linear in a stock of pink salmon at the tails of the adult female size distribution. At the lower end of the size range, egg size was conserved and fecundity declined more rapidly. Thus the potential for fitness differences due to egg size may diminish as fish become smaller, and the effect from reduced fecundity may increase.

This impact of hatchery-induced changes in size at return on productivity is contingent on the degree to which hatchery fish enhance, rather than replace wild fish. Our analyses indicate that density independent conditions in the marine environment determine most of the variability in wild-stock productivity, consistent with similar conclusions by Wertheimer et al. (2003). Physical factors identified as affecting productivity were regional temperatures during the juvenile marine life history phase. These results are also consistent with Pyper et al. (2001), who found survival of pinks salmon stocks along the Pacific rim were associated with regional-scale variations in temperature during the juvenile marine phase.

We estimated the scale of the impact of size changes due to hatchery production on yield of wild fish at 0.52 million fish annually, with a 95% confidence interval of 0.21 to 2.7 million, for brood years 1990-1999, annually. The average hatchery production from these brood years was 24.2 million fish (Johnson *et al.* 2002). The resultant estimated net gain from hatchery production is 23.7 million fish, with a 95% confidence interval of 21.5 to 24.0 million. These numbers confirm the conclusions of Wertheimer *et al.* (2001, 2003) that the hatchery program in PWS has provided large net benefits to the region, but not without some degree of impact to the productivity of the wild stock.

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Table 1. Correlations of size at return of pink salmon to Prince William Sound and productivity of wild pink salmon with 10 biophysical variables. Time period encompasses 1977 through 2001 return years. Variables are described in Methods. Listed are the correlation coefficient r , and the probability (P) that r is significantly different from zero. Numbers in bold were significant at $P < 0.1$.

Variable	Size at Return		Productivity	
	r	(P)	r	(P)
ParentSize	0.198	(0.343)	0.543	(0.005)
SpringAir	0.032	(0.879)	0.318	(0.121)
GOASST-0	0.150	(0.474)	0.505	(0.010)
GOASST-1	0.442	(0.027)	0.144	(0.492)
PDO-0	-0.077	(0.716)	0.073	(0.728)
PDO-1	0.426	(0.034)	-0.106	(0.614)
HatFry	-0.479	(0.015)	-0.394	(0.051)
HatRun	-0.491	(0.013)	0.034	(0.873)
GOARun	-0.589	(0.002)	-0.100	(0.634)
MSI	0.013	(0.952)	0.602	(0.001)

Table 2. Results of forward-backward stepwise regression fit of a multiple linear regression model for size at return and associated biophysical variables for Prince William Sound pink salmon, brood years 1975-1999 (Equation 1, Methods). The regression coefficients, the associated probability (P) that a coefficient is significantly different from zero, and adjusted R^2 (the coefficient of determination adjusted for degrees of freedom) are shown for each step of the regression.

Variable	Step 1		Step 2	
Constant	4.07	(<.001)	1.82	(<.001)
GOARun	-7.7*E ⁻⁹	(0.002)	-6.7*E ⁻⁹	(0.006)
GOASST-1			0.18	(0.075)
R^2 (adjusted)	31.9		38.5	

Table 3. Results of forward-backward stepwise regression fit of the generalized linear version of the Ricker model for productivity ($\ln(R/S)$) to spawner/recruit data and associated biophysical variables for Prince William Sound pink salmon, brood years 1975-1999. The regression coefficients, the associated probability (P) that a coefficient is significantly different from zero, and adjusted R^2 (the coefficient of determination adjusted for degrees of freedom) are shown for each step of the regression. Spawners were always included in the model, other variables could enter or remain in the model if $P < 0.1$.

Variable	Step 1		Step 2		Step 3		Step 4	
Constant	1.93	(<.001)	0.97	(<.014)	-1.74	(0.039)	-4.86	(<.001)
Spawners	-2.5*E ⁻⁷	(0.261)	-3.7*E ⁻⁷	(0.034)	-3.4*E ⁻⁷	(0.017)	-2.7*E ⁻⁷	(0.057)
MSI			23.8	(<.001)	21.6	(<.001)	20.3	(<.001)
Parent Size					0.80	(0.001)	0.68	(0.004)
GOASST-0							0.29	(0.046)
R^2 (adjusted)	1.4		43.5		64.0		69.2	

Table 4. Observed and simulated values for brood years 1990-1999 for size at return and wild-stock productivity ($\ln R/S$, where R is the number of recruits from spawners S) of Prince William Sound pink salmon. Deterministic and bootstrap predictions of size and $\ln (R/S)$ in the absence of hatchery fish were derived from Equations 3 and 4 in the Methods. Yield loss is the difference between observed and simulated (absence of hatcheries) productivity at average annual escapements of 1.42 million fish for the 1990-1999 brood years.

	Observed	Simulations		
		Point Estimate	Bootstrap Average	Bootstrap 95% CI Lower Upper
Size at Return (kg)	1.53	1.61	1.56	1.50 1.64
$\ln (R/S)$	1.14	1.26	1.39	1.19 1.62
R/S	3.14	3.51	4.03	3.28 5.04
Predicted Average Wild-stock Return (millions of fish)	4.45	4.97	5.72	4.66 7.15
Yield Loss (millions of fish)	--	0.52	1.27	0.21 2.70

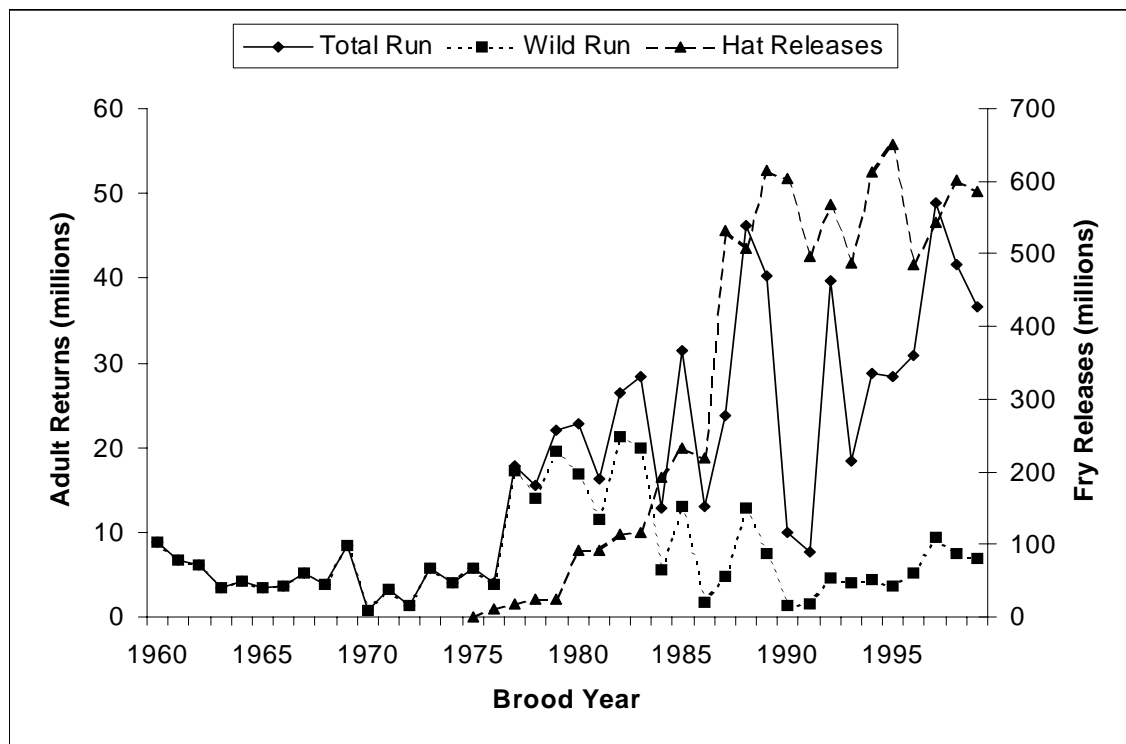


Figure 1. Total run, wild run, and hatchery releases of pink salmon in Prince William Sound, Alaska, 1960-2001.

Chum Salmon Supplementation: Bane or Boon?

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Abstract

The decline of a number of wild salmon populations in Washington State over the last two decades has caused salmon managers to increasingly employ hatchery supplementation to facilitate recovery of salmon stocks that are at risk of extinction. However, this practice has frequently been criticized as having unacceptable negative consequences on salmon populations, and has been described as a failed approach for recovering depleted populations. An early successful application of hatchery supplementation involved two wild summer chum salmon stocks in south Puget Sound. These stocks experienced a severe decline in the late 1970s, in part because of high harvest rates which were directed at hatchery coho salmon. Artificial production techniques were utilized to supplement the three largest spawning populations of summer chum in the region. The supplementation program operated from 1976 to 1991, contributing to summer chum runsizes that returned to and exceeded pre-decline abundance. Harvest rates were reduced in the early 1990s, and the two stocks are currently sustaining themselves without aid of supplementation. Average post-supplementation runsizes, now 2nd and 3rd generation natural origin recruits, are higher than average returns of the pre-decline years.

Introduction

In Washington State, the term “supplementation” is used to differentiate fish culture techniques used to assist recovery efforts for wild salmon populations from the more traditional hatchery programs intended to enhance fisheries. Supplementation for salmonids is generally defined as:

“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.” (WDFW and PNPTT 2000)

Inherent in this definition is the intent to discontinue the supplementation when the wild population has recovered.

The use of salmon culture to routinely assist the recovery of wild salmon populations is a relatively recent, and evolving, technique in salmonid population management. In Washington State the first wild stock supplementation efforts were generally begun in the late-1970s, with continuing applications of the approach in the 1980s and 1990s. Within a relatively short span of years, however, this management approach had already been declared a failure (Steward and Bjornn 1990, Waples 1991).

The early assessments that supplementation had “failed” were in part based on a broad assumption: **“... the general failure of supplementation to achieve management objectives is evident from the continued decline of wild stocks in some areas despite, and perhaps partly due to, increases in hatchery production...” (Steward and Bjornn 1990).**

This conclusion overlooks several factors: 1) it treats supplementation and hatchery fishery enhancement programs together, 2) it does not consider the often overwhelming impacts of other factors for decline (e.g., over-harvest, habitat destruction, ecological interactions, and hydro-power related mortalities), and 3) it was too early to evaluate many supplementation projects.

The most frequently proposed standard of success for supplementation projects is: did the project successfully return the depressed wild salmon population to self-sustainability? (Miller et al. 1990, Waples et al. *in press*). This is a curious criterion because there is no reason to expect supplementation to lead to self-sustainability. The poor performance of a depressed salmonid population is caused by one or more negative factors affecting survival. If these negative influences on survival are not corrected, no amount of supplementation can achieve self-sustainability in a wild population. Authors who use “self-sustainability” as a measure of supplementation success nearly always also state that self-sustaining status is dependent on the correction of factors for decline.

Several authors have evaluated selected salmon supplementation projects in an attempt to determine if any have been successful in achieving self-sustaining populations. Waples et al. (*in press*) reported on their examination of 22 projects and summarized the results of the review of 26 projects by Miller et al. (1990):

“We, like Miller et al. (1990), have not found any examples in which salmon supplementation has been used to help a natural population become self-sustaining.”

Both papers include acknowledgments that there are potential reasons for this result other than project failure like: lack of evaluation, unpublished results, short time spans, lack of correction of factors for decline, and others. They also point out that success can be dependent on a variety of project specific factors: e.g., species of salmon, degree of hatchery intervention, similarity of supplemented fish to the local stock, freshwater residence time, and distance to the ocean.

Even the current attempts to evaluate most projects would seem to be somewhat premature. For example, Waples et al. (*in press*) review 22 supplementation projects with an average start date of 1984: 4 begun in the 1970s, 13 in the 1980s, and 5 started in the 1990s. Since by definition the subject salmon populations are depressed, it can potentially take a decade or more to re-build a population to the point that substantial numbers of spawners are utilizing the natural habitat. Population growth rates can also be largely controlled by the ability (or lack of ability) to correct major factors for decline. For a chinook, chum, or sockeye population made up primarily of 3, 4, and 5 year-old fish, a supplementation project begun in 1984 would not complete its first brood return until 1989, and would have only thirteen more complete brood returns by the year 2002. Under most circumstances, this likely would be insufficient time to re-build the population, correct factors for decline, evaluate the population performance, end the project, and evaluate the self-sustainability of the post-project wild population. The limited documentation of supplementation success to date may in part be because most projects are too recent in origin to evaluate.

In Washington State, supplementation is currently being utilized in situations where a salmon stock is at risk of extirpation and with species that are amenable to the available propagation techniques. Chum salmon are arguably one of the most suitable of the Pacific salmon to supplement. They have an extremely short juvenile freshwater residence time, typically spawn close to marine waters, and have been shown to be highly responsive to hatchery propagation techniques.

The successful supplementation of two southern Puget Sound summer chum salmon stocks (Hammersley Inlet and Case Inlet) that was conducted by the Washington Department of Fisheries (WDF; now Washington Department of Fish and Wildlife - WDFW) and the Squaxin Indian Tribe from 1976

through 1991 is discussed in this paper. The program is described in a variety of reports (Allen and Cowan 1977, Allen and Cowan 1979, Allen et al. 1980, Allen et al. 1981a, Allen et al. 1981b, WDFW and WWTIT 1994, Johnson et al. 1997). These summer chum projects were not included in the previously referenced reviews of salmon supplementation (Miller et al. 1990, Waples et al. in press).

This paper is not meant to be a defense of supplementation as a general salmon recovery approach; the subject is far too complicated to adequately address here. However, it is important to demonstrate that supplementation can be a valuable tool for recovering salmon populations in specific situations.

Background

Puget Sound hosts three chum salmon runs designated by timing: summer chum, which spawn in September and October; fall chum, which spawn primarily in November and December; and winter chum, which spawn from January through March (WDF et al. 1992). All three run segments are currently producing at high levels, a condition which contributed to the NOAA Fisheries (previously National Marine Fisheries Service) 1997 chum salmon status review assessment that the Puget Sound/Strait of Georgia chum salmon are “at or near historic levels” (Johnson et al. 1997). The current strength of the summer chum stocks originating in south Puget Sound, however, represents a major recovery from a period of very low escapements and runsizes that occurred from the late 1970s through the mid-1980s. This recovery was facilitated in part by supplementation projects on the three summer chum streams with the largest populations.

There are three distinct summer chum stocks located in central and south Puget Sound (WDF et al. 1992). The Blackjack Creek summer chum stock is the northernmost of the three stocks, spawning solely in a small stream tributary to Sinclair Inlet (central Puget Sound). The Hammersley Inlet and Case Inlet summer chum stocks spawn in streams flowing into south Puget Sound. The Hammersley Inlet stock occurs primarily in Johns Creek, with an extended distribution that utilizes adjacent Cranberry and Deer creeks. Case Inlet summer chum are represented by major spawning populations in Sherwood and Coulter creeks, and by a small number of spawners in nearby Rocky Creek (see Figure 1).

South Puget Sound summer chum salmon have historically displayed robust, but highly variable abundance. For the nine year pre-decline period 1968 through 1976, summer chum runsizes generally ranged from 8,000 to 40,000 fish with larger returns each fourth year (highs of 132,000 in 1972 and 91,200 in 1976; Table 1). The pattern of large runsizes on a four year cycle is characteristic of Washington State’s summer chum salmon stocks, both in south Puget Sound and Hood Canal (Figure 2).

Two factors caused substantial changes in the management of Puget Sound salmon fisheries in the mid-1970s, tribal fishing rights and hatchery surpluses. A U.S. Federal Court ruling in 1974 affirmed the right of tribal fisheries to take half of the harvestable surplus of Puget Sound and coastal Washington salmon runs. One result of the ruling was that Puget Sound net fisheries were moved from mixed-stock to terminal fishing areas, in part to allow the allocation of the harvest shares for individual tribes in their usual and accustomed fishing areas. At the same time, fishery managers were attempting to find ways to harvest large returns of hatchery coho that were resulting in huge surplus escapements at various WDF hatcheries. Net fishery harvest rates were high for summer chum (1968-1976 mean 54%, range 13% to 77%), because fisheries were targeting hatchery coho stocks returning to Puget Sound (primarily in September and October).

A consequence of the high harvest rates during the 1970s was a steep decline in the escapements and subsequent runsizes of summer chum stocks in south Puget Sound and Hood Canal (Figure 2). Certainly other factors contributed to these declines (e.g., habitat loss, ecological interactions, and climate effects), however, harvest impacts had a major influence. WDF and the local Squaxin Indian Tribe recognized

that the high harvest rates directed at south Puget Sound hatchery coho were excessive for the coincident wild summer chum stocks. In 1976, a program was begun to supplement the two summer chum stocks located in the region, with the result that subsequent south Puget Sound summer chum runsizes stabilized and then increased.

A different approach was taken with Hood Canal summer chum salmon. When local stocks suffered a steep decline in the late 1970s and early 1980s, no supplementation occurred. The Hood Canal summer chum stocks continued to decline and were ultimately listed as a “threatened species” in 1999 under the Endangered Species Act (ESA). Supplementation of Hood Canal summer chum salmon did not begin until 1992 and is discussed in two companion papers (see Johnson and Weller 2003 and Tynan et al. 2003, this volume).

Program Description

Because of concerns that the two south Puget Sound summer chum stocks would not be able to withstand existing harvest rates WDF, in cooperation with the Squaxin Tribe, began supplementation projects in 1976 for both the Hammersley and Case inlet stocks. Allen and Cowan (1978) documented the purpose of the WDF summer chum salmon supplementation program:

“To supplement natural production in streams likely to be impacted by intensive harvesting of artificially produced stocks.”

The artificial production techniques utilized varied from egg incubation boxes with unfed fry releases to the more traditional hatchery approach of rearing and releasing fed fry at a size of approximately 1 gram. The decision to supplement was to a degree pro-active, since the supplementation efforts began before an actual decline occurred.

The supplementation program for southern Puget Sound summer chum salmon was initiated 27 years ago, and was one of the earliest supplementation efforts in Washington State. Artificial production of summer chum occurred over a 16 year period (1976-1991 brood years), and the last age-4 fish resulting from supplementation returned in 1995. There have now been seven years of post-supplementation returns of south Puget Sound summer chum (12 years for Sherwood Creek), which represent 2nd and 3rd generation natural origin recruits (NOR). Only now is it possible to begin to assess the post-supplementation status of the affected stocks.

This evaluation of the south Puget Sound summer chum supplementation projects is based on the four stages of a successful salmon supplementation program as described by Pearsons (2002); termed Baseline, Brood, Building, and Boundary stages. The Baseline stage includes the return years with depressed abundance, which generated the need for some level of intervention (e.g., supplementation). The Baseline stage would be preceded by a pre-decline stage, presumably when the stock was abundant and was self-sustaining. The Brood stage commences with the collection of broodstock from the returning spawners to initiate supplementation, temporarily further depressing the magnitude of natural escapement. The Building stage begins as the artificially produced fish contribute to increasing stock abundance, and ends when freshwater carrying capacity is reached. The final Boundary stage is characterized by a stable, self-sustaining population of natural origin fish, and is achieved through the modification of factors for decline. Figure 3 shows a hypothetical representation of the four stages of a successful supplementation project.

The inherent variability of summer chum runsizes, particularly the periodic extreme high annual values, causes problems in characterizing average abundances (runsize and escapement). This paper presents average abundance values calculated for the varying number of years included in each of the various stages of the supplementation projects. Arithmetic means are presented in the text, followed by geometric means (GM) in parentheses. Each of these means may be affected by the number of cycle

years included in the individual calculations, however, the geometric means tend to discount high values (most often cycle years). Another problem for the analysis of the supplemented populations is that the hatchery fish were not marked, and it is not possible to develop separate abundance estimates for the wild and supplemented contributions to returns. As a result, all abundance numbers presented in the report include the combined wild and artificially produced fish for the years of supplementation returns.

The small Blackjack Creek stock does not enter the same suite of fisheries as the south Puget Sound fish and did not display the same downward trend, presumably because the stock experienced lower average harvest rates (39%) from 1968 through 1979. Accordingly, the remainder of this report will focus on the two south Puget Sound summer chum stocks, and the Blackjack Creek stock (which was not supplemented) is not included in abundance numbers.

Annual runsize and escapement data for the two south Puget Sound summer chum stocks are presented in Table 1, and average runsizes during the various stages of supplementation are presented in Table 2. All escapement numbers presented in this report include both natural spawners and the adult fish removed from the streams for broodstocking.

Pre-decline

The south Puget Sound summer chum had an average pre-decline (1968-1976) runsize of 40,600 (GM = 25,100) fish. Average runsize for the Hammersley Inlet summer chum stock during the pre-decline years was 21,400 (GM = 11,800) fish, with a range of 2,929 to 64,775 fish. Case Inlet summer chum had pre-decline average runsizes of 19,200 (GM = 12,100) fish, ranging from a low of 2,500 to a high return of 67,200 fish.

Decline (Baseline/Brood Stages)

The two stocks in south Puget Sound, Hammersley and Case inlets, are harvested in gauntlet fisheries as they return through Puget Sound, and were subjected to consistently high harvest rates throughout the pre-decline and decline (Baseline/Brood stages) periods (Table 1). Harvest rates for south Puget Sound summer chum returns averaged 54% from 1968 through 1976 (pre-decline), and averaged 56% from 1977 through 1979 (decline) (Table 1). Although average harvest rates are similar for the pre-decline and decline periods, four of the six years immediately preceding the decline period (1971, 1972, 1973, and 1976) experienced higher harvest rates, averaging 70% (range 58-77%).

The summer chum period of decline (Baseline and Brood stages combined) is very short, represented by just 3 years (1977-1979). Because of the inherent variability in wild salmonid abundances, it would typically take one or more generations of low returns for managers to determine that a substantial population decline had occurred. In such a case, the Baseline stage would likely span a period of 4 or more years, and would then be followed by the Brood stage when supplementation egg takes and juvenile releases would begin. The summer chum effort was quite different, with supplementation beginning in 1976, a year before the Baseline/Brood stage, followed by the beginning of the Building stage just 4 years later, in 1980, with both age-3 and age-4 summer chum from two supplementation projects (Johns and Sherwood creeks) contributing to runsizes. Because of the early initiation of supplementation, the Baseline and Brood stages overlap, and last for only 3 years.

In 1979, the return of south Puget Sound summer chum reached a low of 1,700 fish, with a total escapement of only 990 spawners (down from a high of 32,100 spawners in 1972). The decline period averaged runsizes of just 9,100 (GM = 6,400) fish, compared to annual runsizes averaging 40,700 (GM = 25,100) fish during the 1968 through 1976 pre-decline period.

Runsize and escapement levels for the Hammersley Inlet and Case Inlet summer chum stocks are shown in Figures 4 and 5. During the 1977 through 1979 decline period (Baseline/Brood stage),

Hammersley Inlet summer chum experienced average run sizes of only 3,700 (GM = 2,900) fish, ranging from a low of 911 to a high return of 5,293 fish. Average run size for the Case Inlet summer chum stock during the decline years (1977-1979) was 5,400 (GM = 3,300) fish, with a range of 797 to 11,136 fish.

Supplementation (Building Stage)

During supplementation, the overall annual returns of summer chum salmon to south Puget Sound stabilized and then increased to levels higher than the pre-decline years. Average run size for south Puget Sound summer chum during the Building stage of supplementation (1980-1995) was 47,200 (GM = 36,800), up from 9,100 (GM = 6,400) fish during the Baseline/Brood period, and higher than the pre-decline average of 40,700 (GM = 25,100) as well. Run sizes increased through the Building stage, peaking in 1992 at over 140,000 (Figure 2). This increase occurred even though harvest rates on both stocks continued to be high throughout most of the Building stage (Table 1), averaging 50% from 1980 through 1995.

Hammersley Inlet

The Hammersley Inlet stock spawns primarily in the lower reaches of Johns Creek. There are also substantial numbers of summer chum spawning in the nearby Cranberry and Deer creeks, which are both within 2.8 kilometers of Johns Creek. The escapements of summer chum to Cranberry and Deer creeks vary in concert with the Johns Creek population, and the spawners in the three streams are considered to be a single population. The supplementation of summer chum occurred primarily in Johns Creek (with two releases in Cranberry Creek), but it is probable that fish resulting from the hatchery production spawned in all three streams.

The WDF Johns Creek (or Shelton) Hatchery began operation in 1978, although Johns Creek summer chum supplementation began two years earlier. Broodstock were collected at Johns Creek from 1976 to 1991, and great care was taken to collect eggs from the entire temporal range of spawning (pers. comm. Tim Tynan, NMFS). During the years that adult returns included supplementation fish, broodstock collections were from a random mix of natural origin and artificial origin spawners. Resulting fry releases at Johns Creek averaged over 1,500,000 per year (Table 3), making it the largest of the south Puget Sound summer chum projects. Fish were released as fed fry (averaging ~1.25 grams/fish) for all broods except 1977 and 1992, when unfed fry (~0.3 grams/fish) were released. Fry were reared on-site, and at two out-of-basin hatcheries for several years. Fish were reared and released at Johns Creek Hatchery by the Squaxin Tribe for two broods, 1983 and 1986, through a cooperative agreement with WDF. All summer chum released were of Johns Creek origin, although some Johns Creek eggs were taken to other streams for release.

Cranberry Creek was selected by the Squaxin Tribe and WDF as the site for a summer chum egg incubation box program to be operated by tribal staff (similar to the WDF Sherwood Creek project in Case Inlet). Summer chum releases occurred in only two years, although the site was used in other years for incubating eggs for other hatcheries, and for release of fall chum into Cranberry Creek. For the 1976 brood, summer chum eggs taken at Johns Creek Hatchery were loaded into egg boxes at Cranberry Creek, with the resulting release estimated at 1,800,000 of unfed fry (0.38 grams/fish). Summer chum eggs were not again available for the project until a weir was installed in 1980, to trap the returning 4 year-old fish from the 1976 brood release. Although 210,300 eggs were taken at Cranberry Creek that year (Allen et al. 1981b), vandalism to the site resulted in 100% loss before release. A second group of Johns Creek summer chum eggs were brought to the egg incubation boxes for the 1982 brood, resulting in a release of 951,658 unfed fry (0.36 grams/fish).

The Hammersley Inlet stock run size stabilized during the early 1980s, and returned to pre-decline levels by 1988. Average run size for the Building stage (1980-1995) was 30,000 (GM = 20,300) fish,

which was higher than the pre-decline average of 21,400 (GM = 11,800) fish. Runsizes and escapements for all three creeks contributing to the stock increased across the period, peaking in 1992 with a return of over 105,000 summer chum.

Case Inlet

There are two major spawning populations of summer chum in Case Inlet, utilizing Sherwood and Coulter creeks. The nearby Rocky Creek receives very small numbers of spawners. Each of the three spawning streams is within approximately 4 kilometers of one of the other streams. Genetic screening of the Sherwood and Coulter creeks summer chum showed that the two populations are genetically dissimilar, suggesting some degree of reproductive isolation (Phelps et al. 1995). Separate supplementation projects were implemented on both Sherwood and Coulter creeks, using local broodstocks. No supplementation occurred at Rocky Creek because of the very small population size and limited habitat.

Supplementation was initiated for Sherwood Creek summer chum in 1976 (Allen and Cowan 1977). Broodstock were collected at Sherwood from 1976 to 1980, in 1982, and from 1984 through 1986. Like Johns Creek, all egg takes represented the entire duration of spawning, and included randomly mixed natural and hatchery origin fish. In most years, eggs were eyed away from Sherwood Creek, and brought back for final incubation in egg boxes and were volitionally released as unfed fry. In 1979, eggs were hatched and reared away from Sherwood Creek, and were returned for release as fed fry. Coulter Creek origin eggs made up a portion (36%) of the total Sherwood egg box releases for the 1978 brood (Allen et al. 1980). Numbers and size (grams/fish) of fry released are summarized in Table 3.

Coulter Creek Hatchery began operation in 1979. Summer chum adults were trapped for broodstock at Coulter Creek from 1979 to 1991. On at least two occasions eggs from another stream were reared and released at Coulter Creek: Sherwood Creek (1980 brood), and Johns Creek (1982 brood). Releases for all broods were fed fry, with the exception of 1990 and 1991, when portions of the fish were released as unfed fry (0.3-0.4 grams/fish). Supplementation fry releases averaged around 1,200,000 fish annually at Coulter Creek (Table 3).

Analysis of the Case Inlet recovery is complicated by the different start and end times of the two projects, and because of differences in culture techniques employed. The average runsize for Case Inlet during the Building stage (1980-1995) was 17,200 (GM = 14,300) summer chum, well above the Baseline/Brood stage, but still below the pre-decline average of 19,200 (GM = 12,100) fish. This result is somewhat deceptive, since only the relatively modest Sherwood Creek supplementation returns contributed during the early years of the Building stage, while the larger Coulter Creek returns occurred later. The late building stage runsizes averaged 22,900 (GM = 19,900) fish, which exceeds the pre-decline level.

