PROCEEDINGS OF THE 15TH NORTHEAST PACIFIC PINK AND CHUM SALMON WORKSHOP

February 27 - March 1, 1991
Tigh-Na-Mara Resort
Parksville, British Columbia

Pacific Salmon Commission
Canada Department of Fisheries and Oceans

133778

PROCEEDINGS OF THE 15TH NORTHEAST PACIFIC PINK AND CHUM SALMON WORKSHOP

February 27 - March 1, 1991
Tigh-Na-Mara Resort
Parksville, British Columbia

November, 1991

Co-Chairs:
Don Bailey, CDFO
Jim Woodey, PSC

Editors:
Bruce White, PSC
Ian Guthrie, PSC

Pacific Salmon Commission
600 - 1155 Robson Street
Vancouver, B.C., V6E 1B5

Canada Department of Fisheries and Oceans
400 - 555 West Hastings Street
Vancouver, B.C., V6B 5G3

Cover Artwork by
Valerie Luedke, Neo Graphics, Nanaimo, B.C.

THE CONTENTS OF THESE PROCEEDINGS ARE NOT TO BE TREATED AS PUBLISHED MATERIAL. Any reference to these contents should be approved by the author(s) responsible and cited as a personal communication.

The content of the papers in these proceedings are essentially as submitted by the authors. The editors have restricted their activities to standardizing the format and appearance of the documents, and performing a superficial review for minor edits (e.g., spelling).

TABLE OF CONTENTS

TABLE OF CONTENTS CONT'D.

TABLE OF CONTENTS CONT'D.

LIST OF ACRONYMS

ADFG	Alaska Department of Fish and Game
BCMF	B.C. Ministry of Forests
CDFO	Canada Department of Fisheries and Oceans
NMFS	National Marine Fisheries Service
NRIFSF	National Research Institute of Far Seas Fisheries
NSRAA	Northern Southeast Regional Aquaculture Association
NWIFC	Northwest Indian Fisheries Commission
PSC	Pacific Salmon Commission
PWSAC	Prince William Sound Aquaculture Corporation
SFU	Simon Fraser University
UA	University of Alaska
UBC	University of British Columbia
UW	University of Washington
WC	Weyerhauser Company
WDF	Washington Department of Fisheries

LIST OF PAST WORKSHOPS

YEAR	LOCATION	CHAIR	ORGANIZATION
1962	Juneau, Alaska	T. Merrell	BCF
1964	Juneau, Alaska	D. Bevan	FRI
1966	Ketchikan, Alaska	C. Meacham	ADFG
1968	Juneau, Alaska	T. Merrell	BCF
1970	Prince Rupert. B.C.	A. Hartt	FRI
1972	Sitka, Alaska	R. Roys	ADFG
1974	Vancouver, B.C.	T. Bird	CDE
1976	Juneau, Alaska	J. Helle and K. Koski	NMFS
1978	Parksville, B.C.	J. Mason	FMS
1980	Sitka, Alaska	A. Kingsbury	ADFG
1983	Orcas Island, Washington	K. Fresh	WDF
1985	Harrison Hot Springs, B.C.	B. Shepherd	CDFO
1987	Anchorage, Alaska	P. Mundy and K. Tarbox	ADFG
1989	Port Ludlow, Washington	D. Phinney	WDF
1991	Parksville, B.C.	D. Bailey and J. Woodey	CDFO and PSC

STEERING COMMITTEE AND SESSION LEADERS

Co-Chairs	Don Bailey, CDFO Jim Woodey, PSC
Committee Members	Vicki Beck, PSC Dave Blackbourn, CDFO Gordon Berezay, CDFO Jim Cave, PSC Peter Cheng, PSC Steve Cox-Rogers, PSC Jim Gable, PSC Ian Guthrie, PSC Whittier Johnson, PSC Marilyn Joyce, CDFO Wilf Luedke, CDFO Duane Phinney, WDF Bruce White, PSC

Session Chairs

Comparative Performance of Enhancement Facilities	Brian Allee, ADFG
Early Marine Survival and Habitat Utilization	Alex Wertheimer, NMFS
Small Scale Enhancement	Howard Fuss, WDF
Marine Effects on Size, Survival, and Behaviour	Dave Blackbourn, CDFO
Valdez Oil Spill	David Cantillon, NMFS Chuck Meacham, ADFG
Application of Genetic Stock Identification to Fisheries Management	Bruce White, PSC
Logging/Leave Strips	Duane Phinney, WDF

FOREWORD

Traditionally, the Pink and Chum Salmon Workshop has been structured to facilitate the exchange of findings and ideas related to on-going work. We all want and need up-to-date knowledge of investigations taking place in other states and provinces before the information has dried-up in the processing of formal reports. The excitement of learning about new and innovative work should be a primary objective of the presenters and attendees. We trust that all researchers, managers and students experienced some of that excitement during the 1991 Workshop.

The focal session was presented by our Alaskan colleagues working on the impacts of the disastrous 1989 *Exxon Valdez* oil spill. While results of direct impact studies could not be released at the time of the meeting, we now appreciate the depth of thought and speed of action which were required in order to monitor the impacts and investigate the full implications of the spill. We encourage all the oil spill session presenters to publish their results speedily so that other researchers have access to what is possibly the most comprehensive work on the effects of oil spills on salmonids.

Sessions were developed on a range of other topics in order that the Workshop appeal to a maximum number of people. The breadth of studies was impressive and the depth of the investigations was encouraging. The 16th Northeast Pacific Pink and Chum Salmon Workshop, which will be held in Alaska in 1993, should benefit from the quality of on-going work in these fields.

The contact persons for the 1993 Workshop are Bill Smoker (University of Alaska) and Chuck Meacham (ADFG).

Don Bailey

Jim Woodey

ACKNOWLEDGEMENTS

Many individuals were involved in organizing and producing the 1991 Workshop. The Steering Committee was fortunate to be able to tap the Pacific Salmon Commission's and Vicki Beck's depth of experience in organizing meetings. Vicki almost single handedly found and arranged the facilities, acted as the contact with the resort and organized the registration desk. Thanks also go to Ian Todd, Whittier Johnson, Glenna Westwood and Keith Forrest of the Pacific Salmon Commission for assisting in the organization and running of the meetings.

The management and staff of the Tigh-Na-Mara Resort were especially helpful and obliging in handling the room reservations, meeting space and meal preparation. Our thanks go to Lorne Miller and the many others who made our stay so enjoyable.

Particular thanks go to the many contributors who provided financial support or merchandise for the door prizes. We thank the following for their support:

Aquamarine Supply Ltd.
Canada Department of Fisheries and Oceans
E.A. Towns Fishing Supplies Ltd.
Gibbs Nortac Ltd.
J.L. Darling Corporation
J.O. Thomas and Associates Ltd.
Mustang Industries Inc.
Nikka Industries Ltd.
Northwest Marine Technology
Pacific Salmon Commission
Point Four Systems Inc.
Prince Rupert Fishermen's Cooperative
Redden Net Company Ltd.
Redl Sports Distributors
Tigh-Na-Mara Resort
Trans Pacific Fish Ltd.
Washington Department of Fisheries

We gratefully acknowledge the donation by Valerie Luedke (Neo Graphics, Nanaimo, B.C.) of the 1991 workshop logo art work. Her design was a hit on the tee-shirts and now graces the cover on these proceedings.

Last (but certainly not least) we wish to extend our appreciation to Dr. Peter Larkin who spoke from experience, and a bit of distance, about the research and management needs vis-a-vis pink and chum salmon. It was a real pleasure to have the dean of salmon biologists there to stir the waters. Our thanks as well to Ian Todd for his introduction of Dr. Larkin.

Comparative Performance of Two West Coast Vancouver Island Chum Salmon (*Oncorhynchus Keta*) Facilities

B.W. Anderson and D.D. Bailey

Department of Fisheries and Oceans
555 - West Hastings
Vancouver, B.C.

Nitinat and Conuma hatcheries, two Japanese style chum hatcheries located on the west coast of Vancouver Island were compared. The first releases a single stock into an inlet like lake while the second releases five stocks of chum into a fiord like inlet. Since hatchery operation began the returns to these areas have increased from 128,000 to 904,000 for Nitinat and 175,000 to 225,000 for Nootka Sound (Conuma).

The age 3 composition for Nitinat is 18% versus 30% for Conuma. The Nitinat age 3 composition seems to be related to lake productivity while Conuma reflects overall hatchery averages for chum production. The average fry survival for Nitinat hatchery is 3.1% versus 0.9% for Conuma hatchery. This difference is felt to be related to competition for available food, presences or absences of predators, and a more critical optimum time of release for Conuma.

Since 1983 brood year Conuma chum survivals have been very low. This is felt to be more than hatchery related as the wild stocks in Kyuquot Sound located immediately north of Nootka Sound have also experienced a decreased productivity. It is speculated that a possible contributor to this decline is the predation by chub mackerel in the area.

Of the nine major Salmonid Enhancement Program (SEP) chum salmon (*Oncorhynchus keta*) hatcheries, two are located on the west coast of Vancouver Island.

Nitinat Hatchery is located 48° 51'N and 124° 39'W on the south west coast of Vancouver Island, British Columbia near the head of Nitinat Lake at the confluence of the Nitinat and Little Nitinat rivers (Figure 1). Nitinat began operation in 1980 and is the largest Japanese style chum hatchery in SEP. A Nitinat Lake study from 1975-77 concluded that chum fry rear in this estuarine-like lake for up to two months (Fedorenko et al. 1979). The apparent under utilization of lake rearing potential, relative absence of predators, and easy manageability of this area for a terminal harvest made this a desirable enhancement location.

Conuma Hatchery is located approximately 170 km north west of Nitinat hatchery (Figure 2) near the head of Tlupana Inlet at the confluence of Conuma river and Leagh creek (49° 48' N, 126° 25' W). Conuma began operation in 1978 as the first Japanese style chum hatchery on the B.C. coast. Conuma was designed to enhance a number of stocks in a relatively protected terminal harvest area.

Both Nitinat and Conuma hatcheries are designed to produce 25 million and 18 million 1 g chum fry respectively. Nitinat Hatchery is a single stock hatchery while Conuma enhances five rivers emptying into Tlupana Inlet. Both hatchery water supplies are a mixture of surface and well water allowing for some temperature manipulation for fish culture purposes. Well water temperature is 9° C at Nitinat and 8° C at Conuma. Surface water temperatures during incubation and rearing vary from 1.5° to 14° C and 3° to 10° C, respectively.

The incubation technology used at both sites is modified Atkins incubators and substrate lined concrete keeper channels. Fry are reared in concrete raceways at Nitinat and concrete or earthen (recently PVC lined) ponds at Conuma. Chum fry are reared between 30 to 45 days at both sites and released at 1 g size.

Nitinat chum are released directly into the Nitinat River which flows into Nitinat Lake. Nitinat Lake is 23 km long and 1.2 km wide and its surface is a few feet above low tide (Northcote et al. 1964). Usable water depth in the lake is between 10 m at the head of the lake and 30 m at the mouth. Below this depth is a permanent anoxic layer containing detectable levels of hydrogen sulphide.

Conuma Hatchery fry are released into their river of origin either directly as is the case with Conuma stock, or transported by truck or helicopter to the other river systems within Tlupana Inlet. Tlupana is a deep fiord like inlet (Pickard 1963; Tully 1937) which is one of three inlets making up Nootka Sound.

AREA PRODUCTION

Statistical Area production for Nitinat is Area 21-22 (Nitinat) and for Conuma is Area 25 (Nootka Sound) (Figure 3). Adult production (catch and escapement) for area 21-22 (Nitinat) from 1951 to 1982 averaged 127,500 fish (Lightly et al. 1985) and since the hatchery went into production the average return is 904,000 for this area (Figure 4). Area 25 (Nootka Sound) from 1951 to 1982 averaged 175,000 fish and since 1982 average adult production is 225,000 fish for this area (Figure 5). Since the introduction of the hatcheries, the 1978 to 1985 brood hatchery releases have averaged 16.5 million chum from Nitinat and 12,7 million fry from Conuma (Table 1). This is 29% more fry released from Nitinat. Adult hatchery production for the same broods has averaged 698,000 for Nitinat and 74,000 for Conuma. This represents 7 times greater adult production per fry released than Conuma. The calculated exploitation rate for Nitinat and Conuma is 74% and 39% respectively. Clearly, Nitinat hatchery has been much more successful than Conuma.

Table 1. Nitinat and Conuma Hatchery chum production (1978-1985 broods).

Hatchery	No. Fry Released (Millions)	Adult Production (fish)	Catch (fish)
Nitinat	16.5	698,016	516,308
Conuma	12.8	73,946	29,144
% Increase	29%	844%	1671%

AGE COMPOSITION

The average age 3 composition for Conuma Hatchery is similar to SEP hatchery average and greater then Nitinat (Table 2).

Table 2. Average brood year age composition for SEP hatcheries.

Hatchery	Age 3 (%)	Age 4 (%)	Age 5 (%)
SEP	30	66	4
Nitinat	18	73	9
Conuma	30	64	6

Comparison between the two hatcheries is complicated by the data used to calculate age composition. Because of low catches Conuma age composition is based primarily on escapement sampling whereas Nitinat age composition is based primarily on fishery and secondarily on escapement sampling. The age composition error rates between escapement sampling and fishery sampling can be large. Escapement estimation often results in biased age sampling because only a portion of the run is sampled. Variable return year harvest rates also make calculation of age composition difficult.

The number of Nitinat Age 3 returns are further complicated by the total number of fish released, the time of release (early, mid or late release groups), and by the size of fry at release. The more fry released the less percent Age 3 to return. Smaller fry at release results in less percent Age 3 to return and at any size at later releases yields less percent Age 3 to return. We have not observed this pattern for Conuma brood year returns.

HATCHERY CHUM SURVIVAL

Nitinat and Conuma hatchery fry-to-adult survival is shown in Figure 6. Nitinat averaged 3.12% survival but ranged from 0.84% to 7.13% for the 1980 to 1985 broods. Conuma averaged 0.92% survival but ranged from 0.18% to 2.54% for the 1978 to 1985 broods. Similar biases for calculation of age composition are present in calculation of survival. Because escapement is usually underestimated and escapement is such a large portion of Conuma production compared to Nitinat, actual Conuma survival is likely underestimated. Nevertheless, Nitinat was well above and Conuma below the SEP average of 1.7%. Conuma shows a serious decline in survival from the initial years of operation, especially after the 1983 brood year.

The patterns of survival for these two areas reflect the historical returns for these areas (Figures 4 and 5). Nitinat has shown a few very productive years whereas Nootka production has been less variable.

REASONS FOR SURVIVAL DIFFERENCES

FOOD AVAILABILITY

The reasons for the high survival at Nitinat hatchery are assumed to be those iterated by Fedorenko (1979). These include favorable rearing conditions including abundant zooplankton, warm surface water (10-15° C), under-utilized lake rearing potential, and relative absence of predators. The rearing potential of the lake has now been more fully utilized with large numbers of fry and the historical reasons for low production, i.e., low fry numbers to the lake, are no longer relevant. The high annual variability in survivals suggests that these lake rearing conditions are highly variable between years. We hypothesize that at Nitinat inter and intra species competition for available food are major factors affecting survival while at Conuma predation may also be involved.

The reasons for the declining survival at Conuma especially for the 1983 to 1985 broods is less clear. The following discussion evaluates various factors thought to control early marine survival and speculates on the possible reasons for this Conuma decline.

TIME OF RELEASE

A review and comparison of survival versus time of release was done. The comparison was accomplished by counting the total number of releases within a given week for all release years and for the same week counting the total number of releases contributing to within 20% of its maximum brood year survival.

Based on the timing of releases to date Nitinat hatchery returns appear to have a wide window of release from approximately April 19 to May 9 (Figure 7). However for Conuma the optimum time of release is more narrow centering around the third week of April (Figure 8).

The decline in survival at Conuma may be related to this restricted optimum release timing. The mean release date was April 18 for the 78-79 broods but advanced to April 26 for the 80-85 broods. If time of release is a factor in survival the 86-89 brood survival should improve as the mean release date was April 22. Time of release and survival differences suggest that factors influencing survival are different for these two hatcheries.

A comparison of historical trends of productivity between Area 25 (Nootka Sound, Figure 9) and Area 26 (Kyuquot Sound) chum (Figure 10) indicates that they follow almost identical patterns of annual variation. Both showed similar declines from 1987 to 89 return years. This would suggest the poor returns to Nootka are more than hatchery related. The juvenile migration timing for these poor return years also coincides with the occurrence of El Nino events and the observations of great abundance of mackerel in Barclay Sound (Ashton et al. 1985).

The warm waters of El Nino were observed from 1982 through to 1984 (Ashton et al. 1985). At these times many warm water species such as jack mackerel (*Trachurus symmetricus*) and chub mackerel (*Scomber japonicus* Houttuyn, 1782) appear in coastal waters. Further observations of mackerel were made in 1985 (D. Ware, pers. comm.).

PREDATION

Fedorenko (1979) identified few predator species in Nitinat Lake but those caught included coho smolts, sculpins, cutthroat , flounder, birds, mink, and harbour seals. In Tlupana Inlet all the predators mentioned above are present plus other usual predator species found within British Columbia inlets (e.g., rockfish Sebastes spp., lingcod *Opiodon elongatus*, etc.). Conuma stocks are subject to similar causes of mortality as Nitinat plus the additional influence of a greater variety of predators in the nursery area. Predation and food availability are likely both vital factors in fry survival at Conuma.

Nootka Sound temperatures are generally warmer than coastal waters from spring through to fall (Figure 11). Temperatures in Tlupana Inlet are also warmer than temperatures at the head of the inlet than in Nootka Sound. The presence of warm water for long periods of time in Tlupana Inlet is evidenced by the presence of northern anchovy (*Engraulis mordax*) and more recently chub mackerel (*Scomber japonicus*) throughout the summer and fall months. Chub mackerel were observed in the head waters of Tlupana Inlet in early June of 1983, August of 1984 and June of 1985. Mackerel were also observed and captured off Conuma River mouth in September of 1989. The fish weighed approximately 1.8 kg.

If mackerel are present in the estuary during spring releases the predation rates would be expected to be very high and may be a major factor in the low survivals at Conuma for the 1983-85 broods and the resultant low returns observed in Area 25 and 26 from 1987 to 1989.

The presence of mackerel as in early June suggests that they have wintered in Tlupana Inlet. Estuary conditions are such that potential trapping of warmer water fish may occur due to cooling of outer coastal areas while the inlet stays warm until fall rains (Figure 12). This would create a temperature barrier to warm water fishes migrating out of the inlet.

No warm water fishes have been observed in Nitinat lake and predation from this source is unlikely.

CONCLUSIONS

Although chum fry production at Conuma Hatchery is only slightly less than at Nitinat, adult production and fry to adult survivals are substantially lower. Undesirable times of release, higher than normal predation, and predation from El Nino migrating warm water mackerel are all considered to have lowered production and survival. The lowered production is more than hatchery related as confirmed by similar reductions in production of wild stocks in neighboring Kyuquot Sound.

REFERENCES

ASHTON, H.J., V. HAIST, AND D.M. WARE. 1985. Observations on Abundance and Diet of Pacific Mackerel (Scomber japonicus) Caught Off the West Coast of Vancouver Island, September 1984. Can. Tech. Rep. Fish. Aquat. Sci. 1394: 11p.

TULLY, J.P. 1937. Oceanography of Nootka Sound. J. Biol. Board Can., 3(1): 43-69.

PICKARD, G.L. 1963. Oceanographic Characteristics of Inlets of Vancouver Island, British Columbia. J. Fish. Res. Board Can., 20(5): 1109-1144.

LIGHTLY, D.T., M.J. WOOD, and S.R. HEIZER. 1985. The Status of Chum Salmon Stocks of the West Coast of Vancouver Island, 1951-1982, Statistical Areas 22-27. Can. Tech. Rep. Fish. Aquat. Sci. 1366: 150 p.

FEDORENKO, A.Y., F.J. FRASER, AND D.T. LIGHTLY. 1979. Salmonid Resources Review and 1975-1977 Biological Survey, Nitinat Lake, British Columbia. Fish. Mar. Serv. Tech. Rep. 839: 86 p.

NORTHCOTE, T.G., M.S. WILSON, AND D.R. HURN. 1964. Some Characteristics of Nitinat Lake, an Inlet on Vancouver Island, British Columbia. J. Fish. Res. Board Can., 21(5): 1069-1081.

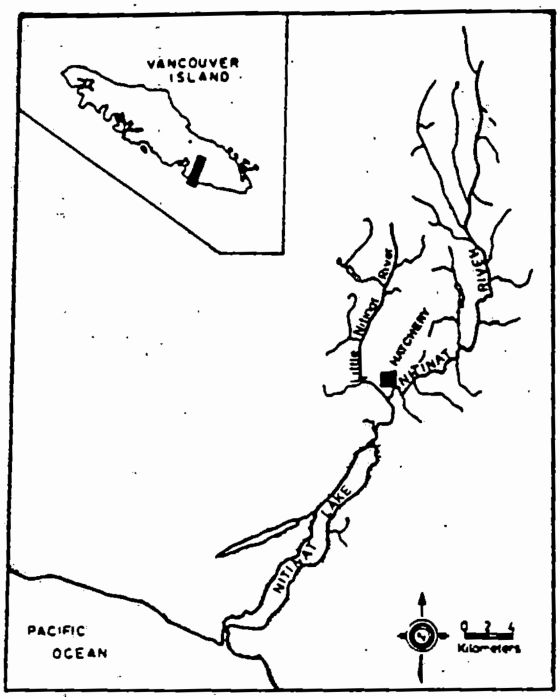


Figure 1. Location of Nitinat Hatchery.

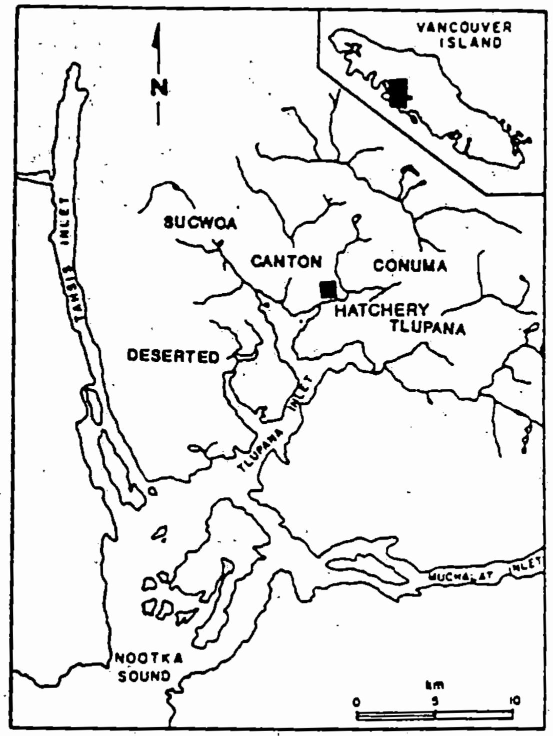


Figure 2. Location of Conuma Hatchery.

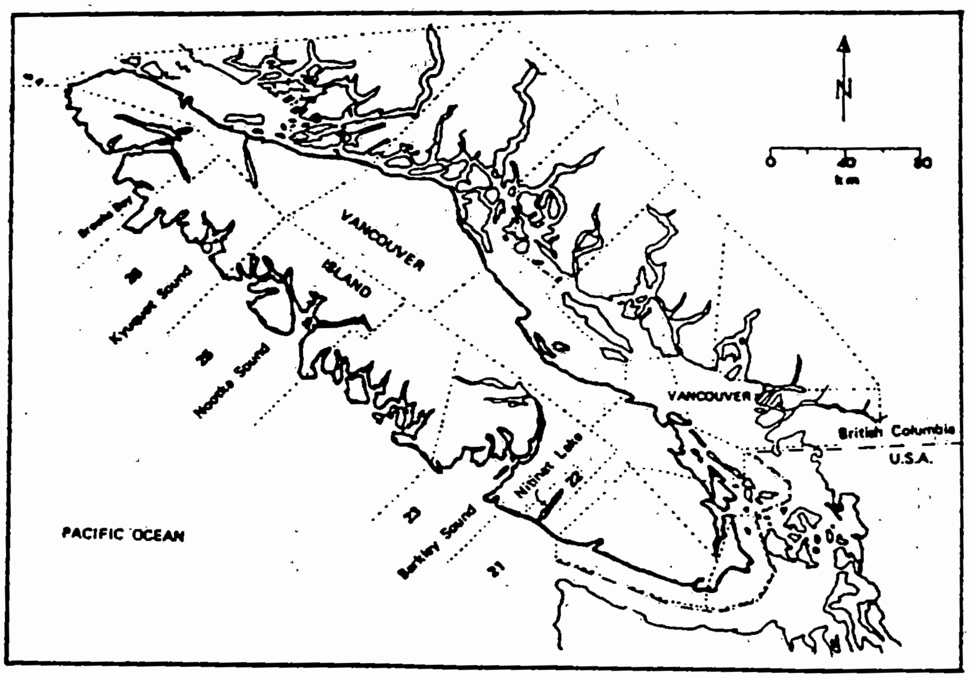


Figure 3. Location of Statistical Areas.

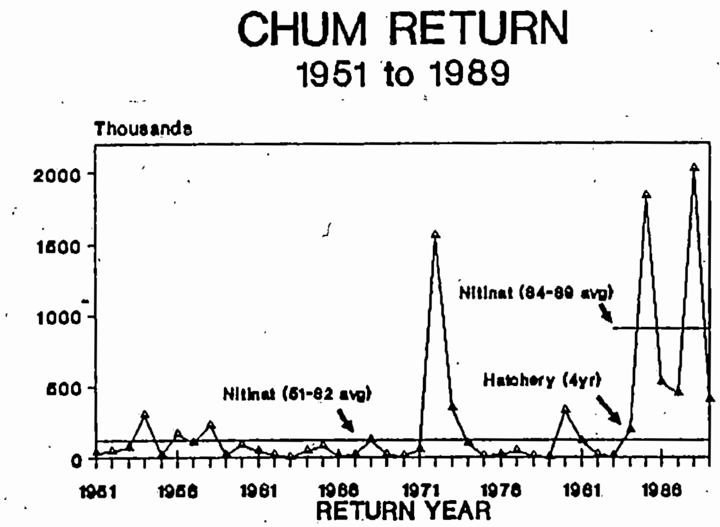


Fig.4 Area 21-22 (Nitinat) Chum production 1951 to 1989.

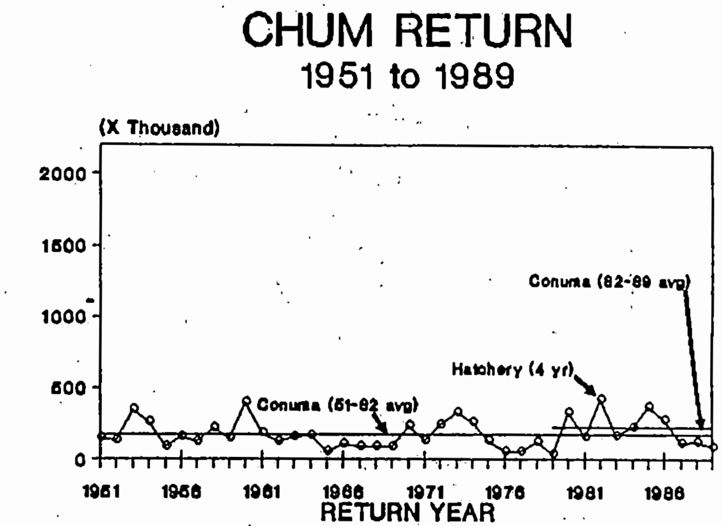


Fig. 5 Area 25 (Nootka) Chum production 1951 to 1989.

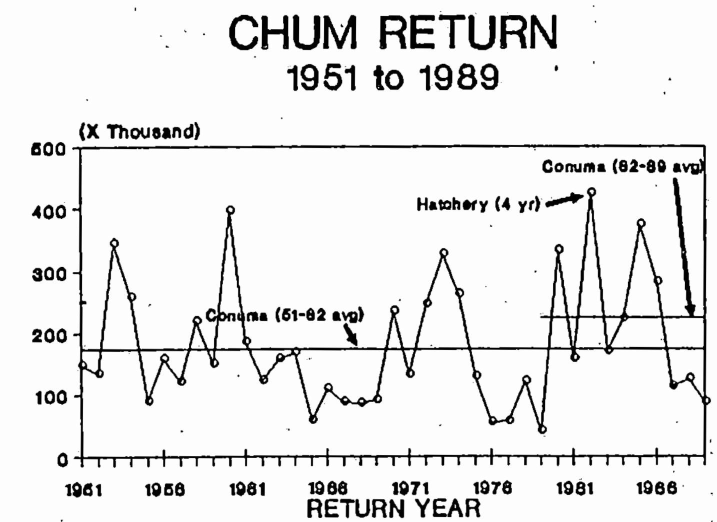


Fig. 9 Area 25 (Nootka) Chum production 1951 to 1989.

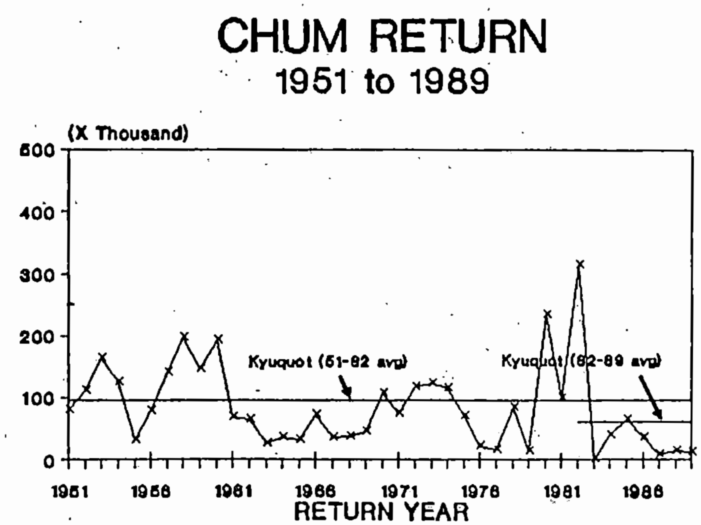


Fig. 10 Area 26 (Kyuquot) Chum production 1951 to 1989.