Sherwood Creek showed the least dramatic increase in runsize of the three projects during its period of supplemented returns (1980-1990), with an average runsize of only 5,000 (GM = 4,500) fish, compared to the Baseline/Brood average of 4,100 (GM = 2,400) summer chum. Supplementation at Sherwood would be expected to have had the smallest impact of the three major projects on runsize for several reasons. First, the project functioned as an egg incubation box project with volitional release of unfed fry for most of its duration, and it is known that releases of chum salmon as unfed fry results in substantially lower survival rates than releases of fish reared to a ~1 gram size. Second, the Sherwood project was the shortest in duration and released significantly fewer fish than the other two projects. Over the duration of the projects, the total number of fish released at Sherwood was only 19% of the Johns Creek total and 29% of Coulter Creek totals. Although Sherwood summer chum did not see dramatic increases, runsize did show a steady upward trend during supplementation.

While Sherwood supplementation had a positive but limited effect on Case Inlet runsize, the Coulter Creek project had a dramatic effect. For Coulter Creek, the period when supplementation fish were returning extended from 1983 through 1995. Average Coulter Creek runsize for that period was 14,000 (GM = 11,000) fish, much higher than the pre-decline and Baseline/Brood stage averages of 5,600 (GM = 3,200) and 1,200 (GM = 800) fish respectively. This recovery took place rapidly, with runsize returning to near pre-decline levels within five years of initiation of supplementation. The total runsize of Coulter Creek summer chum peaked in 1988 at 31,500 fish.

Post-supplementation (Boundary Stage)

The post-supplementation period (Boundary stage) is defined in large part by the return of a population to natural origin recruitment. The first post-supplementation return dominated by natural origin recruits was 1996, and the runsize of south Puget Sound summer chum in that year (121,300 fish) was near pre-decline highs. Available scale data show that age-3 and -4 fish made up 99.5% of returning summer chum in 1996, and the last supplementation fish (age-5, 1991 brood year) would have made an inconsequential contribution to total recruitment.

Post-supplementation summer chum runsizes decreased from the high levels experienced during the late Building stage (from 1988 through 1995), when returns averaged 73,200 (GM = 67,700) fish. A decrease would be expected if the late Building stage supplemented runsizes had exceeded levels sustainable by available habitat. However, the Boundary stage runsize average is still higher than pre-decline levels. Total south Puget Sound summer chum returns averaged 40,700 (GM = 25,100) fish from 1968 through 1976 (pre-decline), and averaged 59,800 (GM = 48,700) fish from 1996 through 2002 (post-supplementation). The post-supplementation averages are moderated somewhat by low values in 1997 and 1999 (Figure 2). South Puget Sound *fall* chum runsizes showed similar lows in those years, suggesting that broad based environmental factors probably impacted both groups of chum salmon.

Harvest management regulations were recently modified for all-citizens fisheries targeting coho in central Puget Sound, where most of the south Puget Sound summer chum harvest typically occurs. From 1988 to 1992, there was an average of 9 days per year open to all-citizen commercial net fisheries during the primary summer chum migration period (September 10 to October 11) in the primary Puget Sound summer chum harvest zone (Seattle/Tacoma area). Since 1993, no gillnet and/or purse seine fishing has occurred in this area prior to October 11. These changes in fishery management were expressly designed to protect depressed wild coho stocks, and coincidentally contributed to a rapid drop in summer chum harvest rates. The average summer chum harvest rate dropped from 50% for 1988 through 1995, to 14% for 1996 through 2002 (Table 1).

Hammersley Inlet

The 1996 return to Hammersley Inlet was the first post-supplementation year dominated by natural origin recruits. Runsize peaked at 74,000 summer chum in 1996, and averaged 40,300 (GM = 32,800) fish through the boundary period, in spite of lows in 1997 and 1999 (Figure 4). This average was well above both the Baseline/Brood average value of 3,700 (GM = 2,900) fish and the pre-decline runsize average of 21,400 (GM = 11,800) summer chum. As mentioned previously, this pattern of high and low runsizes is similar to that seen for south Puget Sound fall chum runsizes since 1996.

Case Inlet

Supplementation at Sherwood Creek ended earlier than the other projects (1986), meaning that any long-term effects of supplementation have had the longest time to appear. Sherwood Creek runsize averaged 7,900 (GM = 6,500) summer chum from 1991 to 2002 (post-supplementation years), above the baseline average of 4,100 (GM = 2,400) fish, but below the pre-decline average of 13,100 (GM = 7,900)

fish. While Sherwood runsizes have yet to return to pre-decline levels, runsize has demonstrated a gradual increasing trend, even though high harvest rates persisted until 1992 (Table 1). Although Sherwood runsizes were low in 1997 and 1999 (1,000 and 4,700 fish respectively), the 2000 runsize (12,800) was the largest to occur since supplementation began, and represented 2nd and 3rd generation NORs. Sherwood Creek is the only supplementation stream where runsizes have continued to increase post-supplementation, probably because the population is still below carrying capacity and the current low harvest rates are allowing continued growth

Coulter Creek runsize showed the quickest recovery of the three supplemented populations. Runsize returned to near pre-decline levels within 5 years of the initiation of supplementation. Like Johns Creek, the 1996 return to Coulter Creek was the first post-supplementation year dominated by NORs, and the runsize of 35,600 summer chum was the largest on record. In spite of a low of 700 fish in 1997, the boundary period average runsize of 10,900 (GM = 6,500) is well above the pre-decline average of 5,600 (GM = 3,200) fish, and the Baseline stage average of 1,200 fish.

As a whole, Case Inlet runsize averaged 19,500 (GM = 14,100) summer chum during the boundary period, very close to the pre-decline average of 19,200 (GM = 12,100), but well above the baseline average of 5,400 (GM = 3,300) fish. This average includes an extremely low runsize in 1997 (1,700), a low which was also experienced by south Puget Sound fall chum stocks.

Discussion

The chronology of south Puget Sound summer chum salmon supplementation (Figure 6) mirrors the four stages of a successful supplementation program as described by Pearsons (2002). The four stages were preceded by a pre-decline period (1968-1976) when south Puget Sound summer chum had an average runsize of 40,600 (GM = 25,100) fish. The Baseline/Brood stage for summer chum (1977-1979) had an average return of 9,100 (GM = 6,400) fish, defining the low point of abundance. The Building stage was represented by the 1980 through 1995 returns, and was characterized by a period of modest increases (1980 through 1987 returns averaged 21,300 (GM = 20,000) fish), followed by robust returns (1988 through 1995 returns averaged 73,200 (GM = 67,700) fish). During the Boundary stage (post-supplementation; 1996-2002), runsizes averaged 59,800 (GM = 48,700) fish.

The last summer chum originating from supplementation projects returned to Sherwood Creek in 1990, and to Johns and Coulter creeks in 1995. The post-supplementation (Boundary stage) fish are now in their second or third generation of natural origin recruitment (the last 7-12 return years), without any evidence of negative consequences from the prior supplementation. The Boundary stage average abundance of 59,800 (GM = 48,700) south Puget Sound summer chum salmon is 47% (GM = 94%) higher than the pre-decline average abundance of 40,600 (GM = 25,100) fish. The Hammersley Inlet stock has increased 88% (GM = 178%) and the Case Inlet stock is 2% (GM = 17%) higher. It is not known if the two summer chum stocks are now at full carrying capacity, because not all factors for decline have been addressed. However, the performance of these stocks as natural origin recruits over the last seven post-supplementation years is strong evidence of successful recovery.

It should be pointed out that the successful supplementation of south Puget Sound summer chum was accomplished using the artificial production approaches of the late 1970s and 1980s. By that time period WDF salmon culture protocols had greatly improved over earlier years, and particular care was taken to select representative broodstock for all projects. However, not all culture techniques used were as sensitive to wild stock protection issues as present hatchery practices, and the methods used were not as rigorous as the supplementation approaches now used to assist the recovery of ESA listed chum salmon stocks (Tynan et al. 2003, this volume, WDFW and PNPTT 2000). It is certain that current approaches to supplementation will have a reduced chance of deleterious consequences for target stocks.

Did the supplementation projects return south Puget Sound summer chum populations to sustainability? No, but the returns of supplementation fish did decrease the extinction risk through a period of over 20 years of high harvest, which was likely a major contributing factor for the decline. When harvest rates were reduced in the early 1990s, the supplemented populations provided sufficient escapement to allow populations to succeed and produce at self-sustaining levels.

Supplementation of a salmonid population at risk of extinction should be seen as a “life boat” that can be used to sustain the population until rescue arrives. Rescue in this case was improved survival resulting from mitigating a major factor for decline. Had harvest rates not been lowered, post-supplementation runsizes may have shown another decline similar to that of the late 1970s and the summer chum could have reverted to Baseline stage abundances. This would not have meant that supplementation failed, only that rescue never came.

While it is impossible to know what would have happened to south Puget Sound summer chum without supplementation, Hood Canal summer chum provide an interesting comparison. Hood Canal runsizes declined at the same time, and for many of the same reasons as the south Puget Sound summer chum runs. Without supplementation the Hood Canal summer chum stocks showed no signs of recovery during the 1980s, and several stocks suffered extirpation. The remaining stocks are now listed as a threatened population under the Endangered Species Act. State and tribal co-managers are currently implementing a comprehensive conservation plan with the goal of recovering the Hood Canal populations (WDFW and PNPTT 2000).

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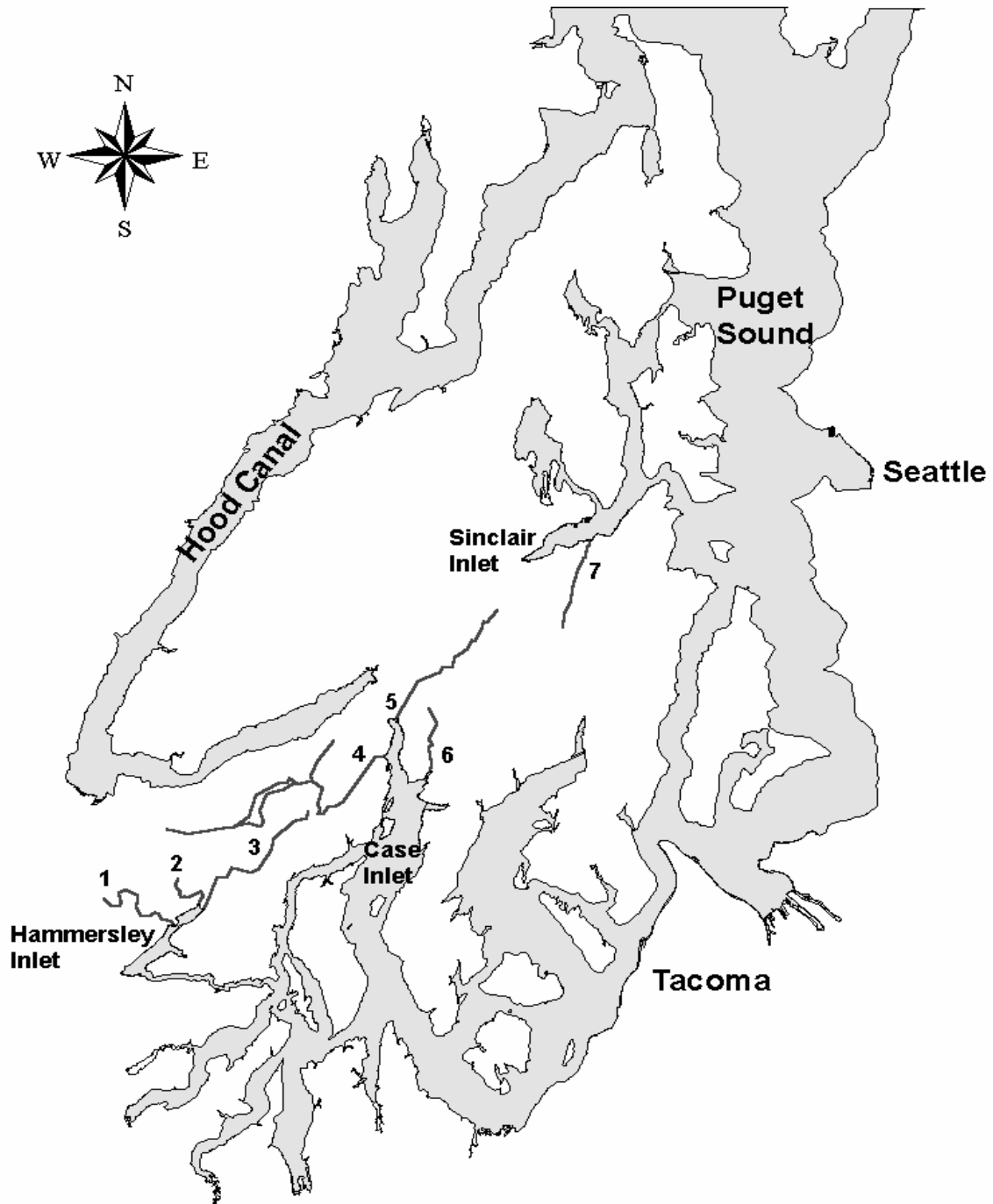


Figure 1. Map showing location of south and central Puget Sound summer chum streams. Streams indicated by number: 1. Johns Cr. 2. Cranberry Cr. 3. Deer Cr. 4. Sherwood Cr. 5. Coulter Cr. 6. Rocky Cr. 7. Blackjack Cr.

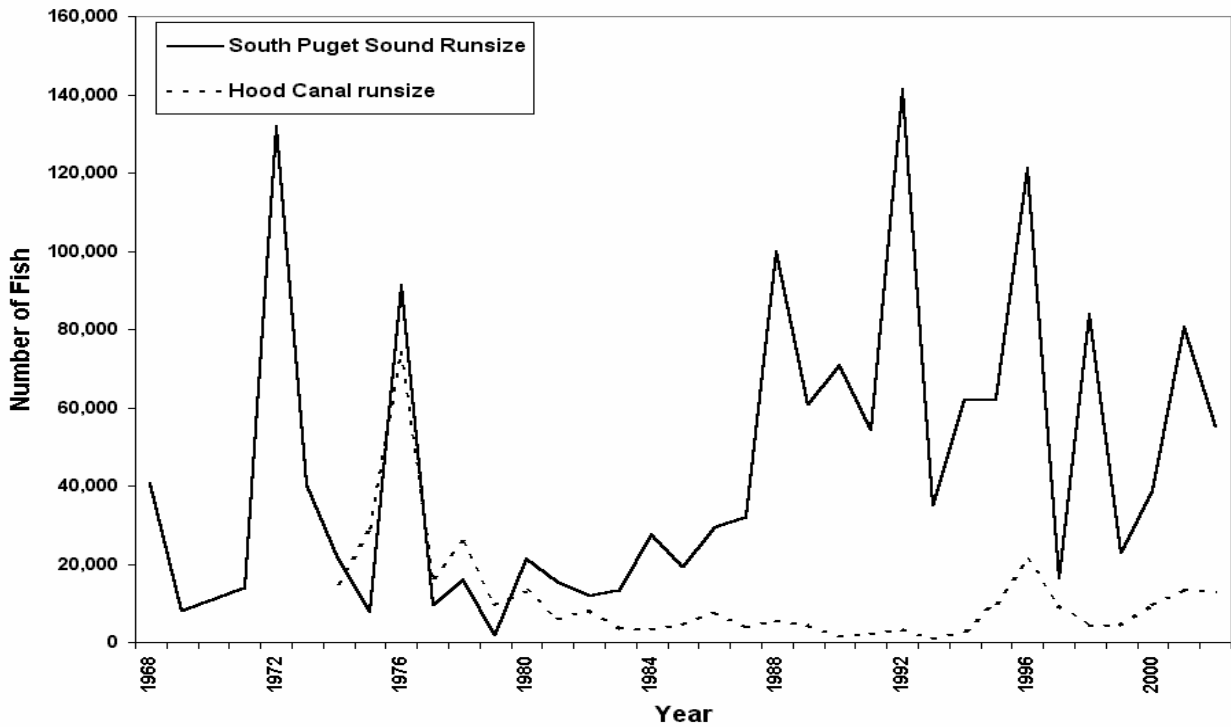


Figure 2. Total runsizes for south Puget Sound (1968-2002) and Hood Canal (1974-2002) summer chum.

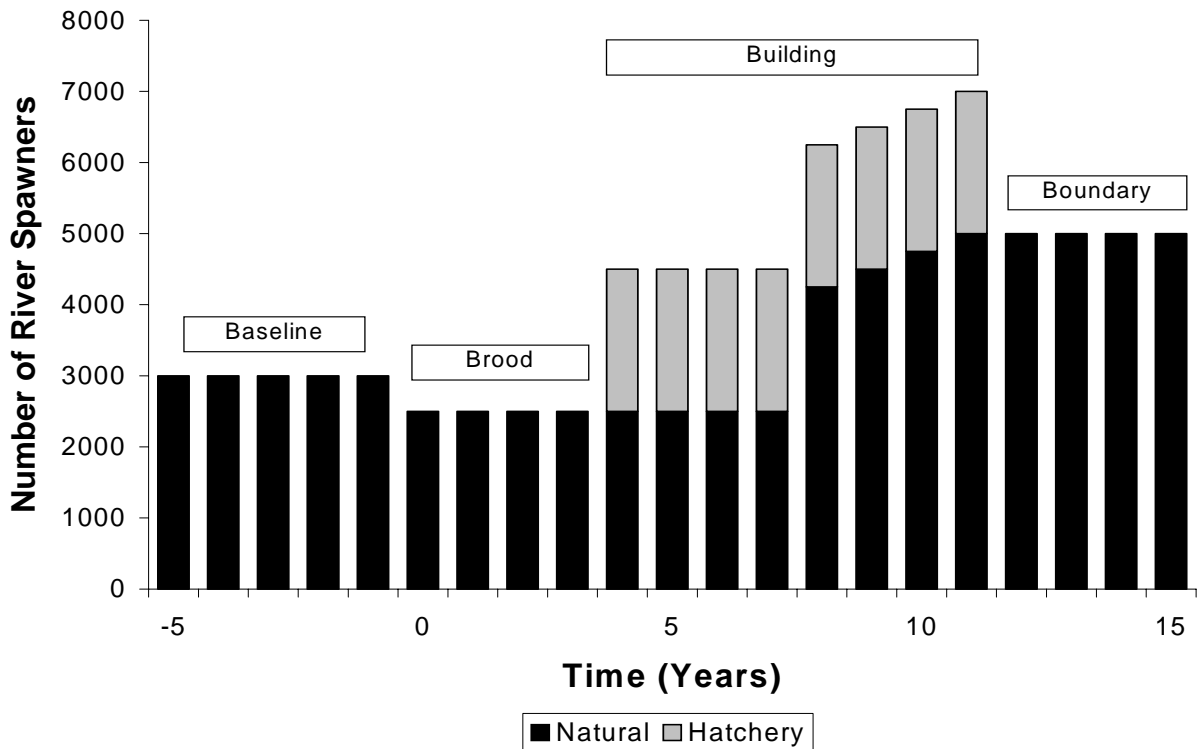


Figure 3. Hypothetical chronology of a successful supplementation program, as presented by Pearsons (2002).

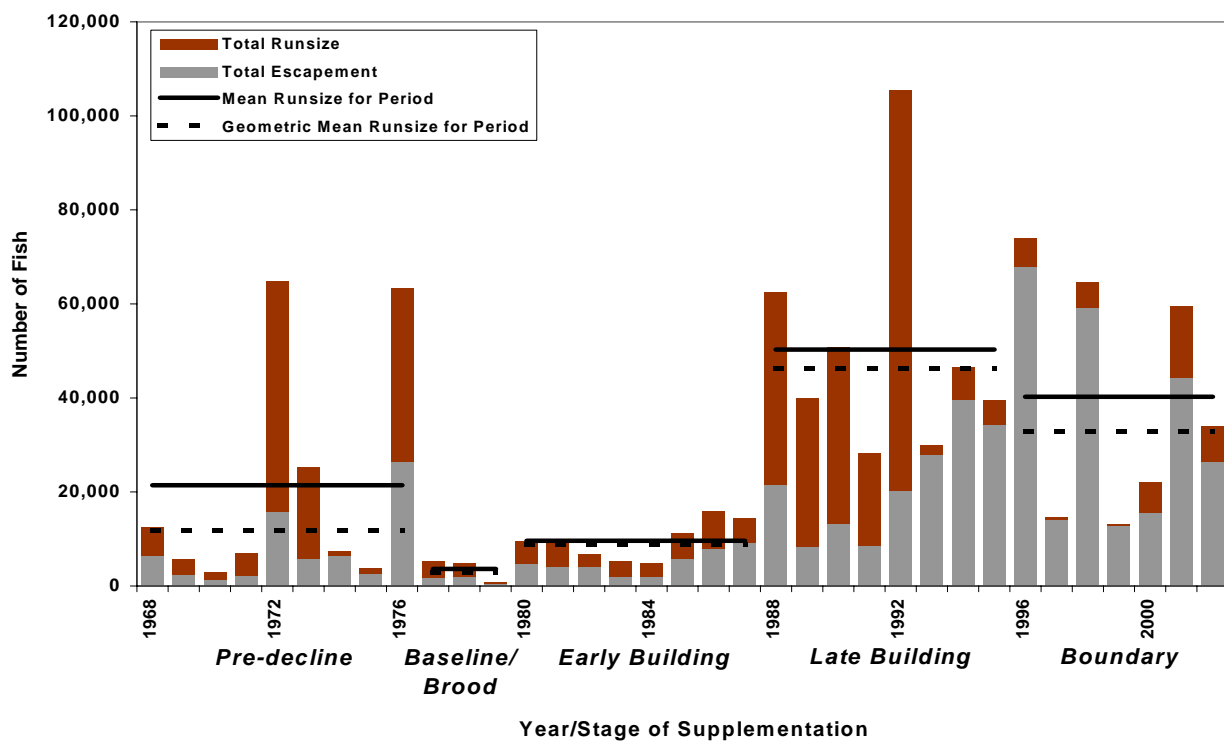


Figure 4. Hammersley Inlet summer chum escapement and runsize, 1968-2002. Horizontal lines indicate mean runsizes during stages of supplementation as described by Pearsons (2002).

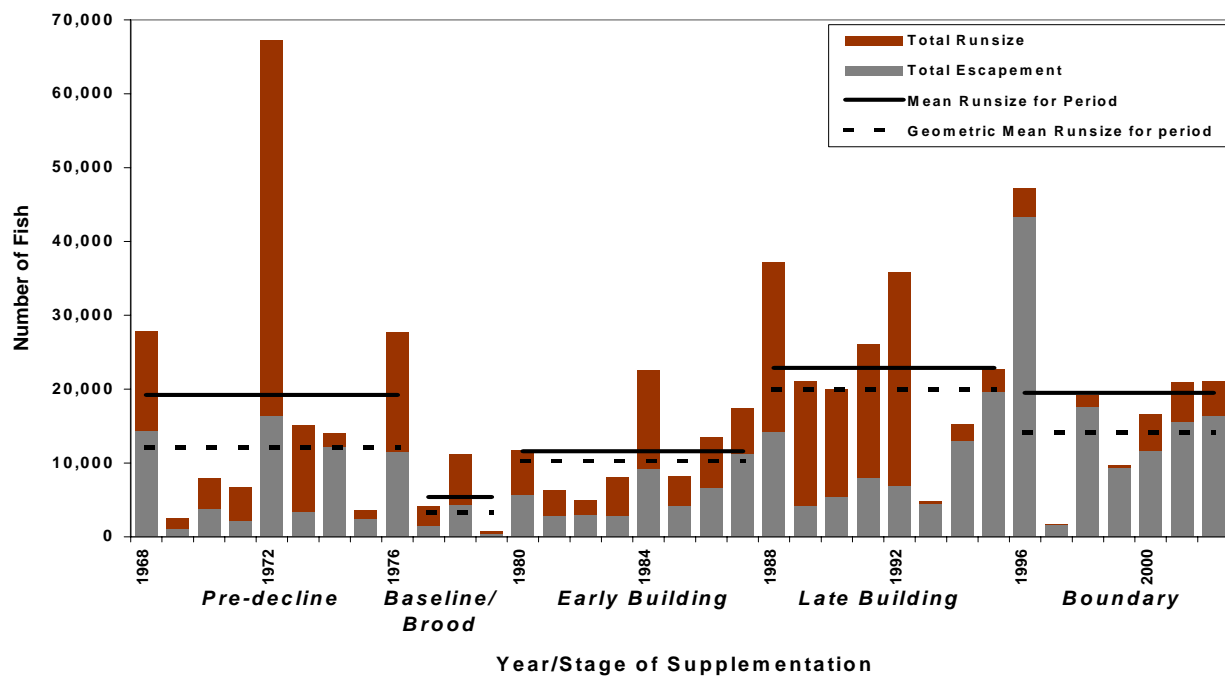


Figure 5. Case Inlet summer chum escapement and runsize, 1968-2002. Horizontal lines indicate mean runsizes during stages of supplementation as described by Pearsons (2002).

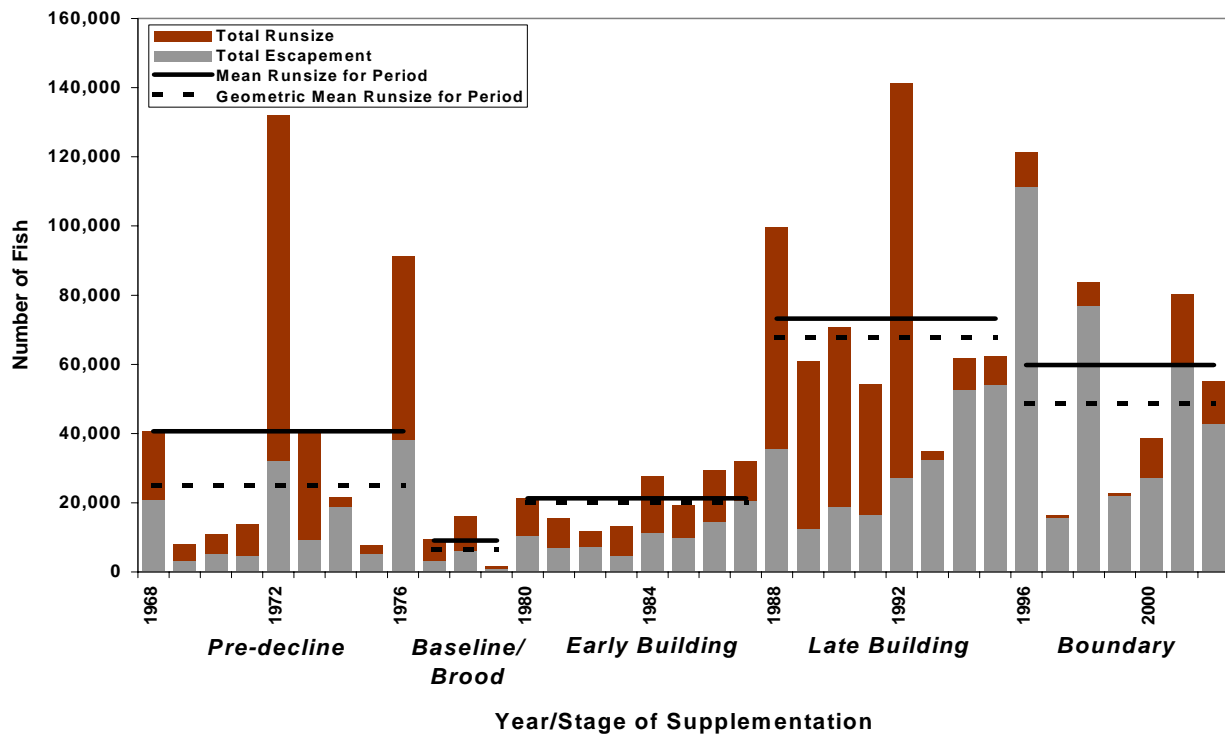


Figure 6. South Puget Sound summer chum escapement and runsize, 1968-2002. Horizontal lines indicate mean run sizes during stages of supplementation as described by Pearsons (2002).

Table 1. Escapement, runsize, and harvest rate data for south Puget Sound summer chum, 1968-2002.

Year	Escapement			Runsize			Harvest Rate (%)
	Hammersley	Case	South Sound	Hammersley	Case	South Sound	South Sound
1968	6,490	14,379	20,869	12,613	27,945	40,558	48.5
1969	2,303	1,030	3,333	5,607	2,508	8,115	58.9
1970	1,398	3,801	5,199	2,929	7,967	10,896	52.3
1971	2,290	2,218	4,509	7,005	6,785	13,790	67.3
1972	15,747	16,342	32,089	64,775	67,222	131,997	75.7
1973	5,799	3,469	9,268	25,274	15,120	40,394	77.1
1974	6,509	12,232	18,740	7,459	14,016	21,475	12.7
1975	2,633	2,467	5,100	3,916	3,670	7,586	32.8
1976	26,526	11,601	38,127	63,430	27,742	91,172	58.2
1977	1,873	1,496	3,369	5,293	4,227	9,520	64.6
1978	1,848	4,271	6,119	4,817	11,136	15,953	61.6
1979	529	463	991	911	797	1,708	41.9
1980	4,650	5,784	10,434	9,467	11,775	21,242	50.9
1981	4,193	2,877	7,070	9,203	6,318	15,521	54.4
1982	4,232	3,091	7,323	6,816	4,978	11,794	37.9
1983	1,836	2,802	4,638	5,237	7,993	13,230	64.9
1984	2,051	9,228	11,280	4,990	22,501	27,491	59.0
1985	5,790	4,211	10,001	11,230	8,167	19,397	48.4
1986	7,853	6,702	14,554	15,812	13,546	29,358	50.4
1987	9,322	11,265	20,587	14,460	17,475	31,935	35.5
1988	21,458	14,258	35,715	62,488	37,262	99,750	64.2
1989	8,270	4,145	12,415	39,868	21,014	60,882	79.6
1990	13,193	5,523	18,716	50,669	20,037	70,706	73.5
1991	8,569	7,924	16,493	28,189	26,068	54,257	69.6
1992	20,282	6,828	27,110	105,446	35,806	141,252	80.8
1993	27,874	4,506	32,380	29,967	4,848	34,815	7.0
1994	39,581	13,044	52,625	46,542	15,338	61,880	15.0
1995	34,218	19,707	53,925	39,492	22,744	62,236	12.0
1996	67,869	43,389	111,258	73,975	47,292	121,267	8.3
1997	14,075	1,646	15,721	14,642	1,712	16,354	3.9
1998	59,278	17,640	76,918	64,621	19,230	83,851	8.3
1999	12,734	9,339	22,073	13,149	9,644	22,793	0.4
2000	15,559	11,658	27,216	22,162	16,606	38,768	29.1
2001	44,312	15,653	59,965	59,461	21,003	80,464	25.5
2002	26,484	16,434	42,918	33,984	21,088	55,072	22.1

Table 2. South Puget Sound summer chum stream, stock, and regional runsize averages for each stage of supplementation.

Period	Timespan	Johns Creek		Sherwood Creek		Coulter Creek	
		Arithmetic	Geometric	Arithmetic	Geometric	Arithmetic	Geometric
Pre-decline	1968-1976	20,400	10,900	13,100	7,900	5,600	3,200
Baseline/Brood	1977-1979	3,400	2,600	4,100	2,400	1,200	800
Early Building	1980-1987	8,900	8,300	4,500	4,000	7,000	4,400
Late Building	1988-1995	40,600	36,800	6,700	6,000	16,200	12,700
Boundary	1996-2002	22,000	16,700	8,600	6,900	10,900	6,500

Period	Timespan	Hammersley Inlet		Case Inlet		South Puget Sound	
		Arithmetic	Geometric	Arithmetic	Geometric	Arithmetic	Geometric
Pre-decline	1968-1976	21,400	11,800	19,200	12,100	40,600	25,100
Baseline/Brood	1977-1979	3,700	2,900	5,400	3,300	9,100	6,400
Early Building	1980-1987	9,700	8,900	11,600	10,300	21,300	20,000
Late Building	1988-1995	50,300	46,200	22,900	19,900	73,200	67,700
Boundary	1996-2002	40,300	32,800	19,500	14,100	59,800	48,700

Table 3. Total numbers and average size at release for summer chum released from south Puget Sound supplementation projects.

Brood year	Johns Creek		Cranberry Creek		Sherwood Creek		Coulter Creek	
	Number	grams/fish	Number	grams/fish	Number	grams/fish	Number	grams/fish
1976	3,719,121	0.93	1,800,000	0.38	500,000	0.38		
1977	205,825	0.28			175,000	0.43		
1978	680,678	0.83			438,000	0.36		
1979	287,340	1.06			32,500	1.75	32,500	1.82
1980	665,000	0.98			977,845	0.36	1,510,147	1.23
1981	1,003,606	1.21					518,630	1.21
1982	2,212,900	1.25			869,186	0.39	1,136,900	1.01
1983	1,230,800	1.38					2,227,600	1.21
1984	1,140,000	1.16			460,815	0.40	2,097,000	1.23
1985	2,500,800	1.57			451,255	0.39	1,367,000	1.21
1986	1,835,000	1.40			757,000	0.40	1,382,800	1.30
1987	2,100,000	1.18					1,159,300	1.30
1988	1,975,000	1.01					1,230,600	1.02
1989	1,956,300	2.45					1,150,000	1.19
1990	1,958,900	1.04					1,153,500	1.35
1991	1,382,700	0.30					1,152,000	0.45

Supplementation Standards for Recovering ESA-Listed Threatened Summer-Run Chum Salmon Populations in the Hood Canal and Strait of Juan de Fuca Regions of Washington

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Abstract

The Washington Department of Fish and Wildlife, the Point No Point Treaty Tribes and the U.S. Fish and Wildlife Service identified standards defining when and how to use artificial propagation for supplementing and reintroducing depleted summer chum salmon populations in the Hood Canal and Strait of Juan de Fuca regions of Washington State. The standards were developed and set forth in the *Summer Chum Salmon Conservation Initiative*¹, a joint resource management plan that defined a comprehensive strategy for recovering summer chum salmon to healthy self-sustaining levels. Following objectives guiding when supplementation and reintroduction would be applied, a decision process was assembled and implemented to select candidate summer chum stock projects. Projects were selected based on an assessment of stock extinction risk status, and an evaluation of potential benefits and risks associated with any proposed projects. Rigorous standards were developed to guide how selected supplementation and reintroduction projects are implemented. Cornerstone standards included limitation on the duration of all projects to 12 years, identification of populations not subject to supplementation as reference stocks, and identification of criteria for adjusting a project, or reducing or terminating it sooner than 12 years. Strategies for minimizing the risk of potential deleterious demographic, ecological, and genetic effects on natural and artificially propagated summer chum salmon were also defined to direct how supplementation would be applied. Monitoring, evaluation, and reporting requirements were also included as standards to allow for tracking of project performance and effects, and to guide program adjustments to ensure that the projects conformed with their objectives.

¹ The *Summer Chum Salmon Conservation Initiative* is available for review through the Washington Department of Fish and Wildlife's web-site - <http://www.wa.gov/wdfw/fish/chum/chum.htm>

Introduction

Responding to severe declines in the abundance and distribution of indigenous Hood Canal and Strait of Juan de Fuca region summer-run chum salmon in the 1980s, the Washington Department of Fish and Wildlife, the Point No Point Treaty Tribes and the U.S. Fish and Wildlife Service developed a resource management plan to preserve and recover remaining stocks. Titled the *Summer Chum Salmon Conservation Initiative* (SCSCI - WDFW and PNPTT 2000), the plan identified the status of regional stocks, factors for their decline, and artificial propagation, habitat, and fisheries harvest management measures that were necessary to recover summer chum salmon in the region to healthy self-sustaining levels.

Included in the SCSCI are rigorous standards that determine when and how hatchery supplementation will be applied as a recovery action. Based on the best scientific data and the collective salmon management experience of the plan authors, these standards were developed with the goal of using artificial propagation to preserve and expeditiously recover extant summer chum salmon populations, and re-establish returns where stocks have been extirpated, while minimizing the risk of deleterious genetic, ecological, and demographic effects to supplemented and un-supplemented stocks. Of particular value was the experience gained during a very successful supplementation program for south Puget Sound wild summer chum stocks conducted from 1976 to 1991 (see Ames and Adicks 2003, this volume).

An over-riding understanding is that supplementation will be applied while other factors causing decreased summer chum abundances are addressed. This approach recognizes that supplementation measures alone will not lead to self-sustainability, or to the recovery of the ESA-listed summer chum populations. Commensurate, timely improvements in the condition of habitat critical for summer chum salmon survival, and implementation of protective harvest management measures, are also necessary to recover the listed populations to healthy levels.

The indigenous summer-run chum salmon populations that are the subject of recovery actions proposed in the SCSCI are listed as “threatened” under the Endangered Species Act (ESA) of 1973 (March 25, 1999; 64 FR 14508). As the Federal agency over-seeing protection of anadromous salmon under the ESA, NOAA Fisheries issued a final ESA 4(d) Rule applying prohibitions enumerated in section 9(a)(1) to protect the populations in January, 2001 (July 10, 2000; 65 FR 42422). Within the final 4(d) Rule, NOAA Fisheries did not find it necessary and advisable to apply ESA protective prohibitions to specified categories of activities that contribute to conserving listed salmonids or are governed by a program that adequately limits impacts on listed salmonids. Among these excepted categories are activities associated with artificial propagation programs, provided that a state or Federal Hatchery and Genetics Management Plan (HGMP) for the program has been approved by NOAA Fisheries as meeting criteria specified in the ESA 4(d) Rule. Supplementation standards from the SCSCI were carried forward in HGMPs assembled for eight individual summer chum stock supplementation and stock reintroduction programs. In March, 2002, NOAA Fisheries endorsed these artificial propagation components of the SCSCI by determining through ESA review that they were adequately conservative to prevent harm to the summer chum populations, and were likely to be beneficial to their recovery.

Active supplementation of selected Hood Canal and Strait of Juan de Fuca summer chum stocks began in 1992, operating concurrently with the development of the principles contained in the SCSCI. From an initial start in 1992 with two stocks at high risk of extinction, supplementation efforts are now contributing to increased returns to five of the eight extant stocks, and reintroduction projects are returning fish to two streams that once contained summer chum salmon (see Johnson and Weller, 2003, this volume).

Following is an overview of guiding standards from the SCSCI that were endorsed under the ESA by NOAA Fisheries, defining when and how to supplement summer chum salmon populations to meet stock recovery, restoration, and listed wild stock protection objectives.

Standards Guiding *When* to Supplement or Reintroduce

By the early 1990s, summer chum salmon populations in the regions were assessed as being at a high risk of extinction and at least four populations had been extirpated. Total spawner escapement had declined to under 1,000 fish, and several populations escaped under 25 fish in consecutive years. The resource co-managers (WDFW and the Point No Point Treaty Tribes) determined that immediate action was required, and supplementation and reintroduction projects were initiated, with commensurate control of negative fisheries harvest and habitat degradation factors, to expeditiously preserve and restore the populations. The overarching standards that guided selection of populations, and when to supplement or reintroduce were that supplementation should only be done to rebuild a population when the population is at risk or extinction, or to develop a broodstock for reintroduction; and supplementation and reintroduction should occur only as part of a comprehensive effort to understand and effectively address factors for decline or extirpation of a population. Following these standards, a decision framework was developed and applied to assess supplementation and reintroduction options relative to SCSCI objectives, provide a strategy for prioritizing potential actions, and for defining the basis for decisions in a transparent manner. The objectives applied in the decision process for developing supplementation and reintroduction projects were:

- *to rebuild summer chum salmon populations at risk of extinction;*
- *to restore summer chum salmon to streams where a viable spawning population no longer exists;*
- *to maintain or increase summer chum salmon populations of selected streams to a level that will allow their use as broodstock donors for streams where the summer chum populations have been lost; and,*
- *to avoid and reduce the risk of deleterious genetic and ecological effects.*

The initial part of the decision process for selecting projects involved general evaluation of existing and recently extinct summer chum stocks as candidates, considering several factors affecting benefits and risks. Candidate stocks were then subjected to more focused assessments of potential risk from hatchery failure, ecological hazards, and genetic hazards. Based on the general evaluation, and the subsequent assessments of risk, a list of selected supplementation and reintroduction projects was generated. Included were existing projects, assuming wild population statuses that existed prior to adult returns from the projects. This selection and risk/benefit determination process is generally described as follows.

In selecting and ranking projects for supplementation or reintroduction, a number of factors bearing on need, urgency, and practicality were considered. These factors included extinction risk ratings for candidate supplementation stocks (based on mean escapement levels and recent population trends); potential population size (reflecting on the magnitude of the stock's historical production relative to the historical overall production in the region); knowledge of the habitat-related factors affecting the stock, and what, if any, habitat recovery actions are on-going or planned; availability of broodstock for the candidate supplementation or reintroduction action; and available resources to implement the action. These factors were rated for each extant and recently extirpated stock. Ranges of rating scores reflected the relative importance of each factor. Details for the rating approach are provided on pages 134 and 135 of the SCSCI. The rating process led to the ranking of candidate summer chum salmon stocks for supplementation or reintroduction.

In furtherance of this selection process, summer chum salmon populations identified as candidates for

supplementation or reintroduction were subject to risk and benefit assessments. The purpose of these stock-by-stock assessments was to help determine whether potential benefits of a project, if implemented, outweighed potential deleterious effects. Outlines and characterizations of potential benefits and hazards of supplementation developed by Waples (1996) and Cuenca *et al.* (1993) were incorporated into the assessment framework to indicate parameters that should be considered in the context of a stock recovery program. Benefits and hazards identified in these documents were applied to objectively weigh and consider the appropriateness of a proposed supplementation program. Lists of potential benefits provided in the documents were augmented by specific benefits anticipated for summer chum salmon populations in the region, and positive results of supplementation already in hand. Benefits considered in the project assessment process, and their assumed, supportive rationale, included:

- *Reduce short-term extinction risk.* Supplementation may be used to reduce the risk that a population on the verge of extirpation will be lost by expeditiously boosting the number of emigrating juveniles in a given brood year.
- *Preserve population while factors for decline are being addressed.* Supplementation may be used to preserve or increase summer chum salmon populations while other factors causing decreased abundances are addressed.
- *Speed recovery.* Supplementation may be used to accelerate recovery of populations by increasing abundances in a shorter time frame than may be achievable through natural production.
- *Establish a reserve population for use if the natural population suffers a catastrophic loss.* Supplementation programs may be used to create an additional reservoir for a particular summer chum genome to prevent loss of the entire population due to natural or anthropogenic catastrophes.
- *Reseed vacant habitat capable of supporting salmon.* Summer chum salmon may be reintroduced to streams where populations have been extirpated and the causes of extirpation are being addressed.
- *Provide scientific information regarding the use of supplementation in conserving natural populations.* Valuable information indicating the effectiveness and effects of supplementation in recovering summer chum salmon can be collected.

Potential hazards to targeted and non-supplemented natural populations that may result from a supplementation or reintroduction program were also assessed. These hazards included:

- Partial or total hatchery failure (potential for catastrophic loss of propagated stock);
- Ecological impacts to natural-origin summer chum through predation, competition, and disease transfer;
- Genetic effects to the propagated and unsupplemented populations (within and among population diversity reduction);
- Donor stock risks (e.g., numerical reduction or selection effects through broodstock collection); and
- Risks to other salmonid populations and species (e.g., redd superimposition impacts on wild pink salmon).

For each candidate supplementation and reintroduction project, each of the above hazards was weighed in terms of its consequence to natural origin populations. This assessment assumed compliance with guidelines, operating criteria, and monitoring measures in the SCSCI to mitigate and/or minimize the effects of each hazard. Determining the likelihood of each hazard was accomplished by considering specific criteria defining effective means (based on the best scientific information or the judgement of experts) for avoiding or minimizing occurrence of the particular hazard. These criteria are identified in Table 3.5 of the SCSCI. A judgement was made in each instance regarding the probability of success

(low, moderate, or high) that each criterion will be met, given the SCSCI's risk aversion guidelines. Results of this hazard risk assessment procedure were incorporated into the final consideration of each project, leading to the final selection of projects. For selected projects, compliance with risk avoidance or minimization criteria used in the assessment process is continuously tracked. Failure to meet criteria defined for each hazard results in application of adaptive management actions. These actions are applied to determine why project objectives are not being met, and then, what changes will be applied in procedure or protocol to ensure that the objective is met in the future.

The outcome of the candidate summer chum population selection process was the identification of stocks selected for supplementation or reintroduction, stocks not recommended for intervention at the present time, pending further assessment, and stocks not recommended for supplementation or reintroduction under the SCSCI.

Standards Guiding When to Modify or Stop a Supplementation or Reintroduction Program

Standards applied to determine when supplementation and reintroduction programs will be modified or terminated were also defined in the SCSCI. By definition, supplementation and reintroduction were proposed to be used as much as possible as short term means to preserve, rebuild, or restore a naturally producing summer chum salmon population through the use of artificial propagation. One intent is to limit the duration of the programs to minimize the risk that adverse effects on the natural-origin population result from the use of artificial propagation. This intent is balanced by the need to allow the program to progress for a sufficient duration of time to allow the target population for rebuilding or reintroduction to be sufficiently recovered or established. Also, as the program progresses there should be an allowance for adequate evaluation of whether the program is effective, and for adaptive management of the program as a result of evaluation findings.

An adaptive management approach was selected in the SCSCI for defining when a supplementation or reintroduction program should be modified or terminated. The selected method combined genetic impact reduction and numerical return goal approaches with the tenets of adaptive management. Included in the approach were decision factors that may be applied as the program progresses, and as data from the program are collected, to allow adjustment of a program (e.g., reducing juvenile hatchery fish release numbers as the number of natural-origin recruits increases), or termination sooner than defined through genetic or numerically-based elements. The approach is generally consistent with factors presented within Hard *et al.* (1992) that indicate parameters to be considered in assessing the utility of a supplementation program. The following six standards were developed and included in the SCSCI to determine when a supplementation or reintroduction program should be terminated or modified.

- 1) The maximum duration of regional summer chum salmon supplementation programs will be based on criteria that minimize the likelihood that potentially deleterious genetic changes occur in the wild population.

This objective is met by applying a three generation maximum duration (12 years) for all summer chum salmon supplementation programs. Geneticists working with the co-managers advised that a three generation maximum duration limits the risk of adverse within and among population diversity reduction effects that could harm the target or conspecific wild populations (S. Phelps, WDFW, pers. comm., April, 1998). This limit also provides two generations (eight years) of adult returns to assess the program, prior to cessation of egg takes. An exception to this duration limit, leading to an increase in the duration of a program, may be acceptable if there have been catastrophic declines in habitat condition, or if other uncontrollable factors affecting summer chum survival emerge during the course of a supplementation effort, making sustainable natural production unlikely. In such a situation, the risk of continuing the

project would be re-evaluated and measured against jeopardy to the status of the target stock that is likely if the program were terminated. Extension of a project longer than three generations necessitates compliance with more rigorous genetic hazard reduction criteria included in the SCSCI.

- 2) If adult return targets are met before the three generation maximum limit is reached, then the program may be reconsidered, and may be reduced or terminated.

Adult return targets defined specifically for each project were based on the magnitude of total adult escapements to consider program reductions, and on escapement of only natural origin recruits resulting from supplementation program and wild-origin fish to consider program termination. Program reduction or cessation determinations may therefore be made as follows:

- When the total summer chum salmon adult escapement meets or exceeds 1974-78 average escapement for the stock for four consecutive years, the desired number of juvenile hatchery-origin fish produced for the program will be reduced, after considering circumstances bearing on the sustainability of the population.
 - When the total number of natural origin recruits escaping to the production stream resulting from the supplementation program and wild-origin fish meets or exceeds 1974-78 average escapement for the stock for four consecutive brood years, the supplementation program may be terminated.
 - When the adult return target used to indicate when a supplementation program should be reduced or terminated is based on another number that will assume precedence over 1974-78-derived goals.
- 3) *Supplementation and reintroduction programs may be terminated if they are no longer believed to be necessary for timely recovery, for reasons other than the success of supplementation or reintroduction, including improvements in ocean survival or habitat condition.*
 - 4) *Supplementation programs will be modified or terminated if appreciable genetic or ecological differences between hatchery and wild fish have emerged during the recovery programs.*
 - 5) *Supplementation programs will be modified or terminated if there is evidence that the programs are impeding recovery.*
 - 6) *Supplementation or reintroduction programs will be modified or terminated if there is evidence that the programs are negatively impacting a non-target ESA-listed salmonid population.*

Standards Guiding How to Supplement or Reintroduce

General and specific guiding principles describing how supplementation and reintroduction programs will be conducted were included in the SCSCI. These principles were applied to help address risks to natural origin fish, and to ensure the effectiveness of supplementation and reintroduction programs selected for implementation through the aforementioned risk/benefit assessment framework. General standards guiding how to supplement or reintroduce are summarized below. A presentation of specific criteria, expanding on these general guidelines, is included in Appendix Report 3.1 of the SCSCI.

An overarching strategy guiding how projects will be conducted is the phased implementation of individual and regional programs, rather than commencing selected programs at maximum levels. This strategy, including step-wise initiation of supplementation programs within the region or the initial release of lower than goal numbers of supplemented fish into a specific watershed, allows for assessment of initial effects of each program in achieving goals, while minimizing risks to wild summer chum populations. An additional overarching strategy is selection and maintenance of non-supplemented wild summer chum populations that comprise a representative spectrum of existing diversity. These

populations will be maintained in a natural state without assistance of supplementation to act as reference populations for tracking effects and benefits of supplementation programs implemented in adjacent watersheds. The stronger unsupplemented wild populations may still be used as donor stocks (subject to risk assessments applied for all candidate programs) to reintroduce summer chum into watersheds where the original population has been extirpated to help maintain population diversity in the region.

Standards addressing individual hatchery hazards scoped in the project assessment process were developed to minimize, when applied, potentially adverse effects on wild populations that may result from supplementation programs. Strategies described in Busack and Currens (1995), Cuenco *et al.* (1993), Kapuscinski and Miller (1993), Waples (1996) and Hard *et al.* (1992) were adapted by co-manager staff with knowledge and long-term experience regarding chum salmon hatchery propagation, life history, and hatchery effects to define risk aversion and minimization methods addressing each hazard category. Following are hazards addressed and key strategies applied to minimize the risk of their occurrence.

- **Partial/total hatchery failure.** Catastrophic loss of summer chum under propagation in a hatchery may occur as a result of dewatering due to power failure or screen fouling, flooding, or poor fish cultural practices. A key method for reducing the risk of catastrophic loss to a supplemented population is propagation of the population at more than one location (including for the purposes of reintroduction). By spreading the risk across programs, the likelihood that the genome will be retained in the event of catastrophic loss at one facility is increased. Other risk reduction methods under this category for hatcheries propagating summer chum included hatchery siting guidelines, emergency response strategies, and back-up hatchery equipment needs.
- **Predation.** The risk of direct predation effects to wild summer chum salmon resulting from the supplementation programs is low, due to the small (1 gram; 53 mm fl) average size of summer chum salmon released through the programs. Indirect predation effects co-occurring wild summer chum potentially posed by the attraction of avian and fish predators to hatchery-origin fish releases are also unlikely. The risk of indirect predation effects is mitigated by juvenile release levels from each program that are small in magnitude (less than 500,000 fed fry per year) relative to the size of the area into which the fish are released (Hood Canal or Strait of Juan de Fuca marine waters), rapid emigration of hatchery fish through freshwater “bottleneck” areas, and likely divergent migratory areas between the hatchery and smaller wild-origin summer chum fry.
- **Competition.** The risk that hatchery program origin summer chum will compete with wild summer chum fry for food is minimized through the release of hatchery fish (53 mm fl) that are larger in size than the wild fry (39 - 41 mm fl). The larger hatchery fish are likely to prey on pelagic rather than epibenthic organisms, and will emigrate and forage in different estuarine realms (offshore) than wild fry, which initially emigrate in very shallow nearshore areas.
- **Disease.** All supplementation and reintroduction projects will apply Pacific Northwest Fish Health Protection Committee (PNFHPC 1989) and Salmonid Disease Control Policy of the Fisheries Co-managers of Washington State (NWIFC and WDFW 1998). These guidelines define rearing, sanitation, and fish health practices that minimize the incidence of disease outbreaks in propagated populations, thereby decreasing the risk of fish pathogen amplification and transmission to co-occurring wild summer chum populations. All hatchery summer chum salmon populations will be inspected by WDFW or USFWS fish pathologists to certify their disease status and health condition prior to release.

Loss of genetic variability between populations. An objective of the SCSCI is to maintain existing genetic diversity among the region's summer chum populations. Diversity-based management measures will be implemented in all programs to minimize the likelihood for outbreeding depression and potential negative effects on wild stock fitness. Key standards are:

- supplementation programs for streams selected under the plan will propagate and release only the indigenous population;
- transfers of each donor stock for reintroduction will be limited to only one target watershed outside of the range of the donor stock to avoid the situation that one or few stocks within the region predominate;
- supplemented and reintroduced populations will be acclimated to the watershed desired for outplanting to ensure that the summer chum retain a high fidelity to the targeted stream;
- for reintroduced populations, where feasible, local adaptation should be fostered by using returning spawners rather than the original donor population as broodstock if the reintroduction is still in progress; and,
- all summer chum produced in hatchery programs will be marked to allow for monitoring and evaluation of adult returns.

Loss of genetic variability within populations. Standards were also developed to reduce the risk that within population genetic variability would be lost as a result of inbreeding depression, genetic drift, or domestication selection. Within population diversity loss risk reduction measures included:

- limitation of the duration of all supplementation programs to a maximum of three chum salmon generations (12 years) to minimize the likelihood for divergence between hatchery broodstocks and target natural stocks;
- collection of broodstock so that they represent an unbiased sample of the naturally spawning donor population with respect to run timing, size, age, sex ratio, and any other traits identified as important for long term fitness;
- use of returning adults produced by a supplementation program, with natural-origin fish, as broodstock over the duration of the program as a measure to increase the effective breeding population size;
- application of spawning protocols will be applied to ensure that hatchery broodstocks are representative of wild stock diversity. These measures include spawning of broodstock proportionately across the breadth of the natural return, randomizing matings with respect to size and phenotypic traits, application of factorial, or at least 1 : 1 male-female mating schemes, and avoidance of intentional selection for any life history or morphological trait. Spawning protocols will equalize as much as possible the contributions of parents to the next breeding generation;
- numerical broodstock collection objectives will be applied to help retain genetic diversity. Minimum broodstock collection objectives are set to allow for spawning of the number of adults needed to minimize loss of some alleles and fixation of others. Maximum collection levels are set for population greater than 200 spawners to allow for at least 50% of escaping fish to spawn naturally each year. For small populations, no maximum is set as an emergency measure;
- hatchery incubation and rearing measures will mimic the natural environment to the extent feasible. Hatchery rearing will be limited to a maximum of 75 days post swim-up to minimize the level of intervention into the natural chum life cycle, reducing domestication selection effects; and,
- all summer chum produced in hatchery programs will be marked to allow for monitoring and evaluation of adult returns.

Allowable Fish Release Levels

The scale of juvenile chum release levels set for each project were guided by the above broodstock collection principles and the condition of the natural summer chum population. Target annual release levels for each watershed based on achieving historical adult run sizes were set as upper limits for each project. The number of fry needed to produce the number of returning adults that will equate to the 1974-78 average run size for the watershed were set as targets. For small populations (<700 escapement), the number of fry needed to assure a minimum population equaling or exceeding 700 was determined. The projects are operated to produce fish at consistent levels, at or near goals between years, leaving no “holes” in production for the terms of the programs. This strategy helps ensure the effectiveness of the programs in quickly boosting abundances, and may assist in maintaining the genetic character of the population between brood years. Monitoring and evaluation results for each project will be used to adaptively manage production strategies, potentially leading to changes in annual production levels.

Disposition of Excess Individuals

Annual adult broodstock collection and juvenile fish release levels associated with each supplementation or reintroduction program are targeted within +/- 10% of levels derived through application of adult collection and fry release criteria in the SCSCI. In the event that circumstances such as unanticipated high adult returns or high egg to fry survival rates lead to possession of fish in excess of program objectives determined by genetic and ecological assessments, supplementation program operators will adhere to set procedures. Adult fish collected at weirs, or captured through other broodstock collection procedures, in excess of 10% of daily, weekly, or total program goals will be returned to the natural environment at the point of capture. The sex ratio of fish returned must be equivalent to the ratio observed at the time of escapement, collection, or capture. In the event that the total number of eyed eggs or juvenile fish are projected to result in a release in excess of the fish release goal (>100% of the target production number), surplus eggs or fish shall be removed from the population in a random manner and destroyed.

Maintenance of Ecological and Genetic Characteristics of the Natural Population

Standards applied under the SCSCI to propagate fish were designed to ensure that rearing units and procedures are as non-invasive into the natural life cycle of the fish as possible. Following are *general principles* that will be applied to meet objectives calling for maintenance of natural population characteristics for fish taken into the hatchery environment (generally from Kapuscinski and Miller 1993). Expanding upon these principles, specific details regarding actions that will be applied to meet genetic and ecological hazard reduction and population rebuilding strategies are presented in Appendix Report 3.1 of the SCSCI.