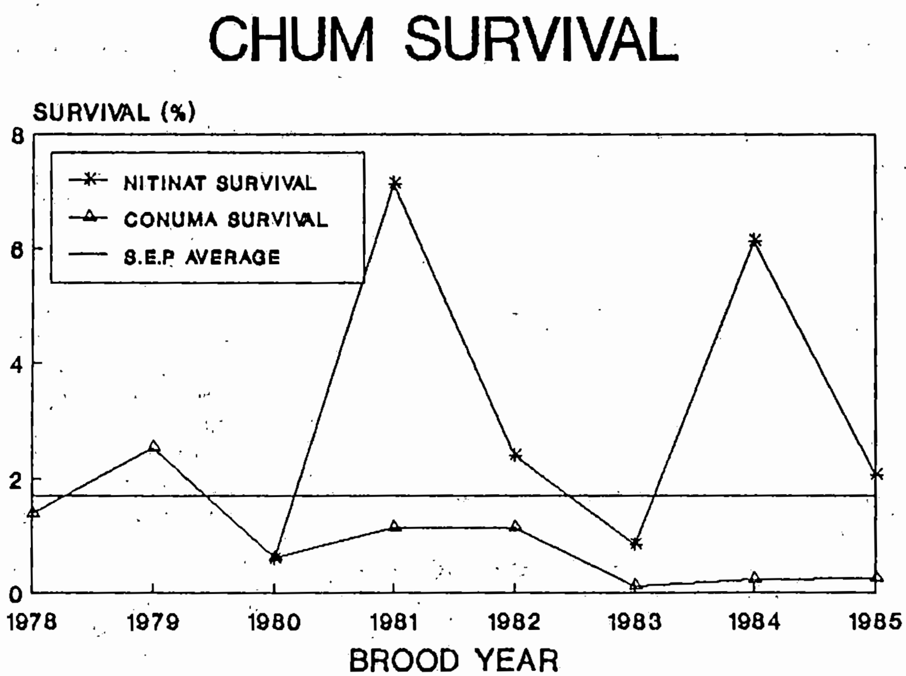


Fig.6 Hatchery chum fry to adult survival (1978-85 broods)

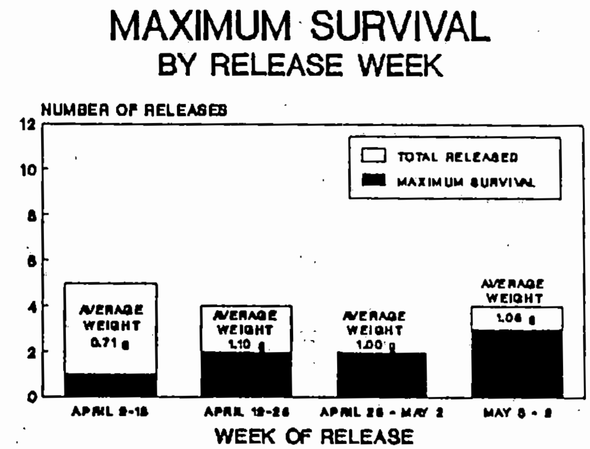


Figure 7. Nitinat survival and time of release.

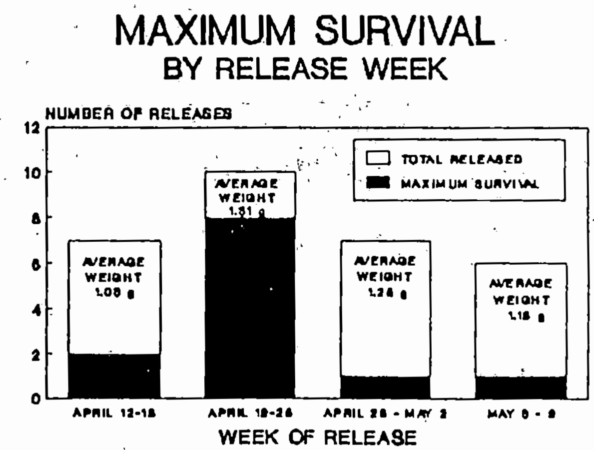


Figure 8. Conuma survival and time of release.

OCEAN TEMPERATURE
(1986 - 1990 average)

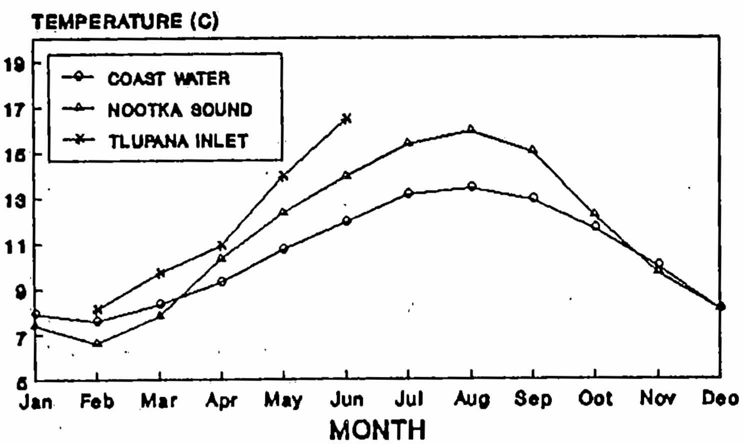


Fig. 11 Monthly mean ocean water temperatures (1986-90).

OCEAN TEMPERATURES
September & October

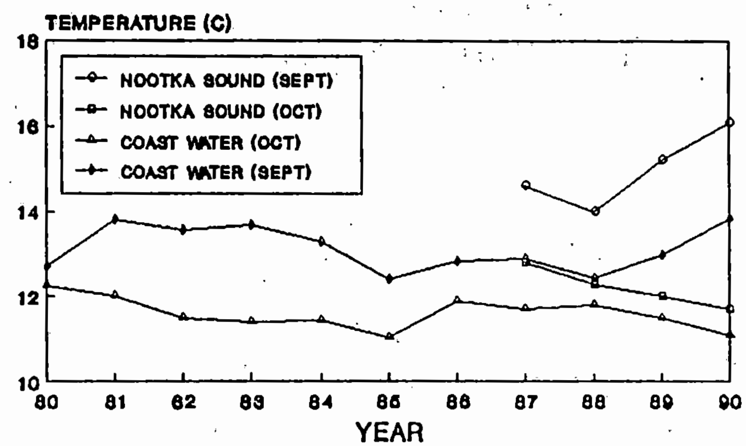


Fig.12 Sept-Oct. ocean water temperatures (1980-90)

Survival, Marine Distribution, and Age at Maturity of Hood Canal Hatchery Chum

Howard J. Fuss and Charles W. Hopley

Washington Department of Fisheries
115 General Administration Building
Olympia, Washington 98504

Hood Canal hatchery is the major producer of hatchery reared chum in Washington state. Since 1974 releases of chum from this hatchery have exceeded 14 million annually and have provided an extensive and important commercial fishery in Puget Sound and Hood Canal. Although survival estimates have been made since 1965, these are based on estimated run sizes and do not quantify contribution rates to the various North American fisheries. Beginning in 1980, five consecutive broods of chum were coded-wire tagged as part of three separate studies. In this paper we have assumed that distribution is unaffected by the various study treatments and treat each tag group as a replicate.

Based on the estimated recovery of over 6,600 tags we found that survival rates range from about 0.6% to nearly 4%. A portion of Hood Canal hatchery chum migrate as far north as the Aleutian Islands, and by August and September of their third or fourth year of life, they are in Southeast (S.E.) Alaska. Alaska recoveries amount to only about 0.1% of the total recoveries. In October the fish are widely distributed from Canada southward to the Tacoma area of Puget Sound. It appears that in some years a portion of the run uses the northern migratory route through the Johnstone and Georgia straits. The total Canadian recovery of tagged fish was 0.5% of the total survival. However, differences in both fishery and sampling intensity may cloud this picture somewhat. Escapement to the hatchery accounts for approximately 22% of the total survival and occurs primarily in November.

The Hood Canal hatchery located in Hoodsport, Washington (Figure 1) is the largest producer of hatchery reared chum in Washington state. Prior to 1975 releases of chum salmon from the hatchery did not exceed 2.5 million fish (9,500 pounds) annually. Since then the program has been increased and now produces in excess of 14 million chum fry annually.

Despite this increased emphasis on chum production, data on ocean distribution of the fish have been lacking and total adult production estimates are developed using run reconstruction methods. Run reconstruction is a method for allocating catches of a particular stock by taking escapement data and then back-calculating the fishery catches in each fishing area. These estimates are then summed to estimate the total run size for the stock. The method assumes that the stock is randomly distributed in mixed stock areas and that the particular stock in question is harvested at a constant rate within the fishery area. Using age data obtained from scale analysis the catches are then broken down into broods and a total run size for each brood is estimated. However, these estimates do not include contribution rates to Canadian fisheries (Strategic Plan Document, Washington Department of Fisheries, unpublished). Based on genetic stock identification (GSI) estimates, the total contribution of U.S. origin chum to the Canadian catch varies annually from 0-20% (Steve Phelps, Washington Department of Fisheries, personal communication). Brood survival estimates based on the total brood adult production divided by the total number of fish released for that brood, have ranged from 0.61-3.77%.

Beginning with the 1980 brood, five consecutive broods of Hood Canal hatchery chum were coded-wire tagged and released as part of three separate studies. The 1980 brood was part of an aborted time and size at release study where all groups were released at the same size on the same day. Four groups in each of the 1981-1983 broods were released as part of an acclimation to brackish water study (Fuss 1985, unpublished, Proceedings of the 1985 Northeast Pacific Pink and Chum salmon Workshop). The 1984 brood consisted of four groups, two released as "small" sized fish (0.88 g) and two released as "large" sized (0.98 g) fish.

We will use these marked groups to develop a profile of survival rates, marine (fishery) distribution, run timing, age at maturity, and harvest rates. The primary assumptions of this analysis are, 1) ocean distribution within and among broods is not affected by treatment, and 2) that each tag group can be used as a replicate.

MATERIALS AND METHODS

Chum salmon were recovered in Alaska, British Columbia, and Washington fisheries from 1983-1989. However, in some areas of Washington (Areas 5, 7, 7A; Figure 1) fisheries were not extensively sampled during this period and in British Columbia sampling of chum for coded wire tags did not occur prior to 1984. In addition, escapement to Hood Canal hatcheries was intensively sampled for marked fish. Stream recovery of tagged fish was not done by WDF, however, personnel from the University of Washington Big Beef Creek research station surveyed some streams north of the Hood Canal hatchery. Each fishery area was assigned an expansion rate by the respective recovery agency and these data along with observed recoveries, fish size, and date and area caught were supplied to the Pacific States Marine Fisheries Commission (PMFC) in Portland, Oregon. The data for each tag group was retrieved, and collated to provide us with observed and estimated (expanded) recoveries by fishery area, month, and year. Estimated recoveries from each brood were then combined by fishery to calculate the percent of the total recovery by area. This was done by dividing the estimated recovery of each fishery area by the total recovery for that brood or the total estimated recovery for all broods combined. Survival estimates were made by dividing the total estimated recovery by the total number of tagged fish released. Survival estimates could be made for individual groups, broods, or combined broods. Survival rate estimates made without the use of coded wire tags were provided to us by Mr. Jim Ames of the Washington Department of Fisheries. This data expressed survival as the number of adults surviving per pound of fish released. We recalculated this data to express it as the number of adults per fish released. This was done by multiplying the number of adults per pound released by the total poundage released (giving the total number of adults produced) and then dividing by the total number of fish released.

RESULTS

SURVIVAL RATES

Survival rates based on run reconstruction estimates of 1965-1984 brood chum salmon released at Hoodsport hatchery have ranged from 0.61%-3.76% (Table 1) (Jim Ames, Washington Department of Fisheries, personal communication). Average survival rates of 1980-1984 brood chum (estimated by coded wire tags) ranged from 0.62-3.23% (Figure 2). In only one brood (1982) was there less than a 30% difference in the survivals estimated by the two methods. Coded wire tags estimated a greater survival of the 1980 and 1981 broods by 134% and 79%, respectively. But for the 1983 and 1984 broods coded wire tag estimates were lower by 31% and 105%, respectively. We also found a declining trend in survival rates when compared to brood years. The average size at release also declined. We found a significant positive relationship between size and survival ($Y= 0.96 * X^{2.54}$; $R^2 = 0.495$, $F= 14.7$, $df= 20$).

DISTRIBUTION

The estimated contribution of Hood Canal hatchery chum to the Washington fisheries plus escapement was 99.4% for the five broods. The contribution to the British Columbia and Alaska fisheries was 0.5% and 0.1%, respectively (Figure 3). The majority (65.9%) of the Washington catches occurred in Hood Canal (Areas 12, 12B, and 12C; Figure 3). Catches elsewhere in Puget Sound amounted to nearly 12% of the total. Most Puget Sound catches were in Areas 10 and 11 (Seattle-Tacoma). Escapement comprised 21.4% of the total survival. Very few stray fish were recovered in the escapement; there were three observed recoveries in the Skokomish river fishery and one observed recovery in Seabeck creek (located approximately 20 miles north of Hood Canal hatchery). There were no recoveries made at the three adjacent Hood Canal hatcheries (Enatai, George Adams and Mckernan hatcheries).

The timing of tag recoveries by fishery area and the proportion of tag recoveries made in each fishery by month is shown in Figure 4. A single recovery of a 1981 brood fish was made in August 1984 in the

Aleutian Island area (55^0 N, 164^0 W) by a groundfish observer vessel. Three other observed recoveries were made in Alaska, two were caught in the southern outside seine fishery (August 1986) and one in the central inside gillnet fishery during September, 1986.

A total of 36 estimated recoveries were made in British Columbia waters. Most fish were captured in October or November. Fish from only three of the five broods were recovered in the Canadian fisheries. Tag recoveries show that in some years a portion of the run uses both the inside (Johnstone and Georgia straits) and outside (southwest Vancouver Island) migration routes. For example, all fish from the 1982 brood were sampled from the Georgia straits net fishery (Figure 5). About three quarters of the 1983 brood fish were recovered in the southwest Vancouver Island net fishery, the remainder were caught in the Juan de Fuca net fishery. About 59% of the recoveries of 1984 brood fish were sampled in the Johnstone Straits net fishery, and 41% in the southwest Vancouver Island net fishery. Interestingly, the 1988 southwest Vancouver Island catch was 66% greater than the Johnstone straits catch for the same year (Bill Tweit, WDF, personal communication).

In Puget Sound, 50 estimated recoveries were made in the Bellingham Bay area (Area 7B) and 100 recoveries in the Port Susan/Port Gardner area (8A). Most of these recoveries were made in November. No recoveries were made in Areas 7 and 7A because these areas were not sampled. Three recoveries were made in Area 5 all in 1985. This area was not sampled in 1983-84 and 1986-1989. In the Seattle/Tacoma area (Areas 10 & 11) 373 fish were caught in October and 131 in November. In Hood Canal (Areas 12 & 12B) about half the recoveries were made in October and half in November. Recoveries were made at Hood Canal hatchery from October-December, with the peak occurring in the third week of November.

AGE AT MATURITY

A single two year old fish was recovered in the Puget Sound fishery (Area 9) during October, 1983. This fish was probably immature. However, the majority of tags recovered were from four year old fish (Figure 6). The 1981 brood showed a strong three year old component (55% of the total catch). Five year old fish comprised less than 5% of the total recoveries in any year.

HARVEST RATES

There were a total of 6,679 estimated recoveries for the five combined broods of Hood Canal hatchery chum. Of this total 78.8% of the recoveries were made in the various fisheries, and 21.2% at the hatchery. The average catch to escapement ratio for the period 1983-1989 was 3.7:1. The ratio for the same period calculated by run reconstruction was 4.9:1 (Strategic Plan for Managing Washington Salmon Stocks, Salmon Program, WDF, Appendices G-I, 1984).

DISCUSSION

Combining data from five broods of chum has shown that survivals range between 0.6%-4.0%. Previous to the release of hatchery chum salmon carrying coded wire tags, ocean distribution of Hood Canal hatchery chum was unknown. The small number of tagged fish recovered in Alaska waters only confirms that an unknown portion of the Hood Canal hatchery chum migrate to these areas. Tagged fish were recovered in British Columbia in both the inside and outside fisheries, indicating the use of both the southern and northern migratory route past Vancouver Island.

What is less clear is how the calculated survival and contribution rates are influenced by either the fishing or sampling intensity in a given year. In 1988 the Johnstone Strait net fishery caught over 1 million fish, and coincidentally recoveries were made in this fishery. In 1987 only 66,000 fish were caught in this fishery and no recoveries of tagged Hood Canal chum were made. Also only three fish all in 1985 were recovered in the Washington Area 5 (Juan de Fuca) fishery. This area was not extensively sampled in the other years. However, estimates made by GSI are that Hood Canal chum (both hatchery and wild) comprised between 18-42 % of this area's catch in 1990 (Phelps et. 1991). Although fisheries in Areas 7 and 7A were not sampled for tagged fish, estimates made by GSI are that Hood Canal chum comprised less than 5% of the area catch.

A complete picture of the timing and migration routes of the Hood Canal hatchery chum cannot be made because of the lack of sampling in some key areas. What can be deduced is the fish appear in southeast Alaska in August and September of their third and fourth years of life. By October they are off Vancouver Island, apparently choosing one or both of the previously mentioned migratory routes, and in Puget Sound and Hood Canal. Once in Puget Sound, they appear to mill in the Seattle/Tacoma area and Hood Canal. By November they are more oriented to Hood Canal, or the area immediately outside the entrance to the Canal. The hatchery begins trapping fish in October, but the run peaks about the third week in November and continues into mid-December.

The majority of the run is comprised of four year old's, but in at least one brood, three year old's comprised the majority. Coincidentally, the highest estimated survival rates occurred in that brood.

There are several interesting pieces of the Hood Canal chum survival rate and distribution puzzle that remain to be found. There are no plans to tag future broods of Hood Canal chum. The only other means to determine this information is through GSI or otolith marking. However, GSI techniques can not unambiguously identify Hood Canal hatchery chum from other stocks of Hood Canal chum. At present, a large scale otolith marking program is not planned and fishery samplers are not routinely taking samples for otolith analysis.

REFERENCES

Phelps, S.R., L. LeClair, C. CdeBaca, and W. Beattie. 1991. Genetic stock identification estimates of the 1990 Washington commercial fisheries in the strait of Juan de Fuca and northern Puget Sound. Unpublished manuscript, Washington Department of Fisheries, Olympia, Washington.

Table 1. Pounds, Numbers and Survival rates of Chum salmon released at Hood Canal Hatchery by brood. Survival rates are estimated by dividing the estimated total brood run size pounds of fry released (method 1) or by coded wire tags (method 2).

			Method 1		Method 2
Brood	Pounds Released	Number Released	Survival number/lb. fish released	Survival per fish released	Survival estimated by CWT
1965	888	278,880	3.225	1.03	na
1966	1,771	554,032	3.629	1.16	na
1967	2,301	678,260	2.199	0.75	na
1968	4,373	1,658,369	2.308	0.61	na
1969	2,424	795,040	3.552	1.08	na
1970	3,036	1,547,406	6.418	1.26	na
1971	3,794	855,110	2.973	1.32	na
1972	4,126	974,568	8.889	3.76	na
1973	9,202	2,125,798	4.477	1.94	na
1974	27,368	8,665,985	6.617	2.09	na
1975	22,776	8,465,125	5.462	1.47	na
1976	24,490	8,859,756	2.619	0.72	na
1977	21,883	7,939,467	6.025	1.66	na
1978	33,256	10,951,447	3.587	1.09	na
1979	24,238	8,627,175	6.097	1.71	na
1980	44,336	15,312,551	2.762	0.80	1.87
1981	23,589	10,481,539	8.020	1.80	3.23
1982	32,058	14,514,244	6.220	1.37	1.19
1983	34,748	15,006,114	6.569	1.52	1.16
1984	60,763	22,614,000	4.710	1.27	0.62

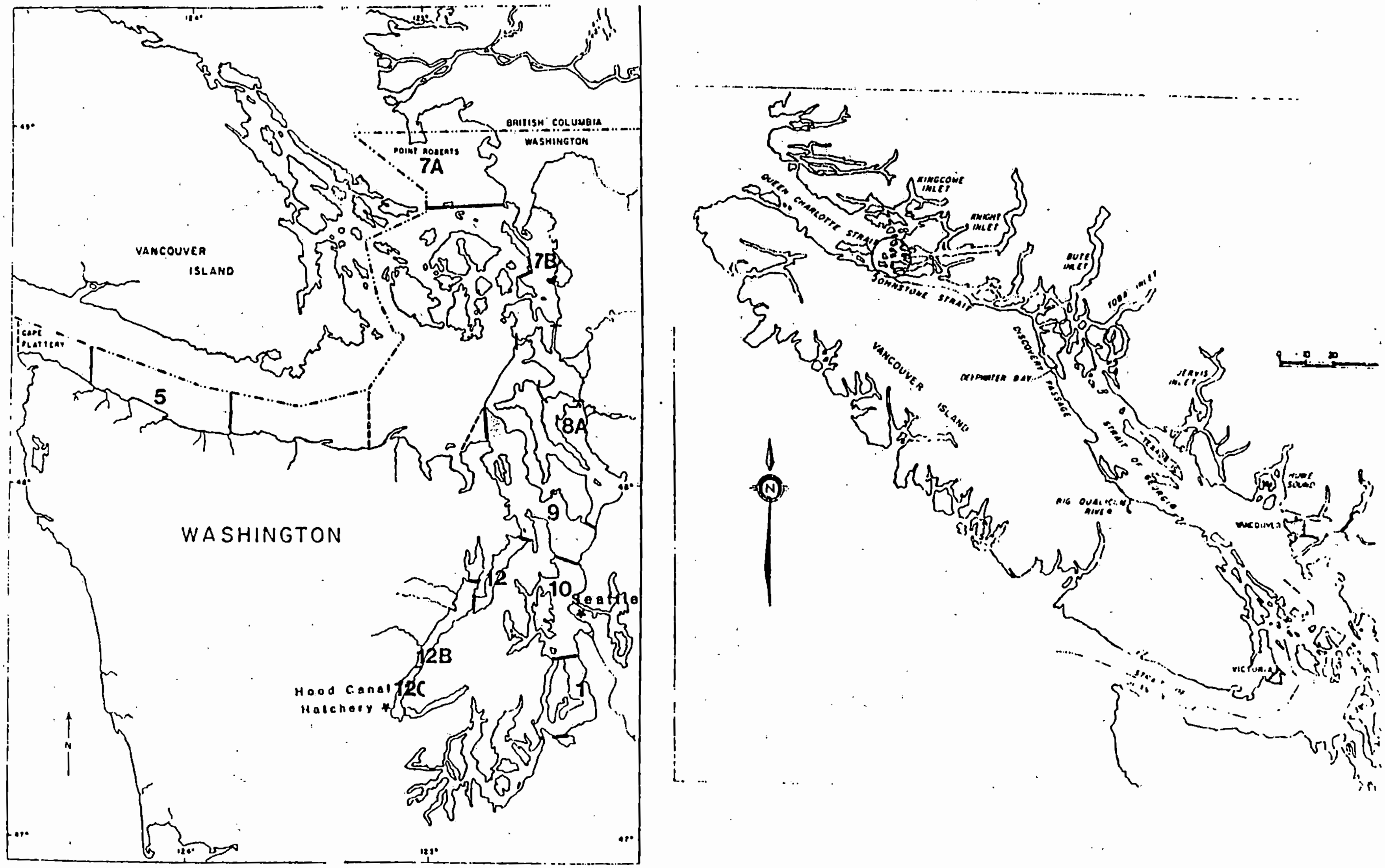


Figure 1. Washington and British Columbia fishery areas where coded wire tagged chum were caught. The location of the Hood Canal hatchery is included.

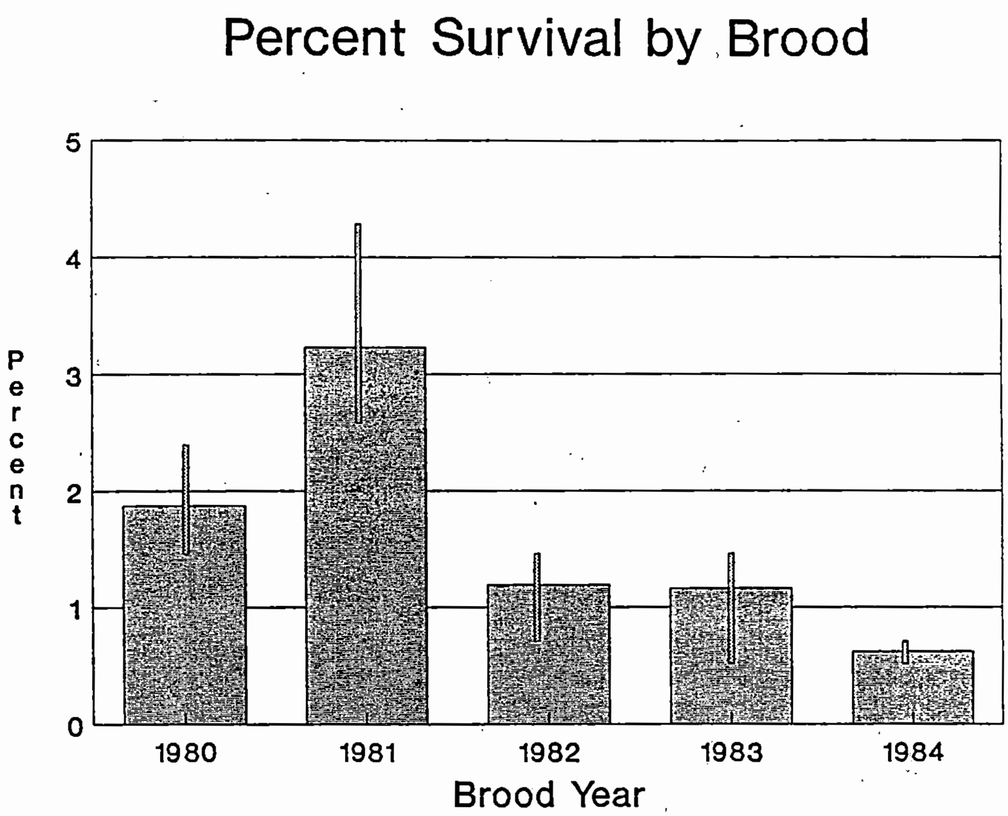


Figure 2. Percent survival estimated by coded wire tag recoveries for broods 1980-1984. Small vertical bars represent the range in survival rates for the brood.

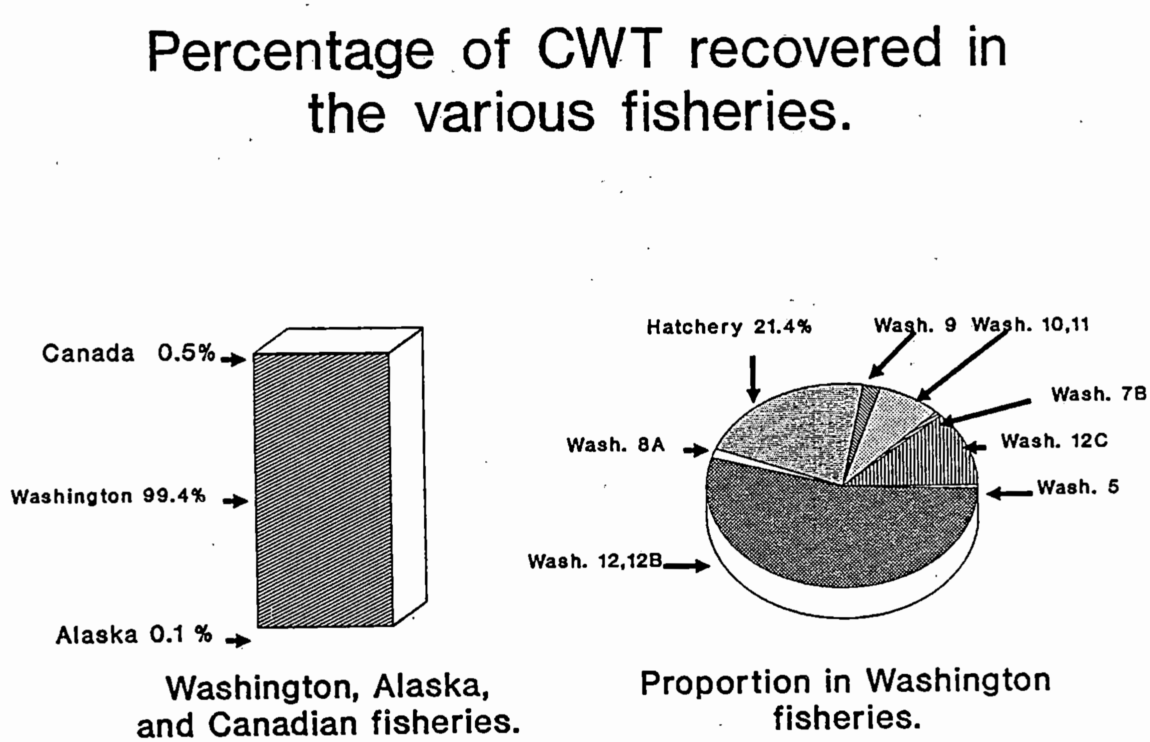


Figure 3. Percent of total survival estimated by coded wire tag recoveries by fishery area of recovery (broods 1980-1984 combined).

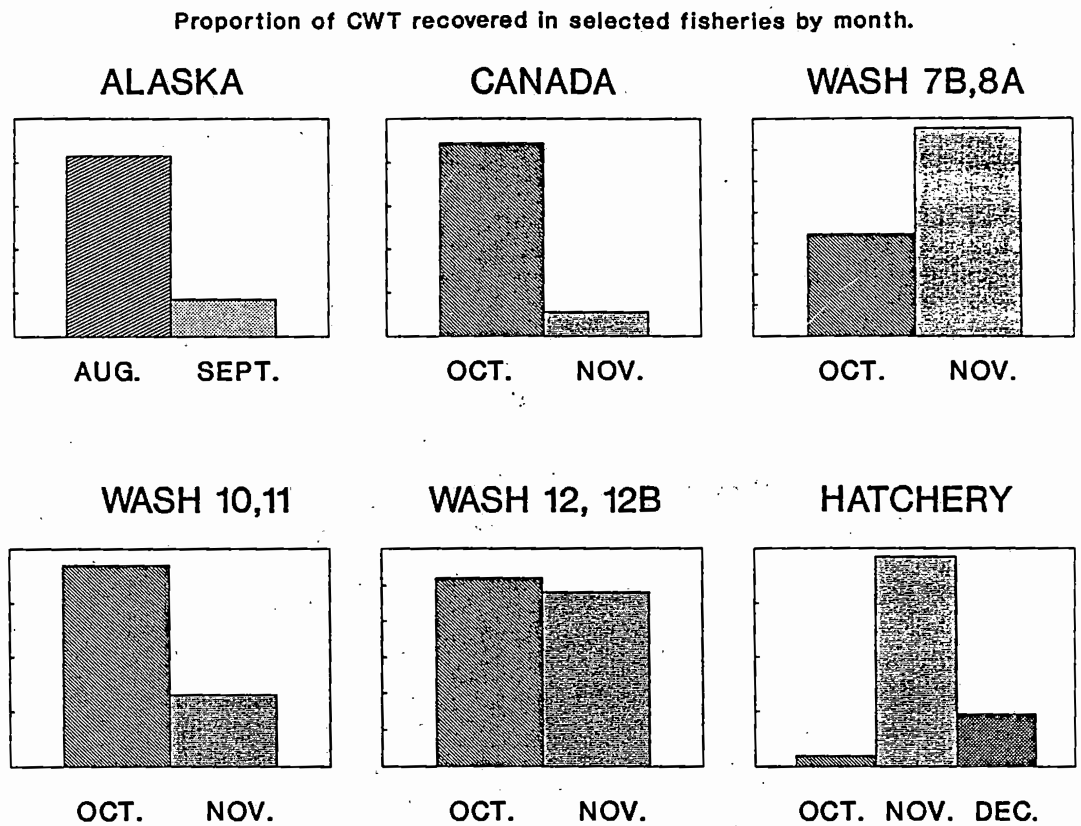


Figure 4. Proportion of total coded wire tag recovery in selected fishery areas of recovery by month (broods 1980-1984 combined).