Broodstock collection and spawning procedures: Collect and spawn broodstock that are fully representative of the genetic and ecological characteristics of the target population (supplementation) or that show the greatest possible similarity in genetic lineage, life history patterns, and ecology of the originating environment (reintroductions). Numbers to collect and procedures for spawning will be consistent with previously described risk aversion measures implemented to minimize potentially deleterious genetic effects to the target population. Examples include: collection of an appropriate number of fish in a manner that minimizes creating genetic differences between the hatchery and wild spawning portions of the population and potential future genetic alterations of the overall population; use of fish collection methods that will help ensure that broodstock are collected in an unbiased manner; and limitation of the

number of fish removed for use as broodstock from a drainage to ensure that the number remaining to spawn in the natural environment will meet minimum population size estimates.

Incubation procedures: Incubate eggs and alevins under density, substrate, light, temperature, and oxygen conditions that simulate or improve upon natural intergravel survival. For example, green eggs, eyed eggs, and alevins will be maintained at densities and flow levels that produce the highest survival and quality to the fry stage. Artificial substrate will be provided in all incubation trays or containers, and embryos will be incubated under dark or low-light conditions. Temperature levels and regimes (daily and monthly, seasonally), and oxygen concentrations, will be maintained to mimic conditions in the natural rearing environment as closely as possible. Fry will immediately be transferred to rearing areas upon volitional swim-up or yolk absorption.

Juvenile rearing procedures: Although freshwater rearing upon swim-up has not been shown to be a natural characteristic for summer chum in the region, rearing environments and procedures applied should attempt to simulate attributes of natural conditions that may promote the development of fitness-related behaviors. Attributes addressed in this regard should include rearing water quality, hydraulic characteristics of rearing areas, feeding conditions, feeding behavior, and health and nutritional status at release. Desirable production strategies for maintaining similarity to the wild population may include rearing all fish of a population under the same conditions and mixing families randomly so that unintentional differences in rearing conditions will affect all families equally. General guidelines directed at meeting these objectives include: rearing fish at densities that will lead to the production of high quality, healthy fed fry; rearing fish under semi-natural habitat and feeding conditions to the extent feasible, especially with regard to flow velocities (exercise) and feed application and distribution practices; rearing fish in a sufficient depth of water to enable chum fry to sound when startled, allowing for the retention of standard predator avoidance behavior exhibited by the fish during migration/rearing in the estuary; introducing feed frequently, and during daylight hours only, to mimic the natural environment (constant food availability) and chum fry behavior within it (continuous feeding during migration, predominantly during daylight hours); minimizing direct human contact with fish during feeding and pond maintenance in order to minimize adverse effects on the population regarding association of humans with food and increased vulnerability to predation; maintenance of temperature levels and regimes (daily and monthly, seasonally), and oxygen concentrations, to mimic conditions in the natural rearing environment as closely as possible; and monitoring fish health during rearing, and apply approved therapeutics if necessary to suppress pathogens.

Smolt release procedures: Release procedures will mimic natural migrational characteristics for the life stage at release, including release location, nocturnal timing, and seasonal timing. General fish release guidelines include: assessment of fish health status of all groups prior to release to ensure that their quality, and likelihood for survival, is high; and release of fish as fed fry at a size that promotes the highest smolt to adult survival rates, that reduces ecological interactions with co-occurring wild summer chum, and that fosters rapid seaward migration. The targeted release size should be achieved quickly (although in deference to natural out-migration timing parameters) to decrease the likelihood of deleterious genetic effects that may be incurred by extended hatchery residence; matching fish release dates with the time period when naturally-produced fish are known to be present as migrants in the estuary; from data provided by existing WDFW, tribal, or private industry monitoring programs, assess estuarine productivity conditions to match releases with the onset of spring-time plankton blooms in the estuary occurring during the summer chum migration period; release hatchery fish as close to the estuary as is feasible to mimic lower river migrational distances experienced by natural fish (but balanced by the desire to spread spawners homing to the stream of release across all available habitat). Releases should be

timed to occur after dusk, but before midnight to mimic the natural stream emigration period exhibited by natural chum fry. For fish reintroduced into stream where the indigenous population has been extinguished, rear and acclimate the fish at the recipient location prior to liberation to enhance homing. Finally, fry production groups should be mass-released, leading to the arrival of large, instantaneous volumes of fish in the estuary, “swamping” freshwater and nearshore predator standing populations. This latter release measure also promotes schooling of fish in the estuary for migration, adhering to a “safety in numbers” prey fish survival strategy.

Monitoring and Evaluation Standards and Implementing Methods

Monitoring and evaluating the effects of supplementation on the natural summer chum population, and the performance of the overall program in recovering summer chum, are critical objectives of the SCSCI. The basic approach for monitoring and evaluation is to collect information that will help determine 1) the degree of success of each project; 2) if a project is unsuccessful, why it was unsuccessful; 3) what measures can be implemented to adjust a program that is not meeting objectives set forth for the project (Cuenco *et al.* 1993); and, 4) when to stop a supplementation project.

Implementation of the monitoring and evaluation program involved responding to concerns regarding the uncertainty of summer chum supplementation and reintroduction effects. To respond to this uncertainty, the basic approach for monitoring and evaluation activities was refined to specifically address the following four elements (generally from Hard *et al.* 1992):

- The estimated contribution of supplementation/reintroduction program-origin chum to the natural population during the recovery process;
- Changes in the genetic, phenotypic, or ecological characteristics of populations (target and non-target) affected by the supplementation/reintroduction program;
- The need and methods for improvement of supplementation/reintroduction activities in order to meet program objectives, or the need to discontinue a program because of failure to meet objectives; and
- Determination of when supplementation has succeeded and is no longer necessary for recovery.

The following framework was defined as the basis for development and application of a monitoring and evaluation program to address the above four elements:

- Restate supplementation/reintroduction goal in context of application. For example, survival monitoring is initially used to provide a basis for assessing success of hatchery returns and ultimately for assessing success of natural origin returns.
- Identify performance measures.
- Develop experimental and sampling design.
- Uniquely mark all hatchery production.
- Collect and analyze data.
- Interpret results.
- Adjust/correct ineffective or inefficient parts of plan.
- Determine how (by what mechanism) revisions will be applied.

The basis for the monitoring and evaluation program set forth in the SCSCI is to address the four elements described above. Monitoring and evaluation responses for some of these elements will provide programmatic information regarding the effectiveness of supplementation within the region. In consideration of implementability and funding concerns, certain monitoring and evaluation activities

providing program-wide benefit were required only for selected programs. Other elements provide program-specific information, and were required for each supplementation and reintroduction effort. Methods applied to address each element were specifically defined, applicable to either selected programs or all programs.

Selected Programs

a) Element 1: Estimate the contribution of supplementation/reintroduction program-origin chum to the natural population during the recovery process.

1. Differentially mark all hatchery-origin summer chum fry to allow for distinction from natural-origin fish upon return as adults in fisheries, at hatchery racks, and on the spawning grounds. This should be accomplished by fin-clipping, otolith (thermal) marking, or another permanent, effective method.
2. Conduct spawning ground surveys throughout the summer chum return to enumerate spawners, and to collect information regarding fish origin (via ad-clip fish observation or random sampling of fish heads for otoliths), and age class composition through scale sampling.
3. Estimate the number of naturally spawning hatchery-origin summer chum contributing to each supplemented population's annual escapement.
4. Monitor escapements of non-supplemented populations to determine the level of straying of supplementation program-origin fish to other drainages.
5. Conduct focused studies to help identify productivity levels (swim-up fry per adult spawner) that can be expected for hatchery-origin fish spawning in the wild. Compare these estimates with fry per spawner levels reported for wild summer chum salmon spawners in the region, or in other regions.
 - a. Enumerate natural escapement of F1 generation reintroduced fish.
 - b. Use F1 chum collected as broodstock to obtain age structure, fecundity, and sex ratio data. Then determine egg retention of spawned out fish that have been allowed to spawn naturally. From this information, estimate natural deposition of eggs in stream.
 - c. Enumerate progeny (out-migrating fry) of F1 adults to estimate egg to fry survival and to establish the baseline number of fry contributing to subsequent brood year returns.
 - d. Capture, sample and pass upstream resultant F2 generation spawners (three, four, and five years later) to assess survival and reproductive success of naturally-spawning hatchery-origin fish.
6. Estimate the total recruitment (fisheries contribution and escapement) of supplementation program origin chum. Compare hatchery fish fry to adult survival rates with estimates for wild fish to measure the effectiveness of each program

b) Element 2: Monitor and evaluate any changes in the genetic, phenotypic, or ecological characteristics of the populations presently affected by the supplementation program. Variably affected programs and populations.

1. Collect additional GSI data (allozyme or DNA-based) from regional summer chum adult populations to determine the degree to which discrete populations exist in the individual watersheds.

2. Continue GSI allozyme collections of summer chum spawners throughout the region for comparison with past collections to monitor changes in allelic characteristics, and with the intent to assess whether the supplementation program has negatively affected the genetic diversity of natural populations (after Phelps *et al.* 1994).
3. To assess the effect of past or on-going supplementation activities on the heterozygosity of target populations, collect tissue samples from representative juveniles for GSI analysis, allowing for a comparison of the genetic diversity of progeny samples to the existing baseline population profile.
4. Continue collecting and archiving DNA samples for future analysis.
5. Monitor natural spawner abundance and distribution of wild and hatchery-origin fish. Determine spawner densities and identify locations of preferred areas. Define annual and longterm changes in spawning distribution of the populations.
6. Determine if spawning ground distribution, timing, and use by hatchery-origin fish is consistent with traits exhibited by wild-origin spawners.
7. If possible, monitor fry emigration behavior upon release to assess whether natural migratory patterns (timing, migration rates, areas used) change.

All Programs

c) Element 3: Determine the need, and methods, for improvement of supplementation or reintroduction operations or, if warranted, the need to discontinue the program.

1. Mark all hatchery summer chum juveniles produced through the supplementation or reintroduction programs to allow for assessments of contribution and natural-origin recruitment rates.
2. Determine the pre-spawning and green egg to released fry survivals for each program at various life stages.
 - a) Monitor growth and feed conversion for summer chum fry.
 - b) Determine green egg to eyed egg, eyed egg to swim-up fry, and swim-up fry to released fry survival rates for summer chum.
 - c) Maintain and compile records of cultural techniques used for each life stage, such as: collection and handling procedures, and trap holding durations, for chum broodstock; fish and egg condition at time of spawning; fertilization procedures, incubation methods/densities, temperature unit records by developmental stage, shocking methods, and fungus treatment methods for eggs; ponding methods, start feeding methods, rearing/pond loading densities, feeding schedules and rates for juveniles; and release methods for one gram fry.
 - d) Summarize results of tasks for presentation in annual reports.
 - e) Identify where the supplementation program is falling short of objectives, and make recommendations for improved fry production as needed.
3. Determine if broodstock procurement methods are collecting the required number of adults that represent the demographics of the donor population with minimal injuries and stress to the fish.

- a) Monitor operation of adult trapping operations, ensuring compliance with established broodstock collection protocols for each station.
- b) Monitor timing, duration, composition, and magnitude of each run at each adult collection site.
- c) Maintain daily records of trap operation and maintenance (e.g., time of collection), number and condition of fish trapped, and environmental conditions (e.g., river stage, tide, water temperature).
- d) Collect biological information on collection-related mortalities. Determine causes of mortality, and use carcasses for stock profile sampling, if possible.
- e) Summarize results for presentation in annual reports. Provide recommendations on means to improve broodstock collection, and refine protocols if needed for application in subsequent seasons.

4. Monitor fish health, specifically as related to cultural practices that can be adapted to prevent fish health problems. Professional fish health specialists supplied by WDFW (or USFWS for federal agency operations) will monitor fish health.

- a) Fish health monitoring will be conducted by a fish health specialist. Significant fish mortality to unknown causes will be sampled for histopathological study.
- b) The incidence of viral pathogens in summer chum broodstock will be determined by sampling fish at spawning in accordance with procedures set forth in the Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State (NWIFC and WDFW 1998).
- c) Recommendations on fish cultural practices will be provided on a monthly basis, based upon the fish health condition of chum fry.
- d) Fish health monitoring results will be summarized in an annual report.

d) Element 4: Collect and evaluate information on adult returns.

This element will be addressed through consideration of the results of previous “Elements 1, 2, and 3,” and through the collection of information required under adaptive criteria that will be used as the basis for determining when to stop a supplementation or reintroduction program.

- 1. Collect age, sex, length, average egg size, and fecundity data from a representative sample of broodstock used in each supplementation program for use as baseline data to document any phenotypic changes in the populations.
- 2. Commencing with the first year of returns of progeny from naturally-spawned, hatchery-origin summer chum, evaluate results of spawning ground surveys and age class data collections to:
 - a) Estimate the abundance and trends in abundance of spawners;
 - b) Estimate the proportion of the escapement comprised by chum of hatchery lineage, and of wild lineage; and
 - c) Through mark sampling, estimate brood year contribution for hatchery lineage and wild-origin fish.
- 3. Using the above information, determine whether the population has declined, remained stable, or has been recovered to sustainable levels. The ability to estimate hatchery and wild proportions will be determined by implementation plans, budgets, and assessment priorities.
- 4. Compare newly acquired electrophoretic analysis data reporting allele frequency variation of returning hatchery and wild fish with baseline genetic data. Determine if there is evidence of a

loss in genetic variation (not expected from random drift) that may have resulted from the supplementation program.

5. Collect GSI and run timing information in summer chum streams where Finch Creek-lineage fall chum have been introduced to evaluate the risks of genetic introgression and spawning ground interaction between the two races.

Annual Monitoring and Evaluation Report

Annual reports describing monitoring and evaluation actions, findings and recommendations will be assembled for each supplementation or reintroduction program. The reports will summarize data collected through monitoring and evaluation activities, provide an analysis of the data and an interpretation of results, and suggest mechanisms for applying revisions necessary to adjust ineffective or inefficient portions of the programs. The annual report will be consistent in content, structure, and detail with annual reports currently required by NOAA Fisheries for hatchery projects authorized under the ESA. Each year, annual monitoring and evaluation reports will be reviewed and evaluated by the co-managers, USFWS, and NOAA Fisheries to assess the effectiveness and effects of the supplementation and reintroduction programs. Adjustments that are needed, if any, will be discussed and implemented as determined to be necessary to meet the objectives of the SCSCI.

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Ongoing Supplementation Programs for Summer Chum Salmon in the Hood Canal and Strait of Juan de Fuca Regions of Washington State

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Abstract

Supplementation is being applied as a strategy to reduce the short-term extinction risk of summer chum salmon populations in the Hood Canal and eastern Strait of Juan de Fuca regions and to aid in their recovery. Appropriate indigenous broodstocks are also being used to reintroduce summer chum to watersheds where they have recently been extirpated. These programs are being operated consistent with rigorous standards presented in the Summer Chum Salmon Conservation Initiative, a joint state-tribal plan to recover healthy, self-sustaining populations. We provide here descriptions and results of hatchery operations, monitoring and evaluation activities, and general program assessments for individual supplementation and reintroduction programs. Overall, broodstocks have been collected each year that represent the donor populations, genetic sampling has been conducted, the hatchery programs have met established survival rate objectives and production goals, and fish reared and released have been marked to assist in determining the contribution of the programs to the summer chum populations. Each of the programs is ongoing and some have just recently begun. Several of the programs were initiated in 1992 and have been very successful in contributing to the return of adult summer chum. Monitoring and evaluation is ongoing.

Introduction

The Hood Canal and Strait of Juan de Fuca summer chum stocks were identified by NOAA Fisheries (previously National Marine Fisheries Service) as an Evolutionarily Significant Unit (ESU) and were listed in 1999 as a “threatened” population under the Endangered Species Act. Prior to the listing, the co-managers, Washington Department of Fish and Wildlife (WDFW) and the Point No Point Treaty Tribes (PNPTT) had begun the development of a summer chum salmon recovery plan. The Summer Chum Salmon Conservation Initiative (WDFW and PNPTT 2000) was completed in the spring of 2000, and the artificial propagation components were subsequently authorized under a NOAA Fisheries Endangered Species Act 4(d) rule as adequately conservative for protection of summer chum; additionally, NOAA Fisheries determined these actions were likely to be beneficial to summer chum (Federal Register 2000).

In Washington State, the term “supplementation” is generally defined as the use of various artificial culture techniques to facilitate the recovery of wild salmon populations at risk of extinction, while minimizing deleterious effects on the wild population (see Tynan et al., this volume). The decision to use

supplementation as a tool to assist the recovery of Hood Canal and Strait of Juan de Fuca summer chum stocks at high risk of extinction built upon the successes of an earlier South Puget Sound summer chum supplementation program (see Ames and Adicks 2003, this volume), coupled with the strong performance of hatchery fall chum programs at a number of Hood Canal hatcheries.

Criteria for Summer Chum Supplementation

With the listing of multiple Washington State salmon populations as “threatened” or “endangered” under the Endangered Species Act, the standards for conducting supplementation projects have become increasingly rigorous. Since most of the supplemented populations are at risk of extinction, it is appropriate for recovery efforts to meet high operational standards to minimize possible deleterious effects of hatchery practices.

The Summer Chum Salmon Conservation Initiative (SCSCI, WDFW and PNPTT 2000) is a recovery plan that requires all hatchery supplementation efforts meet a strict set of criteria (see Tynan et al. 2003, this volume). First, supplementation is to be used only when a summer chum stock is at risk of extinction, or to develop a broodstock in support of summer chum reintroduction to previously occupied habitats. Second, only the local, native fish will be used as a broodstock source (except for reintroduction projects). Third, the plan requires operational standards to minimize impacts to natural populations from potential hazards including: 1) partial or total hatchery failure resulting in a loss of summer chum that had been placed in the hatchery; 2) ecological effects from predation, competition or disease transfer; 3) genetic effects from loss of genetic variability between or within populations; 4) effects from selection or reducing the population size of donor stocks; and 5) effects on other salmonid populations and species. And finally, the plan includes monitoring and evaluation requirements to measure the effects of supplementation on the target stock and other summer chum populations.

Ongoing Supplementation and Reintroduction Programs

Supplementation has been applied as a strategy to help recover summer chum populations in Hood Canal and the eastern Strait of Juan de Fuca since 1992. Several programs were initiated before the SCSCI was completed, but all programs were subsequently evaluated and brought into compliance with the SCSCI. There are currently six supplementation and two reintroduction projects distributed throughout the Hood Canal and Strait of Juan de Fuca summer chum ESU (Figure 1). Programs initiated in 1992 include Big Quilcene River, Lilliwaup Creek, and Salmon Creek supplementation projects. Reintroduction of summer chum into Chimacum and Big Beef creeks began in 1996 and additional supplementation programs were initiated on Hamma Hamma River in 1997, on Jimmycomelately Creek in 1999, and on Union River in 2000. Cooperators participating in the projects with the co-managers include Hood Canal Salmon Enhancement Group (HCSEG), North Olympic Salmon Coalition, Wild Olympic Salmon (WOS), Long Live the Kings (LLTK), and U.S. Fish and Wildlife Service (USFWS). Programs are operated using WDFW and USFWS hatcheries, a private hatchery operated by LLTK, and remote site facilities operated by the cooperators with oversight provided by WDFW.

Monitoring and Evaluation

Critical objectives of the SCSCI include the monitoring and evaluation of the effects of supplementation on the natural summer chum populations and of the effectiveness of the programs in recovering summer chum. The basic approach is to collect information that will help determine: 1) the degree of success of each project; 2) if a project is unsuccessful, why it failed; 3) what measures can be implemented to adjust a program that is not meeting objectives for the project; and 4) when to stop a supplementation project.

Each project is to be fully consistent with the intent and implementation of the monitoring and evaluation component for supplementation programs identified in the SCSCI and described in Tynan et al. (2003, this volume). The recommendations for monitoring and evaluation in the SCSCI respond to concerns regarding the uncertainty of summer chum supplementation and reintroduction effects by addressing the following four elements:

Element 1 - The estimated contribution of supplementation/reintroduction program-origin chum to the natural population during the recovery process;

Element 2 - Changes in the genetic, phenotypic, or ecological characteristics of populations (target and non-target) affected by the supplementation/reintroduction program;

Element 3 - The need and methods for improvement of supplementation/reintroduction activities in order to meet program objectives, or the need to discontinue a program because of failure to meet objectives; and

Element 4 - Determination of when supplementation has succeeded and is no longer necessary for recovery by collection and evaluation of information on adult returns.

Monitoring and evaluation were managed for individual projects, consistent with the above four elements as follows:

Fish marking, mark recovery, and adult returns - The summer chum salmon juveniles (either embryos or fry) produced by each supplementation program are mass-marked (otolith-marked or fin-clipped) prior to release. Spawning ground surveys are conducted throughout the summer chum escapement period to enumerate spawners and to collect information on fish origin and age composition. Examination of otoliths or fin clip ratios from spawned adults provides a method to estimate the number of supplementation (hatchery) fish versus the number of naturally spawning (wild) fish and assists in determining the contribution of the supplementation program to the target population.

Genetic and age sampling - In order to detect any changes in genetic characteristics of populations, periodic allozyme and/or DNA samples have been collected from summer chum since most supplementation programs were started, for comparison to earlier collections. DNA samples are being analyzed to develop a baseline for summer chum (e.g., see Small and Young 2003, this volume); analysis of allozyme samples is in progress. Scales are also collected to age the adult fish (WDFW and PNPTT 2001).

Broodstocking and egg sources - To fully represent the demographics of donor populations, summer chum broodstock are collected randomly as the fish arrive at temporary fish traps (operated by WDFW or project sponsors) in proportion to the timing, weekly abundance, and duration of the total return. Fish not retained as broodstock are released upstream of trap sites to spawn naturally.

Hatchery operations - Records of fish cultural operations are regularly maintained and compiled. Project sponsors in collaboration with WDFW, prepare annual reports which summarize protocols and procedures, temperature unit records by developmental stage, ponding dates, feeding, rearing and release methods, production and survival data, and recommendations for facility or protocol improvements (e.g., see WOS 2000).

Fish health - Fish health is monitored by a WDFW or USFWS fish health specialist in accordance with procedures in the co-managers disease control policy. Summer chum broodstock are sampled for the

incidence of viral pathogens, there has been no significant mortality of broodstock or juveniles from unknown causes, and fish health condition of fry from all projects prior to release has been good. *Hatchery survival rates* - The SCSCI establishes survival rate objectives during incubation and rearing of 90% from green egg to eye-up, 99.5% from eye-up to swim-up, and 95% from swim-up to release. Survival rates are monitored and the summer chum supplementation programs have generally been successful in meeting the objectives.

Individual Project Reports

The description of monitoring and evaluation activities for four supplementation projects and two reintroduction projects are provided below in individual project reports. Projects selected include three in the Strait of Juan de Fuca region and three in the Hood Canal region. The SCSCI (WDFW and PNPTT 2000: Appendix Report 3.2) provides more complete descriptions of the programs, including program objectives, operating procedures and objectives, and broodstock and production data through brood year 1998. A supplemental report to the SCSCI (WDFW and PNPTT 2001) updates the information through brood year 2000, and an additional supplemental report is in preparation with information through brood year 2002.

Salmon Creek - Strait of Juan de Fuca Region

The supplementation program begun on Salmon Creek in 1992 was originally conceived by a local citizen's group, Wild Olympic Salmon, with two basic objectives: 1) to contribute to the restoration of a healthy, natural, self-sustaining Salmon Creek population while maintaining the genetic characteristics of the native stock; and 2) to create surplus adult returns for use as a donor stock for the reintroduction of summer chum into Chimacum Creek. The Salmon/Snow summer chum stock was rated as high risk of extinction based on a precipitous decline in abundance during the 1989-1991 return years, just prior to initiation of supplementation (WDFW and PNPTT 2001).

The Salmon Creek program is comprised of the following: 1) collection of indigenous summer chum broodstock at a temporary WDFW trap at river mile 0.2 on Salmon Creek; 2) holding and spawning of broodstock at the trap site; 3) transfer of eggs and milt to WDFW Dungeness Hatchery for fertilization and initial incubation; 4) otolith marking of eyed eggs (at either WDFW Dungeness Hatchery or Hurd Creek Hatchery, both located on the nearby Dungeness River) and transfer of eyed eggs to vertical stack incubators at a remote site hatchery on Houck Creek, a Salmon Creek tributary; 5) hatching, ponding and initial feeding of fry for two weeks at the Houck Creek site; 6) transfer of fry to saltwater net pens in Discovery Bay within the freshwater plume of Salmon Creek; and 7) rearing of fry to ~1 gram in net pens and release into Discovery Bay. Beginning with brood year 2001, the use of the saltwater net pens was discontinued and fry were either reared in freshwater to approximately 1 gram or volitionally released as unfed fry from remote site incubators.

A summary of the production for each brood year of the project is provided in Table 1. From 1992 through 2002, about 2% to 16% of the total return was used as broodstock. The program has generally met the production targets for number, size, and date of fry released. During 2000, there was a bloom of *Chaetoceros* (a spiny diatom which entangles in gills) in the saltwater net pens in Discovery Bay during April and, as a precautionary measure per a fish health specialist recommendation, the fish were released early at an average size of ~0.6 gram. Numbers produced and survival rates by life stage for summer chum from the supplementation program at Salmon Creek Hatchery from 1992 through 2000 are presented in Table 2. Survival rates from fry release to adult return for summer chum reared in the supplementation program at Salmon Creek are estimated at 4.80%, 1.62%, 0.62%, 1.48% and >1% for the 1994, 1995, 1996, 1997, and 1998 brood years, respectively (Table 3).

The Salmon Creek supplementation program has been very successful in contributing to the return of adult summer chum. The program contributed an estimated 66, 529, 367, 407, and 1464 adults during the 1997, 1998, 1999, 2000 and 2001 return years, respectively. The number of supplementation-origin adults in the 1997 return is, however, an underestimate since otolith marks were difficult to identify on brood year 1994 adults. Supplementation-origin adults generally comprised from 46.6% to 73.4% of the total return to Salmon Creek from 1998 through 2001 (Table 4). The abundance of natural-origin spawners has increased from a mean of 194 adults during 1989-1991 (just prior to initiation of supplementation) to a mean of 587 adults during 1998-2001 (Figure 2). The total return to Salmon Creek during 2002 was 5517 adults, but otolith analysis is not yet available to distinguish natural-origin and supplementation-origin adults.

The Salmon/Snow summer chum stock is now rated as low risk of extinction based on the abundance of adults during the 1997-2000 return years (WDFW and PNPTT 2001). Beginning in 1996, eyed eggs collected from Salmon Creek adults were transferred to Chimacum Creek to reintroduce summer chum to that stream. This program is considered a range extension of the Salmon Creek summer chum and further reduces the stock's risk of extinction.

Chimacum Creek - Strait of Juan de Fuca Region

Chimacum Creek supported an indigenous summer chum population until the mid-1980s, when a combination of habitat degradation and poaching evidently led to their demise (WDFW and PNPTT 2000). Beginning with brood year 1996, eyed eggs from the Salmon Creek broodstock were transferred to, and released from, Chimacum Creek hatchery facilities to reintroduce summer chum to formerly occupied habitat.

The Chimacum Creek program is comprised of the following: 1) collection of indigenous summer chum broodstock at a temporary WDFW trap at river mile 0.2 on Salmon Creek; 2) holding and spawning of broodstock at the trap site; 3) transfer of eggs and milt to WDFW Dungeness Hatchery for fertilization and initial incubation; 4) otolith marking of eyed eggs (at either WDFW Dungeness or Hurd Creek Hatchery) prior to transfer of eyed eggs to vertical stack incubators at a remote site hatchery on Naylor's Creek, a Chimacum Creek tributary; 5) hatching, ponding, and rearing of fry at Naylor's Creek site; 6) transfer of one-half of fry to saltwater net pens in Port Townsend Bay near the mouth of Chimacum Creek; and 7) rearing of fry to ~1 gram in net pens and release into Port Townsend Bay. A summary of the production for each brood year of the project is provided in Table 5.

During brood year 1999, fry reared at the Chimacum Creek Hatchery were released early (i.e., at 0.4 to 0.8 gram vs. goal of 1 gram) due to water quantity, water quality, and rearing vessel limitations. Several improvements were recommended (see WOS 2000) and were made at the hatchery (a freshwater facility) prior to brood year 2000. In addition, two saltwater net pens were installed near the mouth of Chimacum Creek to rear about one-half of the fry prior to release. Brood year 2000 and 2001 fry were successfully reared to a size of 0.8 to 1.2 grams in the freshwater and saltwater facilities and released during April and May. Fry reared at the freshwater and saltwater sites received different otolith marks so the rearing strategies can be evaluated. Since 2000, the program generally met the production targets for number, size, and date of fry released and there has been no significant mortality to unknown causes and fish health condition of fry prior to release was good.