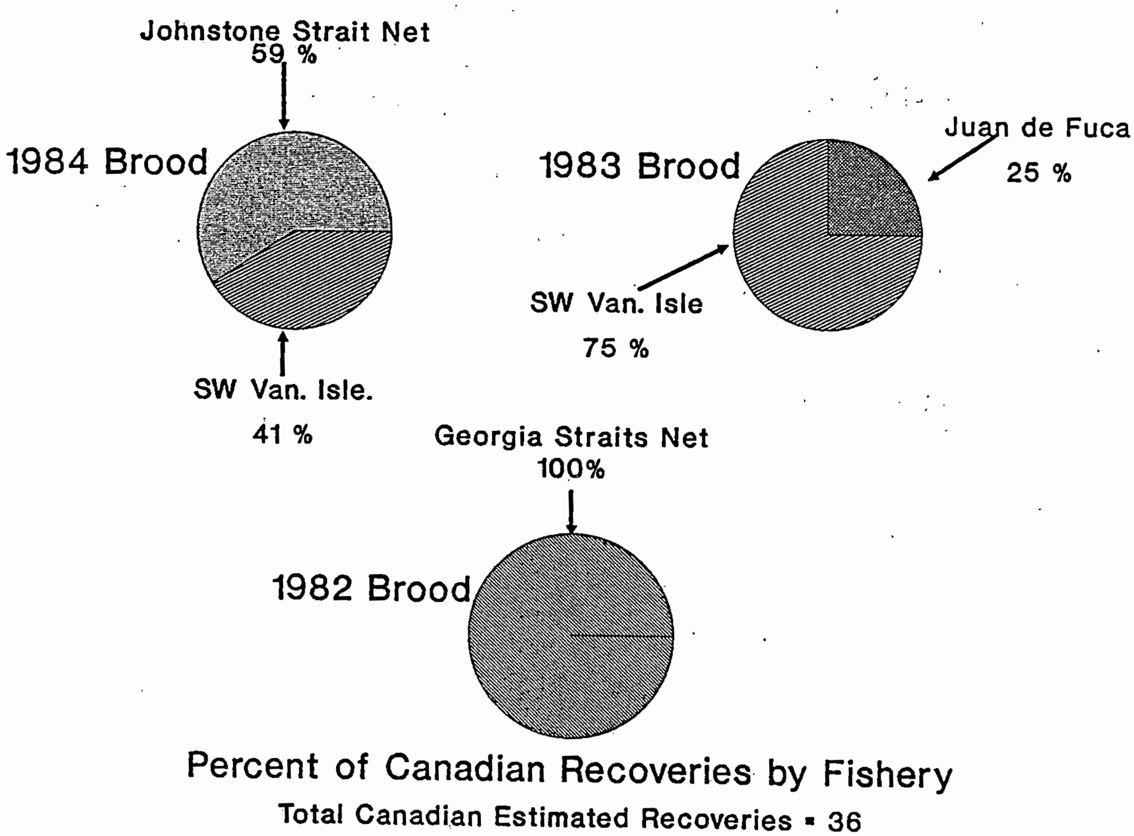


Figure 5. Proportion of coded wire tags recovered in Canada by individual fishery area. Data for 1982-1984 broods only.

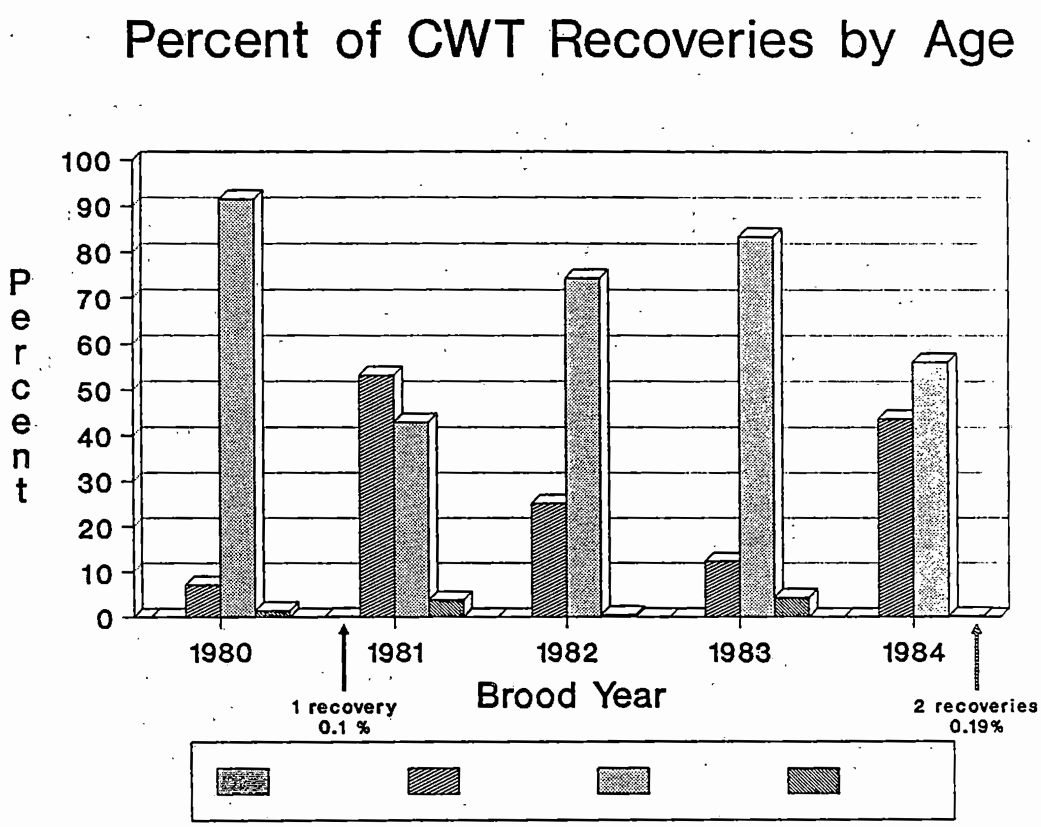


Figure 6. Percent of coded wire tags recovered in all fisheries and at the hatchery by age.

Comparative Performance of Pink Salmon from Two Hatcheries in Prince William Sound

Jeff Olsen

Prince William Sound Aquaculture Corporation
P.O. Box 1110
Cordova, Alaska 99574

The development of the salmon enhancement program in Prince William Sound is described in detail in *Report Number Six, Project Report and Policy Recommendations* (P.W.S.A.C. Allocation Task Force 1990). Large scale pink salmon enhancement programs have been developed at the Armin F. Koernig (A.F.K.) and Wally Noerenberg Hatcheries (W.N.H.) in Prince William Sound. Performance of freshwater and marine life stages of pink salmon of four brood years, 1985-1988, from A.F.K. and W.N.H. were compared. Freshwater life stage performance of pink salmon at each facility as measured by standard survival parameters is similar. Marine life stage performance of pink salmon from each hatchery as measured by percent marine survival is similar. Marine survivals of specific saltwater rearing treatment groups vary within hatchery but the trend is similar between sites. Fed fry released into the zooplankton "bloom" outperform the unfed fry released into the "bloom" and fed fry released after the "bloom". Performance of pink salmon at each hatchery may be enhanced by increasing the number of fed fry released into the zooplankton bloom.

Prince William Sound is located in South Central Alaska about 130 miles southeast of Anchorage. The sound encompasses approximately 9,000 square miles characterized by numerous islands, numerous short streams, long fiords, mountains, snow fields and glaciers (McCurdy et al. 1985). Four species of salmon are indigenous. Pink salmon are dominant followed by chum, sockeye, and coho salmon. A major commercial salmon fishery occurs in the area, and the area is popular for sport fishing, boating, and other forms of recreation.

The climate of Prince William Sound is largely influenced by the Gulf of Alaska and is characterized by relatively heavy precipitation, cool summers, moderate winters and strong surface winds in most locations. The city of Cordova averages 168 inches of precipitation annually.

The Prince William Sound area contains the communities of Valdez, Cordova, Whittier, Tatitlek and Chenega Bay (Figure 7). The majority of the population reside in the communities of Whittier, Valdez, and Cordova.

Five salmon hatcheries are currently in operation in Prince William Sound. The Solomon Gulch Hatchery is owned and operated by the Valdez Fisheries Development Association. The Armin F. Koernig (A.F.K.) and Wally Noerenberg (W.N.H.) hatcheries are owned and operated by the Prince William Sound Aquaculture Corporation (P.W.S.A.C.). The Cannery Creek Hatchery (C.C.H.) is owned by the state of Alaska and operated by P.W.S.A.C. The Main Bay hatchery is owned by the State of Alaska and operated jointly by P.W.S.A.C. and the State of Alaska.

Prince William Sound Aquaculture Corporation (P.W.S.A.C.) is a private non-profit regional aquaculture association headquartered in Cordova, Alaska. P.W.S.A.C. was founded in 1974 following the passage of the Private, Non-profit Hatchery Act. Today P.W.S.A.C. is the largest of seven regional aquaculture associations in Alaska. Table 6 indicates current P.W.S.A.C. hatchery production levels.

The Armin F. Koernig (A.F.K.) hatchery, formerly Port San Juan, is P.W.S.A.C.'s first salmon hatchery. Originally a salmon cannery, the A.F.K. hatchery began pink salmon production in 1975 and released 1 million fry in 1976. Today, A.F.K. has a capacity of 126 million pink salmon eggs. All pink fry are released on station.

The Wally Noerenberg Hatchery (W.N.H.), formerly Esther Island, was completed in 1986 as the largest multi-species salmon ranch in North America. Currently, W.N.H. has the incubation capacity for 206 million pink salmon eggs, 111 million chum salmon eggs, 2.5 million coho salmon eggs, and 1 million chinook salmon eggs. Most fry and smolt are released on station.

Both A.F.K. and W.N.H. share one stock of pink salmon that originated at A.F.K. Hatchery. This stock returns late in the season, peaking mid August (Figure 6). A.F.K. saw its first return of pink salmon in 1977 after two years of off site eggtakes to establish broodstock. The A.F.K. stock was used in 1985 and 1986 to begin the W.N.H. pink salmon program. W.N.H. saw its first return of A.F.K. stock pink salmon in 1987.

METHODS

ADULT RETURN

It is P.W.S.A.C.'s goal to contribute 70% of its return to the Common Property Fishery (C.P.F.). The salmon harvest is managed to return up to 30% of the run to the hatchery for broodstock and corporate cost recovery.

Pink salmon broodstock at A.F.K. and W.N.H. are captured in saltwater using a purse seine vessel. The adults are transferred from the purse seine to $40m^3$ floating cages. The cages are used to transport broodstock to a large saltwater brood enclosure, near the hatchery, barriered from the open bay by a large seine net. Broodstock are allowed to mature in the saltwater enclosure. When ready, the adult salmon volitionally migrate to the freshwater fish pass at the head of each brood enclosure. This process takes three to four weeks.

Adult returns to W.N.H. and A.F.K. as well as adult returns of specific rearing treatment groups presented in this report were derived from analysis of C.W.T. data.

EGGTAKE

Pink salmon eggtakes at A.F.K. and W.N.H. begin in late August and end mid September. All eggs are taken from adults returning to each facility. It is unlikely that outside sources will be needed to meet broodstock needs for the current pink salmon stock.

On or about August 20th, broodstock are sampled in saltwater, near the fish pass, to determine degree or maturation. Typically, the fish pass is opened to salmon movement August 22nd-24th.

Fish move volitionally to a broodstock handling area at each site. Here the fish are sorted for sex and maturity. Identical spawning techniques are used at A.F.K. and W.N.H. Each females eggs are scrutinized for quality before acceptance. If three or more water hardened eggs are found, that females eggs are discarded. The broodstock is managed at both facilities to assure the eggtake goal is met while meeting the quality standard.

All eggs are fertilized using the dry method of spawning. The female to male ratio is never greater than 2.5 to 1. The mean fecundity at A.F.K. and W.N.H. is 1,600 eggs are female. The eggs are fertilized immediately, inventoried, and seeded on incubating trays to water harden. Fertilized eggs are inventoried using the weight method described in *Fish Hatchery Management* (Piper et al. 1982).

One parameter used to measure eggtake quality is percent fertilization (McNeil and Bailey 1975). Daily "fertility" samples are taken to measure percent fertilization and the success of the eggtake to date. Overall, percent fertilization for the eggtake should average 97.5%.

INCUBATION

Both A.F.K. and W.N.H. use zenger box incubators from North Pacific Aquaculture Development (N.O.P.A.D.). Each zenger tray contains approximately $0.17 m^3$ of incubating space and are loaded at between 305,000 and 310,000 eyed pink salmon eggs. Zenger trays are stacked three, five, and six high at A.F.K., and six high at W.N.H.

At A.F.K. all eggs are removed from incubators at eye and re-seeded onto zenger boxes with hatching trays and artificial substrate. The importance of substrate for pink salmon is described in McNeil and Bailey (1975). Prior to eye, all eggs incubate in zenger boxes without hatching trays and substrate green eggs are loaded at between 550,000 and 600,000 eggs per tray. This process of re-seeding allows for all used incubators to be rinsed and conserves water use prior to eye.

At W.N.H. the eggs are not removed from the incubators at eye. Rather, they are loaded at the eyed egg density during eggtake on zenger boxes outfitted with hatching trays and artificial substrate. A cleaner and much larger water source at W.N.H. permit this time saving process.

At A.F.K. and W.N.H. we do not pick eggs. Our high green to eye survivals together with the cold incubation water and the use of hatching trays has eliminated the need to pick eggs. See Table 1 for average incubation temperatures between 1985 and 1989 at A.F.K. and W.N.H.

All egg hatching trays are removed after hatch and dead eggs are enumerated to measure survival.

Alevins remain buried in their incubator until emergence in mid March to mid April. At both A.F.K. and W.N.H. pink salmon are allowed to outmigrate volitionally from incubators via gravity flow and separate plumbing. All outmigrating fry travel through electronic fry counters for enumeration en route to salt water holding pens.

REARING AND RELEASE

At both A.F.K. and W.N.H. pink salmon fry are held and fed in $450 m^3$ saltwater net pens in front of the hatchery until the near shore zooplankton "bloom" begins. The importance of food availability to the early marine survival or juvenile pink salmon has been well documented (Cooney 1989). This "bloom" consisting of calanoid copepods typically begins in mid April and lasts through May, peaking late April and early May. It is believed that by holding our pink salmon fry and matching their release to the zooplankton bloom, we improve their near shore survival.

Pink salmon fry outmigrate at an average weight of 0.23 g per fish. Outmigration at A.F.K. and W.N.H. begins mid March. All fry are collected in 12 m X 12 m X 3 m saltwater pens before release. Currently we are evaluating three rearing and release strategies. (1) Fry are fed for a minimum of ten days and released into the zooplankton bloom late April to mid May as early fed fry. (2) Fry are collected in pens and released after two to three days into the peak "bloom" as "unfed" fry. (3) Fry are fed for a minimum of ten days and released late May as "late fed" fry. Each treatment group is given its own series of half length coded wire tag codes to allow evaluation of the different rearing strategies.

Fry receive a standard commercial diet of soft semi-moist fish food. Maximum pen loading densities vary between sites. At A.F.K., approximately 7 million fry are loaded per pen, a loading density of 3 to 8 kg/m^3. At W.N.H., 12 million fry are loaded per pen, a loading density of 6.7 kg/m^3. Lake Bay, at W.N.H., is much narrower and deeper than Sawmill Bay at A.F.K. and provides greater water movement, allowing higher loading densities.

Twice weekly, near shore plankton levels are monitored at each facility beginning in mid-January and ending in July. Plankton samples are made in two pre-selected locations near the hatchery site using a 1/2 m sample net hauled vertically from 20 meters. (P.W.S.A.C Procedures Manual for Fish Culture and Harvest.) Up to three replicates are made per sample location. Samples are transferred to 250 mL graduated cylinders and allowed to settle 24 hours. The relative density of zooplankton and phytoplankton as well as their percent composition is determined. Currently, no effort is made to distinguish species. The fish culturists look for increasing percent composition of zooplankton, calanoid sp. Our first releases generally occur when the percent composition of calanoid copepods exceed 30% to 50% of the sample volume.

With the exception of one year, 1987, half length coded wire tags have been applied to a portion of pink salmon fry released at A.F.K. and W.N.H. hatcheries since 1985. Methods of tag application, tag recovery and analysis are described by Geirger et al. (1990). The Alaska Department of Fish and Game (A.D.F.&G.) is responsible for tag coded wire tag recovery program as well as the synthesis of data. P.W.S.A.C. with A.D.F.&G. is responsible for the application and data interpretation.

RESULTS

As shown above, procedures used for brood collection, eggtake, incubation and rearing are very similar at each site. The stocks are the same. One would not expect to see a difference in performance of pink salmon at A.F.K. and W.N.H. during the freshwater life stages. In fact, that is the case. A comparison of life stage survivals of pink salmon at A.F.K. and W.N.H. indicate very similar performance. Eggtake quality as measured by average percent fertility differs by no more than 1.5% (Table 2). Egg survivals and fry survival prior to release are also very similar (Table 2). One exception is brood year 1985 W.N.H. green to emergence survival. Poor incubation survival at W.N.H. was due to a water quality problem that was remedied the following year.

Figures 1 and 2 depict odd and even brood year outmigration at A.F.K. and W.N.H. respectively. It is interesting to note that odd year fry seem to outmigrate earlier than even year fry at both facilities. Figure 3 indicates that W.N.H. fry outmigrate earlier than A.F.K. fry by as much as 14 days. This is of particular interest because it may mean that, over time, W.N.H. will release greater percentages of fed fry into the plankton bloom.

Figures 4 and 5 show zooplankton bloom timing for calender years 1986-1989 at A.F.K. and W.N.H. Bloom timing can vary from year to year by as much as 30 days (Cooney 1989). The overall trend at both facilities matches earlier data from A.F.K. Generally, it appears that the peak "bloom" begins in the latter half of April and lasts through mid-May, although the bloom itself extends into June.

Table 3 summarizes zooplankton blooms by site for calender years 1986-1989. It is interesting to note a fairly close match in "bloom" duration between sites within years. Bloom period was extracted from raw plankton data at each facility. The bloom beginning was defined as the point at which the percent composition of zooplankton in the sample exceeded 50%. The bloom ending was defined as the point at which an order of magnitude decrease in the zooplankton relative density occurred. (The Cooperative Fisheries and Oceanographic Studies (C.F.O.S.) in progress in Prince William Sound are investigating the relationships between ocean temperatures, plankton abundance and juvenile salmon survival, both wild and hatchery (Cooney 1989)).

The numbers of fry released per treatment group will vary from year to year depending upon zooplankton timing and fry outmigrating timing. Table 4 illustrates the number of fry released by treatment group and brood year at A.F.K. and W.N.H. for brood years 1985 to 1988. It follows that since bloom timings are similar between sites each year, the release dates for each treatment group will be similar. This is evident if one compares release dates by group for A.F.K. and W.N.H. from a single brood year. Note that in most cases the mean release date of early fed fry is timed closely with the bloom period. The exception is brood year 1987. Here a late bloom forced us to release fry early. The results are evident in Table 5. The lowest percent marine survival for the early fed fry occurred in the 1987 brood year at both facilities.

Mean weight at release by treatment group also compares closely between hatcheries within brood years. This would indicate no apparent site specific size advantage.

It is apparent that W.N.H., because of its earlier outmigration timing is able to consistently target more fish into the early fed group (Table 5). A.F.K. has significantly fewer early fed fry on even brood years. It appears this is due to the late outmigration timing of the even brood years.

A comparison of marine survivals by treatment group, Table 5, indicates in all cases the early fed group out performs the unfed and late fed group. This trend does support a rearing strategy that maximizes the number of early fed fry. Somewhat higher survivals for W.N.H. are interesting. We will evaluate this trend further.

DISCUSSION

It is clear the freshwater life stage performance as outlined in Table 2 is similar for pink salmon at A.F.K. and W.N.H. Procedures for large scale fish culture or pink salmon developed at A.F.K. and employed at W.N.H. have resulted in the very successful hatchery performance of this stock.

It is also evident that performance as measured by overall marine survival is similar between the two hatcheries within brood years.

The revealing aspect of the marine survival data is the performance of the individual treatment groups. It appears that by increasing the percent of fry in the early fed group , a higher overall return of adults could be expected. As shown above the timing of fry outmigration is critical in determining the percent of early fed fish. One future challenge for P.W.S.A.C. fish culturists will be to investigate opportunities to control pink salmon outmigration timing, particularly at A.F.K. Specifically, by increasing rate of development during incubation, the timing of outmigration may be manipulated to increase the number of fed fry released into favorable estuarine conditions.

REFERENCES

Cooney, R.T. 1989. Cooperative Fisheries and Oceanographic Studies (C.F.O.S.): Salmon Production Responses to Inter Annual and Longer Period Variability in Coastal Ocean Temperature, Research Proposal.

Geiger, H.J. 1990. Pilot Studies In Tagging Prince William Sound Hatchery Pink Salmon With Coded-Wire Tags, Fishery Research Bulletin No. 90-02.

McCurdy, M.L., et al. 1986. Prince William Sound/Copper River Comprehensive Salmon Plan. Phase II 5-year plan (1986-1991).

Piper, R.G., et al. 1982. Fish Hatchery Management.

McNeil, W.J., and J.E. Bailey. 1975. Salmon Ranchers Manual.

P.W.S.A.C. Allocation Task Force. 1990. Report Number Six, Project Report and Policy Recommendations.

TABLE 1. ARMIN F. KOERNIG AND WALLY NOERENBERG HATCHERIES: AVERAGE INCUBATION TEMPERATURES, 1985-1986.

	INCUBATION TEMPERATURE (CENTIGRADE)	
MONTH	A.F.K.	W.N.H.
SEP	9.9	12.2
OCT	6.2	7.9
NOV	3.6	4.5
DEC	3.3	2.8
JAN	1.9	1.9
FEB	1.6	1.7
MAR	1.5	1.7
APR	1.5	2.0

TABLE 2. ARMIN F. KOERNIG AND WALLY NOERENBERG HATCHERIES: LIFE STAGE SURVIVALS, BROOD YEARS 1985-1988.

		EGGTAKE	INCUBATION		REARING
BROOD YEAR	SITE	4-CELL FERTILITY	GREEN TO EYE SURV	GREEN TO EMERG SURV	EMERG TO RELEASE SURV
1985	A.F.K.	97.7%	97.2%	93.9%	99.6%
	W.N.H.	---	96.7%	64.0%	99.4%
1986	A.F.K.	98.1%	97.4%	93.2%	99.7%
	W.N.H.	---	97.3%	96.9%	99.6%
1987	A.F.K.	97.1%	95.8%	87.9%	99.5%
	W.N.H.	97.0%	96.9%	86.7%	99.4%
1988	A.F.K.	98.7%	96.6%	92.7%	99.5%
	W.N.H.	95.9%	97.0%	89.0%	99.6%
AVG	A.F.K.	97.9%	96.8%	91.9%	99.6%
	W.N.H.	96.5%	97.0%	84.2%	99.5%

TABLE 3. ARMIN F. KOERNIG AND WALLY NOERENBERG HATCHERIES: NEAR SHORE ZOOPLANKTON BLOOMS, 1986-1989.

		BLOOM		RELATIVE DENSITY*	
YEAR	SITE	PERIOD	DAYS	MEAN	MAX
1986	A.F.K.	4/22-5/08	17	2.57	4.41
	W.N.H.	4/28-5/26	29	5.10	15.82
1987	A.F.K.	4/17-5/08	22	1.77	2.63
	W.N.H.	4/17-5/08	22	2.44	3.74
1988	A.F.K.	5/19-5/24	6	2.29	2.55
	W.N.H.	5/12-5/19	8	5.29	7.64
1989	A.F.K.	4/13-5/22	40	4.34	13.95
	W.N.H.	4/13-5/29	47	4.65	12.05

* ml settled volume/cubic foot of area sampled in vertical tow.

TABLE 4. ARMIN F. KOERNIG AND WALLY NOERENBERG HATCHERIES: PINK SALMON FRY RELEASES, BROOD YEARS 1985-1988.

BROOD YEAR	SITE	BLOOM PERIOD	GROUP	NUMBER (MILLIONS)	MEAN RELEASE DATE	MEAN RELEASE WT (gm)
1985	A.F.K.	4/22-5/08	EF	69.8	5/01	0.25
			LF	43.0	6/01	0.33
	W.N.H.	4/28-5/26	EF	21.9	4/29	0.27
			LF	12.5	5/22	0.37
1986	A.F.K.	4/17-5/08	EF	34.1	5/10	0.25
			UF	40.1	5/02	0.23
			LF	42.0	5/30	0.33
	W.N.H.	4/17-5/08	EF	65.5	5/05	0.27
			UF	10.4	4/21	0.22
1987	A.F.K.	5/19-5/24	EF	89.3	5/06	0.25
			UF	9.2	5/10	0.24
			LF	11.6	5/31	0.36
	W.N.H.	5/12-5/19	EF	184.2	5/07	0.25
			UF	11.3	4/30	0.23
1988	A.F.K.	4/13-5/22	EF	40.7	4/27	0.25
			UF	43.3	5/01	0.24
			LF	32.5	5/19	0.29
	W.N.H.	4/13-5/29	EF	112.2	4/27	0.23
			UF	45.8	4/30	0.22
			LF	1.7	5/24	0.22

EF=Early Fed UF=Unfed LF=Late Fed

TABLE 5. ARMIN F. KOERNIG AND WALLY NOERENBERG HATCHERIES MARINE SURVIVAL OF PINK SALMON, BROODYEARS 1985-1988.

BROOD YEAR	SITE	BLOOM PERIOD	GROUP	% OF TOTAL	% MARINE SURV GROUP	% MARINE SURV ALL
1985	A.F.K.	4/22-5/08	EF	62%	8.1%	
			LF	38%	4.0%	6.8%
	W.N.H.	4/28-5/26	EF	64%	9.8%	
			LF	36%	6.5%	8.7%
1986	A.F.K.	4/17-5/08	EF	29%	---	
			UF	35%	---	
			LF	36%	---	5.2%
	W.N.H.	4/17-5/08	EF	87%	---	
			UF	13%	---	5.1%
1987	A.F.K.	5/19-5/24	EF	81%	3.6%	
			UF	8%	2.9%	
			LF	11%	3.2%	3.5%
	W.N.H.	5/12-5/19	EF	94%	3.8%	
			UF	6%	1.4%	3.6%
1988	A.F.K.	4/13-5/22	EF	35%	6.8%	
			UF	37%	4.9%	
			LF	28%	5.8%	5.8%
	W.N.H.	4/13-5/29	EF	70%	9.9%	
			UF	29%	5.8%	
			LF	1%	3.1%	8.7%

EF=Early Fed UF=Unfed LF=Late Fed

TABLE 6. HATCHERY PRODUCTION LEVELS.

SITE	SPECIES	GREEN EGGS	ADULT RETURN
A.F.K.	PINK	126,000,000	6,196,573
C.C.H.	PINK	152,000,000	6,481,299
W.N.H.I	PINK	170,000,000	9,068,134
	CHUM	111,000,000	2,012,125
	COHO	2,500,000	275,948
	CHINOOK	1,000,000	32,890
W.N.H.II	PINK	26,000,000	4,737,792
MAIN BAY	SOCKEYE		
	-EARLY	100,000	14,099
	-MIDDLE	5,100,000	722,320
	-LATE	2,100,000	288,928

A.F.K.= ARMIN F. KOERNIG HATCHERY
W.N.H.= WALLY NOERENBERG HATCHERY
C.C.H.= CANNERY CREEK HATCHERY

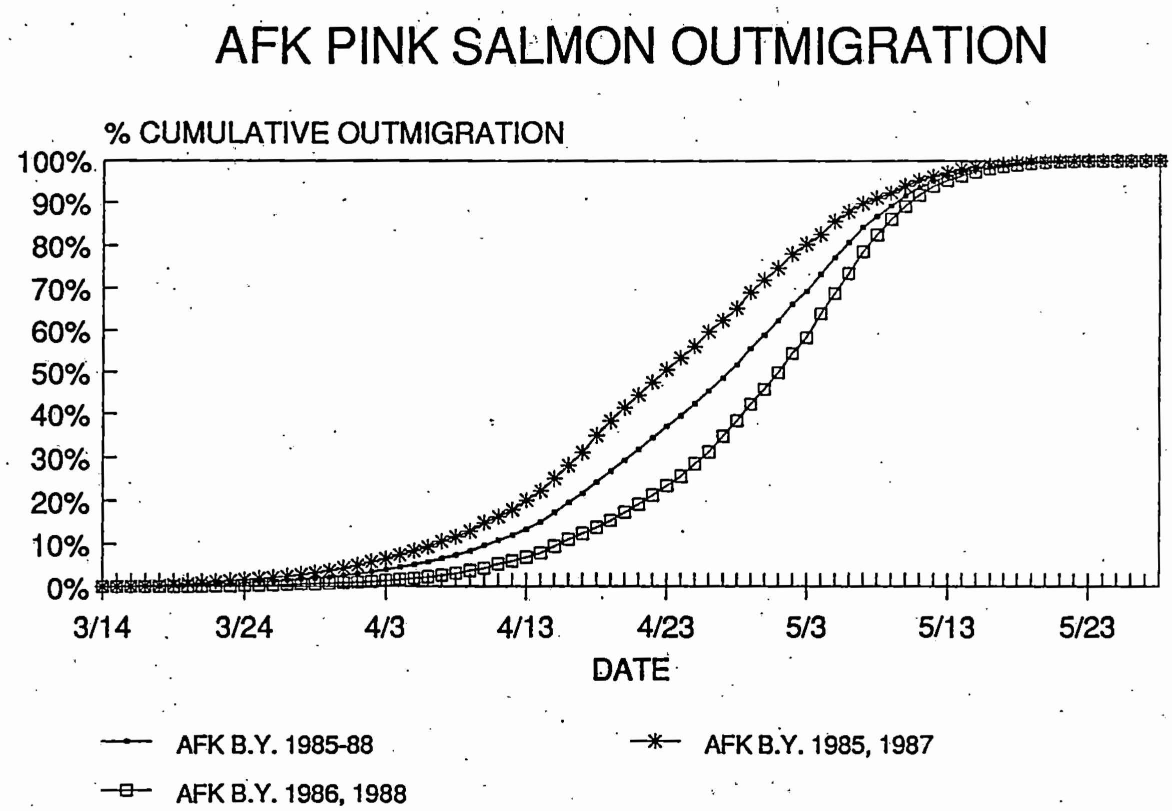


Figure 1. Comparison of odd and even year pink salmon outmigration at AFK hatchery.