The Chimacum Creek reintroduction program has been successful in contributing to the return of adult summer chum to a previously occupied stream. An estimated 38, 52, 903, and 864 summer chum returned to spawn in Chimacum Creek during 1999, 2000, 2001, and 2002, respectively. This was the first natural spawning by summer chum in Chimacum Creek since the mid-1980's.

Jimmycomelately Creek - Strait of Juan de Fuca Region

In the SCSCI, the Jimmycomelately (JCL) Creek summer chum stock was determined to be at a high risk of extinction and a supplementation project was recommended. A supplementation project was initiated with the 1999 brood year as a cooperative effort between WDFW, North Olympic Salmon Coalition, and Wild Olympic Salmon. The goal is to contribute to the restoration of a healthy, natural, self-sustaining population of summer chum that will maintain the genetic characteristic of the native JCL stock (WDFW and PNPTT 2001).

The JCL Creek program is comprised of the following: 1) collection of indigenous summer chum broodstock at a temporary trap at river mile 0.1 on JCL Creek; 2) holding and spawning of broodstock at the trap site; 3) transfer of eggs and milt to WDFW Hurd Creek Hatchery (located on nearby Dungeness River) for fertilization, initial incubation and otolith marking; 4) transfer of eyed eggs to (a) remote site incubators (RSIs) at remote facility on a spring-fed tributary to JCL Creek with volitional release from RSIs into 4' and 6' diameter tanks and (b) vertical stack incubators at a hatchery site on upper JCL Creek with ponding into circular tanks; and 5) rearing of fry to ~1 gram for release into JCL Creek near the estuary.

A summary of the production for each brood year of the project is provided in Table 6. This program is only in its fourth year of operation. Beginning in 2002, examination of otoliths recovered from spawned adults will provide a method to determine the contribution of the supplementation program to the summer chum population. The SCSCI also noted that habitat impacts are high and may be contributing to the risk to the population, and recommended that habitat protection and recovery measures should be addressed concurrent with supplementation project development. Habitat restoration projects have been prioritized, funded, and initiated in freshwater and estuarine areas of JCL Creek.

Big Quilcene River - Hood Canal Region

A supplementation program was started in the Big Quilcene River in 1992, in response to the critical condition of the stock, and to take advantage of a year expected to be relatively strong in the stock's return cycle. The program is operated by the USFWS at the Quilcene National Fish Hatchery (QNFH). Since 1996, the Quilcene program has also contributed eggs and fry to support the re-introduction program for summer chum at Big Beef Creek. The Big/Little Quilcene summer chum stock was rated in the SCSCI as high risk of extinction, based on a precipitous decline in abundance during the 1988-1991 return years, just prior to the initiation of supplementation (WDFW and PNPTT 2001).

The Big Quilcene supplementation program is comprised of the following: 1) collection of indigenous summer chum broodstock in Quilcene Bay or from returns to the USFWS Quilcene National Fish Hatchery; 2) spawning, fertilization, incubation and rearing at QNFH; 3) adipose-clipping of all fry (since 1997); and 4) release of fry at ~ 1 gram into Quilcene River. A summary of the production for each brood year of the project is presented in Table 7.

The QNFH also supported the reintroduction of summer chum into Big Beef Creek with transfers of eyed eggs and/or fry. Beginning in 2001, summer chum returning to Big Beef Creek were used as broodstock for that reintroduction program.

Beginning with brood year 1997, the summer chum fry released at QNFH were adipose-clipped to identify returning adults as either hatchery-origin or natural-origin fish. Hatchery-origin adults comprised 62% of age 3 spawners in 2000, 79% of age 3 and 45% of age 4 spawners in 2001, and 39% of age 3 and 68% of age 4 spawners in 2002 (pers. comm. T. Kane, USFWS). The supplementation program contributed 3318 adults and 1743 adults to the 2001 and 2002 returns, respectively; and supplementation-

origin adults comprised 56% of the 2000 return and 43% of the 2001 return. The abundance of natural-origin spawners has increased from <120 adults during 1983-1991 (just prior to initiation of supplementation) to about 2300 to 2700 adults during 2001 and 2002.

High levels of adult returns appear to be associated with the supplementation program. In fact, escapement of the Big/Little Quilcene stock has exceeded the escapement criterion for program reduction. The criterion is that the annual total of hatchery-origin and natural-origin escapement exceed the mean 1974-1978 pre-decline escapement level (2,607 spawners) for four consecutive years. The program has been successful in building the returns to stable levels with escapements exceeding 2,700 fish every year since adult returns from supplementation began in 1995 (Table 8). Discussions are on-going to determine the appropriate scale of future releases from Quilcene NFH.

The Quilcene summer chum stock is now rated as low risk of extinction based on the abundance of adults during the 1997-2000 return years (WDFW and PNPTT 2001). The establishment of the Quilcene stock in Big Beef Creek is considered a range extension of the Quilcene summer chum, and further reduces the stock's risk of extinction.

Big Beef Creek - Hood Canal Region

Big Beef Creek supported an indigenous summer chum population until the mid-1980s. The reintroduction project began with brood year 1996, when eyed eggs from Quilcene stock summer chum were transferred from QNFH to Big Beef Creek to initiate the reintroduction of a summer chum population there. A summary of the production for each brood year of the project is provided in Table 9.

From 1996 through 1999, all summer chum eggs incubated and released at Big Beef Creek were transferred from QNFH. During 2000, a total of 26,890 green eggs were obtained from female summer chum returning to Big Beef Creek and 55,500 eyed eggs were transferred from QNFH. To foster local adaptation of the reintroduced population, adults returning to Big Beef Creek during 2001 and 2002 were used as broodstock, and no eggs were transferred from QNFH.

The Big Beef Creek reintroduction program has been successful in contributing to the return of adult summer chum to a previously occupied stream. An estimated 4, 20, 894, and 742 summer chum returned to spawn in Big Beef Creek during 1999, 2000, 2001, and 2002, respectively. The first natural spawning by summer chum in Big Beef Creek since the early-1980's occurred during 2001 and 2002.

Union River - Hood Canal Region

The Union River supplementation program is a cooperative effort between the Hood Canal Salmon Enhancement Group and WDFW and was initiated in brood year 2000. The strategy is to boost the abundance of the Union River population to allow for transfers of surplus fish for a reintroduction of summer chum to the Tahuya River using Union River stock. The goal is to reintroduce and restore a healthy, natural, self-sustaining population of summer chum in the Tahuya River. The supplementation program, its goal, objectives, and guidelines are consistent with the SCSCI (WDFW and PNPTT 2000).

The current program is comprised of the following: 1) collection of summer chum broodstock at a temporary trap at R.M. 0.3 on the Union River; 2) holding and spawning of broodstock at the trap site; 3) transfer of eggs and milt to WDFW George Adams Hatchery for fertilization and initial incubation; 4) transfer of eyed eggs from George Adams Hatchery to remote site incubators (RSIs) at Huson Springs facility on a tributary to Union River, with volitional release from RSIs into 16' x 3' x 3' fiberglass raceways; 5) transfer of swim-up fry from George Adams Hatchery to raceways at Huson Springs

facility; 6) rearing of fed fry to ~1 gram for release into Huson Springs and/or for transport to a location near the Union River estuary for release.

This program is only in its third year. A summary of the production for each brood year of the project is provided in Table 10.

Discussion

The supplementation of Hood Canal and Strait of Juan de Fuca summer chum stocks at risk of extinction has been successful in substantially increasing the abundance of summer chum populations. The reintroduction of summer chum to habitats where the local fish have been extirpated has also demonstrated preliminary success. The most immediate benefit of the increased run sizes and reintroductions has been a reduction in the extinction risk for the targeted stocks.

The ultimate goal of both supplementation and reintroduction projects is the establishment of abundant, self-sustaining populations composed of natural origin recruits. It can potentially take several decades to achieve this goal, and the correction of major factors for decline is necessary for recovery to be achieved. Thus, the results from project monitoring and evaluation activities presented here are considered to be preliminary, since the projects are too recent in origin to draw final conclusions. However, several insights are provided on the potential to recover summer chum stocks using supplementation, including:

- the risk of extinction was reduced from high to low for the Big Quilcene and Salmon Creek summer chum stocks following implementation of supplementation programs which contributed adult summer chum to the natural returns and spawning populations;
- summer chum were reintroduced into vacant habitat formerly occupied by summer chum on Big Beef and Chimacum creeks; this is initially considered to be a range extension of the donor stock and further reduces that stock's risk of extinction;
- indigenous summer chum broodstock can be collected in proportion to the timing, abundance, and duration of the total return to the stream and utilized in a supplementation program;
- indigenous-origin summer chum can be incubated, reared and released while following established protocols designed to address hazards with hatchery operations and associated risks to summer chum;
- supplementation programs can be incorporated into existing WDFW and USFWS hatcheries and utilize expertise and experience of current staff;
- new remote hatchery facilities can be developed and operated while minimizing the risk to summer chum;
- new partnerships in the recovery of summer chum can be developed and/or enhanced with community-based groups through supplementation programs; another significant benefit is the nurturing of a stewardship ethic towards wild fish and their recovery and the mutual exchange of ideas and information with dedicated constituents.

Although natural summer chum production is occurring in the region, it appears that impacts to natural processes in freshwater and/or estuarine ecosystems are limiting summer chum production in some years. This re-emphasizes the need for the summer chum recovery program to address all factors affecting summer chum production, including habitat, harvest, ecological interactions, and supplementation. Several habitat restoration and/or acquisition projects have recently been proposed, designed, and funded in the freshwater and estuarine areas of Salmon, Chimacum, and Jimmycomelately creeks along the Strait of Juan de Fuca and for several Hood Canal streams. Completion of these habitat

projects, and others, will help restore habitat function and increase summer chum production and productivity. Harvest management strategies and regimes implemented as part of the Summer Chum Salmon Conservation Initiative are expected to result in, on the average, total exploitation rates of 8.8% on Strait of Juan de Fuca stocks and 10.9% on Hood Canal stocks; these relatively low exploitation rates should also contribute to the recovery of summer chum. As discussed above, the supplementation programs have already contributed substantially to the summer chum adult returns to several streams.

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HOOD CANAL SUMMER CHUM SALMON ESU

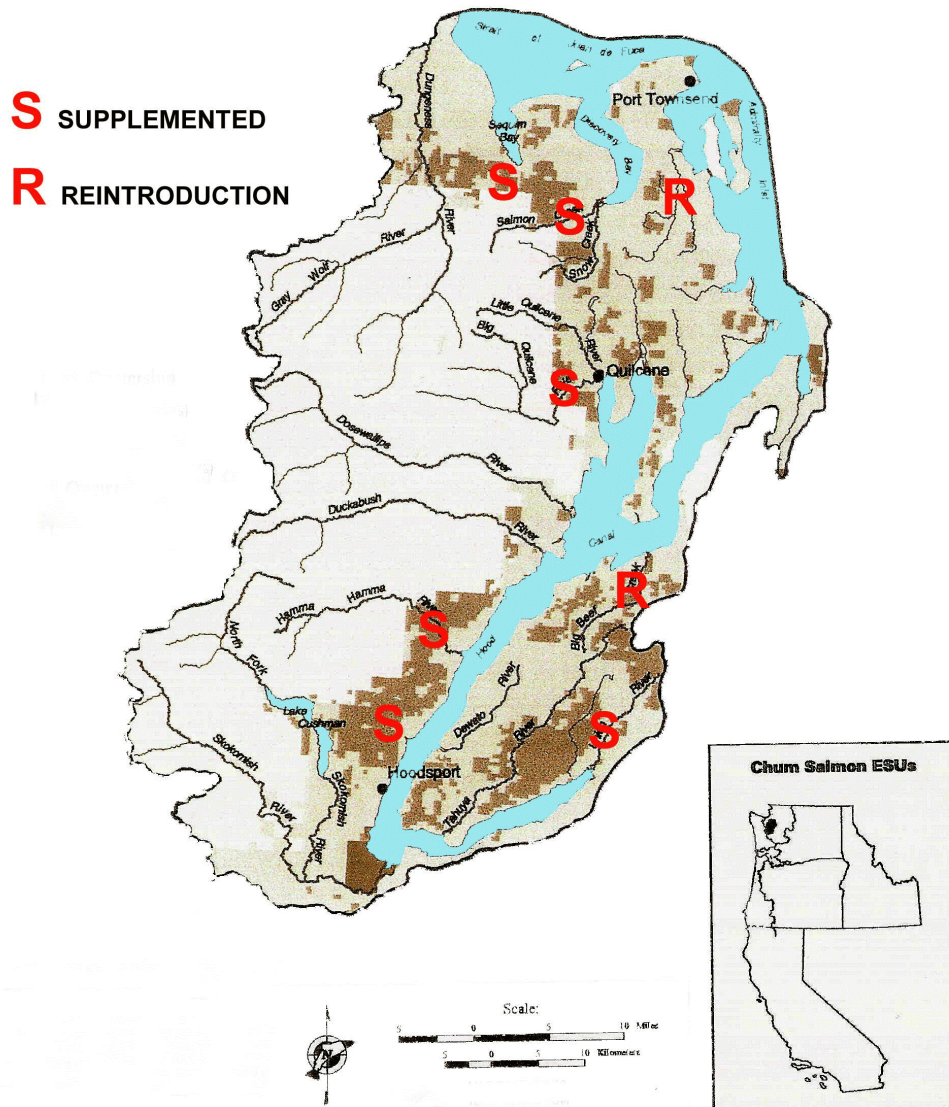


Figure 1. Map of the Hood Canal summer-run chum salmon Evolutionarily Significant Unit (ESU). The locations of ongoing supplementation (S) and reintroduction (R) programs for summer chum populations are shown.

Salmon Creek summer chum

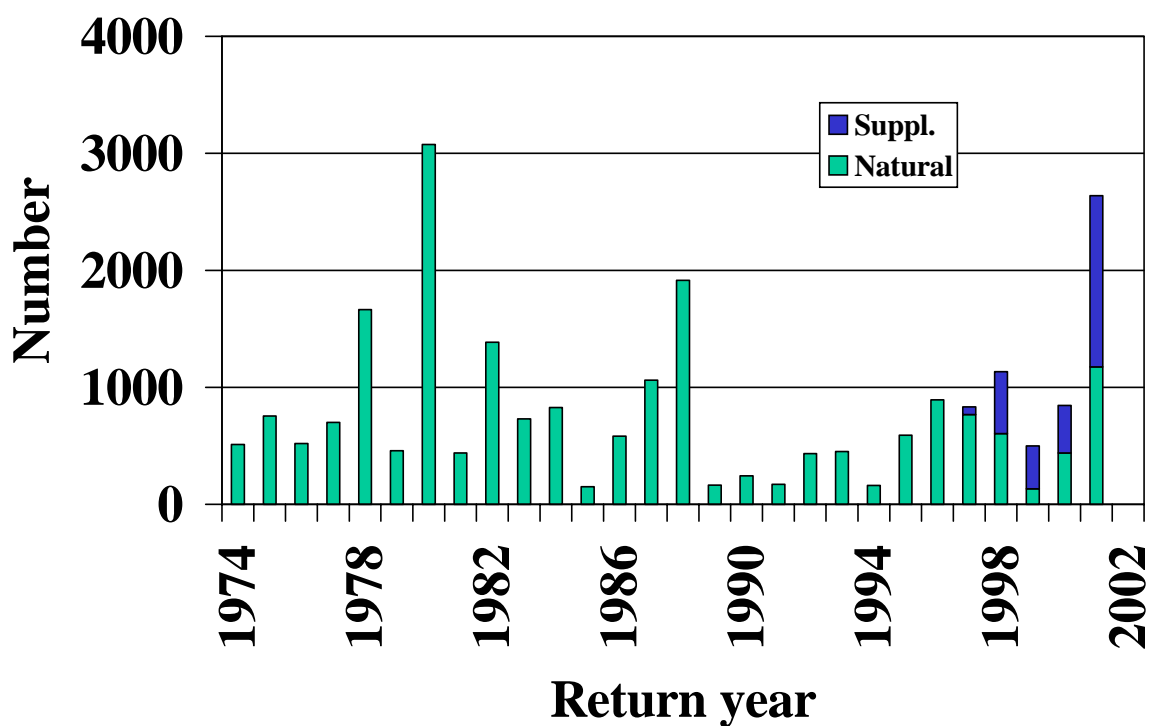


Figure 2. Return of adult summer chum salmon to Salmon Creek, 1974 through 2001. A supplementation program was initiated in 1992 and contributed adults to the return beginning in 1995. Natural-origin and supplementation-origin adults can be distinguished based on otolith marks beginning with return year 1997; however, supplementation-origin adults are underestimated in 1997 (see text).

Table 1. Salmon Creek summer chum salmon supplementation program, brood years 1992-2002.

Brood year	Broodstock			Natural spawners	Percent removed	Fed fry ¹ released	Release size ¹ (gms)	Release date
	Males	Females	Total					
1992	35	27	62	371	14.3%	19,200	1.1	5/7/98
1993	29	23	52	400	11.5%	44,000	1.8	4/27/94
1994	12	12	24	137	14.9%	2,000	1.3	3/31/95
1995	35	18	53	538	9.0%	38,808	1.3	4/23/96
1996	59	50	109	785	12.2%	62,000 ²	1.3	4/8, 4/24/97
1997	60	50	110	724	13.2%	71,821 ²	1.0-1.3	3/31, 4/16/98
1998	65	56	121	1023	10.6%	67,832 ²	1.0-1.3	3/31, 4/21, 5/4/99
1999	34	31	65	434	13.0%	34,680 ²	1.3-2.6	4/23, 6/12/00
2000	71	65	136	710	16.1%	90,435 ²	0.6-1.1	4/14, 4/26/01
2001	77	77	154	2484	5.8%	18,110 ²	1.0-1.1	4/18, 4/27/02
2002	64	64	128	5389	2.3%	72,870 ³	0.35	3/1/02-4/18/02

¹ Release number and size data from Wild Olympic Salmon (1997; 1998) and WDFW files.
² Release numbers do not include 28,788; 36,840; 70,050; 39,170; 73,200; and 79,500 fry of Salmon Creek-origin, released into Chimacum Creek in 1997, 1998, 1999, 2000, 2001, and 2002, respectively.
³ Unfed fry release from remote site incubators

Table 2. Number of eggs, swim-up fry, and fry released and the survival rates by life stage for summer chum salmon reared in the supplementation program at Salmon Creek Hatchery, 1992 through 2000 brood years.

Brood year	Number of eggs or fry					% Survival by life stage			Cumulative % survival		
	Total		Salmon Creek Hatchery			Salmon Creek Hatchery			Salmon Creek Hatchery		
	Green eggs	Eyed eggs	Eyed eggs	Swim-up fry	Fry released	Green egg to eyed egg	Eyed egg to swim-up	Swim-up to release	Green egg to eyed egg	Eyed egg to swim-up	Swim-up to release
1992	46,980	44,280	44,280	18,684	19,200	94.3	42.2	100.0	39.8	39.8	43.4
1993	—	46,300	46,300	26,837	44,000	—	58.0	100.0	—	—	95.0
1994	—	24,200	24,200	2,000	2,000	—	8.3	100.0	—	—	8.3
1995	41,750	39,200	39,200	38,808	38,808	93.9	99.0	100.0	93.0	93.0	99.0
1996	—	114,900 ¹	64,900	62,300	62,000	—	96.0	99.5	—	—	99.5
1997	133,340	112,900 ¹	72,900	71,011	71,821	87.7	97.4	100.0	82.5	82.5	98.5
1998	164,300	149,100 ¹	69,100	68,423	67,807	90.7	99.0	99.1	89.9	89.1	98.1
1999	87,350	78,300 ¹	29,200	28,950	28,400 ²	89.6	99.1	98.1	88.9	87.2	97.3
2000	174,550	165,400 ¹	91,350	90,755	90,435	94.8	99.3	99.6	94.1	93.8	99.0

¹ Total includes eggs taken for both Salmon Creek supplementation and Chimacum Creek reintroduction programs; all green eggs are incubated at Dungeness Hatchery and shipped as eyed eggs to Salmon Creek Hatchery and Chimacum Creek Hatchery.
² Does not include 6,300 fish transferred in June 1 at 256 fpp from Dungeness Hatchery and 6,280 released on June 12 at 175 fpp at RM 0.1 in Salmon Creek after rearing in freshwater there; total release was 34,680 fish for BY 1999.

Table 3. Return from fry to adult for summer chum salmon reared in supplementation program at Salmon Creek, as determined from otolith marks for the 1994, 1995, 1996, 1997 and 1998 brood years.

Stream	Brood year	No. fry released	Return year	Age	Number otolith-marked adults	Return rate by age
Salmon Cr.	1994	2,000	1996	2	—	—
			1997	3	46	2.30%
			1998	4	50	2.50%
			1999	5	0	0.00%
			Total		96	4.80%
	1995	38,800	1997	2	13	0.03%
			1998	3	471	1.21%
			1999	4	148	0.38%
			2000	5	5	0.01%
			Total		637	1.62%
	1996	62,000	1998	2	8	0.01%
			1999	3	219	0.35%
			2000	4	162	0.26%
			2001	5	0	0.00%
			Total		389	0.62%
	1997	71,800	1999	2	0	0.00%
			2000	3	231	0.32%
			2001	4	727	1.17%
			2002	5		
			Total		958	1.48%
	1998	67,800	2000	2	14	0.02%
			2001	3	698	1.03%
			2002	4		
			2003	5		

Table 4. Return from fry to adult for summer chum salmon reared in supplementation program at Salmon Creek, as determined from otolith marks for the 1997, 1998, 1999, 2000 and 2001 return years.

Return year	Total return	Age	Age comp (%)	No. of adults	Otolith marks		Supplementation program		
					(%)	No.	Brood year	No. fry released	Return rate by age
1997	834	2	3.6%	30	44.4%	13	1995	38,800	0.03%
		3	64.3%	536	8.6%	46	1994	2,000	0.29%
		4	30.5%	255	2.7%	7	1993	44,000	0.02%
		5	1.6%	13	0.0%	0	—	—	—
					7.9%	66			
1998	1134	2	0.7%	8	100.0%	8	1996	62,000	0.01%
		3	60.0%	680	69.2%	471	1995	38,800	1.21%
		4	39.3%	446	11.2%	50	1994	2,000	2.50%
		5	0.0%	0	0.0%	0	1993	44,000	0.00%
					46.6%	529			
1999	499	2	0.0%	0	0.0%	0	1997	71,800	0.00%
		3	58.2%	282	75.2%	219	1996	62,000	0.35%
		4	40.7%	197	72.9%	148	1995	38,800	0.38%
		5	1.1%	5	0.0%	0	1994	2,000	0.00%
					73.4%	367			
2000	846	2	6.0%	51	27.3%	14	1998	67,800	0.02%
		3	64.5%	546	42.3%	231	1997	71,800	0.32%
		4	29.0%	245	66.0%	162	1996	62,000	0.26%
		5	0.5%	4	0.0%	0	1995	38,800	0.00%
					48.1%	407			
2001	2638	2	4.4%	116	33.3%	39	1999	34,680	0.06%
		3	42.6%	1125	62.1%	698	1998	67,800	0.97%
		4	52.9%	1397	52.1%	727	1997	71,800	1.17%
		5	0.0%	0	0.0%	0	1996	62,000	0.00%
					55.5%	1464			

Table 5. Chimacum Creek summer chum reintroduction program, brood years 1996-2002.

Brood year	No. eggs received	No. fed fry released	Release size (gm)	Release date
1996	50,000	28,788	0.4-1.5	3/23, 5/9/97
1997	40,000	36,840	0.7	3/27, 4/11, 4/19/98
1998	80,000	70,050	0.6-0.8	3/26, 3/28, 4/21/99
1999	41,300	39,170	0.4-0.8	3/20, 3/31, 4/7, 4/24/00
2000	74,050	73,300	0.8-1.2	4/5, 4/17, 4/18, 4/23, 5/3, 5/10/01 4/18, 4/27, 4/30, 5/2/02
2001	82,490	71,500 8,000 ¹	0.9-1.8 0.35	3/12/02
2002	58,000			

¹ Unfed fry released accidentally into tributary to Chimacum Creek due to tank overflow

Table 6. Jimmycomelately Creek summer chum supplementation program, brood years 1999-2002.

Brood year	Broodstock			Natural spawners	Percent removed	Fed fry released	Release size (gms)	Release date
	Males	Females	Total					
1999	2	2	4 ¹	1	85.7%	3,880	1.0	4/8/00
2000	33	13	46	9	83.6%	25,900	1.0	4/20, 4/28/01
2001	36	32	68 ²	192 ²	23.9%	54,515	0.9-1.2	4/17, 4/26/02
2002	21	15	36 ³	6 ³	63.2%			
¹ Two additional females were trapped for brood stock, but could not be used because they were spawned out.								
² Includes 4 male mortalities in brood stock due to lack of available females; an additional 24 pre-escapement loss due to predation in natural escapement.								
³ Includes 8 male mortalities due to lack of available females and 1 female mortality in brood stock; an additional 15 pre-escapement loss due to predation in natural escapement.								

Table 7. Quilcene National Fish Hatchery summer chum supplementation program, brood years 1992-2002.

Brood year	Broodstock retained			Natural spawners	Percent removed	Fed fry released	Release size, g	Release dates(s)
	Males	Females	Total					
1992	225	186	411	320	56.2%	216,441	1.05	4/13/93
1993	19	17	36	97	27.1%	24,784	1.46	3/30/94
1994	184	178	362	349	50.9%	343,550	1.06	3/27/95
1995	243	256	499	4,029	11.0%	441,167	1.06	3/27/96
1996	438	333	771	8,479	8.4%	612,598	1.34	4/10/97
1997	296	261	557	7,339	7.1%	340,744	1.62	4/2, 4/15/98
1998	313	231	544	2,244	19.5%	343,530	1.28	3/8, 3/22, 4/2/99
1999	81	89	170	2,982	5.4%	181,711	1.03	3/9, 3/24/00
2000	187	195	382	5,126	6.9%	414,353	1.01	3/5, 3/19/01
2001	134	172	306	5,868	5.0%	351,709	0.98	3/3, 3/22/02
2002	174	181	355	3,662	8.8%			

Table 8. Total escapement to Big Quilcene River (natural spawners and hatchery spawned).

Return year	Total escapement
1974	795
1975	1,405
1976	2,445
1977	821
1978	2,978
mean 74-78	2,607
1979	345
1980	375
1981	138
1982	156
1983	64
1984	60
1985	44
1986	15
1987	8
1988	120
1989	1
1990	6
1991	49
1992	734
1993	136
1994	722
1995 ¹	4,520
1996	9,250
1997	7,874
1998	2,792
1999	3,153
2000	5,630
2001	6,185
2002	4,022
¹ First year of returns from supplementation program.	

Table 9. Big Beef Creek summer chum reintroduction program, brood years 1996-2002.

Brood year	Males	Females	Total	Natural spawners	Percent removed	No. eyed eggs from QNFH ¹	No. fed fry released	Release size (gm)	Release date
1996	-- ¹	-- ¹	-- ¹	0	--	168,000 ²	204,000	0.5-0.7	2/7, 3/7/97
1997	-- ¹	-- ¹	-- ¹	0	--	157,000	100,280	0.8	2/9/98
1998	-- ¹	-- ¹	-- ¹	0	--	217,465	214,936	1.1-1.6	2/23, 3/15, 3/29/99
1999	-- ¹	-- ¹	-- ¹	0	--	40,298	39,800	1.4	3/10/00
2000	9	11	20	0	--	81,672 ³	80,550	1.4-1.8	2/26, 3/13/01
2001	34	34	68 ⁴	826	7.6%	--	80,925	1.4-1.7	3/4, 3/14, 3/25/02
2002	32	33	65 ⁴	677	8.8%	--			

¹ Eyed eggs received from Quilcene National Fish Hatchery (QNFH)
² Also received 40,000 swim-up fry from QNFH.
³ Includes 26,172 eyed eggs from Big Beef Cr. fish and 55,500 eyed eggs from QNFH.
⁴ Includes 2 broodstock mortalities in 2001 and 2 broodstock mortalities in 2002

Table 10. Union River summer chum supplementation program, brood years 1997-2002.

Brood year	Broodstock			Natural spawners	Percent removed	Fed fry released	Release size (gms)	Release date
	Males	Females	Total					
2000	30	32	62	682	8.3%	75,876	1.0	2/21, 2/27/01
2001	32	32	64	1486	4.3%	73,472	1.0	2/21, 2/27/02
2002	32	33	65	807	7.5%			

The Hatchery Scientific Reform Group – Its Mission for Puget Sound and Coastal Washington Hatcheries

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Note: background information on this group available at www.lltk.org/hatcheryreform.html.

Extended Abstract

The purpose of this paper is to inform readers about the Hatchery Reform Project currently underway in Puget Sound and Coastal Washington and to outline the role of the Hatchery Scientific Reform Group (HSRG) in it.