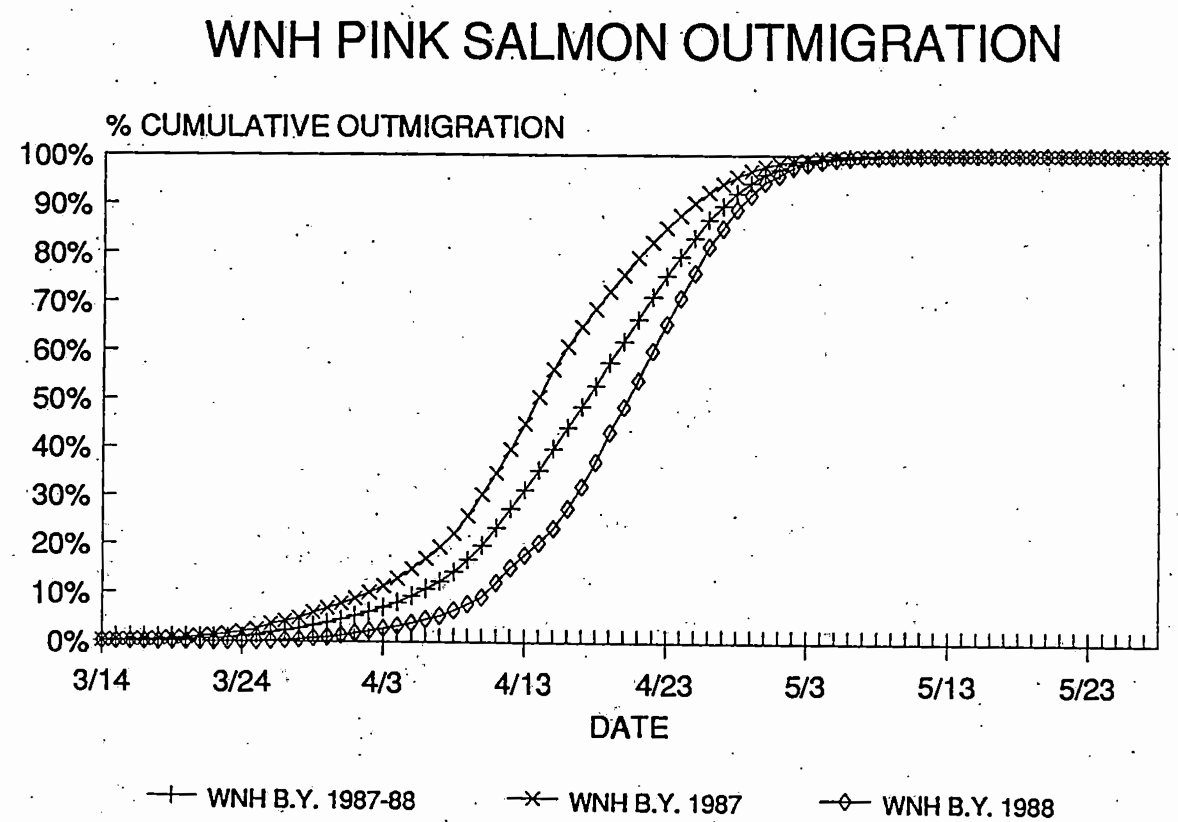


Figure 2. Comparison of odd and even year pink salmon outmigration at WNH hatchery.

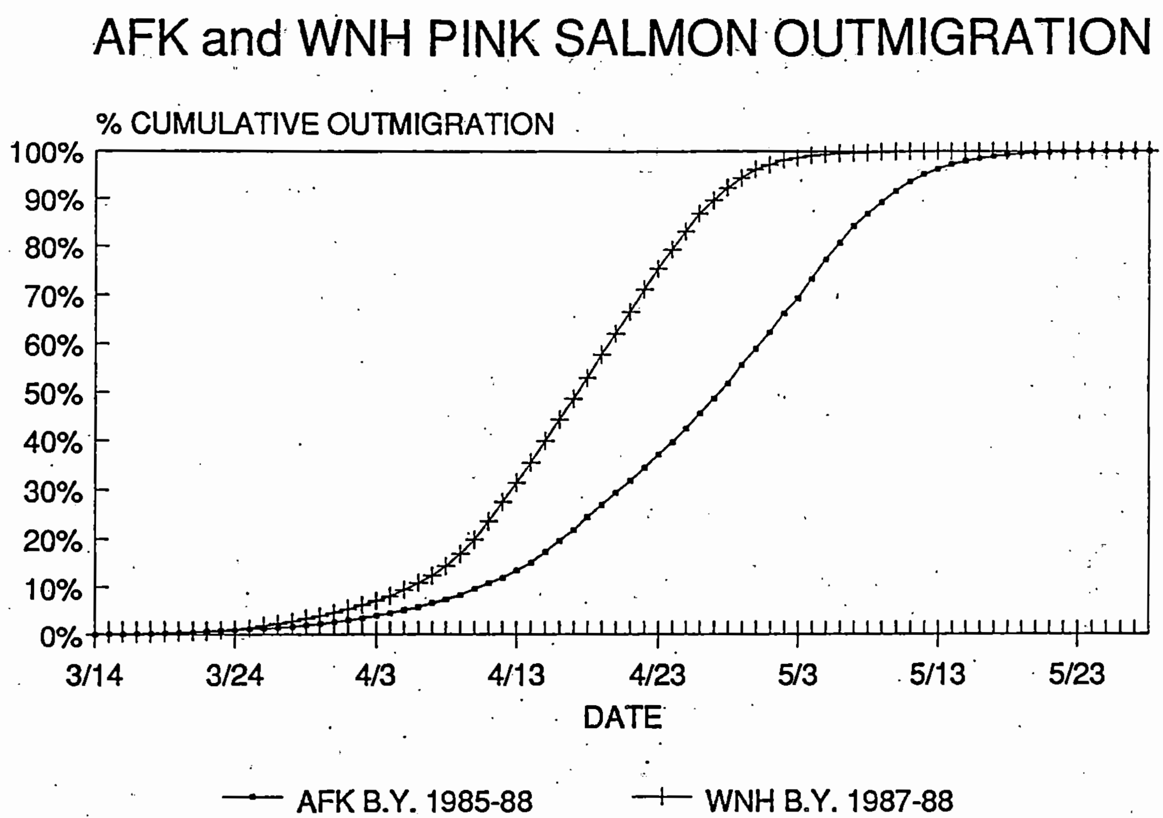


Figure 3. Comparison of average pink salmon outmigration at AFK and WNH hatcheries.

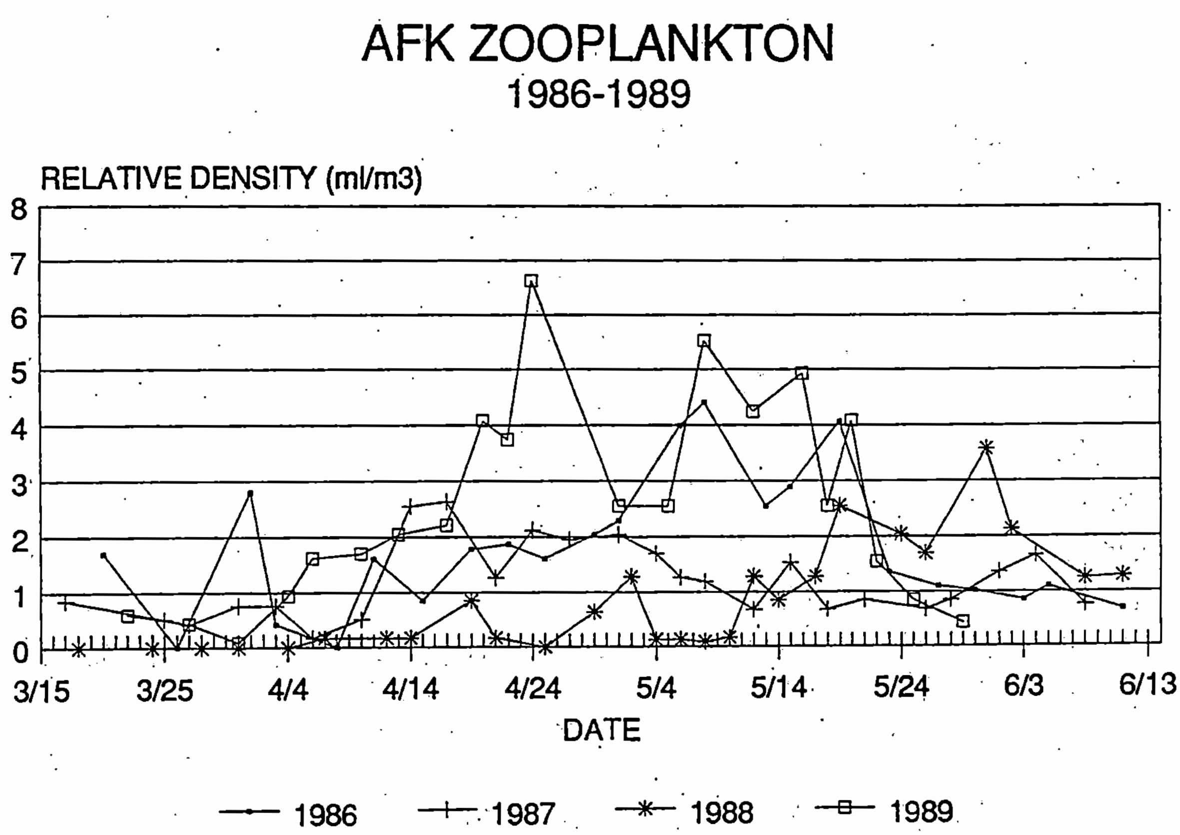


Figure 4. Relative zooplankton density (mL/m^3) at AFK hatchery for calender years 1986-1989.

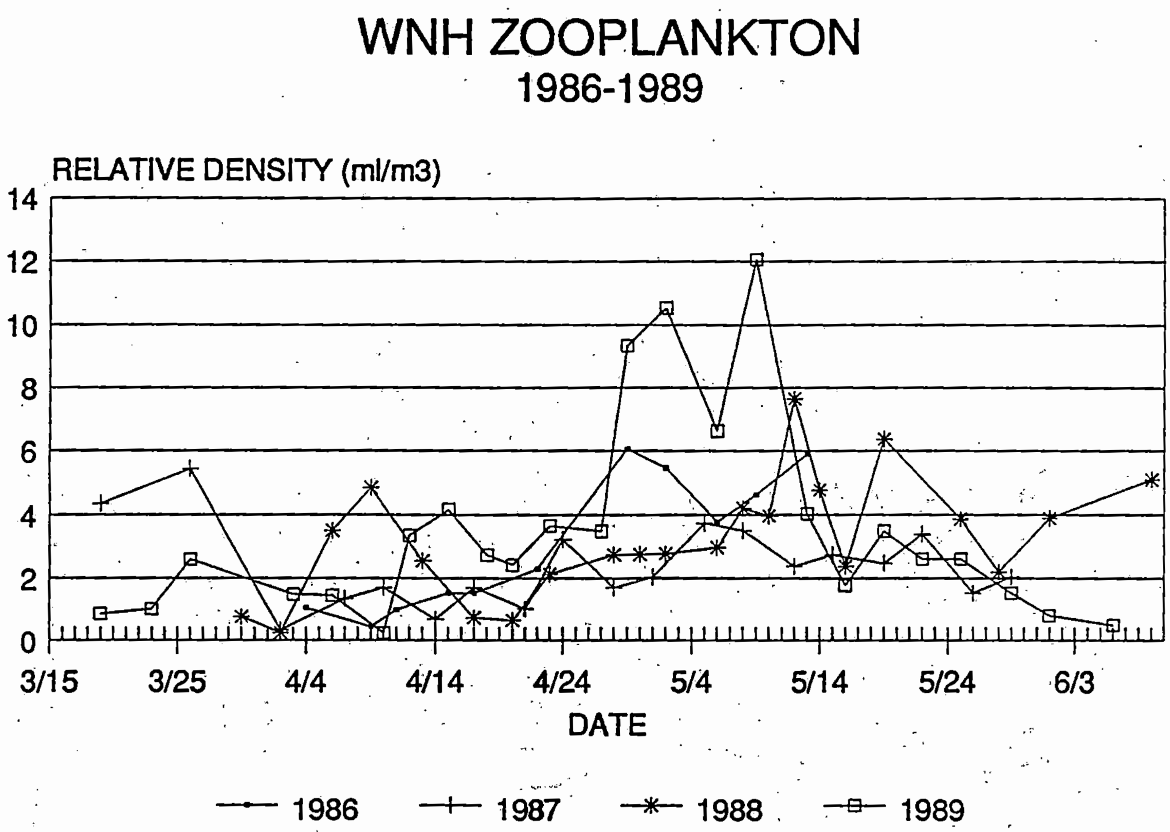


Figure 5. Relative zooplankton density (ml/m^3) at WNH hatchery for calender years 1986-1989.

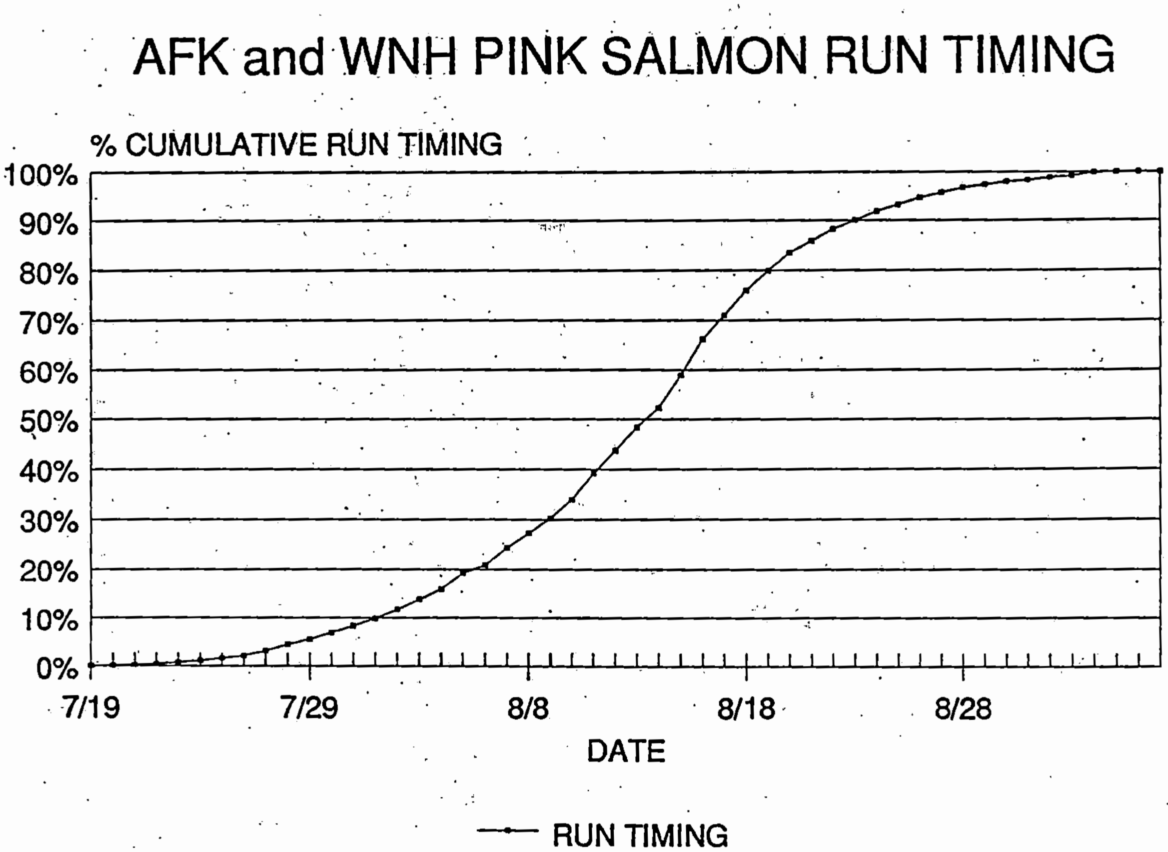


Figure 6. Average adult pink salmon run timing to AFK and WNH hatcheries for brood years 1985-88.

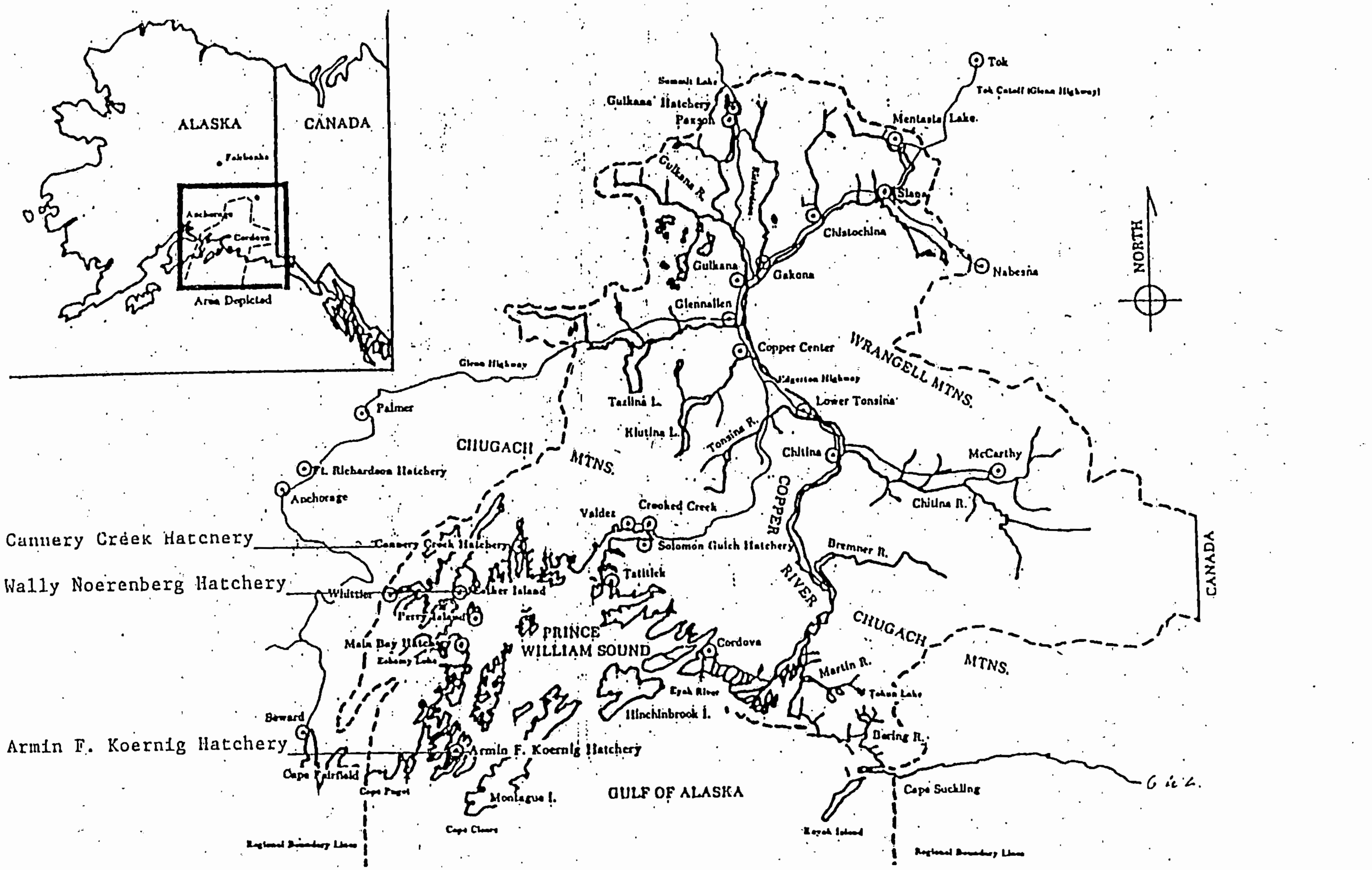


Figure 7. Map of the Prince William Sound area.

Interspecific Interactions Affecting the Survival of Chum Salmon Fry

Arlene Tompkins

Resource Ecology, University of British Columbia
Vancouver, B.C. V6T 1W5

and

C.D. Levings

Department of Fisheries and Oceans, Biological Sciences Branch
West Vancouver Laboratory, 4260 Marine Drive
West Vancouver, B.C. V7V 1N6

The indirect effects of predation by cutthroat trout (*Oncorhynchus clarki*) on the foraging efficiency of chum salmon fry (*Oncorhynchus keta*) in the presence and absence of alternate prey (threespine stickleback, *Gasterosteus aculeatus*) was studied in the laboratory. Behaviourial responses by chum to increased predation risk reduced chum feeding efficiency. Hatchery and wild chum showed opposite dietary shifts in the presence of trout. Hatchery chum responded to trout by a reduction in the number of fish feeding and a reduction in feeding indices. Wild chum reduced feeding rates in the presence of trout. When stickleback were also present, the effects of predation on chum foraging behaviour were reduced.

The importance of estuaries as rearing grounds for juvenile salmonids and non-salmonids has been reported by many researchers (Levy and Levings 1978; Levy et al. 1979; Healey 1980; Simenstad et al. 1982; McCabe et al. 1983). Many fish species may use estuaries simultaneously for feeding, resting, and possibly as sanctuary from predators (McCabe et al. 1983). However, there is concern that significant losses of juvenile salmonids may be occurring in estuaries due to predation and competition (Fresh et al. 1980; McCabe et al. 1983; Murphy et al. 1988). Exposure to intense predation, competition, or both during estuarine residence could reduce fry growth and survival.

Given the number and variety of fish species using the lower Fraser River for feeding and shelter from predators, there is a high probability of interactions between juvenile salmonids and non-salmonids. Preliminary field observations revealed that of all the fish species using nearshore habitats of the estuary, chum salmon fry (*Oncorhynchus keta*) shared the greatest dietary overlap with threespine stickleback (*Gasterosteus aculeatus*) and suggested the potential for interspecific competition if food becomes limited.

I used laboratory observations to quantify the behaviourial responses of chum to interspecific interactions. I examined some of the possible interactions between a predator, cutthroat trout (*Oncorhynchus clarki*), and two dissimilar prey species, chum salmon fry and threespine stickleback.

The direct effects of predation on juvenile salmonids has been documented (see Fresh et al. 1980; Murphy et al. 1988 for reviews). Predators can also have profound non-lethal effects on prey and prey interactions, i.e., reduced feeding rates (Werner et al. 1983), increased competition (Mittlebach 1984), lower food quality (Lima 1988), and reduced survival (Larkin and Smith 1954). Competitive interactions may be intensified if vulnerable size classes or species are concentrated into a common refuge (McCabe et al. 1983; Werner et al. 1983). The indirect effects of predation due to the behaviourial responses of prey occur much more rapidly than reductions in prey numbers and may be more important than the actual losses due to predation. More attention needs to be given to predator mediated changes in diet, habitat, and behaviour that affect interacting species.

Growth and survivorship are positively correlated in many fish (see Ware 1975; Werner 1986, for reviews). Both size and diet will affect competition and predation among fish in estuarine habitats (Murphy et al. 1988). Chum size will influence vulnerability to predators while diet will determine potential competitors. Survival will depend on size (Parker 1971; Hargreaves and LeBrasseur 1986) and size depends on diet and the ability to forage efficiently. Any factor, i.e., competition for food, that decreases individual feeding rates and slows growth rates, prolongs the time spent in vulnerable size classes, and increases the probability of death (Gilliam 1982; Mittlebach and Chesson 1987).

My main objectives were: (1) to compare the indirect effects of predation on chum, and (2) to examine the effects of the availability of alternate prey on the outcome of predation. I tested the hypothesis that chum foraging efficiency decreases with increasing risk and increases in the presence of alternate prey. Chum response to predation in the presence and absence of stickleback was studied by manipulating species combinations and observing changes in foraging behaviour: diet composition, feeding mode (surface, mid-water, benthic), proportion of fish feeding, and feeding rate (a short term correlate of fitness). I predicted that, under increasing predation risk:

1) the proportion of fish feeding and feeding rate of chum should decrease as feeding conflicts with monitoring and avoiding predators,

2) with increased predation risk chum should choose food that requires less visual attention or handling time.

METHODS

Chum fry and stickleback were collected during March-May 1986 and 1988 from two nearshore sites in the Fraser River estuary using beach seines. Additional chum fry were obtained from the Chehalis Hatchery, near Harrison Mills, B.C., and collected from a live trap in the Mamquam River spawning channel, near Squamish, B.C. The use of chum from different sources was necessary due to the limitations of the availability of wild fish. Preliminary laboratory observations revealed differences in feeding and antipredator behaviours between hatchery-reared fry and fry collected from natural habitats. The behaviour of chum obtained from the Mamquam spawning channel was similar to that of chum collected from the Fraser River so hereafter they will collectively be referred to as wild chum and the results from these experiments will be combined.

The effect of predation on chum foraging efficiency in the presence and absence of alternate prey was investigated in a series of experiments manipulating four different species combinations: chum alone, chum with stickleback, chum with a single trout, and chum with stickleback and a single trout. Single species treatments used 20 chum while mixed species treatments used 10 chum and 10 stickleback. Six replicates of each treatment were performed in random order. Fish were provided with three food taxa which represented three feeding habitats: Tubifex (*benthic Oligochaeta*), Daphnia (mid-water *Cladocera*) and adult Drosophila (surface *Diptera*). All experiments began at the time of food addition and lasted one hour.

Each chum was weighed and its fork length measured. Stomachs were removed, weighed wet, and the contents were identified and enumerated. The number of each food taxa consumed was expressed as a percentage of the total food items for each species and treatment (percentage composition by number, Windell and Bowen 1978). A feeding index (food weight/body weight X 100) was calculated as a rough approximation of food consumption. For each treatment the percentage of fish feeding and the feeding rate (number of food items consumed per hour) was determined. Foraging time, the time required for searching, pursuing, capturing and handling prey inclusive, was measured for at least 30 individual chum feeding on each food taxa in the absence of other species.

All percentage data were normalized by arcsine square root transformations. The percentage of the diet composed by each food taxa, the percentage of fish feeding, the feeding rate, and the feeding index were analyzed using two-way ANOVA on the two main factors, trout presence and stickleback presence.

RESULTS

In the absence of stickleback and trout, hatchery chum (Figure 1a, treatment 1) consumed roughly equal numbers of Daphnia and Drosophila. When stickleback were present (treatment 3) Drosophila accounted for a greater percentage ($P=0.01$) of the chum diet. When hatchery chum were exposed to trout they switched markedly to a diet of Daphnia (P=0.002, treatment 2). When hatchery chum were combined with sticklebacks and trout in treatment 4, the composition of the diet was similar to that of hatchery chum alone (treatment 1). Tubifex never accounted for more than 10% of the food consumed by hatchery chum.

Daphnia consistently accounted for the greatest percentage (63%-89 %) of the diet of wild chum in all treatments (Figure 1b). In treatments with trout, wild chum included proportionately more Drosophila in their diet compared to hatchery fish. {\it Tubifex} were rarely taken by wild chum (1%-4 % of the diet).

The percentage of hatchery chum feeding was significantly reduced with increased predation risk (Figure 2a, P<0.001, Table 1). However when stickleback were also available as prey the percentage of hatchery chum feeding was about the same as the predator free condition. The percentage of wild chum feeding did not change in the presence of trout or stickleback (range 85%-99 %, Figure 2a, P>0.21).

Feeding rates of hatchery chum were slightly reduced in the presence of trout (Figure 2b, P=0.27) and were significantly greater in the presence of stickleback (P=0.001). A significant interaction of trout and stickleback presence (P=0.032); implied the rate of feeding by hatchery chum depended on the presence of both trout and stickleback. Feeding rates of wild chum increased with stickleback (Figure 2b, P=0.003) and decreased with trout (P=0.036). In treatments with stickleback and trout, wild chum feeding rates were similar to feeding rates when wild chum were alone. There was no significant interaction.

The amount of food consumed (by weight) by hatchery chum increased in the presence of stickleback (Figure 2c, P=0.028). Neither main factor had any effect on the weight of food consumed by wild chum but a significant interaction of the presence of trout and stickleback (Figure 2c, P=0.026) implied that the weight of food consumed in the presence of trout depended on whether stickleback were present.

Chum detected Daphnia sooner than Drosophila or Tubifex (t-test, P<0.001). Once food was detected, the foraging time per item was the same for any food consumed by chum.

DISCUSSION

Three general conclusions can be made from these experiments. (1) Trout had considerable indirect effects on chum foraging behaviour. Behaviourial responses by chum to reduce predation risk resulted in reduced foraging efficiency. (2) Risk of predation did not affect hatchery chum and wild chum to the same degree. (3) The intensity of the effect of predation risk depended on the presence or absence of stickleback.

Chum were rarely killed by trout but the need to avoid predators affected their feeding behaviour. The relative fitness of chum under the different treatments can be evaluated by comparing their feeding efficiency between treatments. Changes in feeding efficiency can have serious consequences on fitness. Dill et al. (1981) correlated high levels of feeding and growth rates of juvenile coho salmon with greater fitness.

Behaviourial responses by chum to trout predation varied depending on the prey type. Hatchery chum displayed the greatest response to predation risk, resulting in fewer fish feeding, reduced feeding indices, and a dietary shift from surface food items to mid-water Daphnia. By comparison, the diet composition of wild chum remained the same in all treatments. The only significant change for wild chum concerned feeding rates which, as predicted, were reduced in the presence of trout and increased in the presence of stickleback. The reduction in feeding rates in the presence of trout implied that wild chum traded-off food intake for reduced movement, increased vigilance, or flight from predators. By reducing the time spent feeding, chum also reduce the time spent vulnerable to attack, the major component of risk under the control of the prey. These results suggest that wild chum can assess predation risk, influence the probability of detection by trout and regulate the amount of time they are vulnerable to attack.

To properly investigate differences between wild and hatchery fish, comparisons should be made between hatchery and wild fish from the same stock under similar rearing conditions. The experiments were not designed to examine the differences between wild and hatchery chum but the results have practical as well as theoretical interest.

Behaviourial differences shown by hatchery raised fish may be a product of their rearing environment and may reflect differences in past learning or conditioning of the two groups (see Suboski and Templeton 1989 for review). Fry in hatcheries are not exposed to natural stimuli that shape or reinforce normal feeding and antipredator responses (see Suboski and Templeton 1989 for review). Hatchery fish do not learn early in life to recognize wild food and studies have shown that chum develop training biases for food types that they first consumed (LeBrasseur 1969). When hatchery fish are released they may be ill prepared to respond to hazards in the natural environment. Mortality of hatchery fry after release due to starvation and predation may occur because fish fail to recognize natural food and predators. Naive fry must learn to recognize food and predators in order to respond.

Even if hatchery fish learn to recognize and capture live prey this does not ensure survival following release (Paszkowski and Olla 1985). Wild fish should out compete hatchery fry presumably because they are better adapted than hatchery fish to their natural habitat and wild fish have already been selected by predation and competition. Experimental results presented here suggest that post-release mortality could result from inefficient or suboptimal foraging, inappropriate social behaviours, competitive interactions with wild fish, or feeding behaviours that increase the risk of predation. Suboski and Templeton (1989) review studies reporting behaviourial differences between wild and hatchery reared salmonid juveniles and suggest these differences may affect relative survival rates.

The presence of stickleback had beneficial effects on the foraging efficiency of chum, particularly hatchery chum. In treatments with stickleback, chum feeding rates and the feeding indices increased. When stickleback were added to predator trials, the diet composition, the proportion of fish feeding, and feeding indices of hatchery chum were similar to treatments of hatchery chum alone. Stickleback had a similar effect on wild chum feeding rates.