There are over 100 hatchery facilities in Puget Sound and Coastal Washington operated by WDFW, Puget Sound and Coastal Indian tribes, and the USFS. These hatcheries produce more than 100 million juvenile salmon and steelhead every year, playing an important role in the North Pacific sports and commercial fishing economy and in meeting tribal treaty harvest obligations. The hatcheries, however, have also been identified as one of the factors responsible for the depletion of wild salmonid stocks.

In the fiscal year 2000, the US Congress adopted and funded the recommendations of an advisory team of leading scientists, launching the Puget Sound and Coastal Washington Hatchery Reform Project. Then- Senator Slade Gorton (R-WA), Senator Patty Murray (D-WA), Congressman Norm Dicks (D-WA), and Washington Governor Gary Locke all supported the project.

The Hatchery Reform Project is a systematic, science-driven redesign of how hatcheries will be used to achieve two purposes: 1) helping to recover and conserve naturally spawning populations; and 2) supporting sustainable fisheries. The appropriation language provided funding to: 1) establish an independent scientific panel to ensure a scientific foundation to hatchery reform; 2) provide a competitive grant program for needed research on hatchery impacts; 3) support state and tribal efforts to implement new hatchery reforms; and 4) provide for a facilitation of a reform strategy by an independent third party, to ensure implementation of reform.

The scientific group (panel) is composed of five independent scientists (selected from a pool of candidates nominated by the Past Presidents Council of the American Fisheries Society) and four agency scientists designated by WDFW, the Northwest Indian Fisheries Commission, NFMS, and USFWS. Like the independent scientists, the agency scientists are responsible for evaluating scientific merits and are not to represent agency policies. The nine scientists serving on the scientific Group have a broad range of experience. Their scientific disciplines include biology, genetics, ecology, fisheries management, fish culture, fish pathology, biometrics, and other disciplines.

Seeking to go beyond merely complying with ESA directives that hatcheries be operated to minimize risks to endangered fish, the managers of Washington's salmonid resources embraced this new vision of reforming hatchery programs to provide benefits to the process of recovering wild salmon and supporting sustainable fisheries. The managers requested that a Hatchery reform Coordinating Committee be established to focus on the "big picture" of this effort to reform hatcheries. The Coordinating Committee

includes representatives of the Tribes, WDFW, NFMS, USWS, Long Live the Kings, and the science advisory team members not serving on the Scientific Group. The purpose of the committee is to ensure a successful working relationship between the independent science panel, manager leadership, and the managers' own science teams.

The third party facilitator specified by Congress is Long Live the Kings (LLTK), a private, non-profit organization whose mission is to restore wild salmon to the waters of the Pacific Northwest. LLTK's role includes providing and staff support to the scientific panel and Coordinating committee; as well as helping the managers and the scientific panel communicate hatchery reform progress to Congress, state legislators, stakeholder groups, and the public.

In the project's first year, the HSRG developed a number of tools to assist with the reviews and for the managers' use: 1) the **Scientific Framework** which assembles what is and is not known about how hatcheries can and cannot help to recover naturally spawning populations and support sustainable fisheries. The document was reviewed by over 200 scientists and stakeholders. The document is published on the project's website; 2) the **Benefit/Risk Assessment Tool** which allows the HSRG and the managers to evaluate the relative benefits and risks associated with specific actions and choices in hatchery management -- in a scientifically sound and methodical manner; 3) the **Hatchery Operational Guidelines** which give operational procedures consistent with the Scientific Framework, to assure genetic integrity, the prevention of disease, provide new guidelines for optimal fish rearing and administrative functions, and limit adverse ecological impacts; 4) the **Monitoring and Evaluation Criteria** which will be used to determine the success of a hatchery program. The criteria will provide a blueprint on how to collect and evaluate data relating to the health of out-migrating smolts, stray rates of returning adults, the effect of the hatchery on fish size and run timing, etc.; and 5) a **Research Program** which will attempt to fill gaps in knowledge related to hatcheries and for which the HSRG has awarded competitive grants totalling over \$1.5 million to date.

In preparing for the hatchery reviews, the HSRG concluded that they would best be done on a regional scale because this would take into account the cumulative effects of hatchery production, stock status, habitat conditions, and harvest goals. The Coordinating Committee concurred with this approach and with the ten regions identified by the Scientific Group. The regions identified are: Eastern Straits, South Sound, Stillaguamish/Snohomish Rivers, Skagit River Basin, Nooksack/Samish Rivers, Central Sound, North Coastal, Hood Canal, Willapa Bay, and Grays Harbor. It is turning out that the regional approach is the correct one because the HSRG is finding that stock status, habitat quality, and the purposes that the managers have prescribed for each region differ significantly. A consideration of the Puget Sound/Coastal hatchery system as a whole would have resulted in broad-brush recommendations not suited to these regional differences. Conversely, the usual level of decision making -- by program or facility -- would not have permitted the best use of the hatchery system as a system.

Regional reviews normally take place over two three-day meetings, held in the region over two consecutive months. The facilitation team works with the regional managers and state and tribal science teams to assemble a briefing book containing four key categories of information on: 1) regional goals for conservation, harvest, and other purposes; 2) stock status (biological significance and population viability); habitat status (current and future); and 4) hatchery programs. The briefing book is made available to the scientific Group ahead of the regional review meetings. The latter start (day 1) with a tour of the region arranged by the facilitation team and the regional managers, to complement the briefing book information and to provide the HSRG with a better understanding of the region and its hatchery facilities. During the next four days of the review, the HSRG meets with the managers to complete all the information required by the Benefit/Risk Tool. On day 2 of the meeting, information on the goals for the affected stocks and habitat, and on the objectives of the current hatchery programs is presented. On day 3, the HSRG learns how current operations compare with the HSRG's guidelines for a) accountability and

education, b) genetics and conservation, c) fish physiology, morphology and ecology, and d) culture methods. On day 3 the regional hatchery managers are present to fill in any operations information not provided in the briefing book or during the field tour. On day 4, the HSRG reviews any additional information provided by the regional managers and evaluates whether the hatchery programs are consistent with their short- and long-term goals. This involves identifying the risks and benefits from each hatchery program to all hatchery and wild stocks in the region. On day 5, the HSRG applies all the information it has acquired to making preliminary recommendations on the regions' hatchery programs and then decides on how best to present the results to the regional managers at the next day's informal review session. On the 6th (and final day) of the regional review, the HSRG provides the regional participants with an informal review of the region. The session involves oral presentations. No written report is provided. The regional managers have the opportunity to ask questions and engage in discussion. Only after all three or four regions in any particular group are reviewed will the HSRG draft its written report on the group. The report will take into account any actions taken and last-minute information provided by the regional managers, and includes the written reactions of the managers to the HSRG's recommendations.

The HSRG is now in the process of reviewing the final group of regions but already it has some accomplishments to report. It has prepared and refined the necessary tools for evaluating hatchery programs -- tools that should also be of use to hatchery program managers. It is already seeing many of its recommendations implemented -- recommendations that range from the fine-tuning of hatchery programs to the discontinuing of hatchery programs and even to the closure of one hatchery. It has developed a number of area-wide recommendations that apply to all hatchery programs and that all hatchery program managers would do well to consider applying to their hatchery programs. It has supported important research that promises to throw light on a number of questions relating to various hatchery practices that need answers. Finally, it is in the process of developing strategies that should help to ensure that it leaves a lasting legacy: that managers from now on make a habit of monitoring, evaluating, and adaptively managing their hatchery programs on a regular basis.

Session 8

Session Leader: Tracy Cone (CDFO)

Poster Presentations and Other Displays

Benthic Fauna, Juvenile Fish Feeding and Food Interrelations in Chum Salmon Basis Hatchery Watersheds (Kamchatka)

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Introduction

There are 5 acting Salmon Hatcheries in Kamchatka currently and several new ones to be built. The increase of hatchery salmon percent in important natural salmon nursery and feeding watersheds of Kamchatka creates the need to study the processes occurring in newly populations and in the area inhabited by them.

Hatchery juvenile chum salmon has been usually released in the time when wild juvenile chum salmon migrate down the river, therefor the adaptation of hatchery juvenile salmon to natural environment relays to several negative aspects. Juvenile chum salmon should interrelate to each other and to environment. The interrelations can be more or less hard dependently to some terms: the concentration of down stream migrants, competitors and predators, the abundance of forage organisms, the period of feeding and down stream migration, morphophysiological characteristics, hydrology in spring-summer months. Therefore, especial strategy of release is required to make the hatchery juvenile chum salmon survival in the basis Salmon Hatchery watersheds better. Development of benthos and, hence, the food supply depends on the warming of the watershed. It is found (Zhuykova, 1975) that poor feeding of major part of Maliy Takoy River (Sakhalin) chum salmon population until mid May takes place due to low water temperature in the river for this period (3-4° C); under the increase of the temperature up to 7-11°C the feeding has been intensified. The role of predators is great. In the years of low chum and pink salmon abundance the predators consume 15-30% of juvenile stock (Levanidova, 1969). In the years of high abundance of these species the role of predators has been less important, and predation has been minor factor of natural mortality. The elimination of down stream chum and pink salmon migrants takes place in the period of mass down stream migration.

Salmon Hatcheries in Kamchatka are situated either at the rivers and at the lakes. In the current article we present the results of the studies carried out in two chum salmon basis hatchery watersheds - the river and the shallow brackishwater lake.

Material and Methods

The material was collected in the Paratunka River and in the shallow brackishwater lake Bolshoy Viluy (Figure 1). The studies aimed two directions: 1 - benthos state, 2 - the character of feeding and food interrelations between wild and hatchery juvenile chum salmon.

Figure 1

Benthos samples were collected using Levanidov's trap (the square of catch 0.12 m²); fishes were sampled using juvenile trap net.

Common well known methods were used for the analysis of fish feeding (Guideline ..., 1974). The content of stomachs was analyzed. All calculations (feeding intensity, component frequency, the number and the mass of organisms by species in stomach content) were carried out taking into account total number of fish in a sample including the individuals which stomachs were empty. Feeding intensity was estimated from the indexes of consumption and from the number of none feeding fish.

The method of Shorygin (1952), consisting in food similarity assessment for two groups of fish from the sum of minimum percents of mutual objects met, was used to compare food spectrum.

Results and Discussion

Paratunka River. Salmon Hatchery is situated in the mediate reaches of Paratunka River (Figure 2).

Figure 2

The composition of benthofauna varies extensively and includes *Vermes* (*Olygochaeta*, *Planaria* and *Nematoda*), *Entomostraca* (*Ostracoda*, *Harpacticida*, *Cyclop sp.*, *Chydorus sphaericus*, *Daphnia sp.*) and *Malacostraca* (*Hammaridae*), *Mollusca*, *Tardigrada*, *Hydrocarina* and larval *Insects* (*Chironomidae*, *Plecoptera*, *Ephemeroptera*, *Trychoptera*, *Collembola*, *Simuliidae*).

Bottom communities have been maximum dense in April; till June the abundance of organisms has been decreased gradually (Figure 3).

Figure 3

The dynamics of benthos invertebrate abundance depends on one group of organisms - larval chironomids. The group determines the structure of bottom community and plays the most important role in juvenile salmon feeding.

In total there are 34 species of larval chironomids from five subfamilies: *Diamesinae*, *Orthocladinae*, *Chironominae*, *Tanypodinae* and *Prodiamesinae*. More than a half number of the species belongs to two subfamilies: *Orthocladinae* (18) and *Diamesinae* (6) (Table 1). Representation of the subfamilies is of typical inhabitants of quick-running cold-water streams. The composition of chironomid species has been enlarged along warming the watershed.

Table 1

The composition and the dynamics of development of chironomids are determined by two factors - metamorphosis (transformation into pupa and imago) and elimination by fishes. In April the abundance of chironomids is maximum because their majority is of larvae to be consumed by wild juvenile fish only. A sudden decrease in larval chironomid abundance in May-June is determined by metamorphosis and extremely intense consumption by wild and hatchery juvenile fish.

The dynamics of chironomids is as next:

	Abundance ($1 \times 10^3/m^2$)			Biomass (g/m^2)		
	April	May	June	April	May	June
1999	41.4	8.8	1.7	11.6	2.7	0.4
2000	33.0	3.3	1.0	7.2	0.7	0.4

Juvenile pink and chum salmon use to migrate from mid April to first 10-day period of June. During down stream migration in Paratunka River juvenile pink salmon is poor feeding, the majority offish observed has empty stomachs. Juvenile pink salmon was feeding mostly on chironomids, moreover, if to estimate from food composition in stomachs, juvenile pink salmon isn't concluded to be passive. Larval chironomids observed in stomachs were mostly at III-IV stage, it being their composition various. Average indexes of consumption in April took $25.6-80.5^{0}_{000}$, in May - $26-66.9^{0}_{000}$.

General forage organisms in the feeding of hatchery and wild juvenile chum salmon (and pink salmon) were chironomids at various stages. The composition of larval chironomid species in fish stomachs was various, large individuals at III-IV stages being dominating. Juvenile chum salmon feeding intensity in the course of migration varied as next: forage consumption had been decreased evidently in first and second 10-

day periods of May, while the rest time it was high. Feeding intensity decrease took place as a result of the increase of the abundance of juvenile down-stream migrants. To the first and second 10-day periods of May there has been extremely high number of down-stream migrants including juvenile pink and a majority of wild and hatchery chum salmon released.

A very high food similarity index was typical for all migrants. Interspecies food similarity between pink and chum salmon varied in the range 56.7-89.3%. Food similarity between wild and hatchery chum salmon in April took 81.2%, in May – 63.5%, in June 67.5%. A high index of food similarity is typical for these fishes for the whole period of down-stream migration in all river biotopes.

In the course of the whole observation period hatchery juvenile chum salmon in the river consumed less volume of food it being compared to wild chum salmon.

According to the results of the studies carried out the release of Paratunsky Hatchery juvenile salmon is concluded to be launched from late April to go for a longer period being compared to that in former years. That should make the press of predation minimized and the use of forage resources more balanced.

Bolshoy Viluy Lake has a 100m junction channel to Avachinsky Bay (Figure 4). Invertebrate inhabitants of the lake bottom ecosystems are represented by freshwater, brackishwater and marine species. The species are of *Vermes*, *Entomostraca* and *Malacostraca Crustacea*, *Mollusca*, *Tardigrada* and larval *Insects*. The composition and the distribution of species in bottom ecosystems vary through out of the lake. For example, in the north and northwest parts *Eurytemora* are dominating in the abundance, the hammaruses and olygochets are biomass dominants. Bottom ecosystems in the east and south-east parts are mostly inhabited by hammaruses, chironomids and olygochets. Near the very sea (southern part) the ostracods and the olygochets are the most frequent, it being chironomids and *Kamaka kuthae* the dominants in the biomass.

Figure 4

The abundance and the biomass of benthos invertebrates during whole the period of vegetation is very high; the most intense development of organisms takes place in June, average abundance and biomass takes $143.3 \times 10^3/\text{m}^2$ and $117.0 \text{ g}/\text{m}^2$ respectively.

The ichthyofauna in the lake consists of starry flounder *Platichthys stellatus*, Asian *Hypomesus olidus* and pond *Hypomesus japonicus* smelts, chars *Salvelinus alpinus*, herring between wild and hatchery chum salmon in April took 81.2%, in May – 63.5%, in June 67.5%. A high index of food similarity is typical for these fishes for the whole period of down-stream migration in all river biotopes.

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Clupea pallasii pallasii, coho salmon *Oncorhynchus kisutch*, cut trout *Salvelinus leucomaenus*, chum salmon *Oncorhynchus keta*, three-spine *Gasterosteus aculeatus* and nine-spine sticklebacks *Pungitius pungitius*.

The release of juvenile chum salmon took place during 10-12 days in June. First two days juvenile chum salmon was in vicinity of the hatchery, than it began to emigrate from the places of release. The character of hatchery chum salmon feeding transformed in the course of migration. Juvenile chum salmon feeding near the hatchery was poor, on the water plant residuals and detritus mostly. Average index of food consumption was equal to 11 o/ooo. In the course of emigration from the area closed to the hatchery food spectrum has been enlarged; general objects of feeding were imago insects (mostly chironomids). The studies carried out in 1999 and 2001 revealed significant difference in the character of juvenile chum salmon feeding. In 2001

the consumption of forage organisms by hatchery chum salmon increased several times as much it being compared to that in 1999 (Table 2). That significant difference occurred due to the transformation of migration ways: in 1999 juvenile salmon totally migrated along the marine-side shore of the lake only, whence in 2001 - along both shores. Moreover, in 2001 the number of hatchery juvenile salmon released was by one third less. The index of food similarity for juvenile chum salmon and other species was insufficient at the beginning and increased to the end of migration (at the expense of consumption of imago insects by all fish species).

Table 2

The species to predate on juvenile chum salmon in Bolshoy Viluy Lake were the chars of various ages, starry flounder, coho salmon and cut trout. The species were mass in the places of chum salmon hatchery release, and fed on juvenile chum salmon extensively. In the course of chum salmon emigration and chum salmon density decrease in the area near the hatchery, the intensity of elimination due to predation was decreased significantly. In the other parts of the lake hatchery chum salmon wasn't found in stomachs of predator species.

To the end of July hatchery juvenile chum salmon left this lake totally, a few number of juvenile salmon was observed in the channel between the lake and Avachinsky Bay.

The results obtained over the studies on the basis Paratunsky and Viluchinsky Salmon Hatchery watersheds make us to conclude that the survival of hatchery juvenile chum salmon can be increased if release period is enlarged and a multi-direction migration (along the both shores of Bolshoy Viluy Lake) is provided.

Citation

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Shorygin, A. A. The feeding and food interrelations of fish in Kaspiyskoye Sea. Moscow: Nauka. 1952. 253 p.

Zhuykova, L. I. The feeding and the growth of juvenile fall chum salmon in Maliy Takoy River//Izv. TINRO. 1975. V. 95. P. 36-46.

Figures and Tables

Figure 1. The location of the hatcheries mentioned in the map of Kamchatka.

Figure 2. The plane of the Paratunsky Salmon Hatchery basis watershed.

Figure 3. The abundance of benthos invertebrates and larval chironomids in Paratunka River.

Figure 4. The plane of the Viluchinsky Salmon Hatchery basis watershed.

Table 1. Larval chironomids in the Paratunka River benthofauna (the percent from the total abundance).

Table 2. Hatchery juvenile chum salmon feeding intensity in 1999 and 2001 in the lake Bolshoy Viluy, /₀₀₀.

Table 1. Larval chironomid in the Paratunka River benthofauna (the percent from the total abundance).

Species	April		May		June	
	1999	2000	1999	2000	1999	2000
Subfamily Tanypodinae						
<i>Ablabesmia</i> sp.	0.6	0.1	0.6	1.1	0.3	12.5
Subfamily Diamesinae						
<i>Diamesa</i> sp. juv.	-	-	0.6	-	0.3	-
<i>Diamesa davisi</i>	-	1.8	0.6	-	-	0.2
<i>Diamesa gregsoni</i>	-	0.1	0.1	-	-	-
<i>Diamesa tsutsui</i>	-	0.8	-	-	-	-
<i>Pagastia orientalis</i>	0.0	0.3	0.1	-	0.4	1.5
<i>Prodiamesa olivacea</i>	-	0.3	0.1	-	-	-
<i>Pseudodiamesa</i> spp. juv.	-	-	0.1	-	0.3	-
<i>Pseudodiamesa</i> gr. <i>braniskii</i>	1.3	-	0.3	-	-	0.4
<i>Pseudodiamesa nivosa</i>	-	0.1	-	-	0.3	1.6
Subfamily Prodiamesinae						
<i>Odontomesa fulva</i>	7.6	1.6	5.4	7.6	9.8	1.8
Subfamily Orthocladiinae						
<i>Corynoneura</i> gr. <i>scutellata</i>	-	-	0.3	-	0.1	-
<i>Cricotopus sylvestris</i>	0.0	0.7	0.0	-	-	2.4
<i>Diplocladius cultriger</i>	2.1	56.2	1.2	1.0	0.5	0.2
<i>Eukiefferiella</i> spp. juv.	-	-	-	0.1	-	-
<i>Eukiefferiella gracea</i>	-	0.5	0.0	-	-	-
<i>Euryhapsis cilium</i>	-	-	0.2	-	-	-
<i>Heterotrissocladius</i> gr. <i>marcidus</i>	0.8	3.8	0.8	2.1	4.0	1.3
<i>Hydrobaenus</i> gr. <i>lapponicus</i>	8.5	6.8	2.9	0.1	0.8	0.2
<i>Orthocladius</i> (<i>Euorthocladius</i>) sp. 1	-	0.0	0.4	-	0.1	-
<i>Orthocladiina</i> indet. juv.	-	-	2.8	-	-	-
<i>Orthocladius</i> spp. juv.	2.0	2.0	4.1	2.9	1.5	10.9
<i>Orthocladius obumbratus</i>	0.1	1.3	10.3	4.0	3.9	2.0
<i>Orthocladius thgonolabius</i>	-	-	0.9	-	-	-
<i>Parakiefferiella</i> sp.	-	0.4	0.2	0.8	0.1	-
<i>Paracladius conversus</i>	-	-	1.5	-	-	-
<i>Paratrachocladius skirwithensis</i>	-	0.1	-	-	-	-
<i>Parorthocladius</i> sp.	-	0.7	0.0	-	-	-
<i>Reosmittia</i> sp.	-	-	0.0	-	0.1	-
<i>Stilocladius</i> sp.	-	-	0.0	-	-	-
<i>Thinimanniella clavicornis</i>	-	-	0.1	-	-	1.3
<i>Tvetenia bavahca</i>	-	-	0.2	-	-	-
Subfamily Chironominae						
<i>Chironominae</i> indet. juv.	3.0	2.7	6.3	5.2	38.0	0.9
<i>Harnischia fuscimana</i>	4.6	2.0	2.8	11.5	6.0	24.2
<i>Micropsectra</i> gr. <i>praecox</i>	69.1	17.7	55.6	63.5	7.8	33.2
<i>Polypedium</i> sp.	0.0	-	0.1	-	-	4.5
<i>Sergentia</i> gr. <i>coracina</i>	0.3	-	1.3	0.1	23.6	-
<i>Stictichironomus</i> sp.	-	-	-	-	2.1	-
<i>Tanytarsus</i> sp.	-	-	0.1	-	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0

Table 2. Hatchery juvenile chum salmon feeding intensity in 1999 and 2000 in the lake Bolshoy Viluy, ‰.

Year	Near the hatchery	Sakharny Spring	Near the sea
1999	2.8	5.8	8.3
2000	25.2	147.0	276.8



Figure 1



Figure 2

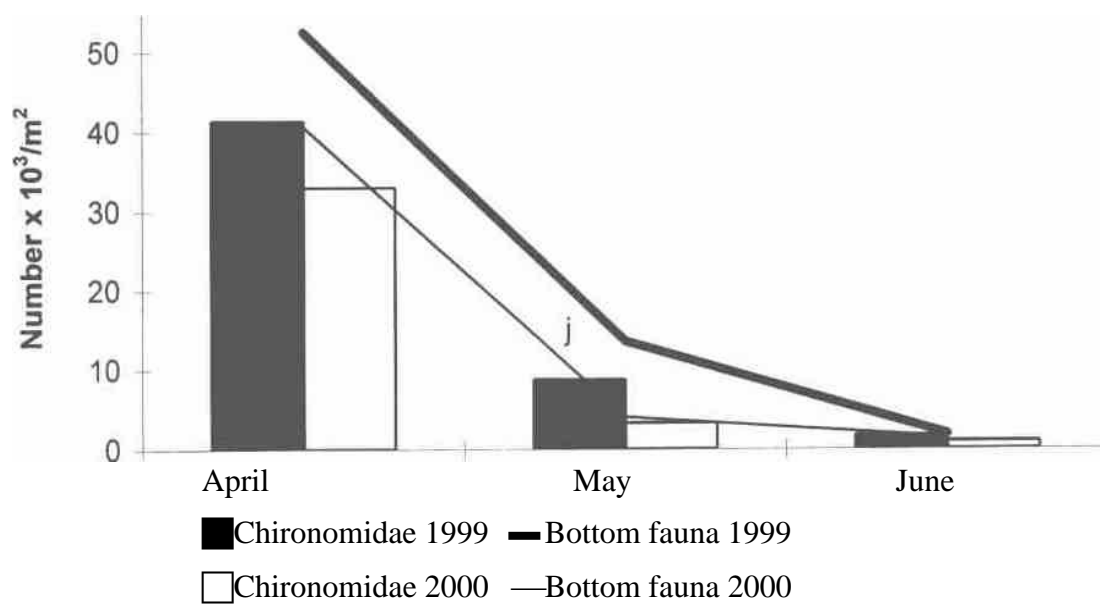


Figure 3

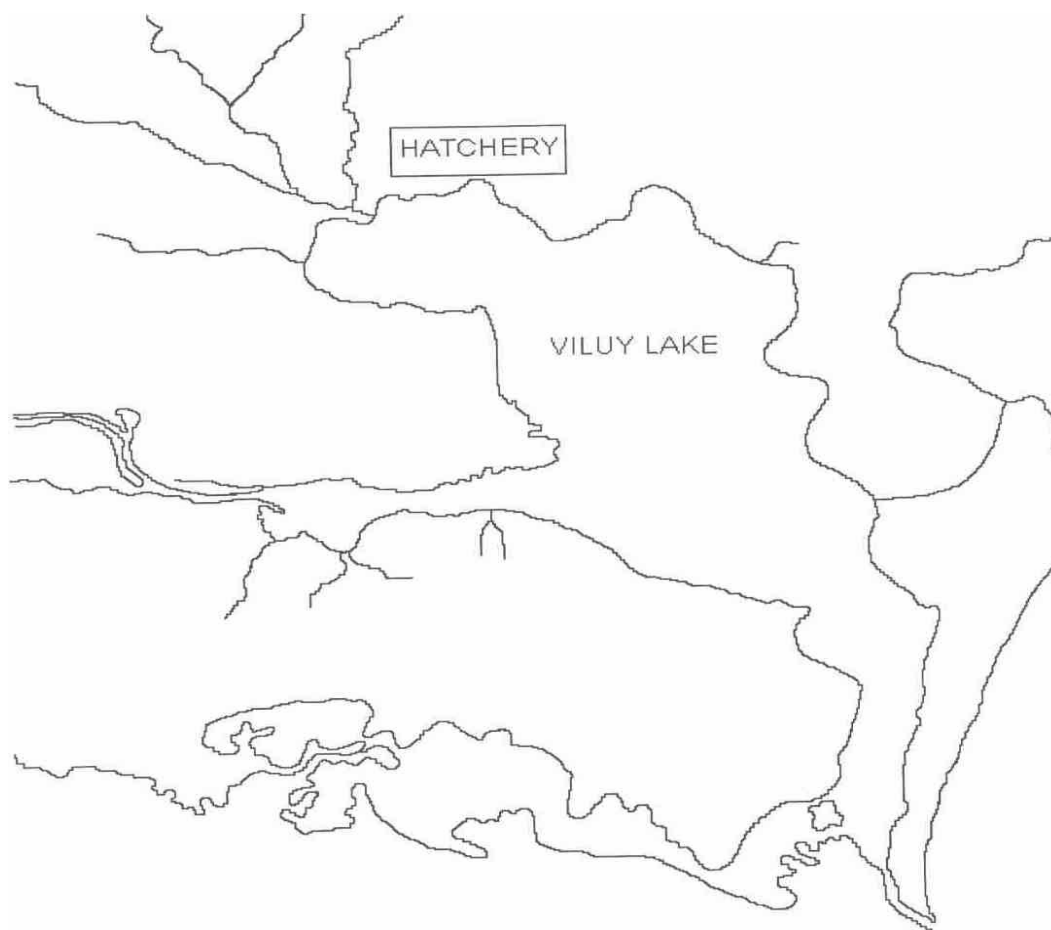


Figure 4

Structure and Dynamics of the Paratunka River Chum and Pink Salmon Stocks, East Kamchatka

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Extended Abstract

Qualitative and quantitative characteristics of adult chum salmon and pink salmon from mediate reaches of Paratunka River have been analyzed for the period 1994-2002. Problems of interaction between these two species have been discussed.

Paratunka River until it has been falling into Avachinskaya Bay passes through the most human-inhabited area in Kamchatka Region - Petropavlovsk and Yelizovo Cities. With extensive development of traffic net throughout the basin of Paratunka River the spawning grounds of Pacific Salmon have been more available for people including poachers. In the same time the area mentioned is the area where salmon hatcheries are situated. Since 1993 chum salmon release from the Paratunsky Hatchery into the tributary of Paratunka River has got up to 20×10^6 individuals every year which have been returning to the river for spawning in several years.

That human activity on the artificial reproduction hardly can bring no effects to the Paratunka River ecosystem including Pacific Salmon populations. Therefore dynamics and structure of local Pacific Salmon populations should be studied in a complex for the period since early 1990 (Zaporozhets, Zaporozhets, 2000, 2001).

Material and Method

For the purposes of collecting the materials a control every-morning river drift-net catch has been used by lab workers from KamchatNIRO from late June to late October in a certain plot of Paratunka River. This plot of 2 km in length approximately is accepted as ichthyological survey "standard" plot. Composition of species, individual fish length and mass, sex ratio, gonad mass, average egg mass in the catches have been described and scale samples have been collected. The number of post-spawners and unpicked, as a result of poaching, fishes has been estimated in spawning grounds within the upper reaches of Paratunka River.

Scale samples have been taken from the area upper the lateral line between dorsal and adipose fins as it was recommended by NPAFC (Knudsen, 1985; Davis et al., 1990). European system of Pacific Salmon age coding has been used (Koo, 1962) according to the recommendations of NPAFC (Davis et al., 1990). Total sample size collected in 1992-2002 of chum salmon and pink salmon were 7850 and 1520 specimens.

Results and Discussion

Materials from annual ichthyological surveys in the standard plot of Paratunka River, accomplished in the course of spawning run, i.e. for 3.5-4 months, provided graphic reconstruction of statistical dynamics on average catches. These data on the average number of fishes of every species in the catches have been shown in the Figure 2.

Chum salmon is one of dominant species in Paratunka River. Chum salmon spawning migration to mediate reaches usually lasts about two months and a half. Pioneer chum salmon (large males of

older ages) use to come there in early July when water temperature in the river gets more than 6°C. Females always come for spawning later and stay more time being compared to males. The maximum of the first wave of run takes place in late July – early August; the second wave has been maximum in mediate or late August. The water in the river by this time gets warmed up to 8-9°C. By September the mass migration of chum salmon to the mediate reaches of Pratunka River has been over; by the end of the month, when water temperature has got decreased up to 6°C and lower again, chum salmon gets catchable within the area much more upward the stream, on the spawning grounds only. Data from KamchatNIRO's annual assessments and our own collected materials from biological analysis of salmon indicate of gradual decrease of chum salmon abundance right until 1998. We have supposed that an increase of chum salmon abundance for next years is a consequence of reproduction in Paratunsky Hatchery (Zaporozhets, Zaporozhets, 2000, 2001).

Data review for recent years indicates the dominance of males in number. The percent of males in the catches varies extensively (from 52 to 81%) no matter high or low the stock abundance is. Nevertheless a general tendency has been revealed that the percent of females has been decreasing in the course of migration mostly at the expense of poaching.

It has been found that the age structure of chum salmon escapement varies not only in the course of spawning run, also from year to year (Figure 3). Mostly contributing ages (up to 98%) in the age structure of Paratunka River stock are 0.3 and 0.4, dominating in different years alternately. For the studied period we can establish the fact of older average age of spawners it being similar to that in the other regions of intense chum salmon hatchery reproduction (Helle, Hoffman, 1994, 1995). The older age has been created at the expense of increasing 0.4 age group.

Analysis of Paratunka River chum salmon biological parameters confirms generally accepted correlation according to which chum salmon males are more large, being compared to females of the same age; fish size (and mass) and fecundity (although not in that clear way) have been increased with aging (Figure 4, Figure 5).

Studied the dynamics of these characteristics shows increased body size, independently to sex of spawners, and fecundity in chum salmon, returning for spawn in the age 0.3 and 0.4. This fact revealed does not coincide to the results by other sources (Helle, Hoffman, 1994, 1995, 1998; Azumaya, Ishida, 2000; Volobuev, 2000). It could be suggested that this chum salmon stock demonstrates less competition for the forage resources, being compared to other stocks. Due to the processes, taking place in this population, average mass of adults has got increasing (Figure 6).

Pink salmon. For recent 50 years generations from odd years have been dominating in the East Coast of Kamchatka. For the studied period pink salmon abundance, estimated from our catches, corresponded clearly to the two-year cycle. The most abundant run was observed in 1997 (up to 130 fishes in the catch), the most poor run - in 2002, when less than 1 pink was observed in the catch. Thus, interannually changes of pink salmon stock abundance should be reckoned as significant indeed.

Spawning run in mediate reaches of Paratunka River usually takes one month and a half approximately – from late July until September. In rare cases pink salmon can be met in the river by the end of September. However, this time is mostly the time of pink salmon mass spawning in the upper reaches of the river, where pink salmon sometime use to compete with chum salmon for the spawning grounds. Like in the case of chum salmon large males of pink salmon use to go upward the stream first. Females come and have finished their run later than males. Body size of spawners as a rule has got decreasing to the end of spawning run. Body length, mass and fecundity vary interannually (Figure 7). Actually no one of these changes does correlate to the stock abundance reliably.

Sex ratio in pink salmon similar to that in the other salmon changes in the course of spawning run and from year to year, it being a little bit less than 1 in average. A certain relation between sex ratio

and stock abundance for the period studied has not been revealed. Average length/mass parameters are slightly different in males and females usually, moreover variations of the parameters in males are more extensive being compared to those in females. However no one of the differences has been found reliable.

Relations Between Chum Salmon Population Characteristics

Among the problems, concerning stock structure and abundance of Paratunka River Pacific Salmon, the relation between pink salmon run and chum salmon age structure should be studied first of all on our view. This relation has been always studied extensively actually. It is found, however, that the relation has not been revealed as permanent reliable and obvious (Salo, 1991). Therefore, we analyzed the data we obtained for 1994-2002 on pink salmon abundance and chum salmon age structure in Paratunka River (Figure 8).

The analysis of the relation between average number of adult pink salmon in a standard catch (same river locality and gill net) sampled in the course of spawning run and age of dominant chum salmon generation (for the same fishery season) demonstrated rather clear negative correlation between these characteristics: Spearman's rank correlation coefficient was $R = -0.78$; the level of statistical significance $p=0.013$.

Biological sense of the relation, as known, consists in the fact that chum salmon recruitment rate is regulated by the terms of feeding at the end of the third year of life. These terms, in particular, pink salmon abundance in the area of chum salmon feeding for this time, determine the age of chum salmon spawning majority would it be of 0.3 or 0.4 (Nikolayeva, 1974; Birman, 1985; Salo, 1991). Therefore an increase of 0.4-old chum salmon number should take place in the years next by abundant pink salmon run. That takes place in our case.

Taking into account the phenomenon we can try to forecast the dominant age of chum salmon entering the river. However, we should not neglect complicated probabilistic character of the processes occurring in ecosystem. It should be noted, that any other well-correlated dynamical characteristics in these species were not found. Among these characteristics analyzed were the size and mass of fish, fecundity, run and sex ratio, age structure and average age of spawners.

Otherwise, intriguing tendency for the area studied to concern chum salmon abundance dynamics cannot be omitted. The fact is that hatchery chum salmon return coefficients demonstrate annual alternation of generations released in survival rate. For example, average return coefficient for odd years in the generations released from 1993 to 1999 was 0.2%, whereas for even years it was 0.5%. Similar tendency was discovered for Ketkino Salmon Hatchery as well.

As known, pink salmon runs at the East Kamchatka are usually abundant in odd years. The progenies emerging from the rivers in even years could compete to hatchery juvenile chum salmon theoretically. Nevertheless, that does not take place in practice (or else the data on chum salmon runs should be exactly contrary). Therefore, the fluctuations observed were determined by another reasons. However the last statement does not exclude annual pink salmon stock abundance fluctuations to be of these reasons. One of reasons might be significant juvenile chum salmon removal by predators in the offshore in the years when the abundance of juvenile pink salmon was relatively low (Karpenko, 1998). That certainly took place at the east of Kamchatka in odd years. Moreover, in the years of low stock abundance juvenile pink salmon quickly migrate into pelagic zone, whereas juvenile chum salmon use to stay in the off-shore for a long period and get eliminated extensively (V.I. Karpenko, personal communication).

We think that the effect should be taken into account in the analysis of hatchery chum salmon returns. The studies on survival rate comparison in wild and hatchery populations inhabiting one river basin should be continued.

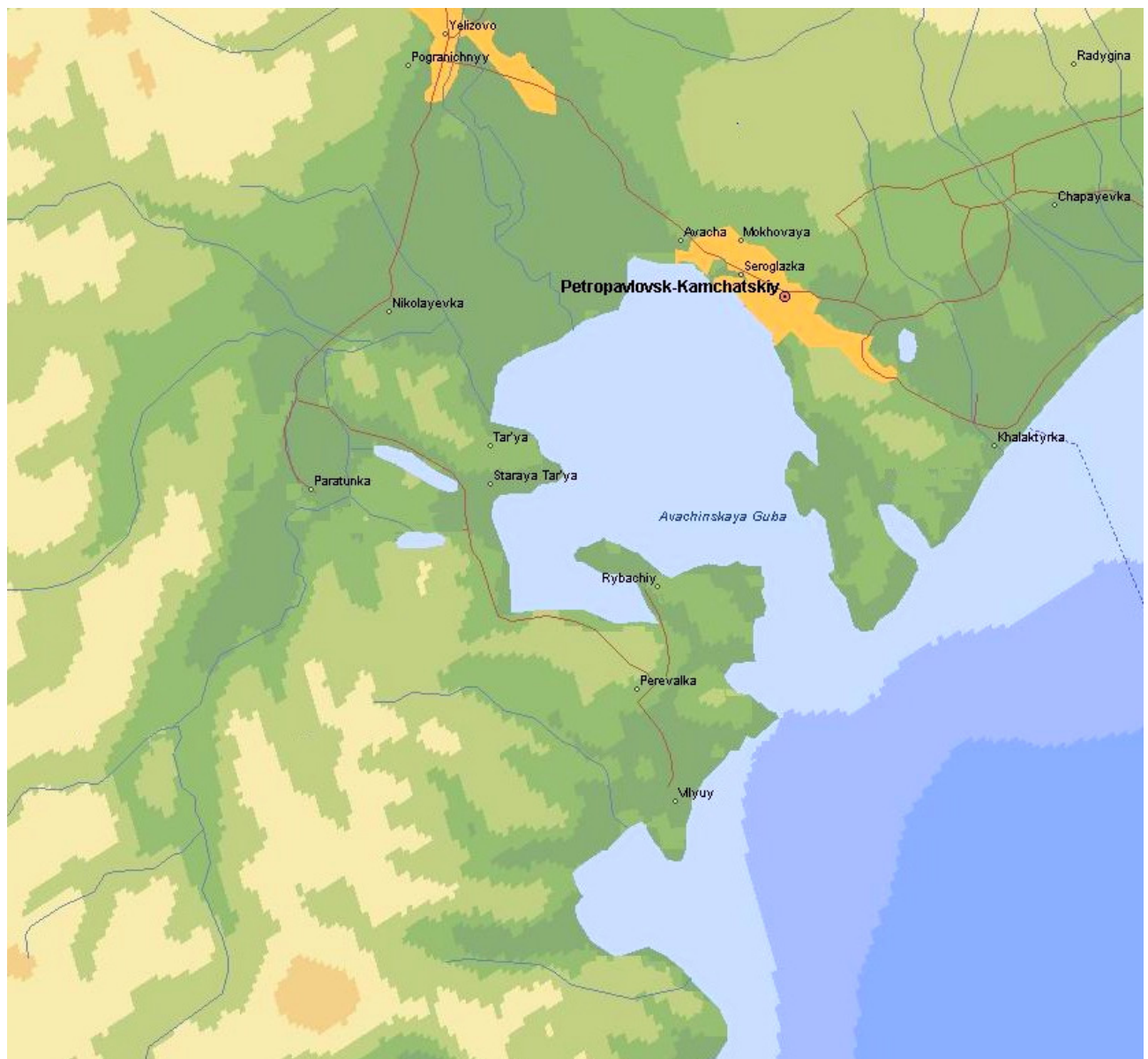


Figure 1. The map of Avachinskaya Bay and Paratunks River basin.

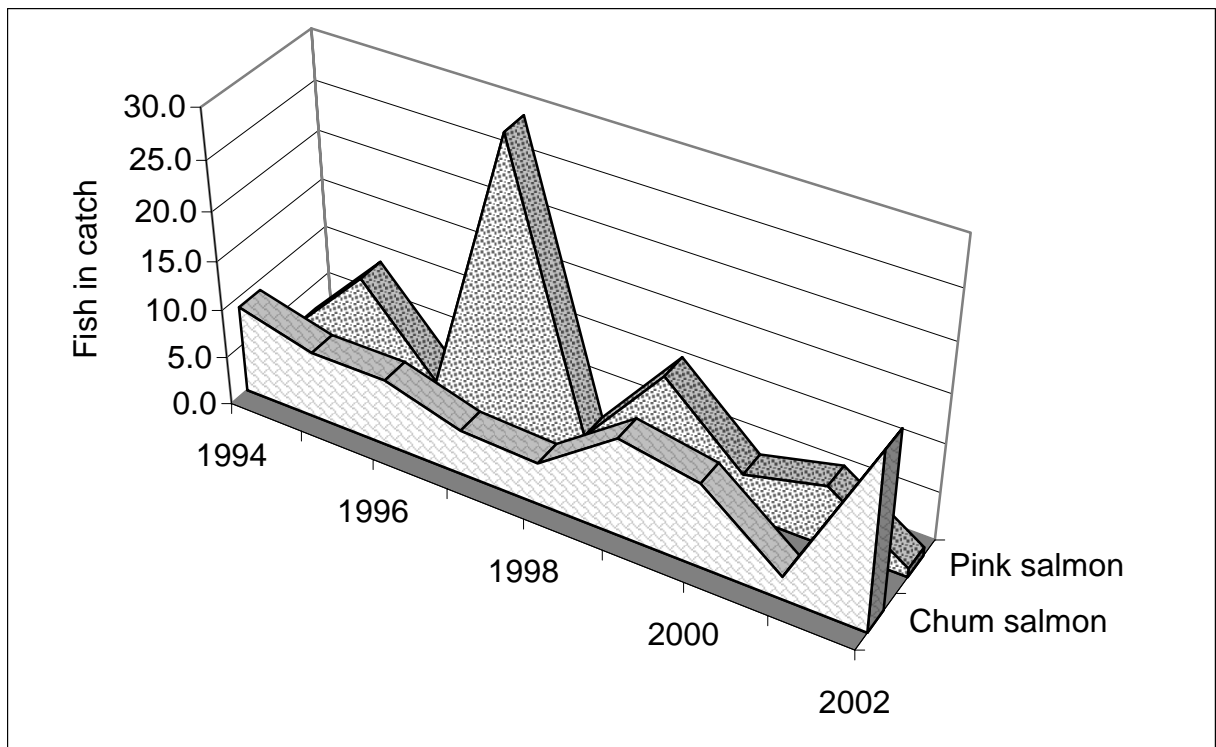


Figure 2. Composition of species in the catches from the data of ichthyological surveys.

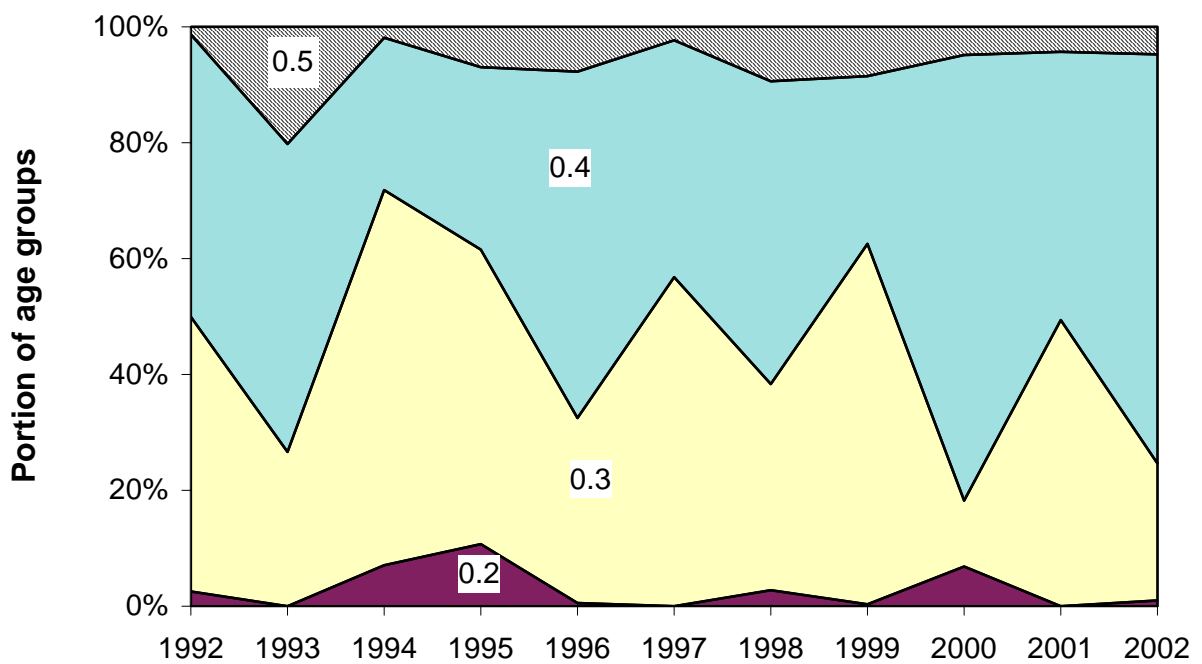


Figure 3. Dynamics of age classes in Paratunka River chum salmon for 1994-2002.

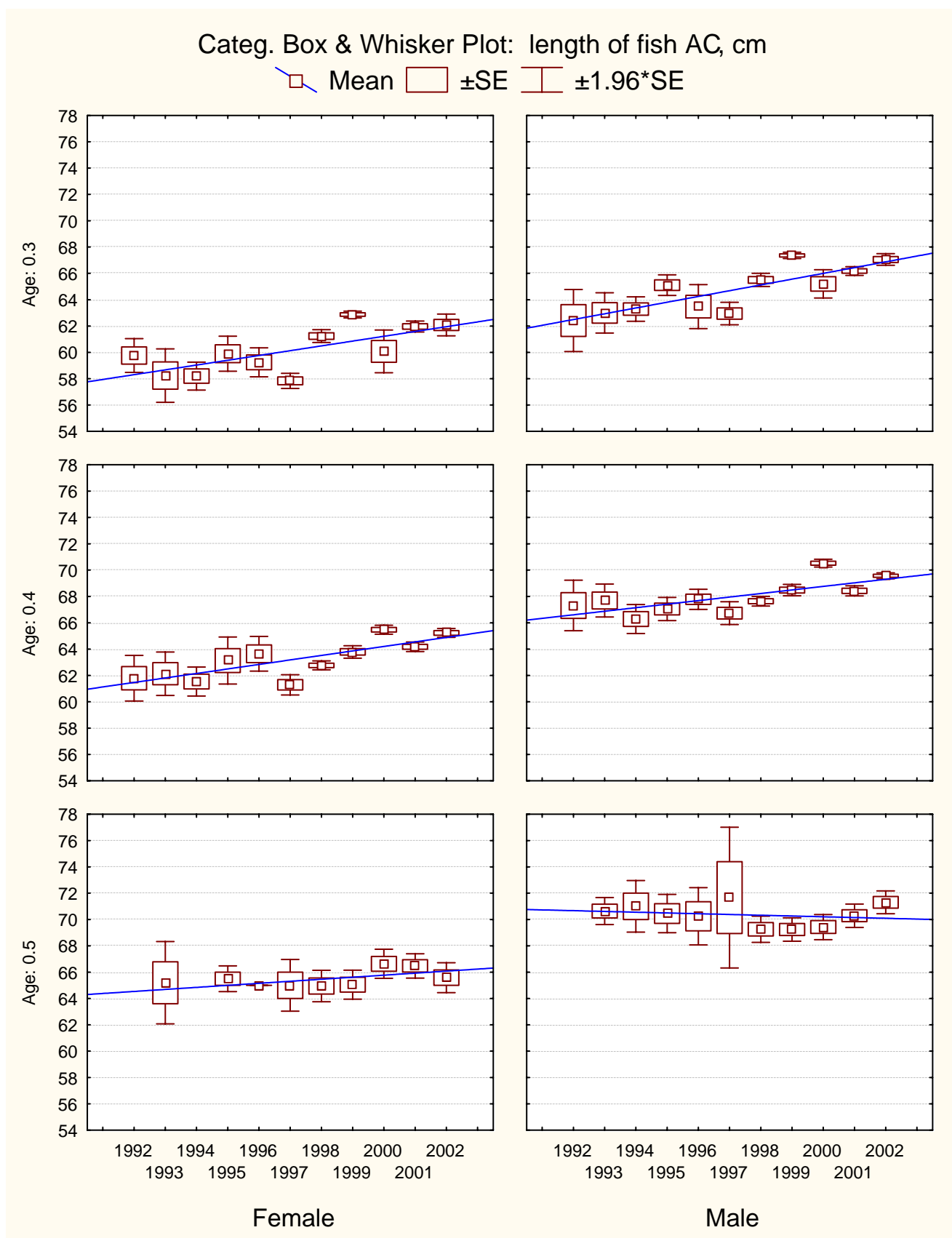


Figure 4. AC length dynamics of Paratunka River chum salmon of various age and sex for the period 1992-2002.

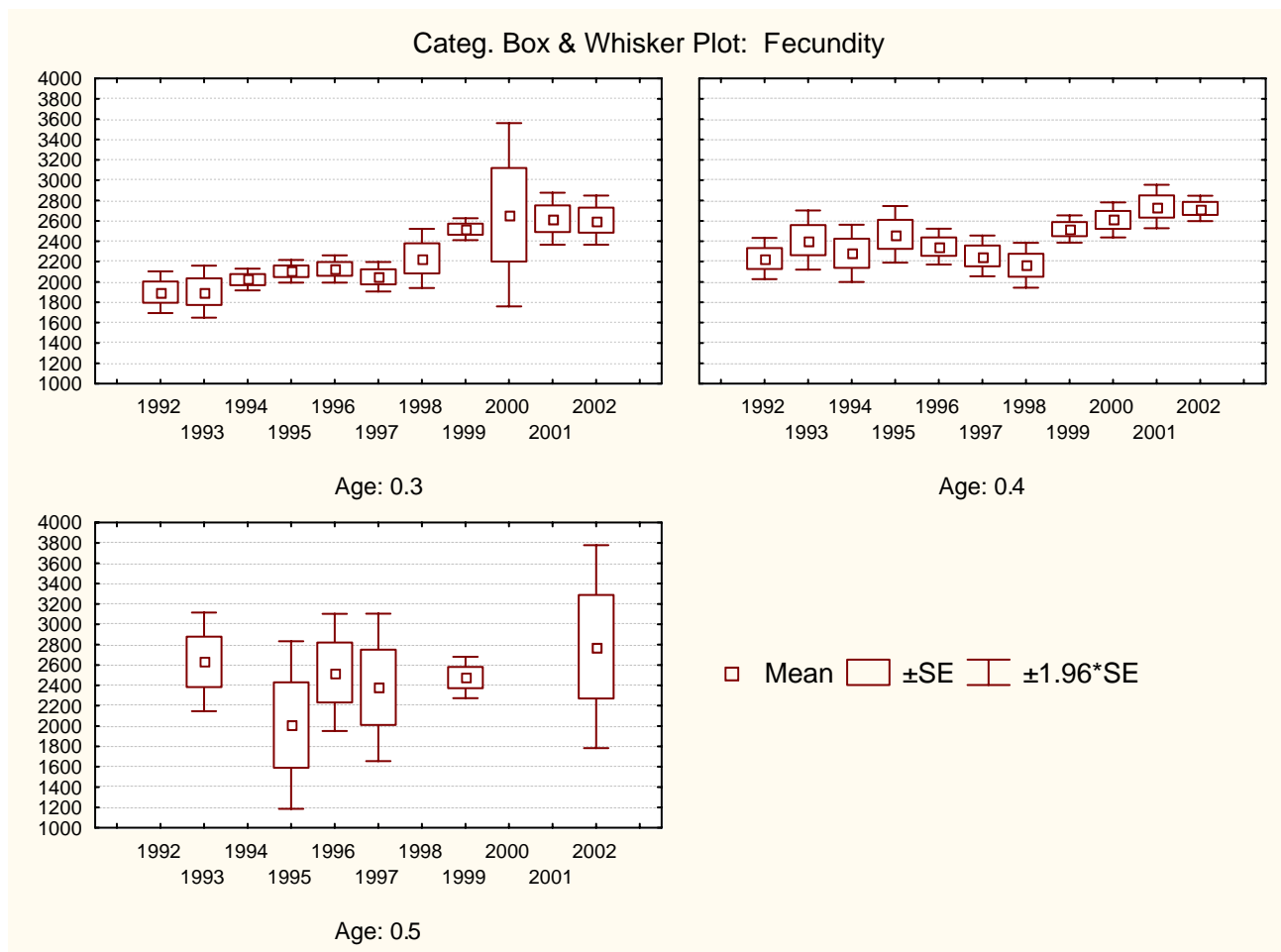


Figure 5. Fecundity of Paratunka River chum salmon of various ages for the period 1992-2002.

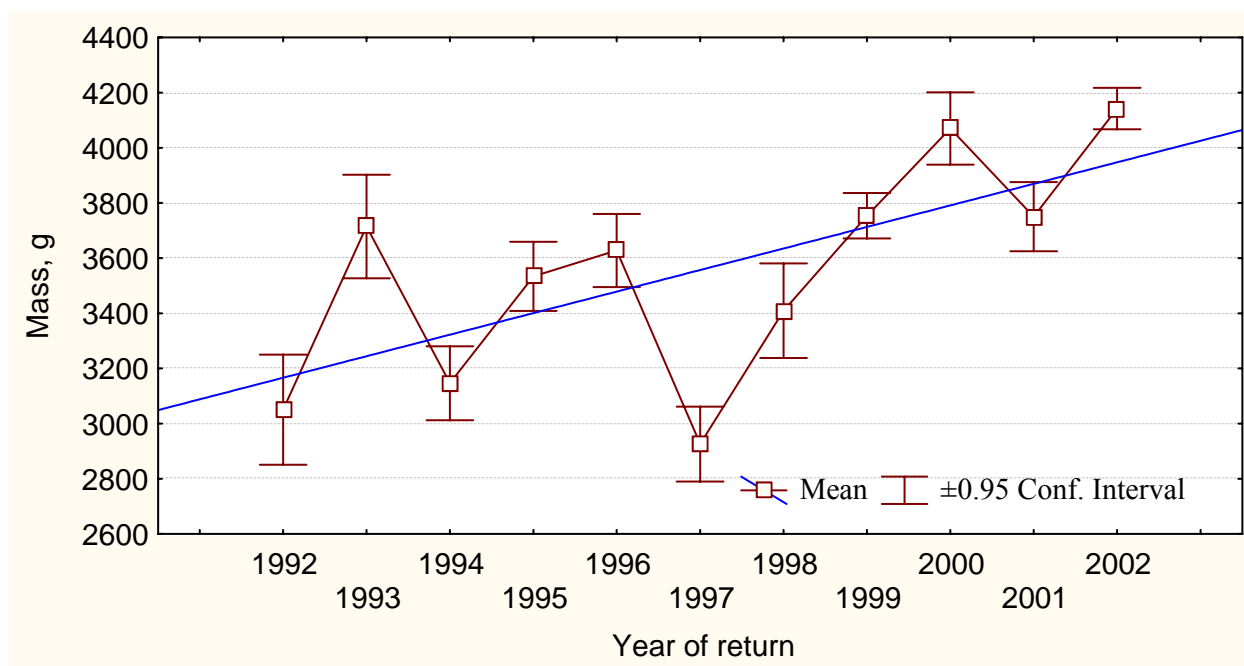


Figure 6. Statistical changes of average mass of Paratunka River chum salmon for 1992-2002.