There are several possible explanations for the positive effects of stickleback presence on chum foraging behaviour. Stickleback may function as dithering animals (Barlow 1968); the presence of stickleback may have a calming influence on chum behaviour. A second alternative is that of observational learning. Watching stickleback feeding may facilitate or enhance chum feeding behaviour, i.e., facilitate prey detection. Obrebski and Sibert (1976) suggest that stickleback may actually increase food availability for chum by increasing disturbance of the substrate surface. This did not seem the case in our experiments. The increase in feeding rates cannot be attributed to increased Tubifex in the diet of chum. A third possible explanation is that replacing chum with an equivalent number of stickleback reduced intraspecific competition for food. In mixed species trials without trout, the diets of both hatchery chum and stickleback tended to include more food types that were not shared. In mixed species groups, overall competition may be reduced if each species has different preferences (Allan and Pitcher 1986).

These results illustrate the potential effects of species interactions on the feeding efficiency and ultimately, the fitness of chum salmon fry during estuarine residence. Chum fry traded-off feeding efficiency for predator avoidance. To avoid capture, chum monitored predator movements to avoid encounters and fled when attacked. Predator avoidance reduced the time available for feeding, resulting in fewer fish feeding, reduced feeding rates and shifts in the types of food items consumed. When chum altered their feeding behaviour and activity levels to avoid trout, they also affected their encounter rates with stickleback and with the common resources required by both.

ACKNOWLEDGEMENTS

We thank Dr. C.C. Lindsey for his support and assistance. This work was funded by an NSERC grant to Dr. C.C. Lindsey, by a Department of Fisheries and Oceans grant, and by an NSERC post-graduate scholarship.

REFERENCES

Allan, J.R., and T.J. Pitcher. 1986. Species segregation during predator evasion in cyprinid fish shoals. Freshwater Biology 16: 653-659.

Barlow, G.W. 1968. Dither - A way to reduce undesirable fright behavior in ethological studies. Zeitschrift fur Tierpsychologie 25: 315-318.

Dill, L.M., R.C. Ydenberg, and A.H.G. Fraser. 1981. Food abundance and territory size in juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Zoology 59: 1801-1809.

Fresh, K.L., R.D. Cardwell, B.P. Snyder, and E.O. Salo. 1980. Some hatchery strategies for reducing predation upon juvenile salmon (*Oncorhynchus keta*) in freshwater. In B.R. Melteff and R.A. Neve (ed). Proceedings of the North Pacific Aquaculture Symposium 1980. University of Alaska, Fairbanks.

Gilliam, J.F. 1982. Habitat use and competitive bottlenecks in size-structured fish populations. Ph.D. thesis, Michigan State University, East Lansing.

Hargreaves, N.B., and R.J. LeBrasseur. 1986. Size selectivity of coho (*Oncorhynchus kisutch*) preying on juvenile chum salmon (O. Keta). Canadian Journal of Fisheries and Aquatic Sciences 43: 581-586.

Healey, M.C. 1980. Utilization of the Nanaimo River estuary by juvenile chinook salmon, *Oncorhynchus tshawytscha*. Fisheries Bulletin 77: 653-668.

Larkin, P.A., and S.B. Smith. 1954. Some effects of the introduction of the redside shiner (*Richardsonius balteatus*) on the Kamloops trout (*Salmo gairdneri kamloops*) in Paul Lake, British Columbia. Transactions of the American Fisheries Society 83: 161-175.

LeBrasseur, R.J. 1969. Growth of juvenile chum salmon (*Oncorhynchus keta*) under different feeding regimes. Journal of the Fisheries Research Board of Canada 26: 1631-1645.

Levy, D.A., and C.D. Levings. 1978. A description of the fish community of the Squamish River estuary, British Columbia: relative abundance, seasonal changes, and feeding habitats of salmonids. Canada Fisheries Marine Service Manuscript Report 1475: 63 p.

Levy, D.A., T.G. Northcote, and G.J. Birch. 1979. Juvenile salmonid utilization of tidal channels in the Fraser River estuary, British Columbia. University of British Columbia, Westwater Research Center Technical Report 23: 70 p.

Lima, S.L. 1988. Vigilance and diet selection: a simple example in the dark eyed junco. Canadian Journal of Zoology 66: 593-596.

McCabe, G.T.Jr., W.D. Muir, R.L. Emmett, and J.T. Durkin. 1983. Interrelationships between juvenile salmonids and nonsalmonid fish in the Columbia River estuary. Fishery Bulletin 81: 815-826.

Mittlebach, G.G. 1984. Predation and resource partitioning in two sunfishes (*Centrarchidae*). Ecology 65: 499-513.

Mittlebach, G.G., and P.L. Chesson. 1987. Predation risk: indirect effects of fish populations. Pages 315-332. In W.C. Kerfoot and A. Sih (ed). Predation: direct and indirect impacts on aquatic communities. University Press of New England, Hanover and London.

Murphy, M.L., J.F. Thedinga, and K.V. Koski. 1988. Size and diet of juvenile Pacific salmon during seaward migration through a small estuary in Southeastern Alaska. Fishery Bulletin 86: 213-222.

Obrebski, S., and J. Sibert. 1976. Diet overlaps in competing fish populations in the Nanaimo River estuary. Pages 139-146. In C.A. Simenstad, and S.J. Lipovsky (ed). Fish food habits studies. 1st Pacific Northwest Technical Workshop. University of Washington, Seattle.

Parker, R.R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. Journal of Fisheries Research Board of Canada 28: 1503-1510.

Paszkowski, C.A., and B.L. Olla. 1985. Foraging behavior of hatchery-produced coho salmon (*Oncorhynchus kisutch*) smolts on live prey. Canadian Journal of Fisheries and Aquatic Sciences 42: 1915-1921.

Simenstad, C.A., K.L. Fresh, and E.O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. Pages 343-364. In V.S. Kennedy (ed). Estuarine comparisons. Academic Press.

Suboski, M.D., and J.J. Templeton. 1989. Life skills training for hatchery fish: social learning and survival. Fisheries Research 7: 343-352.

Ware, D.M. 1975. Relation between egg size, growth, and natural mortality of larval fish. Journal of the Fisheries Research Board of Canada 32: 2503-2512.

Werner, E.E. 1986. Species interactions in freshwater fish communities. Pages 344-358. In J.M. Diamond and T. Case (ed). Ecological communities. Harper and Row, Publishers, New York.

Werner, E.E., J.F. Gilliam, D.J. Hall, and G.G. Mittlebach. 1983. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64: 1540-1548.

Windell, J.T., and S.H. Bowen. 1978. Methods for study of fish diets based on analysis of stomach contents. Pages 219-226. In T.B. Bagenal (ed). Methods for assessment of fish production in fresh waters. I.B.P. Handbook No. 3, Blackwell Scientific Publications, Oxford and Edinburgh.

Table 1 Statistical probabilities from the results of two-way ANOVA under the null hypothesis of no effect of the presence of trout and stickleback on percentage feeding, feeding rate, and feeding indices of hatchery chum and wild chum. *P* values of less than 0.05 are considered significant.

	factor	hatchery chum	wild chum
percentage feeding	trout	<0.001	0.215
	stickleback	<0.001	0.277
	trout × stickleback	<0.001	0.392
feeding rate	trout	0.270	0.036
	stickleback	0.001	0.003
	trout × stickleback	0.032	0.430
feeding index	trout	0.318	0.427
	stickleback	0.028	0.136
	trout × stickleback	0.183	0.026

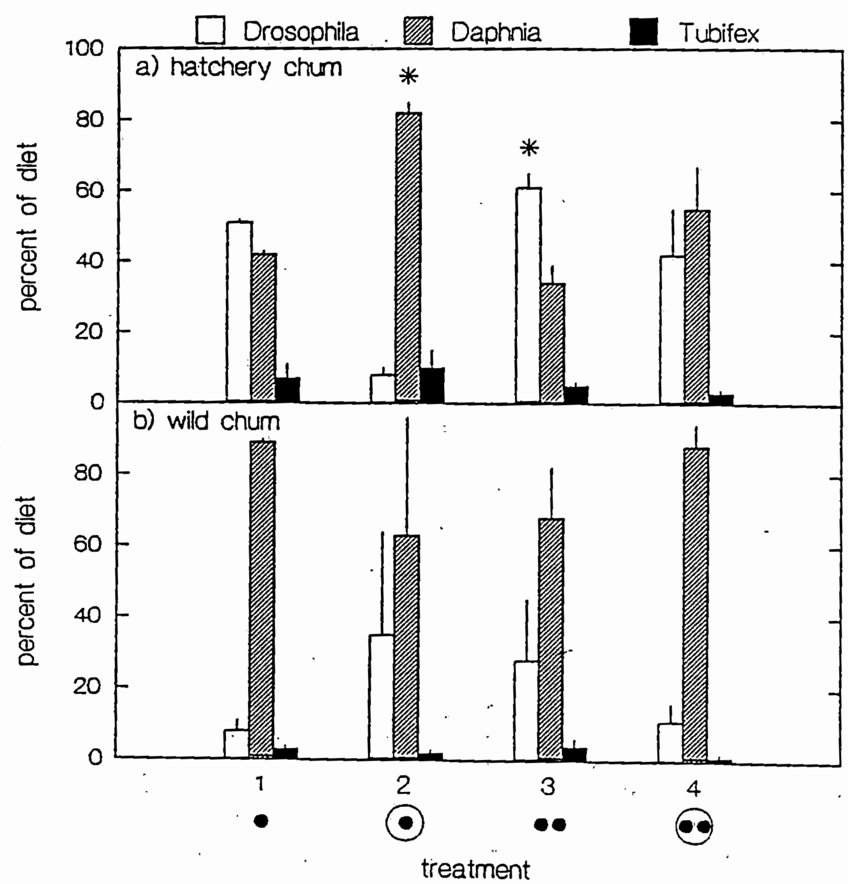


Figure 1 Mean composition of the diet of a) hatchery chum and b) wild chum under four treatments: 1—chum only; 2—chum with trout; 3—chum with stickleback; and 4—chum with trout and stickleback. The number of filled circles (•) denote the number of prey types and the open circles (○) denote trout present. An asterisk (*) indicates significant differences between treatments. The vertical line is the 95% confidence interval for the mean.

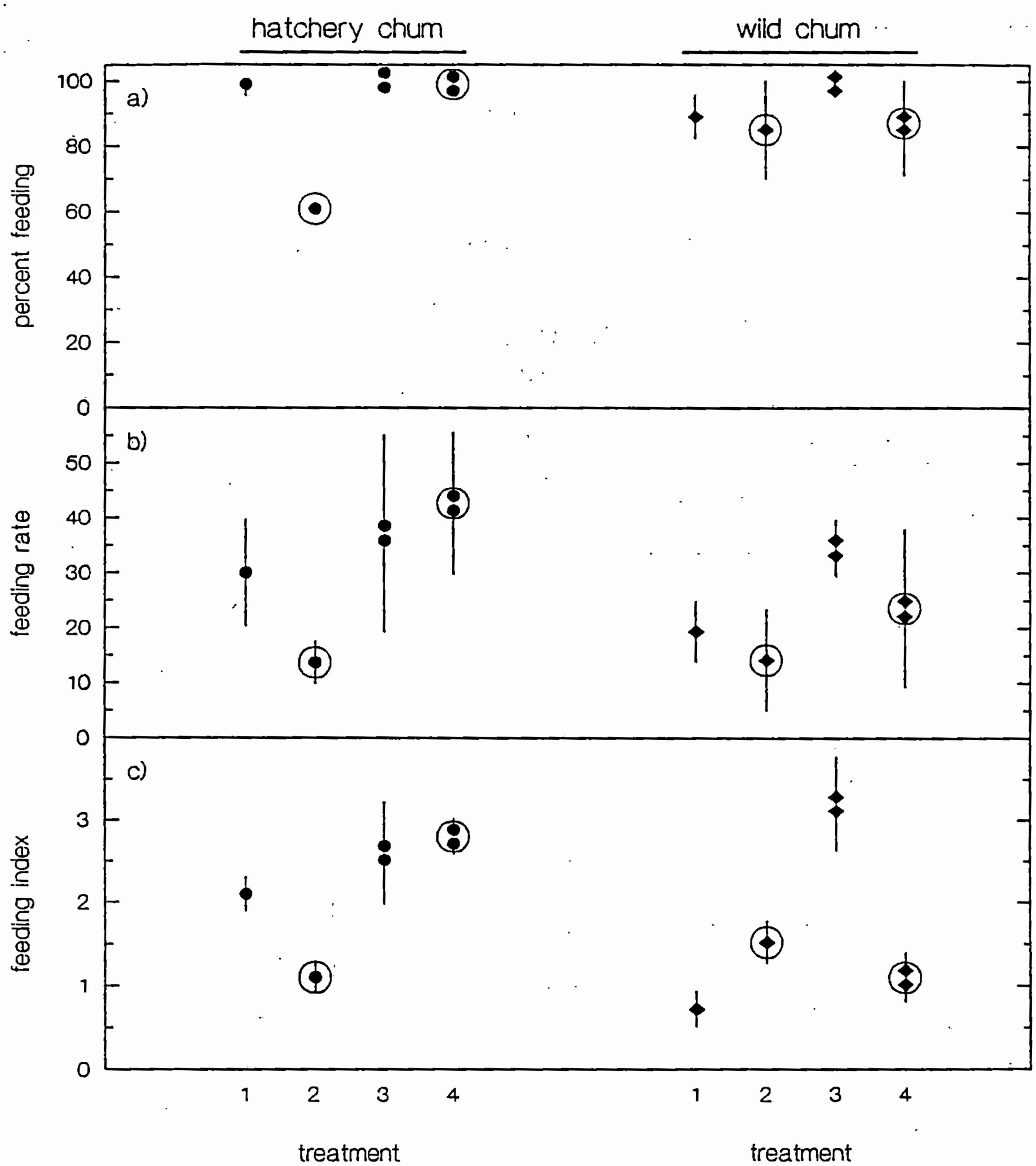


Figure 2 The percentage of fish feeding, feeding rate, and feeding index (weight of stomach contents/body weight × 100) of hatchery chum (•) and wild chum (♦) under four treatments: 1—chum only; 2—chum with trout; 3—chum with stickleback; and 4—chum with trout and stickleback. The number of filled symbols denotes the number of prey types and the open circles (◯) denote trout present. Vertical lines are 95% confidence intervals for the mean.

Diets and Feeding Rates of Juvenile Pink and Chum Salmon in Hecate Strait, British Columbia

Michael C. Healey

Westwater Research Centre
The University of British Columbia
Vancouver, B.C. V6T 1Z2

Juvenile pink (*Oncorhynchus gorbushcha*) and chum (*O. keta*) salmon were sampled in Hecate Strait, British Columbia, during July and August, 1986 and 1987. The objectives were to describe seasonal and species-specific patterns of feeding and to test assumptions and predictions of models relating feeding success of juvenile salmon during their first summer at sea to survival and recruitment. A wide variety of taxa were consumed by both species, but only a few taxa made up most of the fishes' daily food intake. Diet composition was more similar between species within sampling periods than within species among sampling periods, although there were some apparent species-specific feeding preferences. Patterns of changing diet composition with increasing time and distance between samples were consistent with expected mesoscale patterns of plankton patchiness in coastal waters. Juvenile salmon fed selectively on larger sized taxa in the plankton community and larger salmon fed on larger prey. Contrary to the assumption of one model, however, young salmon did not switch to larger prey later in the summer. Weights of stomach contents and estimated daily ration were small enough to limit growth rates, and the hypothesis that limitation of growth during early ocean life affects survival and recruitment cannot be rejected.

NOTE: Complete text of this paper, which includes information on sockeye salmon, will appear in Transactions of the American Fisheries Society early in 1991.

Relationship of Early Marine Growth and Survival of Juvenile Pink Salmon to Marine Water Temperature and Secondary Production in Auke Bay, Alaska

Donald Mortensen, Joyce Landingham, Alex Wertheimer and Sidney Taylor

Northwest and Alaska Fisheries Center
National Marine Fisheries Service
Auke Bay Laboratory
P.O. Box 210155
Auke Bay, Alaska 99821

Fry from four brood years of pink salmon in Auke Creek, Alaska, were tagged as they emigrated into the marine waters of Auke Bay. Growth rates of tagged fish recovered in the nearshore zone ranged from 3.1-7.1%. Early emigrants had the lowest growth rates, and growth rates were also lower for all tag groups during the first half of their nearshore residency. Water temperature was the only environmental parameter consistently correlated with growth. Comparisons of expected and observed growth rates suggested that prey availability as well as low temperatures were constraining growth during the early part of the nearshore residency. Early marine growth rates were significantly related to intra-annual survival relative to emigration timing. Growth rate could significantly explain a large measure of interannual variability ($R^2 = 0.84$) only if one year (1987 brood) was considered separately. The relationships between growth conditions, emigration timing, and the variability of survival are discussed.

Juvenile pink salmon (*Oncorhynchus gorbuscha*) typically enter the nearshore marine environment concurrent with the spring phytoplankton bloom and resultant zooplankton bloom; this timing presumably has evolved to utilize the spring bloom as a food source (Murphy et al. 1988). The initial estuarine residency is a critical phase in the early marine life history of salmon; survival during this period can significantly affect year-class strength (Parker 1968; Walters et al. 1978; Bax 1983). Rapid growth during this early marine period may be important in minimizing mortality due to size selective predation (Parker 1971; Hargreaves and LeBrasseur 1985).

The objectives of this study were to examine the relationship of growth of juvenile pink salmon to water temperature and secondary production during early marine residence, and to investigate the relationship of emigration timing and early marine growth with intra- and inter-annual variability in marine survival.

METHODS

This research focused on the Auke Creek pink salmon population. Auke Creek is a small, lake fed stream which empties into Auke Bay, a subarctic embayment in northern southeast Alaska. The National Marine Fisheries Service maintains a two-way counting weir located at the confluence of Auke Creek with Auke Bay.

Wild juvenile pink salmon emigrating from Auke Creek were captured daily from late March to mid-May at the fish counting weir. Components of each years outmigrant population of juveniles from the 1985-1989 brood years were coded-wire-tagged, with a different tag code used for each week's emigrants. The tagged fish were released into Auke Creek just above tidewater between 18 and 24 hours after tagging.

Nearshore areas of Auke Bay were sampled for juvenile pink salmon from late March to early July using a 37 m long x 3 m deep beach seine. All captured juvenile salmon were speciated, counted and checked for coded wire tags at the capture site; tagged fish were retained for tag recovery and size measurements. Weekly samples of untagged fish were also retained for size and stomach analysis from an index site on Spuhn Island in Auke Bay. Beginning in 1987, offshore areas of Auke Bay (>100 m from shore) were sampled weekly, at night, using a 6.1 m wide x 3.0 m deep surface trawl. All tagged salmon and a sample of juvenile pink salmon from each tow were retained for lengths, weights and recovery of coded-wire tags.

Water temperatures at 1 m were recorded daily for Auke Bay. The Spuhn Island site was sampled weekly for littoral epibenthic crustaceans in 1987-1989, using either an epibenthic pump or sled. Zooplankton data for the upper 5 m and upper 40 m water column in Auke Bay were collected concurrent to our study by the University of Alaska (Coyle and Paul 1990).

Stomach contents of fish sampled to determine feeding habits were weighed and prey items identified, measured and counted. The volume and dry weight of each prey category were then calculated. The Index of Relative Importance (IRI; Pinkas et al. 1971) was then computed from stomach data.

The instantaneous growth rate for each individual coded-wire tagged juvenile pink salmon was calculated using the exponential model:

$$g = \frac{(\ln W_2 - \ln W_1)}{t} 100$$

where g is the instantaneous growth rate in weight, expressed as %bw/d, during the time period t, and W_1 and W_2 represent the fish weight at the beginning and end of time (t) respectively. To determine how water temperature and food abundance relate to growth in the estuary, individual instantaneous growth rates were correlated with average daily surface water temperature and prey biomass over time period (t). The average daily biomass of prey was calculated for three different habitats: zooplankton from the upper 5 m of the water column; zooplankton for the upper 40 m of the water column; and harpacticoid copepods from the epibenthic samples. The average daily biomass for epibenthos and 40 m zooplankton was also computed. Correlation analysis and stepwise regression (Zar 1974) were employed to determine significant correlations and provide partial correlation coefficients for each of the above parameters.

To determine whether the growth rate of tagged juvenile salmon in Auke Bay was limited by prey availability, the differences (residual) between an expected growth rate, based on the average water temperature experienced from release to recapture, and the individual observed growth rate for each tagged fish were calculated and plotted against average water temperature. A simple linear model between growth and temperature was derived for expected growth rate from data on the growth of juvenile pink salmon held in several culture situations at various water temperatures and fed at maximum ration (Mortensen and Savikko in preparation). This relationship was $g = 0.391 + 0.264\,T$, where T is temperature. R^2 of the model over temperatures ranging from 3-15 °C was 0.88.

Growth rates of the tagged pink salmon were also computed for two time periods or growth stanzas again using a linearized exponential model. The early period was considered to occur from day of release to May 5 and the late period from May 5 to June 25 for each year. These dates were chosen because of the distribution of tag recoveries and the observed changes in weights of juveniles between the two periods. Growth rates of tagged groups within a year were calculated for the early period; the mean of these growth rates was then used to estimate the initial weight for each tag group for computation of the growth rates in the late period. The pooled growth rate in the late period was then calculated as the mean of the individual tag group rates. Differences in growth rates between periods and years were tested using analysis of covariance (ANCOVA) and the Newman-Kuels multiple comparison test (Zar 1974).

Survival of fish from each of the release groups for each of the emigrant years 1986 through 1989 (brood year 1985 through 1988) was determined from the number of fish returning to the Auke Creek weir. Survival rates were adjusted by estimates of annual exploitation rates in the seine fishery (Alaska Department of Fish and Game data). Intra-annual differences were tested for significance using the Newman-Kuels multiple comparison procedure. Growth rates and survival of the individual release groups within each year were calculated as a proportion of the highest observed. Proportional growth rate was regressed against proportional survival to determine the degree to which growth rate is a predictor of intra-annual survival. Actual growth rates were regressed against survival to determine the relation between growth and inter-annual survival.

RESULTS

The downstream migration of wild pink salmon juveniles from Auke Creek into Auke Bay began in early-March and ended by mid-May with peak outmigration between mid-April and early-May. From 1986 to 1989 (brood years 1985-1988), 51,904, 17,049, 36,422 and 42,625 juvenile pink salmon were coded wire tagged, respectively. These numbers represented between 31% and 45% of the total fry emigration.

Pink salmon fry were present in the nearshore area of Auke Bay from late March until the end of May or first week in June (Figure 1). The fish were most abundant in May; 80%-90% of the catch occurred between May 5 and June 1. Pink salmon had virtually left the nearshore area by late May or early June. Catch in townet samples offshore increased coincidental with the decline in catch in the beach seine sets; most of the offshore catch occurred in late May and June (Figure 1). By mid-July of each year the juvenile pink salmon had left Auke Bay. Based on recaptured tagged fish, maximum residence times in the bay ranged from 20 to 73 days.

Water temperatures at 1 m generally increased rapidly from 3-5 °C in late March to 10-13 °C in June (Figure 2). Although there was considerable variability in the temperature pattern from year-to-year, temperatures were rapidly increasing by early May in each of the four years.

Both epibenthic prey (harpacticoid copepods) and zooplankton (calanoid copepods, euphausid larvae, *Oikopleura*, and fish eggs and larvae) were utilized by the pink salmon during their nearshore residency (Figure 3). There was no temporal pattern in the utilization of these resources; the pink salmon appeared to switch between the prey categories, perhaps in response to the population dynamics of particular prey species.

Growth rates of individual tag groups varied considerably within and between years, from a low of 3.08% to a high of 7.06% (Table 1). Within each year, the earliest emigrants had the lowest growth rates. Growth rate then generally increased with emigration timing, with the highest growth rates associated with the later emigrants (Figure 4). An exception to this trend was in 1989, when emigration extended until mid-May; the growth rate was markedly lower for these late fish.

When growth rates were computed for early (April 1 - May 6) and late (May 6 - June 16) periods, there was a significant ($\underline{P} < 0.05$) difference between the mean growth rates for the two periods. In a given year, growth rates were lower in the early period. Mean growth rates in the early period were generally around 3.0%bw/d, except for 1989, when growth during this period was 4.9% (Table 1). During the later period, growth rates exceeded 5.0%, except for 1986, when it was 4.9% Growth rates estimated for tagged fish were consistently higher than the "apparent" growth rates estimated from the mean weights of samples of untagged fish (Table 1).

Water temperature was the only environmental parameter measured that was significantly ($\underline{P} < 0.05$) correlated with growth rate over all years (Table 2). For temperature, both simple and partial correlations were significant in each year, and in every year except 1988, temperature explained the most variability of the parameters tested. For zooplankton, 5 m biomass was not significantly related to growth in the three years data were available, while 40 m integrated water column was significantly correlated two of the four years of the study, and was the parameter more highly correlated with temperature in 1988. Epibenthic indices were significantly correlated with growth two of the three years data were available; in both cases, the relationship was negative (Table 2). Because the feeding habit studies showed that the pink salmon were switching between epibenthic and zooplankton resources during the nearshore phase, growth rate was also correlated with a combined index of epibenthic abundance and 40 m zooplankton. This combined index did not fit the growth data as well as either abundance index considered independently.

The residuals between observed growth rates of tagged fish and expected growth for fish fed at maximum ration indicated that a higher proportion of fish at relatively low average water temperatures (early emigrants) were below expected growth rates compared to fish at higher water temperatures (later emigrants; Figure 5). The residuals had significant ($\underline{P} < 0.01$) positive slopes for all four years. The slope of the residuals was lowest in 1988, when a higher proportion of the observations fell below the expected line throughout the temperature range observed.

Mid- to late April emigrants generally had significantly ($\underline{P} < 0.05$) higher survival than the earliest emigrants within a year (Figure 6). When emigration extended into May, survival again decreased; the last emigrants from both the 1985 and 1988 broods had significantly lower survival.

The intra-annual survival of code-wire tagged juvenile pink salmon exhibited a pattern similar to that of the growth rates. Regression of growth rate against survival indicated a highly significant relationship ($R^2 = 0.62$, $\underline{P} < 0.001$; Figure 7). The measurement of growth rate for the one obvious outlier in Figure 7 was calculated from a small sample of three fish. When this point was removed from the regression a closer fit was observed ($R^2 = 0.78$, $\underline{P} < 0.001$). Generally, within year survival increased with growth rate. Based on significant differences found in survival between release groups, "significance boxes" were placed around points in the plot of growth rate versus survival, delineating overlapping groups with low, medium and high survivals.

Growth rate as %bw/d was regressed against survival of each release group. When all years were considered in the regression, there was not a significant relationship between growth and survival ($R^2 = 0.02$, $\underline{P} > 0.39$; Figure 8). The 1987-brood data points had a distinctly different trajectory than the other years (Figure 8). There was a good fit for the other three years ($R^2 = 0.85$, slope = 1.76, $\underline{P} = 0.001$). Survivals of the 1987-brood were also significantly related to growth when this year was considered separately ($R^2 = 0.94$, slope = 0.40, $\underline{P} = 0.001$).

DISCUSSION

Pink salmon fry were abundant in the nearshore areas of Auke Bay in April and May; by the end of May or early June, the fish had moved to more pelagic habitats. Growth rates during this period of nearshore residency were low during April, and increased significantly in May. These changing growth conditions were reflected in lower average growth rates for early emigrants relative to later emigrants. Growth rates estimated from tagged fish were substantially higher than the "apparent" growth of untagged pink salmon. Growth rates of individual tag groups ranged from 3.1-7.1% bw/d. These rates are within the 1.5-7.6% range of growth rates previously reported for pink salmon during their initial marine residency (LeBrasseur and Parker 1964; Healey 1980) in other studies.

Fish growth is extensively influenced by water temperature and prey density (Brett et al. 1969; and Weatherley and Gill 1987). To attain maximum growth at a particular temperature, prey concentrations must be high or must be delivered to the rearing areas at a high rate by currents. In this study water temperature was the factor which was consistently correlated with early marine growth. Indices of prey abundance were not consistently correlated with growth, and, for epibenthic harpacticoids, were inversely related when significant. This lack of linear correlation may be largely due to the high and variable productivity of zooplankton and littoral epibenthos in subarctic ecosystems such as Auke Bay (Cordell 1986; Coyle and Paul 1990). Assuming there is some threshold level of prey density required to sustain maximum growth of the juvenile salmon, then the pronounced spikes in prey populations associated with the spring bloom may mean that much of the variability in prey is occurring above the density threshold, therefore masking any direct prey abundance:growth relationship. Any such relationships should occur primarily before or after prey population peaks. The residual analysis of expected growth of pink salmon versus initial growth indicates that food abundance is limiting growth at low water temperatures, i.e., that the low growth rates observed in the early period of nearshore residency were constrained by food availability as well as lower temperatures. The emigration of Auke Creek pink salmon extended from late-March to mid-May, with most of the fish synchronized within a 2-3 week period peaking in mid-April or early May. Holtby et al. (1989) proposed that the similar synchronous emigration timing of chum salmon may be adaptive to a broad emigration time window in terms of advantageous conditions in the estuarine environments, with synchrony a mechanism to saturate predators. The results of our study show that growth conditions are consistently lower for early emigrants, indicating the quality of the rearing environment is not the same throughout the emigration period. Within years, growth rate was also significantly related to survival. Secondary production in Auke Bay predictably peaks in May or early June (Coyle and Paul 1990);

temperatures are also predictably higher in this period (Figure 2). It would appear adaptive to emigrate later in the spring than the timing observed at Auke Creek, so as to ensure optimum growth conditions. Fish that emigrate early spend more time in the low growth period, take longer to reach a particular size than do later emigrants, and are therefore exposed to size-specific predation over a longer period. Despite spending more time in low growth conditions, however, the early emigrants will have the advantage of being larger at a given date than subsequent faster growing emigrants. Thus there is an advantage in avoiding size-selective predation by being on the "leading edge" of the synchronous emigration to marine waters, but that advantage is constrained by poorer growth conditions early in the spring.

The abundance of potential predators (coho salmon, dolly varden and sculpins) in the nearshore also increases rapidly in May (Taylor 1988), which may emphasize the importance of larger size in avoiding predation. Late emigrants, although encountering good growth conditions, may not be able to effectively outgrow the increasing predation pressure, as indicated by the decline in survival of May emigrants from the 1985 and 1988 broods.

While growth rate was significantly related to survival intra-annually, the trajectory of this relationship was not consistent from year-to-year. For three of four years, growth rate was an excellent predictor of survival, explaining 85% of the observed variability. The anomalous year was 1988 (1987 brood), which was also the year the highest growth rates were observed (Table 1). Predator interactions or conditions after the fish had moved offshore may have changed the relationship of growth and survival, although within the 1987-brood early marine growth was still strongly related to survival. Identification of such anomalous years may be important in understanding how growth conditions and other factors interact to drive interannual variation.

REFERENCES

Bax, N. J. 1983. Early marine mortality of marked juvenile chum salmon released into Hood Canal, Puget Sound, Washington, in 1980. Can. J. Fish, Aquat. Sci. 40:426-435.

Brett, J. R., J. E. Shelbourne and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, (*Oncorhynchus nerka*), in relation to temperature and ration size. J. Fish. Res. Board Can. 26: 2363-2394.

Cordell, J. R. 1986. Structure and dynamics of a epibenthic harpacticoid assemblage and the role of predation by juvenile salmon. M.S. Thesis, University of Washington, Seattle. 134 p.