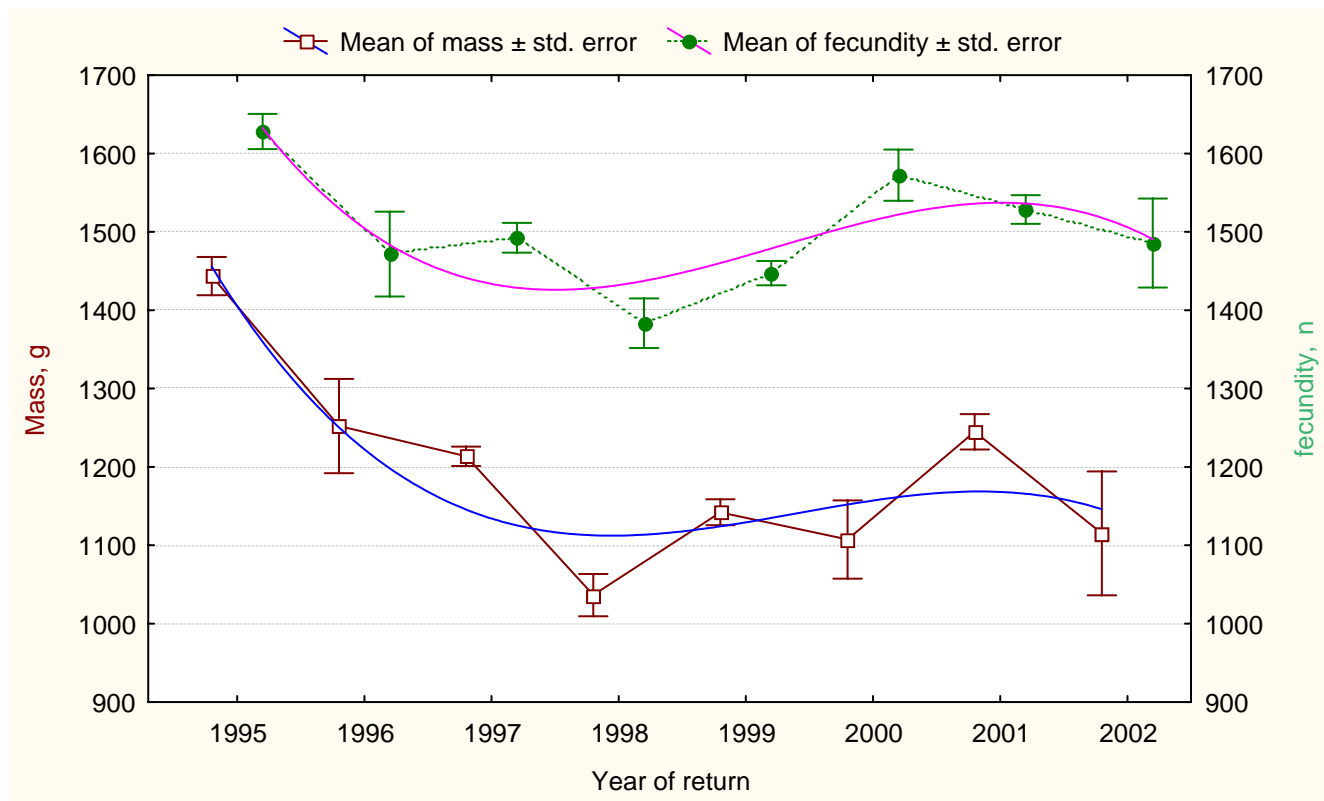


Figure 7. Statistical changes of average mass and fecundity in Paratunka River pink salmon for 1995-2002.

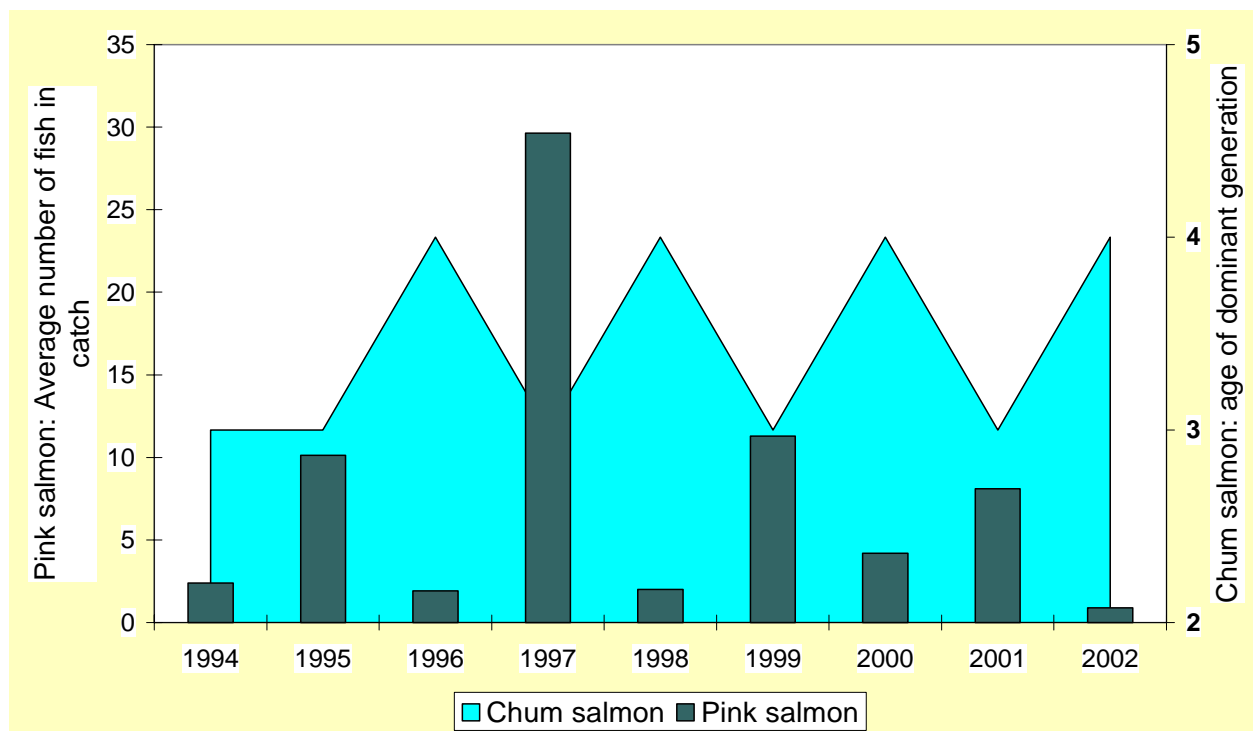


Figure 8. Pink salmon abundance dynamics in the catches and age dynamics of dominant chum salmon generation in Paratunka River for 1994-2002.

Fixed-Location Hydroacoustics as a Method of Enumerating Adult Pink Salmon in the Lower Kwinamass River, 2001-2002

Richard J. Bussanich¹, Robert C. Bocking¹, Donald J. Degan² and Anna-Maria Mueller²

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2.Aquacoustics Inc, P.O. Box 1473 29824 Birdie Haven Court, Sterling, AK, USA 99672-1473

Extended Abstract

Nisga'a Treaty implementation requires an improved understanding of the accuracy of the pink escapement estimates in the Nisga'a Treaty Area. Traditional estimates of pink salmon escapement in the Ksi X'anmas (Kwinamass River) and other coastal streams have been based on counts of adult fish in the main creeks and rivers from aerial surveys (helicopter and fixed-wing) during the peak spawning periods. This study presents the hydroacoustic techniques used to enumerate adult salmon and estimate pink salmon escapement to the Ksi X'anmas during summers 2001 and 2002. The project involved two phases: Phase 1) a testing and development stage (2001), and Phase 2) an Operational Phase (2002). The utility of using acoustics to monitor migratory behaviour and abundance in large, turbid rivers such as the Ksi X'anmas is high; however, the reliability of the acoustic data depended on using visual counting tower techniques to validate species composition.

A suitable study site was selected approximately 2.2 km from the outlet, and a 200-kHz acoustic system with a digital split-beam transducer was installed. Data were collected continuously from 29 July to 15 August 2001 and 12 July to 26 August 2002. We estimated a pink escapement of 139,677 from 31 July to 15 August 2001 using tower counts. Tower counts were expanded over 24 h, and summed for the 16 d study period. An escapement of 154,000 (124,302 and 183,698; 95% CI) pink was estimated acoustically, based on summing the hourly passage using a simple 2-fold expansion of a 30-min count. In 2002, pink salmon passage densities were too high to count effectively using fish tracking methods used in 2001, therefore, we echo integrated the data to provide acoustic fish counts. Echo integration is based on the premise that the total returned energy is proportional to the number of fish, and does not require the ability to resolve individual fish. The main potential sources of error for echo integration in this dataset are differing swim speeds among fish schools, non-uniform distribution of fish within the beam, and possibly shading during extremely high passage events. However, empirically, the regression of echo integration values on good quality visual counts gave results reasonable enough to pursue echo integration as a method to estimate fish passage in the Ksi X'anmas, even without accounting for the potential sources of error.

Pink escapement to the Ksi X'anmas from 22 July to 25 August 2002, was 629,808 (588,986 and 670,631; 95 % CI). Daily escapement estimates using tower counts was limited to a total 15 d (i.e., 26 July to 1 August, 4 August to 7 August, and 18 August to 21 August) due to reduced visibility. We estimated a pink escapement of 193,865 by expanding over 24 h, and summing for these 15 d. The 2002 study findings suggest conventional aerial surveys are underestimating pink escapement up to 6-fold (e.g., pink escapement estimates of 125,000 and 100,000 for 2001 and 2002, respectively). Fish passage peaked in late July when daylight high tides occurred and peaked again August 5 through 15, but passage rates dropped around August 1 and 20 when the tides were weakest. Pink salmon movement was strongly influenced by tide and daylight in both years. The strongest peaks occurred on strong tides during daylight hours. When strong high tides occurred at night rather than during daylight hours, pink salmon moved at dusk and dawn rather than during the night high tide. The study was funded as part of the Nisga'a Final Agreement.

Migration and Run Timing of Summer vs. Fall Chum Salmon on the Yukon River, Alaska

Judy Berger¹, Bonnie Borba² and Lisa Seeb¹

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*2. Alaska Department of Fish & Game, Division of Commercial Fisheries
Fairbanks, Alaska 99701-1599
email: bonnie_borba@fishgame.state.ak.us*

Abstract

We monitored variation in entry timing of summer and fall-run chum salmon in the Yukon River in Alaska over a four-year period (1999-2002) using genetic markers. Chum salmon were collected by gillnetting at the Pilot Station sonar site (river km 197) from early July to mid August. Genetic stock identification methods can accurately and precisely discriminate summer- and fall-run chum salmon. When possible, 200 chum salmon were randomly subsampled proportional to the daily passage rate by bank orientation. In 1999, fall-run chum were not detected until the July 19-25 sampling period. In the subsequent years, fall-run chum salmon were noted as early as July 5-11 sampling period. In 2001, the summer chum salmon showed a significant decline in abundance during the July 12-18 sampling period, up to two weeks prior to the decline observed in the other years.

Video of Spawning Behavior in Pink and Chum Salmon

Manuel Esteve

University of Barcelona, Gran Via Corts Catalanes, 585 08007 Barcelona, Spain

Note: see slides by Manuel Esteve in the Biology and Ecology Session and see website
<http://students.washington.edu/manu19b/UWspawnings.html>
(Fisheries Data, Manu Esteve's salmon spawning videos).

Use of the Kalman Filter and State-Space Models of Stock and Recruitment to Estimate Trends in Productivity of 120 Stocks of Pacific Salmon

Brian J. Pyper and Milo D. Adkison

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

Randall M. Peterman

School of Resource and Environmental Management, Simon Fraser University

Abstract

A recent development in modeling stock-recruit relationships is the use of state-space formulations in which parameters are estimated via Kalman filtering. For example, formulating the Ricker model with an explicit time-varying parameter provides a flexible framework for simultaneously estimating low-frequency (e.g., decadal-scale) and high-frequency trends in stock productivity. If important sources of climate-induced variation follow slowly changing, decadal-scale patterns, such state-space models offer potentially valuable tools for reconstructing trends in productivity of fish stocks and for rapidly detecting future shifts in productivity. To examine the utility of state-space models of stock and recruitment for salmon populations, we developed four state-space representations of the Ricker model and applied them to 120 data sets of pink, chum, and sockeye salmon in the Northeast Pacific. In particular, the models differed by which Ricker parameter – a (density-independent changes in productivity) or b (density-dependent changes) – was assumed to vary over time and by the form of that time-varying process (either a random walk or an AR(1) process). In addition, for each data set, we used model-selection criteria to compare these four models with two forms of the standard Ricker model (i.e., with and without autocorrelated errors). While the standard Ricker models typically provided the best fits across data sets, the state-space model with a random walk a -parameter was best in 17 cases, most of which were for northern chum and sockeye stocks. Moreover, this model clearly outperformed the other three state-space models in terms of model-selection criteria, statistical properties, and interpretations of results for management.

Application of Kalman filter models of stock and recruitment to 120 stocks of Pacific salmon

Brian J. Pyper and Milo D. Adkison, Juneau Center, School of Fisheries & Ocean Sciences, University of Alaska Fairbanks
 Randall M. Peterman, School of Resource & Environmental Management, Simon Fraser University

Background

- A recent development in modeling stock-recruit relationships for salmon populations is use of Kalman filter (state-space) models
- In contrast to traditional models, Kalman filter models can have time-varying parameters, which may be useful for stocks that experience trends in productivity
- Peterman et al. (2000) used simulations to examine a Kalman filter form of the Ricker model with a time-varying a parameter
- They found that this Kalman filter model provided better parameter estimates than the standard Ricker model when the "true" simulated a parameter followed various types of trends

Objectives

- To examine the applicability of Kalman filter models for Pacific salmon stocks, we compared 4 such models with 2 forms of the standard Ricker model by fitting each model to 120 stocks



Alternative Models

1. Standard Ricker model (RK)

$$\ln(R_t / S_t) = a + b \cdot S_t + V_t$$

2. Ricker model with AR(1) errors (AR)

$$V_t = \phi V_{t-1} + Z_t$$

Kalman filter models

3. a parameter follows a "random walk" (a-RW)

$$a_t = a_{t-1} + W_t$$

4. a parameter follows an AR(1) process (a-AR)

5. b parameter follows a "random walk" (b-RW)

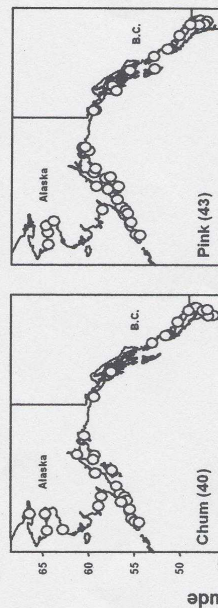
6. b parameter follows an AR(1) process (b-AR)

Estimation and model ranking

- Each model was fit to the 120 data sets using maximum likelihood (ML)
- All estimates were conditioned on the first year of data to make ML values comparable across all models
- To rank models for a given stock, we used the Akaike Information Criterion corrected for small sample size (AICc)
- We also examined instances in which the ML fit indicated that a model had reduced to a simpler model (e.g., if $\phi = 1$ for the a-AR model, then the a-AR reduced to the a-RW)
- We refer to reduced models as "degenerate"

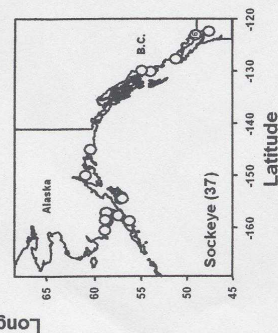
References:

Peterman, R.M., Pyper, B.J., Laporte, M.F., Adkison, M.D., and Walters, C.J. 1998. Patterns of covariation in survival rates of British Columbia and Alaskan sockeye salmon (*Oncorhynchus nerka*). *Can. J. Fish. Aquat. Sci.* 55:2602-2617.
 Pyper, B.J., Peterman, R.M., Backhouse, C.J., and Wood, C. 2002. Spatial covariation in survival rates of Northeast Pacific chum salmon (*Oncorhynchus keta*). *Trans. Amer. Fish. Soc.* 131:343-353.



Salmon data

We obtained spawner and recruit data for 120 wild stocks of pink (*O. gorbuscha*), chum (*O. keta*), and sockeye (*O. nerka*) salmon. Data series ranged in length from 15 to 47 years (brood years 1948-1996, average length 31 years). For details, see Peterman et al. (1998), Pyper et al. (2001), and Pyper et al. (2002).

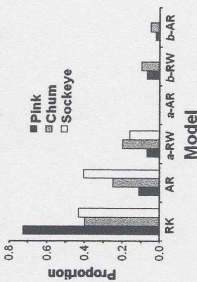


For more information, please contact B. Pyper (b.pyper@uaf.edu)

Results => All models

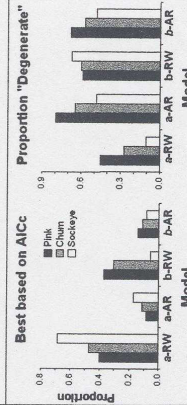
- Across stocks, standard forms of the Ricker model were preferred (63 for RK; 30 for AR)
- This was especially clear for pink stocks
- Kalman filter models were best for 27 stocks

Best model based on AICc



Results => Kalman filter models

- When only comparing Kalman filter models, the a-RW model performed best (55 stocks)
- The a-RW model was also the most stable; over 50% of the other model fits were "degenerate"



Conclusions

Models with time-varying parameters appear appropriate for 22% of stocks examined. The most common form had a "random-walk" a parameter. Models with AR(1) terms were over-parameterized.

Recovering Threatened Summer Chum in Quilcene Bay

Tom Kane

U.S. Fish and Wildlife Service, 510 Desmond Drive SE, Suite 102, Lacey, Washington, 98503

Abstract

Through the efforts of the Western Washington Fish and Wildlife Office, Quilcene National Fish Hatchery, Washington Department of Fish and Wildlife, Point No Point Treaty Council and NOAA-Fisheries, the threatened summer chum salmon run is recovering to pre-listed numbers in Quilcene Bay, Washington. This salmon species was listed as threatened in 1999. We are now in the 11th year of a 12-year hatchery supplementation program for this species. To bolster natural runs, adult summer chum are captured in Quilcene Bay and transferred to Quilcene NFH where fish are spawned and their progeny released into the Big Quilcene River. This program has been highly successful. Returns of Quilcene summer chum salmon have increased from a low of 50 fish in 1991 to an average of 4,000 fish today. The Quilcene run is an important part of the recovery actions for this species. Along with other actions being taken to re-establish runs of this species in Puget Sound, the Service is playing a key role in helping to re-establish nearby runs in Hood Canal through hatchery intervention.



U.S. Fish & Wildlife Service

Recovering Threatened Summer Chum in Quilcene Bay Aquatic Species Conservation

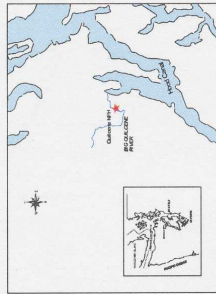


They're back!

Through the efforts of the Western Washington Fish and Wildlife Office, Quilcene National Fish Hatchery, Washington Department of Fish and Wildlife, Point No Point Treaty Council and NOAA-Fisheries, the threatened summer chum salmon run is recovering to pre-listed numbers in Quilcene Bay, Washington. This salmon species was listed as threatened in 1999.

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To bolster natural runs, adult summer chum are captured in Quilcene Bay and transferred to Quilcene NFH where fish are spawned and their progeny released into the Big Quilcene River.

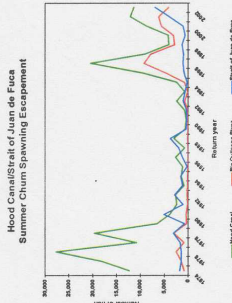


Quilcene NFH is located in northern Hood Canal.



FWS biologists Tom Kane and Dave Zajac, major contributors to the summer chum recovery effort, collect broodstock from Quilcene Bay.

This program has been highly successful. Returns of Quilcene summer chum salmon have increased from a low of 50 fish in 1991 to an average of 4,000 fish today. The Quilcene run is an important part of the recovery actions for this species.



Along with other actions being taken to re-establish runs of this species in Puget Sound, the Service is playing a key role in helping to re-establish nearby runs in Hood Canal through hatchery intervention.

Quilcene National Fish Hatchery
1000 N. 1st St.
Quilcene, WA 98280
Tel: 360/685-1100
Fax: 360/685-1101

Kane_Postter-sorter-picture.doc

Population Dynamics of Chum Salmon in the Columbia River Gorge

Nancy Uusitalo

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Abstract

Chum salmon natural production in the Columbia River is primarily limited to the tributaries downstream of Bonneville dam with a majority of the fish spawning in the Washington tributaries of the Columbia River. Historically, the annual Columbia River chum salmon run was estimated to be 1,000,000. By the 1950s the run size had decreased to an estimated 25,000 fish. Since 1959, the population has been relatively stable with the run size ranging from 300 to 10,000. On May 24, 1999, the National Marine Fisheries Service listed the Columbia River chum salmon Evolutionary Significant Unit as threatened under the Endangered Species Act. In 1999, the United States Fish and Wildlife Service, Columbia River Fisheries Program Office was funded by the Bonneville Power Administration to monitor adult and juvenile chum salmon populations in Hardy Creek and Hamilton Springs. Adult chum salmon were monitored by operating weirs and conducting spawning ground surveys. Population estimates for returning adult chum salmon were calculated each fall using the Area-Under-the-Curve program. Emigrating chum salmon smolts were monitored and enumerated by operating fyke nets and the data were analyzed using a Stratified Population Analysis System (SPAS) program to produce population estimates. During both the adult and juvenile sampling seasons, biological data (ex: scales for age analysis, length, sex, species and development stage) were collected to provide a better understanding of the population dynamics and life history of the Columbia River chum salmon.

Fraser River Pink Salmon Stock Assessment Program

Brad Fanos, Tracy Cone, Ken Peters, Rick Rempel, and Rob Tadey

Lower Fraser Area, Stock Assessment, Fisheries and Oceans Canada, 100 Annacis Island – Unit 3, Delta, B.C., V3M 6A2

Abstract

An overview of the Fraser River Pink salmon stock assessment program from 1957 to present was provided. Fraser River pink salmon stocks, their life history and the assessment methods used to estimate fry abundance and adult escapement were described. Annual estimates of abundance and survival are presented for Fraser Pink fry out-migration and adult escapement.

Brad Fanos and Tracy Cone



Acoustic Imaging: A New Frontier in Fish Research

Tim Mulligan¹, Peter Withler², George Cronkite¹, and John Holmes¹

1. Fisheries and Oceans Canada, Applied Technology, Pacific Biological Station, Nanaimo, B.C., V9T 6N7

2. Pacific Eumetrics Consulting Ltd., Nanoose, B.C., V9P 9C9

Abstract

High density, milling behaviour and boundary detection limit our ability to enumerate fish with single-beam and split-beam hydroacoustic systems. The Applied Physics Laboratory at the University of Washington has developed a high definition imaging sonar - DIDSON (Dual frequency IDentification SONar) - that produces near video quality images of aquatic objects, including fish. The Stock Assessment Division, Science Branch, Pacific Region, is planning to acquire a unit when they become available for purchase. Here we demonstrate three potential uses of this new technology in the Pacific region: (1) behavioural studies of salmon migration, (2) estimating the daily upstream flux of migrating salmon with tracking software, and (3) enumerating groundfish species such as rockfish (*Sebastes* spp.). All of these aspects are illustrated in the accompanying computer presentation.

Acoustic imaging: A new frontier in fish research

Tim Mulligan¹, Peter Withler², George Cronkite¹ and John Holmes¹

1. Fisheries and Oceans Canada, Applied Technology, Pacific Biological Station, Nanaimo, B.C., V9T 6N7
2. Pacific Eumetrics Consulting Ltd., Nanose, B.C., V9P 2B8. Email: pwithler@shaw.ca



ABSTRACT

High density, milling behaviour and boundary detection limit our ability to enumerate fish with single-beam and split-beam hydroacoustic systems. The Applied Physics Laboratory at the University of Washington has developed a high definition imaging sonar - DIDSON (Dual Frequency Identification SONar) - that produces near video quality images of aquatic objects, including fish. The Stock Assessment Division, Science Branch, Pacific Region, is planning to acquire a unit when they become available for purchase. Here we demonstrate three potential uses of this new technology in the Pacific region: (1) behavioural studies of salmon migration, (2) estimating the daily upstream flux of migrating salmon with tracking software, and (3) enumerating groundfish species such as rockfish (*Sebastes* spp.). All of these aspects are illustrated in the accompanying computer presentation.



TECHNOLOGY

The DIDSON sonar is a small portable system, measuring 30.7 cm L x 20.6 cm H x 17.1 cm W and weighing 7.0 kg in air. This system has two frequencies (1.0 MHz

and 1.8 MHz) and uses 48 and 96 acoustic beams (each with a beamwidth of 0.3-0.4° H x 12° V), to provide a field of view of 29°. The sonar images are sent as digital arrays for display on a computer and as NTSC video for a monitor and VCR at refresh rates of 4-21 frames/sec.

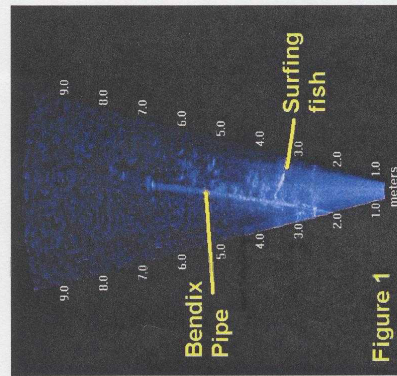


Figure 1

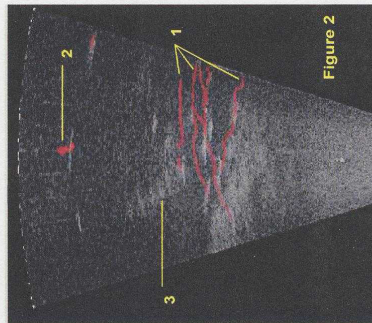


Figure 2

1. Behavioural Studies

Figure 1 (left) is a screen shot that shows sockeye salmon in the Copper River, AK, "surfing" on the crest of a pipe (diagonal line) on the bottom. This behaviour, which cannot be easily detected with split-beam sonar, may seriously bias upstream flux calculations and escapement estimates.

Experiments Needed to:

- Map beam coverage
- Range testing
- Determine detection probabilities
- Devise sampling schema
- Marine and freshwater testing
- Remote operation (reliability, power consumption)
- Comparisons with video imaging, tower counts, other data acquisition methods

3. Groundfish Enumeration

Marine species that live in close association with the bottom are not detectable in conventional acoustic surveys because of the strong bottom signal. Stationary background object images can be removed on the DIDSON screen to improve the image of moving fish. Figure 3 (below) demonstrates the ability to detect a rockfish on the bottom.

2. Estimating Upstream Flux of Salmon

A proof-of-concept application of the alpha-beta tracker algorithm (also used in radar applications) by P. Withler demonstrates the potential for tracking multiple targets in DIDSON output (Figure 2 - left). Tracking is used to estimate the direction of travel and speed of fish targets through the acoustic beam and these data are then used in calculating the upstream flux of migrating fish. Three features are visible in Figure 2: (1) red lines representing fish tracks overlaid by the tracking software as it follows fish from right to left; (2) a mass of red from a tethered fish; and (3) light objects such as boulders or other features on the bottom. Fish counts are made visually from the screen with a handheld counter.

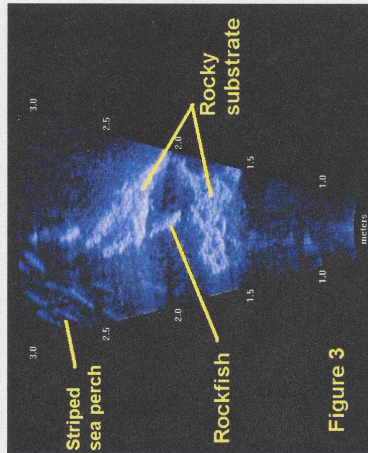


Figure 3

Perceived Advantages

- Specialized training not needed
- Background objects can be removed to improve image
- Fewer blind spots
- Can operate in shallow water (about 0.5 m)
- Output is recorded as video so do not have to monitor continuously
- Designed for operation in turbid conditions

Some Limitations

- Range is between 1 and 30 m
- Quantitative data (other than fish counts) requires extensive video analysis
- Provides data on 2-D position of object not 3-D (e.g., range and left-right, but not distance from bottom)

Results of the 21st Northeast Pacific Pink and Chum Salmon Workshop Questionnaire

The results of the questionnaire provided to participants at the Workshop indicated that most individuals considered all aspects of the Workshop to be highly satisfactory. Organizers of the 2005 Pink and Chum Workshop may find it useful to review the preference towards specific topic areas that were indicated by 2003 Workshop participants.

5 (strongly agree) to 1 (strongly disagree):

Sample Size (number of respondents – total attendance was 125) = 60

Meeting Format and Program

Category Average

Amount of time per speaker was appropriate	4.7
Number of speakers was appropriate	4.7
The length of the workshop was appropriate	4.7
The presentations were of good quality	4.4
The topics were interesting and relevant	4.4
Amount of time for discussion was adequate	4.3

Accommodations and Facilities

The location of the meeting room was appropriate	4.8
The hotel accommodations were good	4.8
Transportation to workshop and hotel was reasonably easy	4.7
The meeting room was adequate	4.7
The audio-visual equipment was adequate	4.7
The food at the social and banquet was good	4.5

Topics of Interest for the Next Workshop

Biology/ecology	4.6
Conservation biology/endangered species	4.6
Fisheries management	4.4
Habitat assessment and restoration	4.3
Marine survival and forecasting runs	4.3
Migration and homing	4.3
Genetic studies	4.2
Enhancement techniques	4.1
Socio/Economic implications of management	3.7
Education/community involvement	3.6
Industry concerns/product development	3.4