Coyle, K. O. and A. J. Paul. 1990. Interannual variations in zooplankton population and biomass during the spring bloom in an Alaskan subarctic embayment. p. 179-228. In D. A. Ziemann and K. W. Fulton-Bennett (eds) APPRISE - Interannual Variability and Fisheries Recruitment.

Hargreaves, N. B. and R. J. LeBrasseur. 1985. Species selective predation on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) by coho salmon (*O. kisutch*). Can. j. Fish. Aquat. Sci. 42:659-668.

Healey, M. C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia, p. 203-229. In W. J. McNeil and D. C. Himsworth (ED.). Salmonid ecosystems of the North Pacific. Oregon State Univ. Press, Corvallis.

Holtby, L. B., T. E. McMahon, and J. C. Scrivener. 1989. Stream temperatures and inter-annual variability in the emigration timing of coho salmon (*Oncorhynchus kisutch*) smolts and fry and chum salmon (*O. keta*) fry from Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 46: 1396-1405.

LeBrasseur, R. J. and R. R. Parker. 1964. Growth rate of central British Columbia pink salmon (*Oncorhynchus gorbuscha*). J. Fish. Res. Board Can. 21:1101-1128.

Murphy, M. L., J. F. Thedinga, and K V. Koski. 1988. Size and diet of juvenile Pacific salmon during seaward migration through a small estuary in southeastern Alaska. Fish. Bull. Vol. 86(2):213-222.

Parker, R. R. 1964. Estimation of sea mortality rates for the 1960 brood-year pink salmon of Hook Nose Creek, British Columbia. J. Fish. Res. Board. Can. 21:1019-1034.

Parker, R. R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. J. Fish. Res. Board. Can. 25:757-794.

Parker, R. R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28:1503-1510.

Pinkas, L., M. S. Oliphant, and I. L. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. Bull. Cal. Fish Game 152: 1-64.

Taylor, S. G. 1988. Inter- and intra-annual survival of pink salmon (*Oncorhynchus gorbuscha*) returning to Auke Creek, Alaska in 1986 and 1987. In APPRISE Annual Report-1987. Vol. 1 Tech. Rep. p. 547-571.

Walters, C. J., R. Hilborn, R. M. Peterman, and M. J. Staley. 1978. Model for examining early ocean limitation of Pacific salmon production. J. Fish. Res. Board Can. 35:1303-1315.

Weatherley, A. H., and H. S. Gill. 1987. The biology of fish growth. Academic Press, London.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Table 1. Growth rate (%bw/d) of tagged juvenile Auke Creek pink salmon recovered in Auke Bay, 1986 - 1989. Growth rate by periods (4/1 - 5/6 and 5/7 - 6/16), standard deviation (s) and coefficient of determination (R^2) are also presented for tagged and untagged fish.

Year	Time period	Release date	Growth rate	s	R^2
1986	4/7 - 6/16	4/7	3.08	0.218	0.92
		4/15	4.07	0.220	0.96
		4/22	3.41	0.245	0.90
		4/29	4.21	0.186	0.98
		5/6	4.00	0.250	0.74
	period 1	tagged untagged	2.93	0.237	0.84
	period 2	tagged untagged	4.82	0.221	0.83
1987	4/1 - 6/16	4/1	3.82	0.153	0.88
		4/8	4.31	0.159	0.90
		4/15	4.55	0.216	0.90
		4/22	4.58	0.137	0.95
	period 1	tagged untagged	3.14	0.203	0.78
	period 2	tagged untagged	5.40	0.173	0.94
1988	4/1 - 6/16	4/1	4.02	0.191	0.59
		4/7	4.63	0.127	0.92
		4/15	5.96	0.220	0.92
		4/22	6.23	0.259	0.94
		4/29	7.06	0.265	0.89
	period 1	tagged untagged	2.95	0.208	0.62
	period 2	tagged untagged	6.66	0.274	0.60
1989	4/7 - 6/16	4/7	3.44	0.277	0.92
		4/15	4.67	0.351	0.99
		4/22	5.81	0.231	0.95
		4/29	5.35	0.248	0.89
		5/6	6.11	0.296	0.91
		5/13	4.59	0.243	0.89
	period 1	tagged untagged	4.88	0.287	0.44
	period 2	tagged untagged	5.40	0.202	0.82

Table 2. Simple and partial (S/P) correlation coefficients between the instantaneous growth rate of juvenile pink salmon and average water temperature; average harpacticoid biomass; average biomass of prey integrated from 40m to surface; average biomass of prey in the upper 5m; and average biomass of harpacticoids + prey from the integrated water column. An (*) indicates a significant ($p<0.05$) correlation.

Year	Average water temperature	Average harpacticoid biomass	Average integrated column biomass	Average biomass in upper 5m	Average biomass of harpacticoids + integrated column
1986	0.696*/0.696*	NA/NA	0.630*/0.187*	-0.187/-0.046	NA/NA
1987	0.312*/0.312*	-0.201*/-.201*	0.193/0.114	0.228/0.046	-0.195*/-0.251*
1988	0.423*/0.275*	0.337/0.000	0.505*/0.505*	0.472/0.228	0.402/0.093
1989	0.354*/0.354*	-0.226*/-0.118*	0.057/0.003	NA/NA	-0.114/-0.052

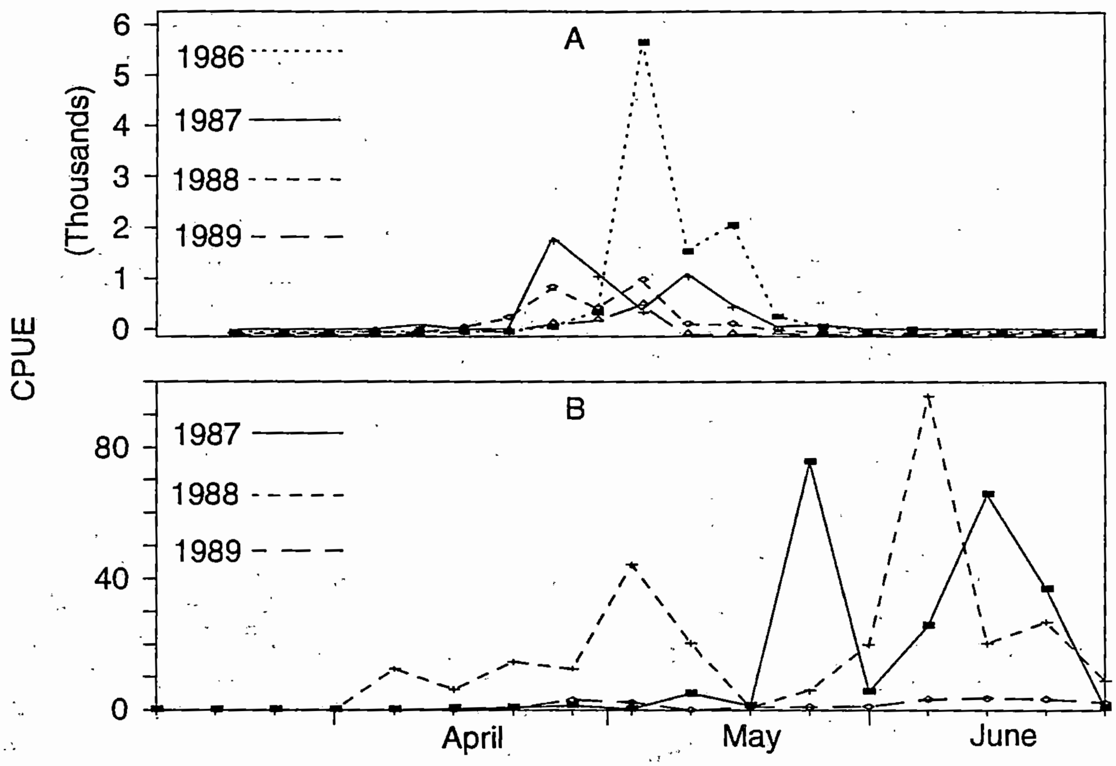


Figure 1. Catch-per-unit effort (CPUE) of juvenile pink salmon at nearshore (A) and offshore (B) sampling sites in Auke Bay, 1986 - 1989.

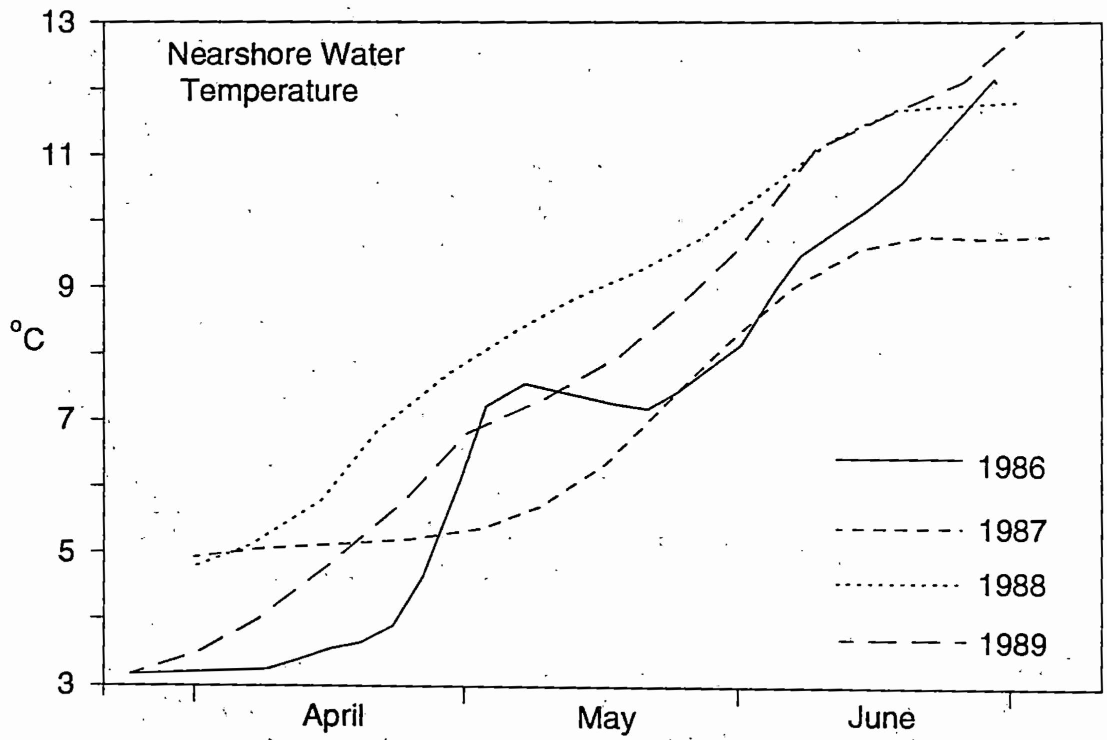


Figure 2. One meter water temperatures taken at nearshore sampling sites in Auke Bay, 1986-1989.

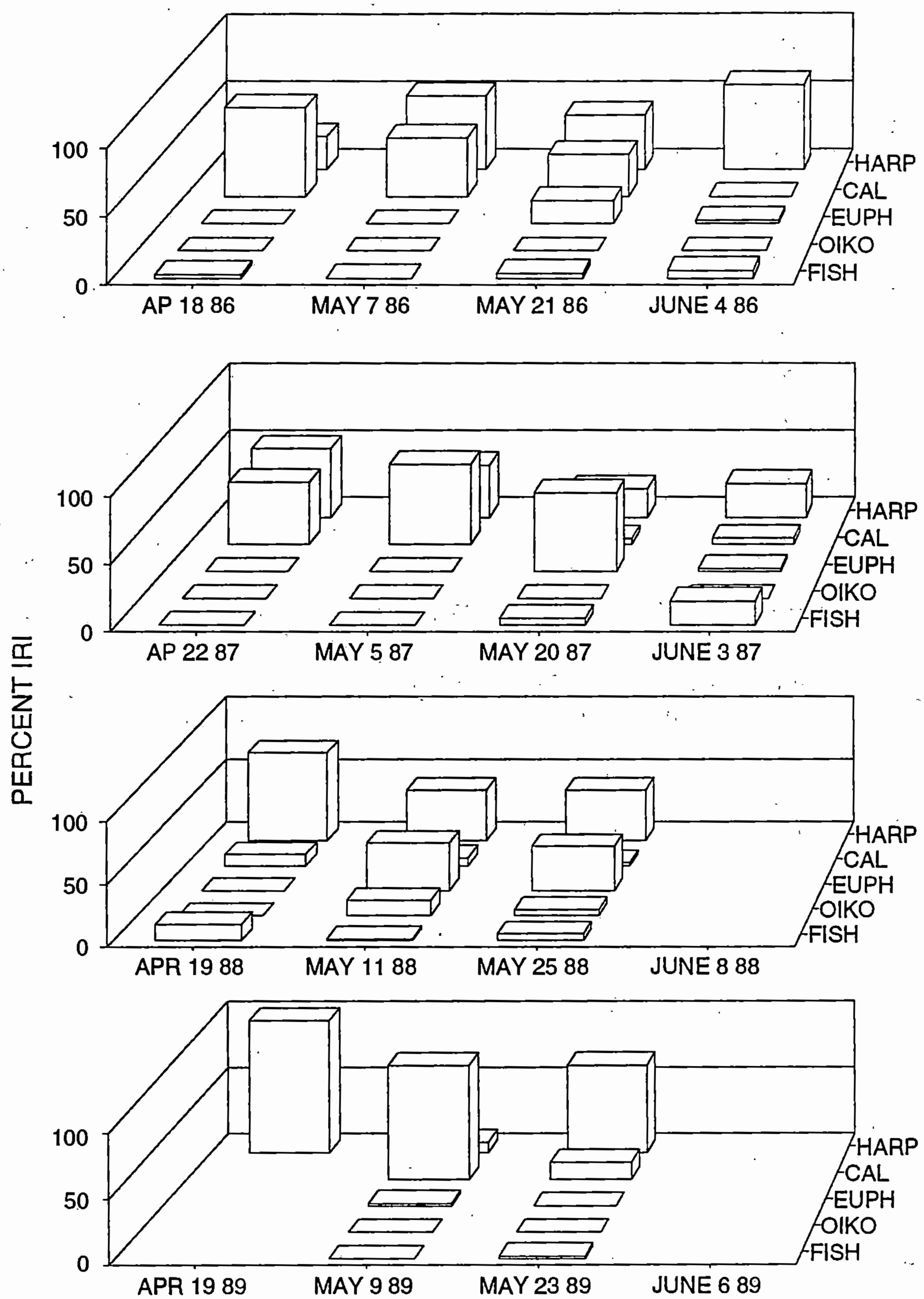


Figure 3. Percent Index of Relative Importance (IRI) of principal prey items found in the stomachs of juvenile pink salmon captured over time at the Spuhn Island index site, 1986 - 1989. HARP = Harpacticoid copepods; CAL = Calanoid copepods; EUPH = Euphausids; OIKO = Oikopleura and FISH = Fish larvae.

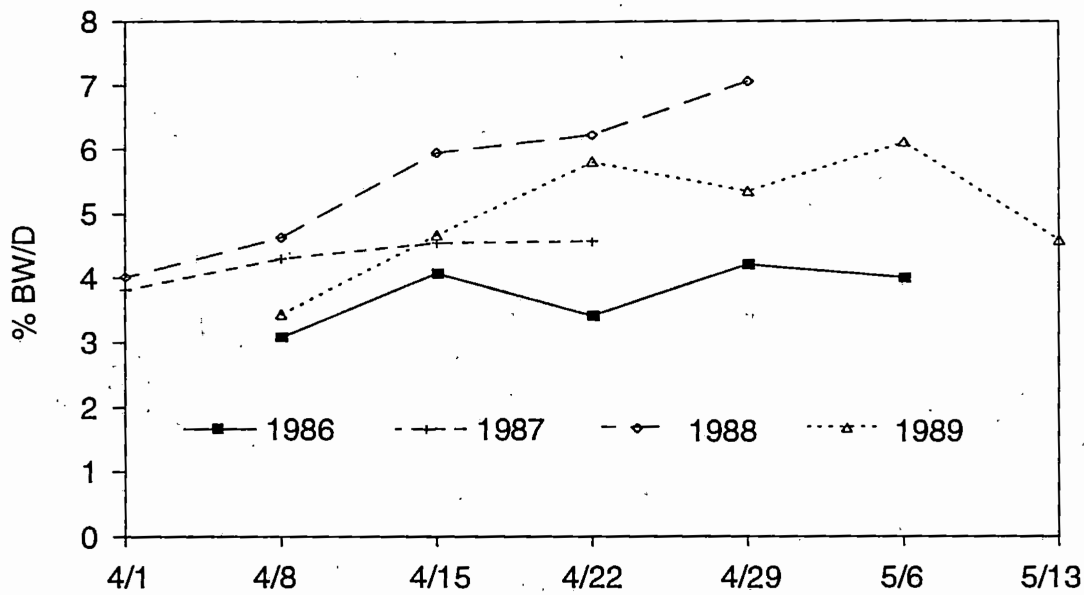


Figure 4. Growth rates (%bw/d) of tagged juvenile Auke Creek pink salmon recovered in Auke Bay, 1986 - 1989.

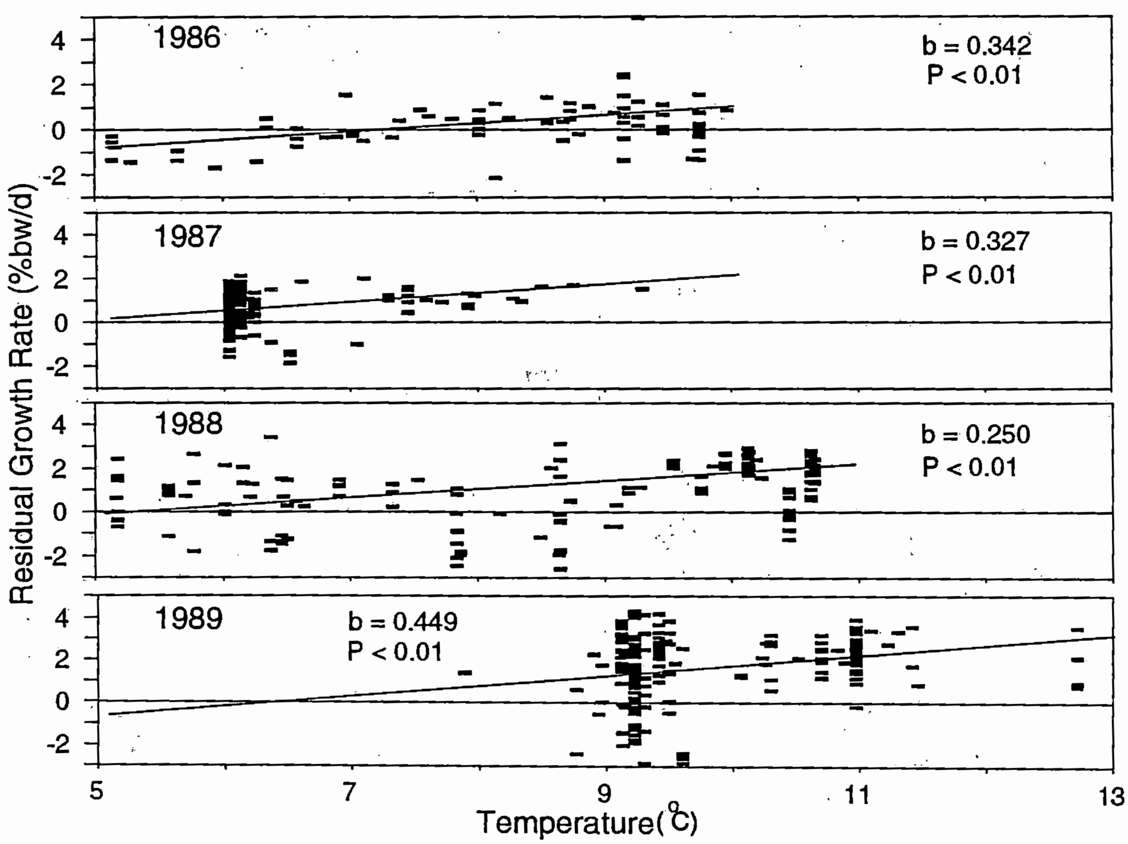


Figure 5. Residuals between the observed growth rate of tagged juvenile pink salmon and expected growth rate of juvenile salmon fed excess ration. Year shown refers to recovery year.

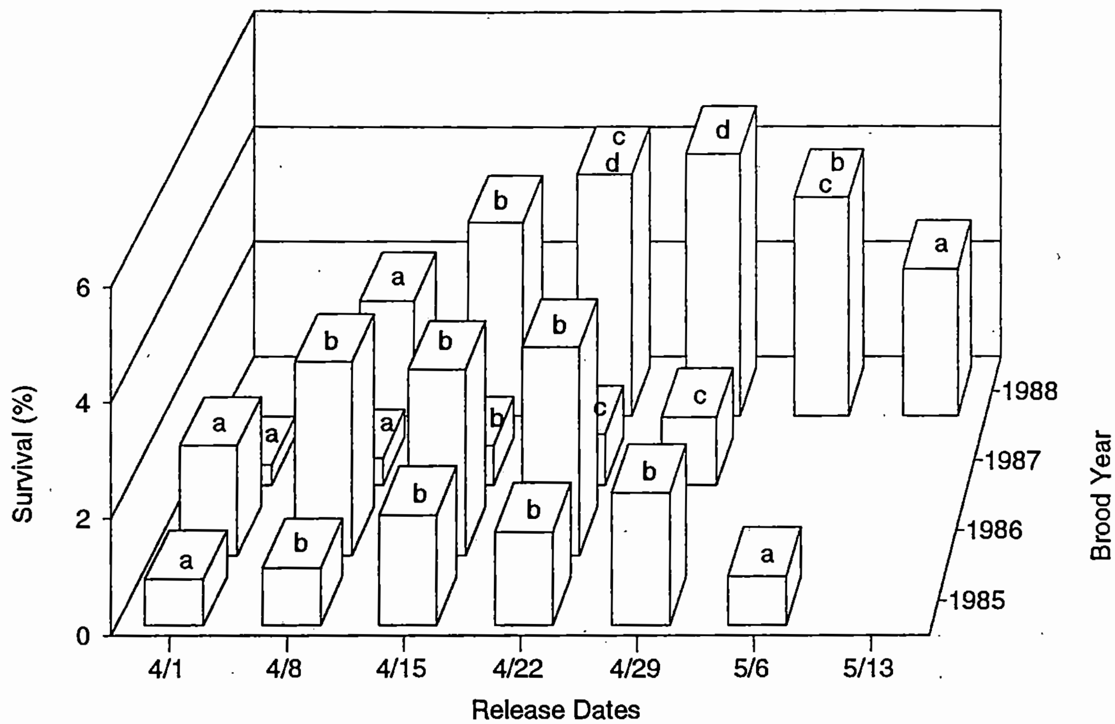


Figure 6. Percent survival of tagged Auke Creek pink salmon (brood years 1985 - 1988) released between 4/1 and 5/13. Bars containing different letters are significantly different (P < 0.01).

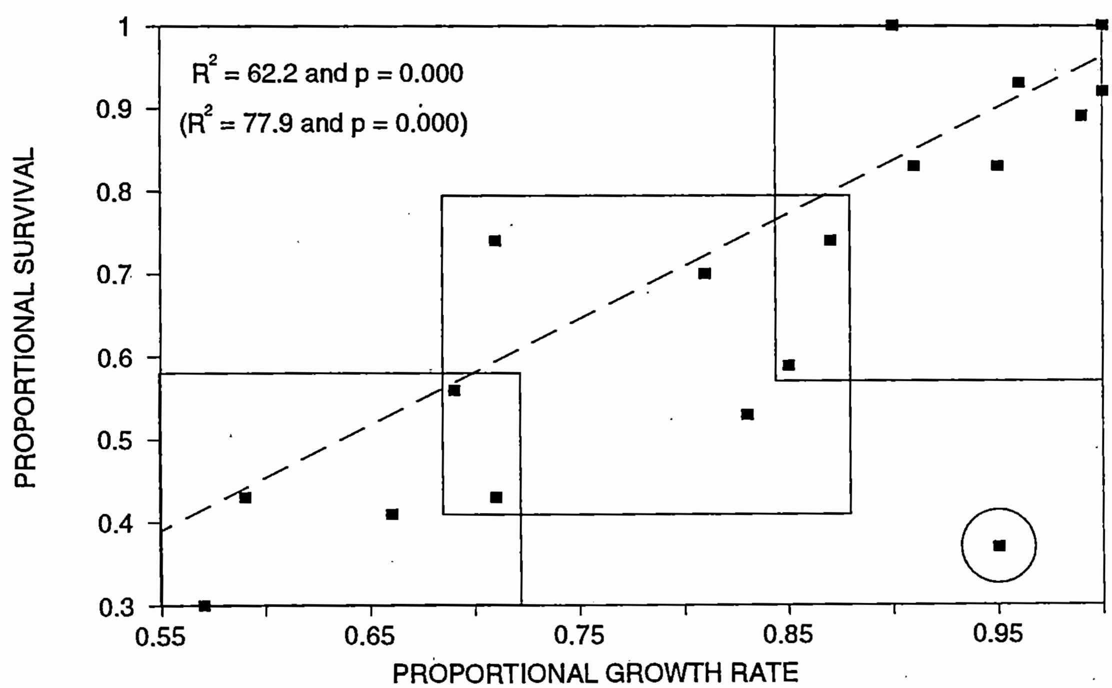


Figure 7. Regression of proportional survival vs. proportional growth rate of tagged Auke Creek pink salmon. The circled point is an outlier and the rectangles surround points which are statistically similar based on survival.

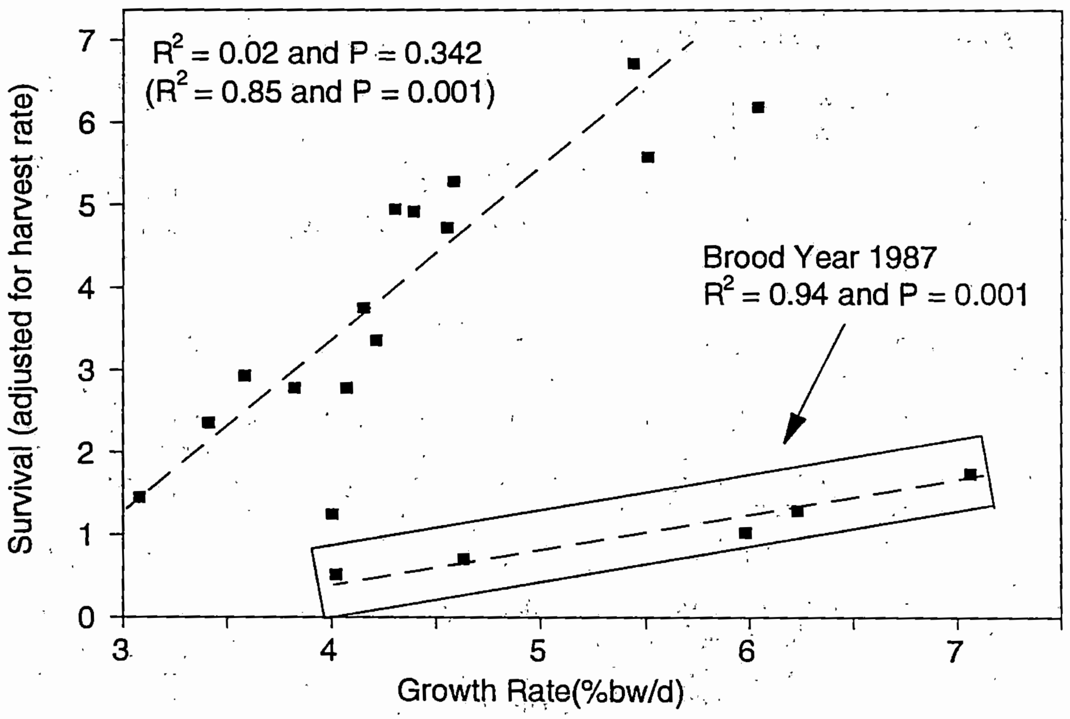


Figure 8. Regression of adjusted survival vs. growth rate (%bw/d) of tagged Auke Creek pink salmon. The points within the rectangle are the survivals from brood year 1987.

Regional-Level Investigations of Pink Salmon Production Responses to Interannual Variations in Ocean Temperatures: Cooperative Fisheries and Oceanographic Studies (CFOS)

Robert T. Cooney and T. Mark Willette

School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
Fairbanks, Alaska 99775

Cooperative Fisheries and Oceanographic Studies (CFOS) utilizes time-series data collections and experimental research to determine how interannual fluctuations in coastal ocean temperature and zooplankton stocks affect the production of pink salmon in the northern Gulf of Alaska. Successes with coastal hatchery production have been attributed, in large part, to the development of release strategies that presumably maximize the growth potential of fry relative to temporally varying plankton forage fields. In contrast, the success of wild populations may be related more to the proportion of fry out-migrating into optimal food and temperature conditions each year. Statistical relationships between total survival (freshwater and marine), sea surface temperature (SST) from April through July and pelagic food stocks for fry are discussed for wild pink salmon populations in Prince William Sound from 1982 to present as an example of the cooperative program approach.

In January 1990, the Alaska Sea Grant College Program initiated a jointly-funded five-year study to examine the effects of coastal ocean temperature and fry food on pink salmon production in Prince William Sound, Alaska. With direct and in-kind support from Alaska Department of Fish and Game (ADF&G) and the non-profit private coastal salmon hatcheries in the region (Prince William Sound Aquaculture Corporation; Valdez Fisheries Development Association), CFOS seeks to test the assertion that run size in pink salmon is generally set during the first few weeks of early ocean residence. This notion finds support in the reviewed literature (Parker 1968; Hartt 1980; Bax 1983; Nichelson 1986; Ricker 1976; Foerster 1968).

Willette (1985) reported that pink salmon production in Prince William Sound is dependent upon ocean temperatures affecting both the fry and adults. For even-year runs, numbers of returning adults are directly related to SST conditions experienced by the fry. For odd year fish, spring temperatures affecting the returning adults also predict the strength of runs resulting from the progeny of these fish. Later statistical studies, using all returns for the Gulf of Alaska over a 25-year period, demonstrated that approximately 50% of the interannual variability in run size of pink salmon could be explained by ocean SST experienced during early ocean residence (Willette and Cooney 1991).

The CFOS program was undertaken in Prince William Sound on the premise that a quantitative understanding of local temperature and fry forage conditions each year would provide the means to more accurately predict the strength of runs. This information is also intended to assist the public and private-sector hatcheries in the region optimize their production under widely varying conditions of coastal ocean climate. 50% or more of the pink salmon harvested in Prince William Sound now originate from four local hatcheries, and production increases are planned.

BACKGROUND

Prince William Sound is a large fjord/estuary situated at the northern-most reaches of the Gulf of Alaska. The region is approximately 8,800 km^2 in size and communicates with the open Gulf of Alaska via the Alaska Coastal Current (ACC). This well-defined wind and freshwater-forced westward flow originates in southern southeastern Alaska and can be traced around the margin of the Gulf of Alaska as far west as Unimak Pass (Royer 1981). A portion of the ACC enters the Sound via Hinchinbrook Entrance and leaves through Montague Strait (Figure 1). The current exhibits strong seasonal and interannual signals associated with variations in wind forcing and coastal run-off (Royer et al. 1990)

Approximately 20% of Prince William Sound is deeper than 200 m. The deep portion of the region (depths to 800 m) provides suitable over-wintering habitat for oceanic zooplankton populations advected in by wind-forced cross shelf flow and the coastal circulation (Cooney 1986). Large populations of oceanic copepods *Neocalanus plumchrus* and *N. cristatus* occur below 300 m in the Sound from September to February of each year. The copepodid stages of these oceanics, supplemented by populations of other abundant overwintering neretic copepods (*Calanus marshallae* and *Pseudocalanus spp.*) appear in late March in the upper 20 m. A Neocalanus "bloom" composed largely of stage III-V copepodids is characteristic of the region from late April to late May. The timing of this bloom is apparently dependent upon ocean temperature, occurring earlier during warmer-than-average years (Willette and Cooney 1991). As Neocalanus begins to leave the surface layers in mid-May, stage III-adult *Calanus marshallae* take their place. A similar phasing of large calanoids has been observed in Auke Bay, Alaska (Coyle et al. 1990).

Studies of pink salmon fry feeding behavior and forage stocks in Prince William Sound have demonstrated ties with both benthic and pelagic food webs (Barnard 1981; Cooney, et al. 1981; Urquhart 1979). When the numbers of food items in stomachs are tabulated, harpacticoid copepods and small pelagic calanoid species (*Pseudocalanus* and *Acartia*) consistently comprise the major elements. However, when the mass of the food is determined, very often 50% or more of the stomach contents of fry are composed of the larger calanoid copepods, Neocalanus and Calanus (Cooney 1990).

Historically, runs of wild pink salmon (odd and even) averaged about 5.0 million fish between 1960 and the late 1970's when sudden increases to 15 million fish or more occurred (Figure 2). This higher abundance was maintained until about 1985 when declines in run strength began to reduce the production to former levels. During this latter period, several private sector hatcheries in the region (Prince William Sound Aquaculture Corporation; Valdez Fisheries Development Association) began contributing to the common property fishery. Public and private enhancement has resulted in a steady increase in overall hatchery-released production since 1978. Approximately 550 million salmon fry and smolts were released by the Prince William Sound Aquaculture Corporation alone in 1990. This amounted to more than 40% of the combined production for all other salmon hatcheries in the State (PWSAC 1990).

OCEANOGRAPHIC MONITORING AND EXPERIMENTAL STUDIES

Since they have been releasing fry, the private-sector hatcheries in the region have monitored ocean temperatures and sampled zooplankton prior to, during and following the release of juveniles. A 1/2 m net (0.243-mm Nitex) is used to fish a vertical water column at selected locations from 20 m to the surface on a specified time schedule from March through early June of each year. Settled plankton volumes are recorded to the nearest mL along with an estimate of percent zooplankton (pink) and phytoplankton (green/brown color) volume contributing to the total measurement. Attempts are made to release fry near the peak of the large calanoid bloom.

Under CFOS, the monitoring program has been expanded to include the period 15 January to 15 July, with sampling at selected locations twice weekly (weather permitting). Following the settled volume measurements, plankton samples are preserved for later transfer to the University of Alaska.

To supplement the plankton watch, all hatcheries are also routinely recording local weather and measuring sea-surface temperatures daily. The Wally Noerenberg Hatchery (WNH) at Esther Island is deploying a self-contained CTD (SeaBird) to 100 m during the period of the plankton watch. ADF&G is lowering a similar CTD (to 400 m) at selected locations in the Sound on a monthly or more frequent schedule. ADF&G is also fishing a 1/2 m net (to 400 m) to supplement the CTD data. Sea surface temperature measurements and visible particulate fields are being observed using NOAA satellite data available at the University of Alaska Fairbanks Satellite Laboratory.

The University CFOS effort involves coordination of weather and ocean monitoring programs and participation in specific experimental studies. Factors affecting the timing, duration and standing stocks of large calanoids (Calanus and Neocalanus) associated with the May/April "bloom" are being studied to describe phasing of the two species and levels of interannual variability. Seasonal changes in total lipids and the caloric content of these same large calanoid populations are also being investigated relative to the entry timing of wild and hatchery populations each year. Post emergent recaptures of hatchery-released and wild fry provide continuing information on fry food dependencies and fry otoliths are being collected for measures of absolute growth rates and dates of emergence. For comparative purposes, several oil-spill related salmon studies sponsored by ADF&G will eventually contribute information on the growth of coded-wire tagged fry in the region.

Historical records of Prince William Sound salmon catches and escapements are being used to search for relationship with long-period time-series of temperature and fry food stocks available for the region. In this regard, monthly average surface mixed-layer temperatures have been obtained from 1947 to the present from the Climate Research Group at Scripps Institution of Oceanography. Coastal upwelling indices are also being studied for correlation with salmon production records. This information is available through the NOAA/NMFS Pacific Environmental Group at Monterey, California. The latter time-series can be used to determine levels of variability in wind forced coastal flow and possible other effects associated with the delivery or washout of zooplankton populations each spring.

PRELIMINARY CFOS RESULTS

CFOS research is designed to take advantage of between- and within-year differences in temperature and food for fry monitored near each of the hatcheries in Prince William Sound as a tool for investigating cause and effect. Counts of fry released and estimates of returning adults (brood stock and common property fishery) provide the critical measure of marine survival. Marine survivals have varied within and between years at all hatcheries although there is a strong degree of coherence in the annual time-series suggesting modification by common factors (Figure 3). A similar time-series of catch and escapement for wild stocks is being used to search for relationship between return per spawner, return per average alevin density in index streams and marine conditions experienced by wild juveniles.

HOMOGENEITY IN 1990 SST TEMPERATURES

Seasonal trends in observed daily SST exhibit the kinds of differences in magnitude and phasing predicted in the design of the study (Figure 4). Calculations of degree days (April through May) ranged from 348.6 at the AFK hatchery in the southwestern Sound, to 369.5 at the Noerenberg hatchery and 409.4 at Cannery Creek in the northern portion of the region. This gradient in upper-layer temperatures is probably related to relative differences in the stability of the water column at each of these locations. The Norenberg and Cannery Creek facilities front on the deep open sound and a wide fjord. In contrast, the AFK hatchery is situated in the southwestern corner of the region in a area where narrow passages and inlets amplify upper-layer tidal mixing processes. The result is a slight reduction in surface temperatures in the more energetic area.

1990 ZOOPLANKTON FORAGE

As predicted, the timing, duration and amounts of zooplankton also differed in the waters adjacent to each hatchery. In 1990, the "large calanoid" bloom began in early April with zooplankton settled volumes rising to their highest values by early June at two of three locations (Figure 5). Initial inspection of the species composition in these collections indicates that late May and June populations in 1990 were composed of very large numbers of small neretic zooplankters including Podon, Evadne, Acartia, Centropages, and Pseudocalanus. Unlike most years, the "Neocalanus" bloom was unusually weak in late April and May at all locations, but appreciable numbers of *Calanus marshallae* appeared in late May and early to mid-June at the northern sound stations.

1990 zooplankton settled volumes, measured at the AFK hatchery, were converted to food days (average settled volume during the bloom times the duration of the bloom in days) for comparison with other years for which this information is available. Compared this way, the 1990 forage stock ranks only 7th in the AFK time-series dating back to 1981 (Figure 6). The AFK time-series also demonstrates that while the amplitude of forage stocks can vary markedly from year to year, the timing of the peak of the large calanoid stock can shift as well (Figure 7).

PREDICTING WILD STOCK RETURNS - A PRELIMINARY MODEL

If predation operating during the first 30-60 days of early ocean residence generally sets the limits on marine survival of pink salmon, factors affecting losses to fish and bird predators during this time should be predictive of future run success. In the absence of a means to assess predation losses directly, it has generally been assumed that the growth rate of the juveniles at this critical time is the important predictive variable. Slow growth implies a longer residence time at the most vulnerable smaller sizes, while faster growth presumably reduces the period of greatest risk. These relationships have been investigated and described for salmon populations at other Pacific coast locations (Parker 1971; Healy 1982; Taylor 1977 and Walters et al. 1978). In lieu of direct measurements of absolute growth each year, correlation is being sought by CFOS between adult survival and measures of forage abundance and upper layer temperatures occurring during early ocean fry residence (April-July).

As noted above, the historical record of calculated forage days from the AFK hatchery demonstrates considerable variability from year to year over the period 1981 to present. In most years, the large copepod "bloom" lasts much less than 60 days (thought to be the duration of wild fry emergence), meaning that only a portion of the out-migrating fry encounter elevated forage each year. If food and temperature conditions modify early fry losses to predation as hypothesized, it should be possible to demonstrate a relationship between run size or total survival and early ocean growth conditions experienced by the fry.

A simple product-moment correlation for annual return, return per spawner, return per fry index (average number of alevins per m^2 in index streams) and several measures of food and temperature was performed to search for statistical relationships (Table 1). As expected from previous studies, reasonable correlations are apparent between run parameters and spring and early summer SST. Relatively strong correlations are also evident with zooplankton abundance. Surprisingly, little correlation was found between run parameters and an index of growth conditions accounting for the duration and magnitude of the bloom and average temperatures for April through July of each year (oceanic growth index [OGI]). However, upon closer examination, the details of this latter correlation do appear to point to a rather well-defined linear relationship between total survival (return per spawner) and fry growth conditions, compromised by some obvious discrepancies (Figure 8).

If the warmest fry year (1981) and the two coldest fry years in this time series (1982, 1985) are excluded, a "core" relationship is exposed that links the wild return per spawner to ocean temperature and fry food with an r^2 value exceeding 0.98 (Figure 9). Strictly speaking, this kind of subjective manipulation must be considered statistically dubious. However, we argue that a linear model predicting the wild return per spawner with high accuracy 66% of the time is probably worth exploring further. For example, lower-than-predicted returns during the two coldest years may be related to unrecognized temperature effects on the timing and duration of the normal two month out-migration (significant delays in leaving natal streams, etc.). In contrast, fry entering under quite warm conditions and encountering very low planktonic food resources may be able to successfully exploit alternative epibenthic food webs to a much greater degree than normally would be the case.

Obviously, there are factors yet to be accounted for that influence the ability of any simplistic approach to successfully predict salmon production at a higher rate (70%-90% of the cases). In this regard, we clearly understand the limitations of using a model that attempts to account for losses to predation without actually including measures of interannually varying predator abundance. However, until the means for obtaining predator information becomes available, the approach described above will continue to be used as an investigative tool to direct specific inquires about temperature modulation of matches between wild fry and their food resources each year.

These and related phenomena will be examined in greater detail for both wild and hatchery stocks as the 5-year CFOS study progress, with advantage being taken of the different sets of "experimental conditions" afforded by natural levels of interannual variability in fry food and coastal ocean temperature. ADF&G has new information on the timing and pattern of fry entry into coastal waters as the result of oil-spill studies in Prince William Sound that is expected to have fundamental application to the overall CFOS study (Sharp 1991).

FUTURE DIRECTION FOR CFOS

Increasing focus on fry growth rates and entry timing into marine waters will place new emphasis on the importance of documenting matches with optimal growth conditions. If the surviving wild fry each year are primarily those that happen to out-migrate into the zooplankton bloom, a back-calculation of entry dates, determined from otolith growth records, should correlate with the timing and duration of the large calanoid bloom in most years.

In a more important sense, understanding the conditions that influence the production of salmon from hatchery and wild stocks in Prince William Sound represents a fundamental step in evaluating the carrying capacity of this system to successfully rear increasing numbers of hatchery-released juveniles. Certainly there must be some upper-limit beyond which measurable effects on the salmon themselves and other species will become apparent, perhaps even detrimental. At present, very little is understood about factors defining the carrying capacity of any marine system, beyond the usual theoretical considerations arising from levels of primary production and general food-web transfer efficiencies. CFOS hopes to forge a better understanding of this phenomenon in Prince William Sound as a major contribution of the overall study.

ACKNOWLEDGMENTS

Time-series observations from the AFK hatchery, 1981-1990, and temperature and plankton abundance from AFK, CCH and WNH in 1990 were supplied by the Prince William Sound Aquaculture Corporation as part of the CFOS study. The time and effort needed to collect this information by hatchery managers and technical staff is acknowledged.

Alaska Department of Fish and Game in Cordova supplied historical run statistics, fry index information and marine survivals for hatchery stocks. Mr. Sam Sharr and Mr. Larry Peltz are acknowledged for these contributions.

REFERENCES

BARNARD, D.R. 1981. Prey relationships between juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) in Prince William Sound Alaska. M.S. Thesis, University of Alaska, Fairbanks. 72 p.

BAX, N.J. 1983. Early marine mortality of marked juvenile chum salmon released into Hood Canal, Puget Sound. Can. J. Fish. Aquat. Sci. 40:426-435.

COONEY, R.T. 1986. The Seasonal occurrence of *Neocalanus cristatus, Neocalanus plumchrus* and *Eucalanus bungii* over the shelf of the northern Gulf of Alaska. Continental Shelf Res. 5:541-553.

COONEY, R.T. 1990. Prey fields and the feeding behavior and growth of pink salmon fry released from the Armin F. Koernig Hatchery at Sawmill Bay, Evans Island, Alaska; May and June, 1989. In Early Marine Salmon Injury Assessment In Prince William Sound; Fish/Shellfish Study No.4, State of Alaska. 46 p.

COONEY, R.T., D. URQUHART and D. BARNARD. 1981. The behavior, feeding biology and growth of hatchery-released pink and chum salmon fry in Prince William Sound, Alaska. Alaska Sea Grant Rep. 85-5. University of Alaska, Fairbanks. 114 p.

COYLE, K.O., A.J. PAUL and D.A. ZIEMANN. Copepod populations in a spring bloom in a subarctic embayment. J. Plank. Res. 12(4):759-797.

FOERSTER, R.E. 1968. The sockeye salmon. Fish. Res. Bd. Can. Bull. 162. 422 p.

HARTT, A.C. 1980. Juvenile salmonids in the oceanic ecosystem - the critical first summer. In Salmonid Ecosystems of the North Pacific, W. J. McNeil and D. C. Himsworth, eds. Oregon State Univ. Press, pp. 25-57.

HEALEY, M.C. 1982. Timing and relative intensity of size- selective mortality of juvenile chum salmon during early sea life. Can. J. Fish. Aquat. Sci. 39:952-957.

NICHELSON, T.E. 1986. Influences of upwelling, ocean temperature and smolt abundance on marine survival of coho salmon (*Oncorhynchus kisutch*) in the Oregon production area. Can. J. Fish. Aquat. Sci. 43:527-535.

PARKER, R.R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. J. Fish. Res. Bd. Can. 25:757-794.

PARKER, R.R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Bd. Can. 28:1508-1510.

PWSAC. 1990. Prince William Sound Aquaculture Corporation 1990 annual report. Cordova, Alaska. 20 p.

RICKER, W.E. 1976. Review of the growth rate and mortality of Pacific salmon in saltwater, and non-catch mortality caused by fishing. J. Fish Res. Bd. Can. 33:1483- 1524.

ROYER, T.C. 1981. Baroclinic transport in the Gulf of Alaska. Part II. A freshwater driven Alaska Coastal Current. J. Mar. Res. 39:251-266.

ROYER, T.C., J.A. VERMERSCH, T.J. WEINGARTNER, H.J. NIEBAUER and R.D. MUENCH. 1990. Ocean circulation influencing the Exxon Valdez oil spill. Oceanography 3(2):3-10.

SHARP, D. 1991. Methodology for assessment of injury to pink salmon using coded wire tagging. Annual Pink and Chum Salmon Workshop 1991 (this volume).

TAYLOR, S.G. 1977. The effect of timing of downstream migration on marine survival of pink salmon. M.S. Thesis, Univ. Alaska Southeastern Senior College, Juneau. 40 p.

URQUHART, D.L. 1979. The feeding, movement and growth of pink salmon (*Oncorhynchus gorbuscha*) fry released from a hatchery in Prince William Sound, Alaska. M.S. Thesis, Univ. Alaska Fairbanks, Fairbanks. 111 p.

WALTERS, C.J., R. HILBORN, R.M. PETERMAN and M.J. STALEY. 1978. Model for examining the early ocean limitations of Pacific salmon. J. Can. Fish. Aquat. Sci. 41:126-133.

WILLETTE, T.M. 1985. The effects of ocean temperatures on the survival of odd- and even-year pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. M.S. Thesis, Univ. of Alaska, Fairbanks. 115 p.

WILLETTE, T.M. and R.T. COONEY. 1991. An empirical orthogonal functions analysis of sea surface temperature anomalies in the North Pacific Ocean and cross-correlations with pink salmon (*Oncorhynchus gorbuscha*) returns to southern Alaska. Annual Pink and Chum Salmon Workshop 1991 (this volume).

Table 1. Product-moment correlations between wild stock run parameters and variables thought to influence pink salmon production in Prince William Sound, 1982-1990.

	AVETEMP	AVEZOOP	DURBLM	FDDAYS	PZOOP	OGI
WR	0.5838	0.5697	-0.0174	0.1110	0.3158	0.2384
WRFI	0.4298	0.4710	0.0898	0.1524	0.4950	0.2803
WRS	0.6837	0.6184	-0.1446	0.0770	0.1963	0.2271

	APTEMP	MATEMP	JLTEMP	JNTEMP
WR	0.4094	0.3333	0.5628	0.6931
WRFI	0.3975	0:2831	0.3056	0.5285
WRS	0.3537	0.5663	0.7852	0.6482

Where:

WR	= Annual return of wild pink salmon
WRFI	= Wild return per fry index
WRS	= Annual wild return per spawner
AVETEMP	= Average NEGOA SST temperature April-July
AVEZOOP	= Average zooplankton abundance (mL/m^3) in calanoid bloom
DURBLM	= Duration of the calanoid bloom in days
FDDAYS	= Product of AVEZOOP and DURBLM
PZOOP	= Peak zooplankton (mL/m^3)
OGI	= Oceanic growth index (product of FDDAYS and AVETEMP)
APTEMP	= April NEGOA SST temperature
MATEMP	= May NEGOA SST temperature
JLTEMP	= July NEGOA SST temperature
JNTEMP	= June NEGOA SST temperature

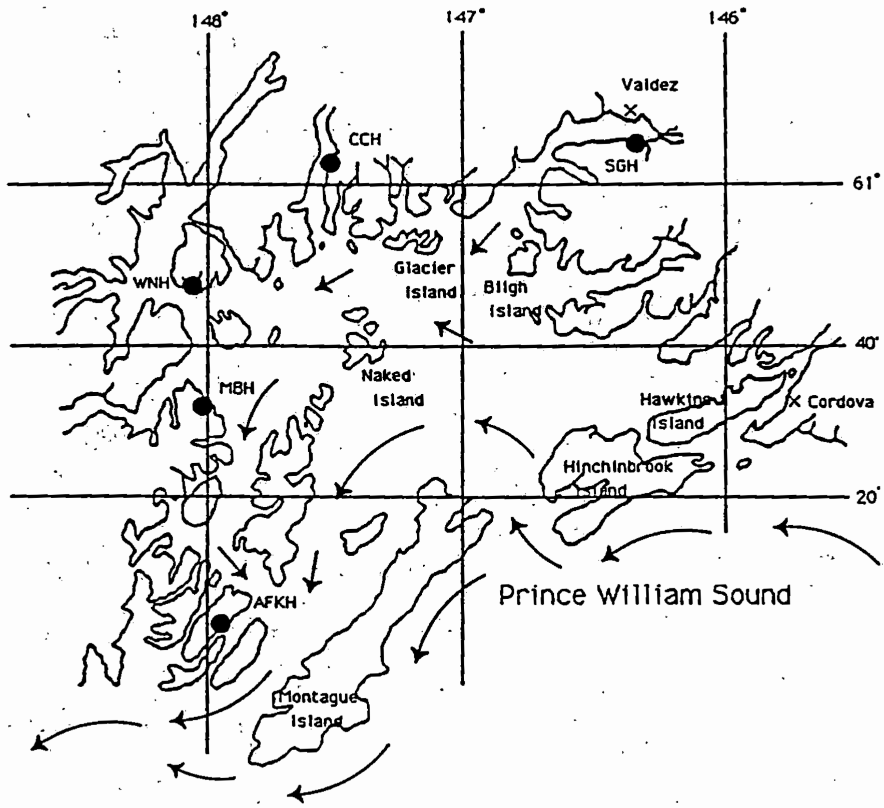


Figure 1. Generalized surface circulation and the distribution of salmon hatcheries in Prince William Sound. SGH is the Solomon Gulch Hatchery, CCH is the Cannery Creek Hatchery, WNH is the Walley Noerenberg Hatchery, MBH is the Main Bay Hatchery (red salmon only) and AFKH is the Armin F. Koernig Hatchery.

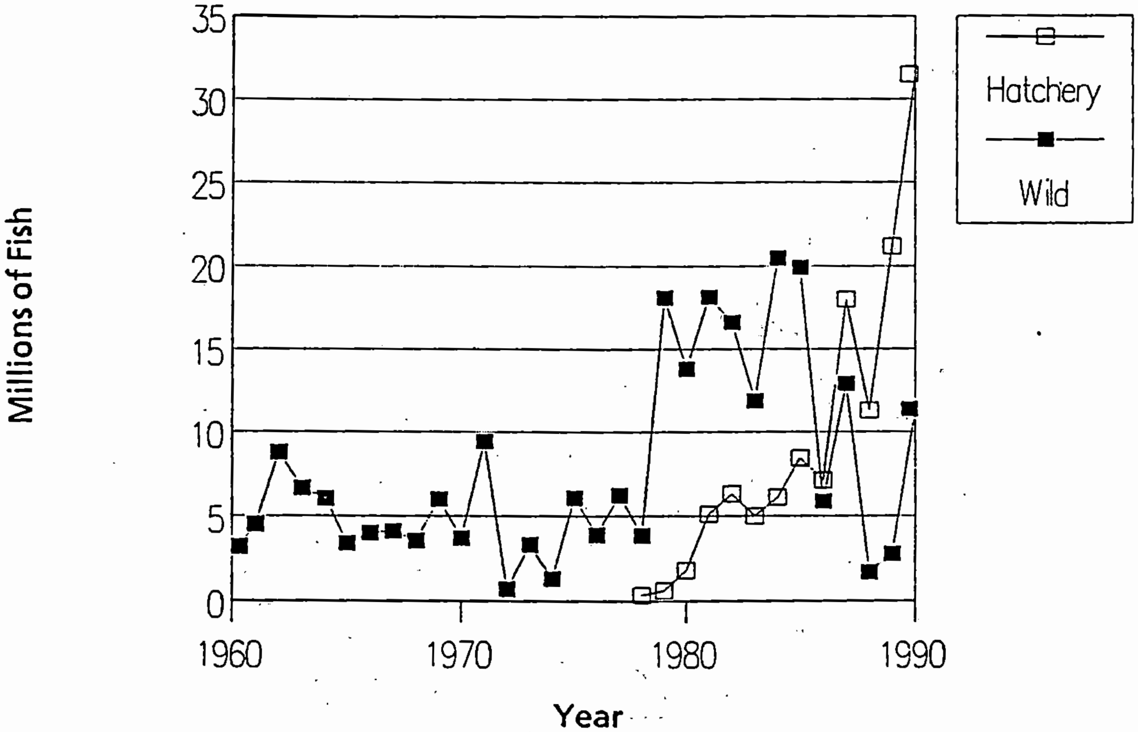


Figure 2. Wild and hatchery-released pink salmon returns to Prince William Sound, 1960 - present.

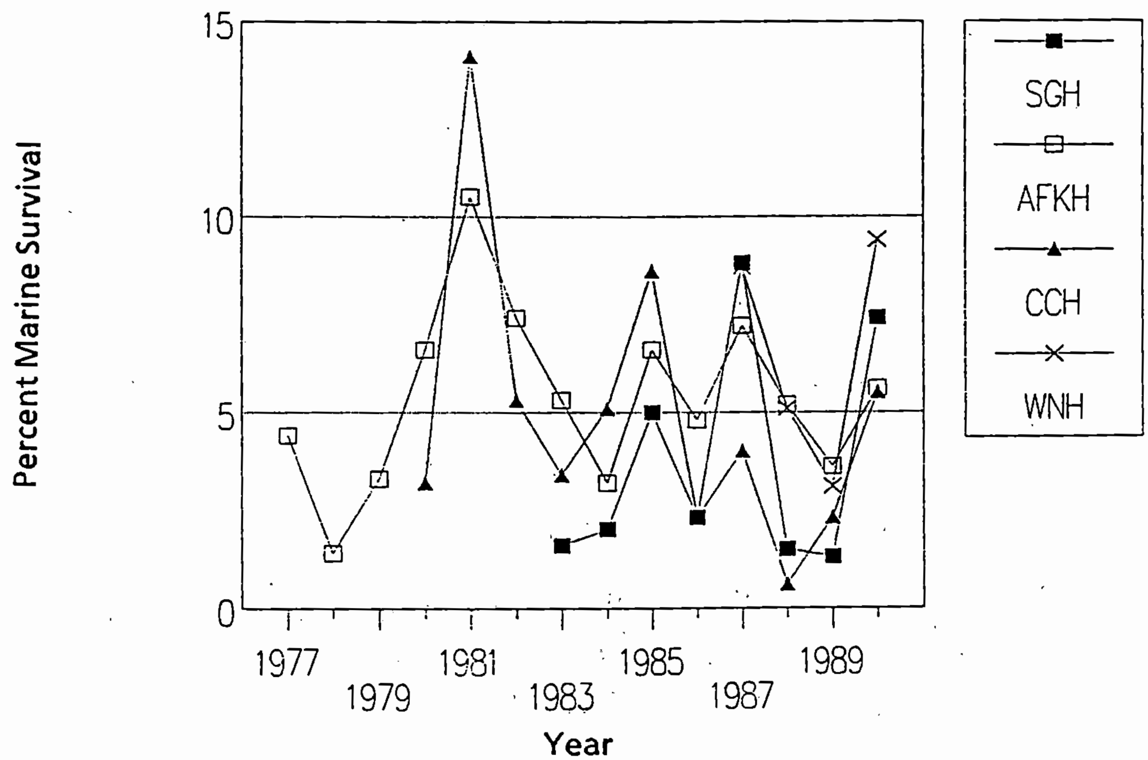


Figure 3. Total marine survival for hatchery-released pink salmon in Prince William Sound by location for the period 1977 - present.

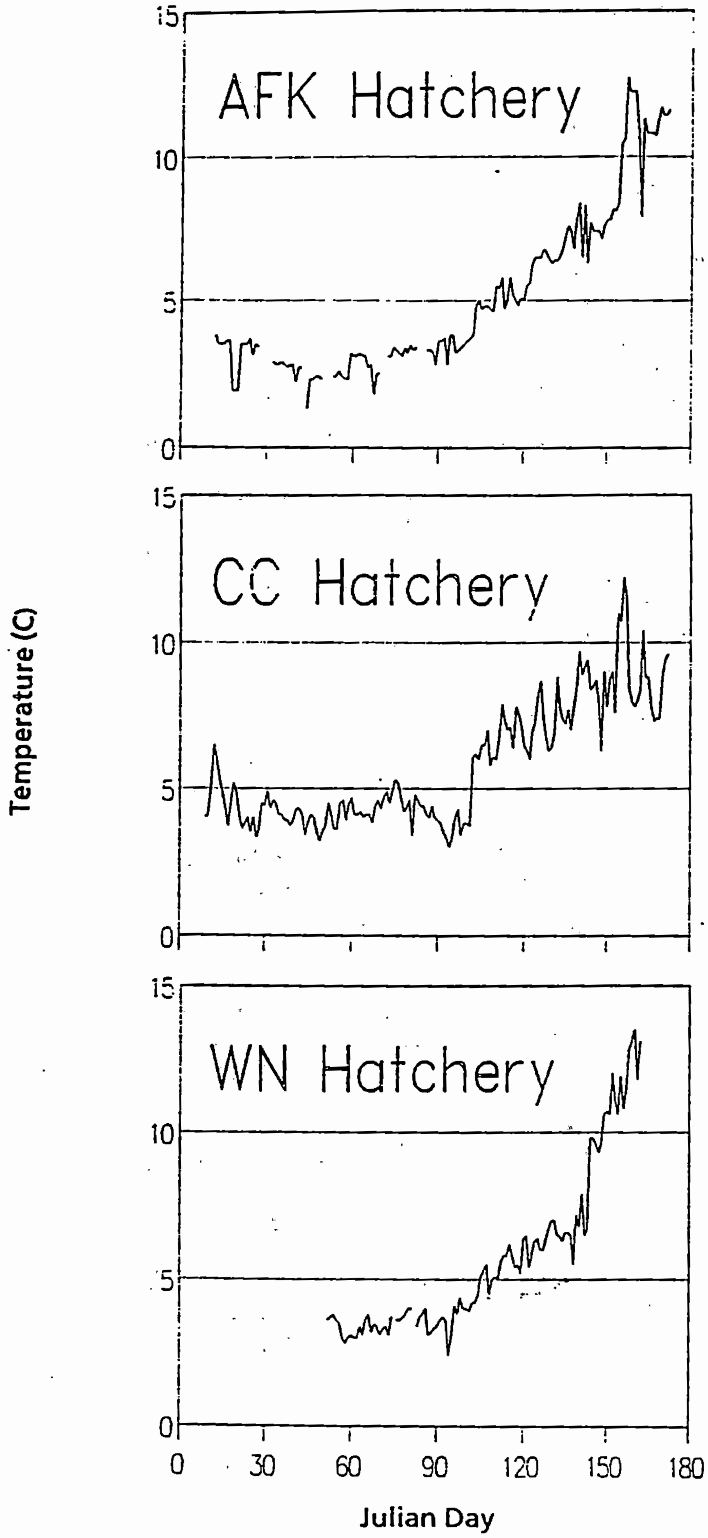


Figure 4. Daily sea surface temperature measurements at three hatcheries in Prince William Sound, January - July, 1990.

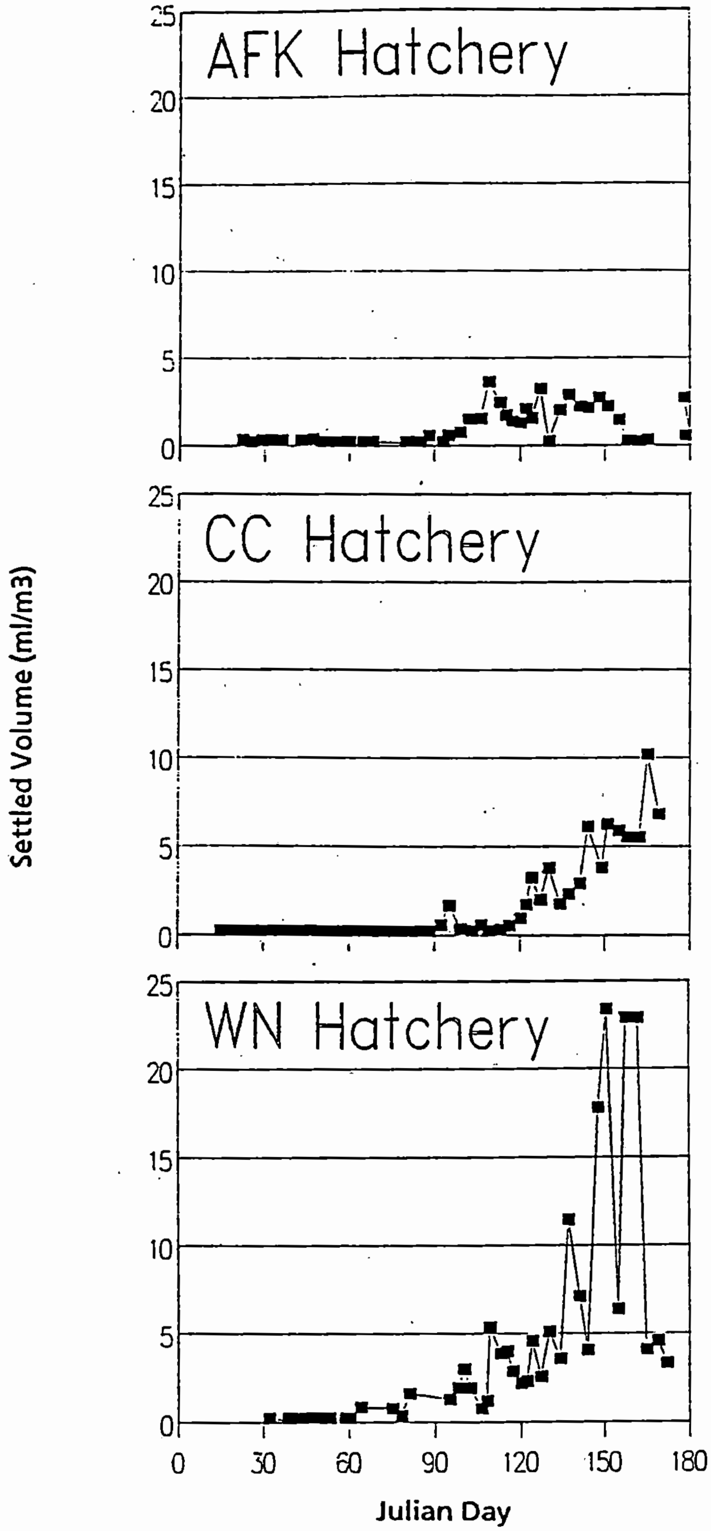


Figure 5. Twice-weekly measurements of zooplankton stocks at three hatcheries in Prince William Sound, January - July, 1990.

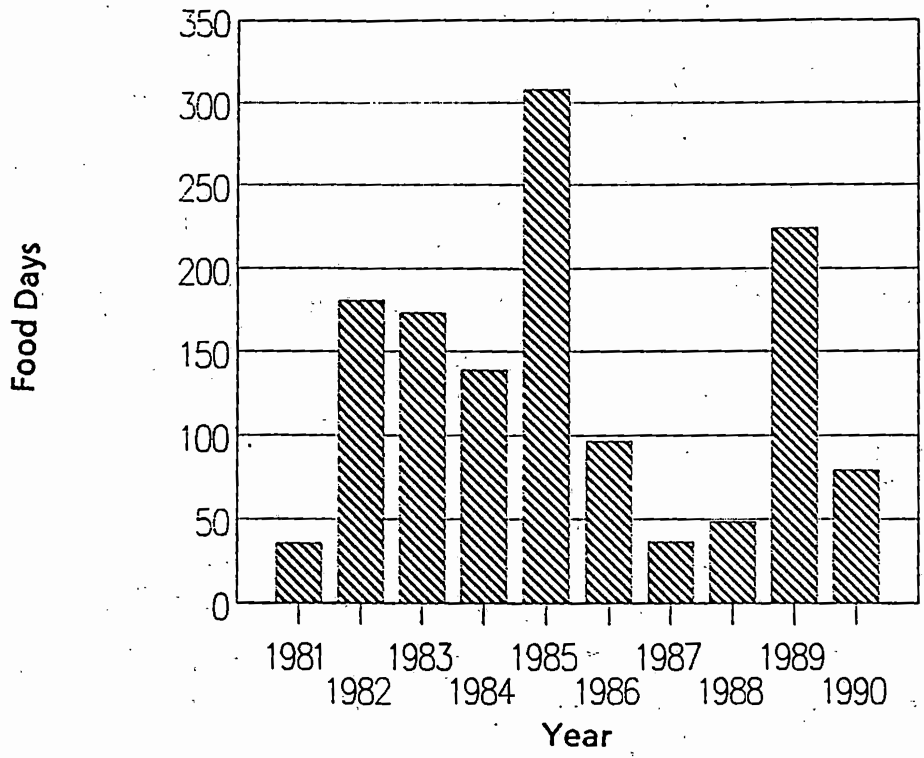


Figure 6. Calculated food-days for zooplankton stocks at the AFK Hatchery, 1981 - present.

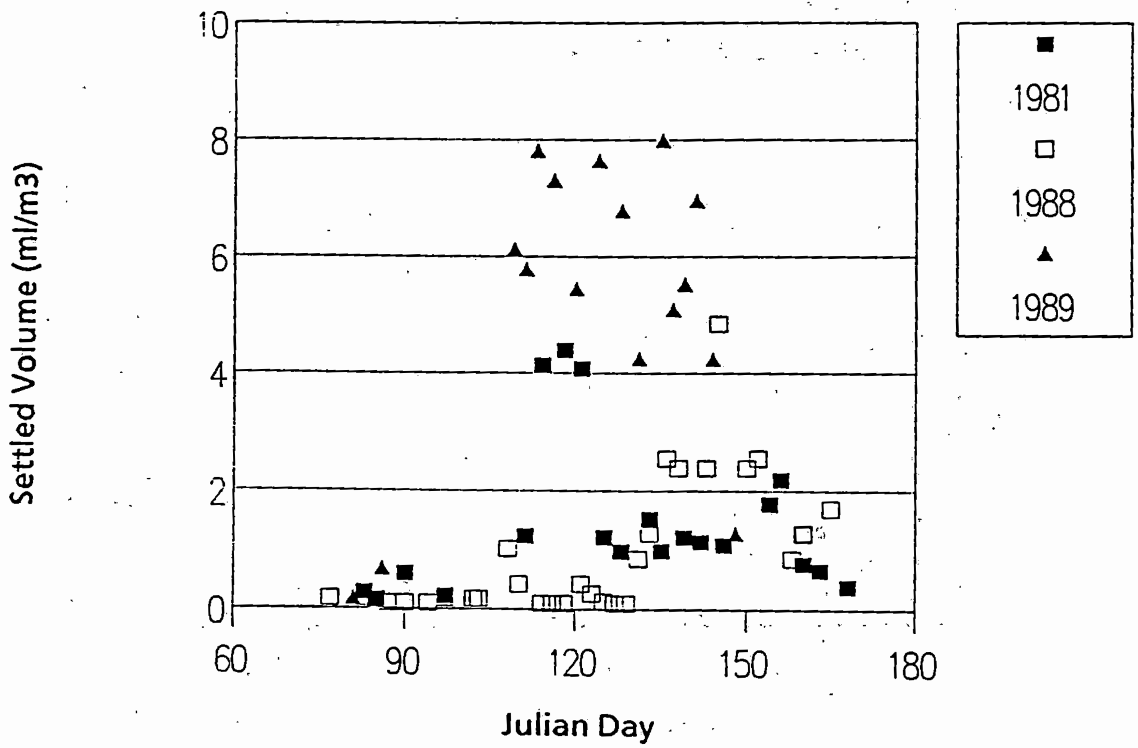


Figure 7. Zooplankton settled volumes for three selected years at the AFK Hatchery illustrating differences in the magnitude and peak timing of the calanoid bloom.

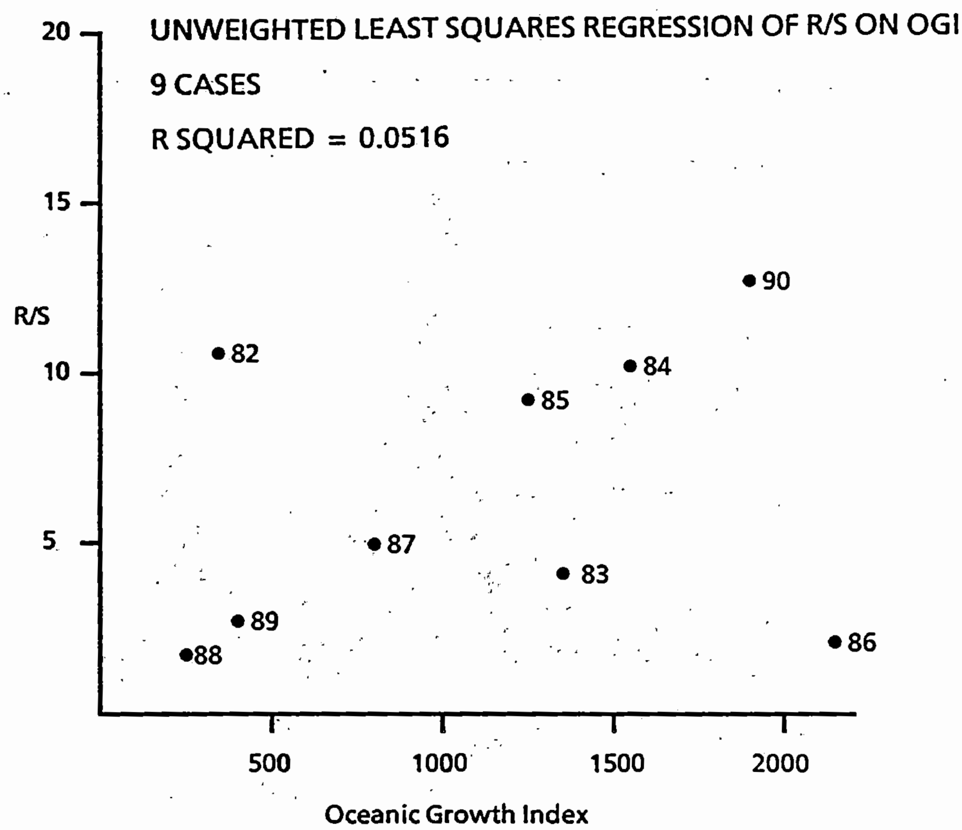


Figure 8. Scatter-plot and linear regression for the relationship between returns per spawner (WRS) and the oceanic growth index (OGI) for wild stock returns in Prince William Sound, 1982-present.

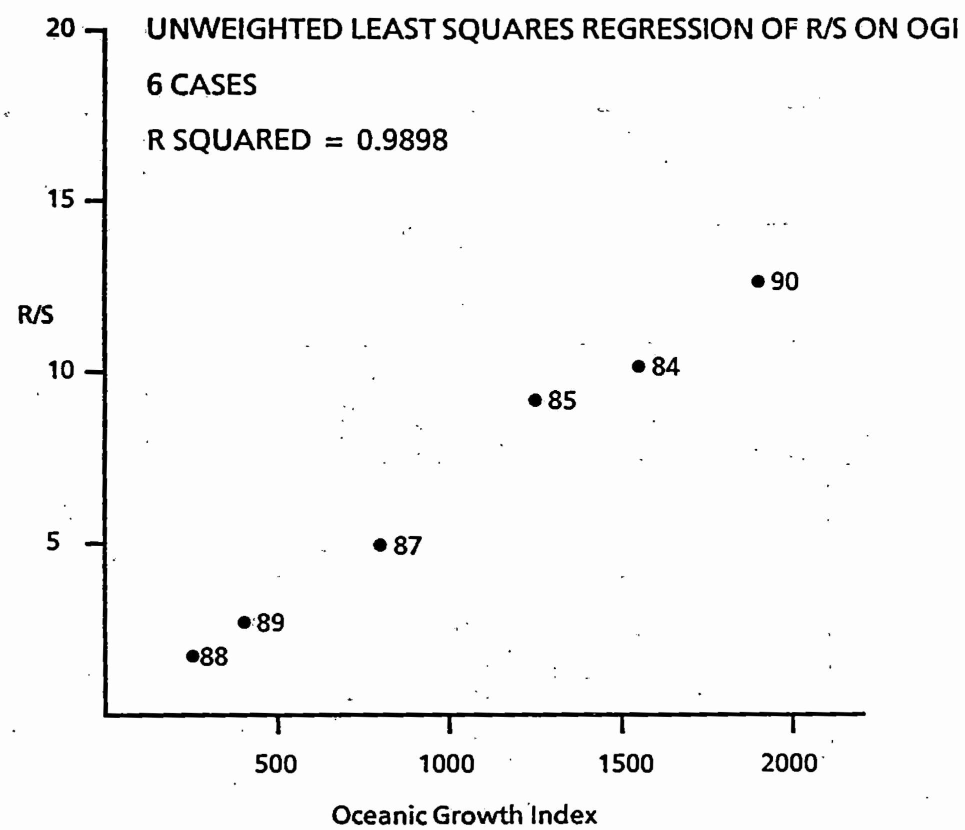


Figure 9. Scatter-plot and linear regression for the relationship between returns per spawner (WRS) and the oceanic growth index (OGI) for wild returns in Prince William Sound, excluding the return years 1982, 1983, and 1986.

Distribution, Size and Feeding Habits of Juvenile Pink Salmon in Nearshore Habitats of Northwestern Prince William Sound

M. Sturdevant, A. Celewycz, M. Pritchett and A. Wertheimer

Auke Bay Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
11305 Glacier Highway
Juneau, Alaska 99801

From April through June, 1989, 134,747 juvenile pink salmon were captured in 152 beach seine sets in northwestern Prince William Sound, Alaska. Three different habitat types were sampled in two bay and two migration corridor locations. Habitats were characterized by beach gradient: low (1-10%), medium (11-25%), and steep (>45%) grades. Abundance of pink salmon fry in the nearshore environment peaked in late May. The pattern of catches indicated that juvenile pink salmon migrated quickly out of bays into corridors and aggregated at steep gradient beaches. After mid-May, juvenile pink salmon were larger in corridors than bays. Pelagic zooplankton from vertical plankton hauls and epibenthic organisms from sled tows were more abundant in corridors than bays. Calanoid copepods were the most abundant pelagic zooplankter, while harpacticoid copepods were the most abundant epibenthic organism. Pelagic zooplankton were the dominant prey in all habitat types in bays. Epibenthic prey were the most important prey resource in low gradient habitats, but pelagic zooplankton dominated the diet in steep and medium gradient habitats, where most of the fish were captured. The rapid movement of juvenile pink salmon from more protected waters to migration corridors may be an adaptive feeding strategy timed to take advantage of a copepod community which is advected into Prince William Sound from oceanic waters in the late spring.

After entering saltwater from their natal streams, pink salmon fry remain near shore for one to two months before moving offshore. As much as 77% of total ocean mortality occurs in the first 40 days at sea (Parker 1968). The rapid growth characteristic of pink salmon fry during the nearshore residency period (LeBrasseur and Parker 1964; Healey 1980) depends on abundant food resources (Bailey et al. 1975; Cooney et al. 1981) and may allow juvenile pink salmon to escape size-selective predation (Parker 1971; Hargreaves and LeBrasseur 1985). Early marine conditions are therefore critical to fry survival.

The diverse waterways and islands of Prince William Sound include nearshore beach habitats ranging from extensive tidal flats to sheer cliff walls. Utilization of different beach habitats by shoreline-oriented pink salmon fry migrating from bays through migration corridors en route to the Gulf of Alaska is not well-understood. Some habitats may provide conditions more advantageous for pink salmon fry than others, thereby enhancing survival. Knowledge of nearshore habitat utilization during the critical early sea life of salmon is important for understanding the impact of environmental perturbations, such as coastline development, hatchery releases or oil spills, on juvenile salmon and their prey fields.

In March, 1989, the Auke Bay Laboratory, National Marine Fisheries Service, designed a study to assess the impact of the *Exxon Valdez* oil spill on shoreline-oriented pink salmon fry in Prince William Sound. The objectives were to determine if the distribution, size, available prey and diet of juvenile pink salmon varied 1) between oiled and non-oiled areas, 2) between time periods, 3) between embayments and migration corridors, or 4) between different nearshore habitats. Because results related to oil damage cannot be released to the public at this time, this report will only cover results from non-oiled areas.

METHODS

Four sampling locations were located in northwestern Prince William Sound (Figure 1). We selected two embayments, McClure Bay and Long Bay, as well as two migration corridors leading to the Gulf of Alaska, Culross Passage and Wells Passage. Three different habitat types classified by beach gradient were selected in each bay and corridor: low (1-10%), medium (11-25%) and steep (>45%) gradients, respectively.

A 37 m long beach seine was used to sample locations approximately every two weeks from April through June, 1989. All sampling was restricted to a tidal range of -0.3 m to +1 m to minimize variability between sites due to tide. Fish catches were sorted, enumerated, and checked for coded-wire tags (CWT's). Samples of up to 60 individuals per set were fixed in 10% buffered formalin for later size and stomach analysis.

Pelagic zooplankton abundance at each site was assessed using a half-meter diameter, 0.243 mm mesh conical plankton net hauled vertically adjacent to beach seine sites, from 20 m in depth to the surface. The abundance of epibenthic organisms was indexed using an epibenthic sled with a 0.33 m diameter, 0.243 mm mesh plankton net attached to a frame on runners which held the net approximately 0.08 m above the substrate. The sled was hand-towed along an undisturbed 10 m transect adjacent to each beach seine site at actual tidal levels ranging from -1 m to +0.3 m. In addition, to test for differences in epibenthic prey availability at different tide levels, the sled was used to sample every 0.7 m over a 1.3 vertical meter tidal range at the bay sites.

The diet of juvenile pink salmon was described from the contents of 322 excised and weighed pink salmon fry stomachs. Prey organisms were identified to the lowest practical taxon, counted and categorized according to the production systems they originated from, as pelagic zooplankton, epibenthos and drift insects. Zooplankton were further categorized as large calanoid copepods ($\geq$ 2.5 mm length), small calanoids (< 2.5 mm length) and other zooplankters. Epibenthos was divided into harpacticoid copepods and other epibenthic organisms. Weights of prey organisms were substituted from known values in Auke Bay, Alaska (J. Landingham, unpubl. data) and Prince William Sound (Cooney et al. 1981). A subsample of stomachs collected in May from low gradient habitats in corridors was analyzed for specific harpacticoid composition and compared to the epibenthic sled harpacticoid composition using Strauss' Linear Selection Index (Strauss 1979). To determine whether a size-diet relationship existed, fish weight was regressed against the percent weight of primary diet categories, including total zooplankton, total epibenthos, harpacticoids and the two calanoid size groups.

The univariate approach to analysis of variance (ANOVA) of a repeated measure design (Frane 1980) was used to analyze abundance and size of juvenile pink salmon and natural logarithms of the biomass of pelagic zooplankton and epibenthos. The factors were time period, bay/corridor, habitat, and location, all of which were completely crossed except for location, which was nested within bay/corridor. In the size analysis, the data were pooled over locations because of large numbers of empty cells, and two separate time period analyses were run, late April to early May, and mid-May through June. In the analysis of biomass of pelagic zooplankton, habitat was not a factor.

RESULTS AND DISCUSSION

DISTRIBUTION AND SIZE OF JUVENILE PINK SALMON

The catch distribution indicated that pink salmon fry did not reside for long periods in bays before moving out to migration corridors (Figure 2). Significantly ($\underline{P}$ = 0.061) more pink salmon fry were caught in corridors than in bays (Figure 2). Pink fry abundance in nearshore waters peaked in late May and early June in corridors, while peak abundance in bays occurred in April and declined towards zero in May. Fry sampled in bays reflected the localized production, whereas fish sampled along migration corridors represented mixed stocks of juveniles that had migrated from bays and were en route to the Gulf of Alaska (Figure 3). At only one site, Wells passage, were substantial numbers of CWT's recovered (Figure 3); that site was only five miles across a passageway from Esther Hatchery, which released 170 million pink salmon fry in 1989. CWT's were captured only at corridor sites in northwestern Prince William Sound; we found no evidence of fish entering the bays. Similarly, Cooney et al. (1981) noted rapid movement out of Sawmill Bay into passageways of southwestern Prince William Sound.

Juvenile pink salmon were much more abundant in corridors than in bays in all three habitats (Figure 4). In corridors, there was a significant difference in fry abundance between the different habitats ($\underline{P}$ = 0.001); more fish were captured in the steep gradient habitat than the other two habitats combined. In bays, there were no significant differences in pink salmon fry abundance between habitats ($\underline{P}$ > 0.100).

The mean fork length of pink salmon juveniles exhibited little change over time from April to early May in both bays and corridors (Figure 5). Pink salmon sizes were not significantly different between bays and corridors during that time ($\underline{P}$ > 0.100). These mean sizes do not reflect actual growth rates because they are derived from large numbers of unmarked fish which could migrate between areas. The lack of increase of mean sizes during April and early May and the similarity of sizes between bays and corridors are attributed to the influx of large numbers of smaller fish outmigrating from streams into the marine environment at the same time that individual fish were growing larger. Beginning in late May and through June, however, pink salmon juveniles were larger in corridors than in bays ($\underline{P}$ < 0.001; Figure 5). This indicates a size-related progression of fish from bays to corridors, and is further evidence that most fish moved quickly to the corridors and did not re-enter the bays. When pink salmon outmigration from streams ended in late May, fish sizes increased at the same rate in both bays and corridors (Figure 5).

Habitat was also significant in explaining the variation in pink salmon sizes from late May through June ($\underline{P}$ < 0.001). Pink salmon were largest in the steep gradient habitat, followed by medium gradient and then the low gradient habitat. This indicates a size-related progression of fish from the lower gradient habitats to the steep gradient habitat before the fry leave nearshore waters for offshore waters later in the season, similar to that observed in southeastern Alaska (Celewycz 1989).

PREY ABUNDANCE

The biomass of zooplankton was significantly greater in corridors than in bays ($\underline{P}$ = 0.042) in April and May (Figure 6). By early June, zooplankton biomass declined to almost zero in both bays and corridors. Calanoid copepods were the most abundant zooplankter at all sites in both bays and corridors (Figure 7). At each site, calanoids were at least three times more abundant than all other pelagic organisms combined. The most abundant calanoid genera were *Pseudocalanus* and *Calanus*. The biomass of epibenthos was three times higher overall in corridors than in bays, although this difference was not significant ($\underline{P}$ > 0.100). Epibenthos peaked in April in bays (Figure 8), while the peak in corridors occurred in May. The later peak in corridor epibenthos coincided with the time of peak pink salmon fry abundance in corridors. By June, when juvenile pink salmon were moving from nearshore to offshore waters, the biomass of epibenthos had reached a low in both bays and corridors. The dominant epibenthic organism in both bays and corridors was harpacticoid copepods (Figure 9). Harpacticoids comprised at least 60% of the biomass of epibenthic organisms at each site. The most abundant harpacticoid genera were *Harpacticus* and *Tisbe*.

In all three habitats, epibenthic organisms were more abundant in corridors than bays, although this difference was not significant ($\underline{P}$ > 0.100; Figure 10). There were no significant differences in the biomass of epibenthos between habitats ($\underline{P}$ > 0.100), although the biomass was highest in medium gradient habitats and lowest in steep gradient habitats (Figure 10). There were no significant differences in epibenthic biomass between tidal levels ($\underline{P}$ > 0.100).

JUVENILE PINK SALMON DIETS

The diets of pink salmon juveniles differed between bays and corridors. In bays, pelagic zooplankton were by far the most important dietary items at all habitats, comprising 64%-90% of the dry weight (Figure 11). Calanoid copepods comprised 57%-87% of total dietary dry weight. Epibenthic crustaceans were never more than 11% of the diet. Drift insects were important only at steep gradient sites (34%).

In corridors, epibenthic organisms comprised a higher percentage of pink fry diets than they did in bays (Figure 12). Pelagic zooplankton again dominated the diets at medium gradient and steep gradient habitats (60% and 65% dry weight, respectively); however, in low gradient habitats, epibenthic organisms, primarily harpacticoids, were most important in the diets of juvenile pink salmon (56%). Drift insects comprised less than 5% of the diet at all habitats.

The taxonomic composition of harpacticoids in pink salmon fry stomachs was compared to the harpacticoid composition of sled samples from the time of peak epibenthic abundance and the location where harpacticoids dominated the diet (Figure 13). *Harpacticus* comprised over 56% of the harpacticoids consumed, while *Dactylopodia, Laophontidae* and *Tisbe* together comprised nearly 42%. The percent weights of *Harpacticus* and *Dactylopodia* in stomachs were higher than their percentages in the nearshore epibenthic environment (Figure 13), while *Laophontidae* and *Tisbe* were relatively more abundant in the environment than the diet. The Strauss Selection Index indicated that *Harpacticus* and *Dactylopodia* were positively selected for, while *Tisbe* and *Laophontids* were less important prey. These prey genera are common in salmon fry stomachs (e.g., Kask et al. 1982; Landingham and Mothershead 1987).

Researchers in other areas have noted a stronger preference for harpacticoid copepods by juvenile pink salmon than we found in northwestern Prince William Sound. In Auke Bay, southeastern Alaska, harpacticoids dominated the diet during the early nearshore residency of pink salmon fry; pelagic zooplankton only became important later (Landingham and Mothershead 1987). In Washington (Kaczynski et al. 1973) and British Columbia (Godin 1981), the preferred prey of shoreline-oriented pink salmon fry was epibenthic harpacticoid copepods. Kaczynski et al. (1973) speculated that the production of epibenthic harpacticoids may be a limiting factor for pink salmon fry populations during the critical nearshore phase, and that this period forms a distinct ecological stage in their lives. Cooney et al. (1981) supported these findings, noting that harpacticoids were 66-82% of the first food of juvenile pink salmon migrating from Sawmill Bay into southwestern Prince William Sound. Juvenile pink salmon left Sawmill Bay within a few days, however, and calanoid copepods were then the largest biomass component of pink salmon fry diets, even though harpacticoids were often numerically dominant. Young fish were therefore flexible in their feeding habits depending on available food resources.

Our results confirmed that pelagic zooplankton, primarily calanoid copepods, dominated pink salmon fry diets in northwestern Prince William Sound. The rapid movement of the fry from more protected bays to migration corridors may be an adaptive feeding strategy timed to take advantage of the increasingly available calanoid copepod community in late spring. Oceanic circulation processes influence the prey available in the Prince William Sound basin. Large, oceanic calanoid species which overwinter and reproduce at depth (*Neocalanus plumchrus, N. cristatus*) migrate to the surface and are advected into shallow waters, with peak abundance occurring in late spring (Cooney 1986). Here they mix with neritic, smaller calanoid forms whose abundances increase in response to the spring phytoplankton bloom. A seasonal succession of smaller forms (e.g., *Calanus marshallae, Metridia spp., Pseudocalanus spp.*) follows the decline of the large species in mid- late-summer (Cooney 1986). In our study, a mixture of large and small calanoid species dominated the diet of juvenile pink salmon, even though fry were well-within the size limit previously found for fry whose diet was as much as 95% harpacticoids (Kaczynski et al. 1973). Easily-captured, relatively high calorie harpacticoids (Volk et al. 1984) which are produced locally rather than transported according to circulation patterns may provide a dietary staple when pelagic zooplankton are not available; this is suggested by the greater frequency of occurrence and numbers of harpacticoids found in stomachs of fish from Prince William Sound. Juvenile pink salmon of all sizes consumed both harpacticoids and calanoid copepods (Figure 13). We found no significant correlations between fish size and percent biomass of any of the diet categories.

Our results suggest that the nearshore diet may be a result of where fish are sampled and what types of habitats are available to them. By our definition, sites in the Washington, British Columbia and Auke Bay studies mentioned above are comparable to low gradient habitats, characterized by substantial epibenthic production. Most of Prince William Sound, however, consists of steep rocky shorelines, where epibenthic and harpacticoid production are lowest but pink salmon fry are most abundant. Such regional variation requires description of habitat-specific feeding habits to determine the importance of available prey resources for juvenile salmon. The distribution and relative abundance of the fish within habitats in bays and corridors must also be considered when interpreting dietary differences between locations.

REFERENCES

Bailey, J.E., B.L. Wing and C.R. Mattson. 1975. Zooplankton abundance and feeding habits of fry of pink salmon and chum salmon in Traitor's Cove, Alaska, with speculations on the carrying capacity of the area. Fish. Bull. 73: 946-961.

Celewycz, A.G. 1989. Distribution and sizes of juvenile pink and chum salmon in five habitats in Auke Bay, Alaska. pp. 54-57 in: 14th Northeast Pacific Pink and Chum Salmon Workshop. P.A. Knudsen, ed. Washington State Dept. of Fisheries.

Cooney, R.T., D. Urquhart, and D. Barnard. 1981. The behavior, feeding biology, and growth of hatchery released pink and chum salmon fry in Prince William Sound, Alaska. Univ. Alaska, Sea Grant Rep. 81-5. 114 p.

Cooney, R.T. 1986. Zooplankton. p. 285-303 In D.W. Hood and S.T. Zimmerman (eds.). The Gulf of Alaska: Physical Environment and Biological Resources. NOAA OCS study, MMS 86-0095.

Frane, J. 1980. The univariate approach to repeated measures- foundation, advantages, and caveats. BMDP Tech. Rep 69. 34 p.

Godin, J.G.J. 1981. Daily patterns of feeding behavior, daily rations, and diets of juvenile pink salmon (*Oncorhynchus gorbuscha*) in two marine bays of British Columbia. Can. J. Fish. Aquat. Sci. 38:10-15.

Hargreaves, N.B. and R.J. LeBrasseur. 1985. Species selective predation on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) by coho salmon (*O. kisutch*). Can. J. Fish. Aquat. Sci. 42: 659-668.

Healey, M.C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. In W.J. McNeil and D.C. Himsworth (eds.), Salmonid Ecosystems of the North Pacific, p. 203-230. Oregon State Univ. Press, Corvallis.

Kaczynski, V.W., R.J. Feller, and C. Clayton. 1973. Trophic analysis of juvenile pink and chum salmon in Puget Sound. J. Fish. Res. Board Can. 30: 1003-1008.

Kask, B.A., J.R. Sibert, and B. Windecker. 1982. A check list of marine and brackish water harpacticoid copepods from the Nanaimo estuary, southwestern British Columbia. Syesis 15: 25-38.

Landingham, J. and P. Mothershead. 1987. Feeding habits of juvenile pink salmon in nearshore and offshore areas of Auke Bay. In APPRISE Annual Report, SFOS APP87-100. School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, pp. 449-469.

LeBrasseur, R.J. and R.R. Parker. 1964. Growth rate of central British Columbia pink salmon (*Oncorhynchus gorbuscha*). J. Fish. Res. Board Can. 21: 1101-1128.

Parker, R.R. 1968. Marine mortality schedules of salmon of the Bella Coola River, central British Columbia. J. Fish. Res. Board Can. 25: 757-794.

Parker, R.R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish Res.Board Can. 28: 1503-1510.

Strauss, R.R. 1979. Reliability estimates for Ivlev's Electivity Index, the Forage Ratio, and a proposed Linear Index of Food Selection. Trans. Am. Fish. Soc. 108: 344-352.

Volk, E.C., R.C. Wissmar, C.A. Simenstad, and D.M. Eggers. Relationship between otolith microstructure and the growth of juvenile chum salmon (*Oncorhynchus keta*) under different prey rations. Can. J. Fish. Aquat. Sci. 41: 126-133.

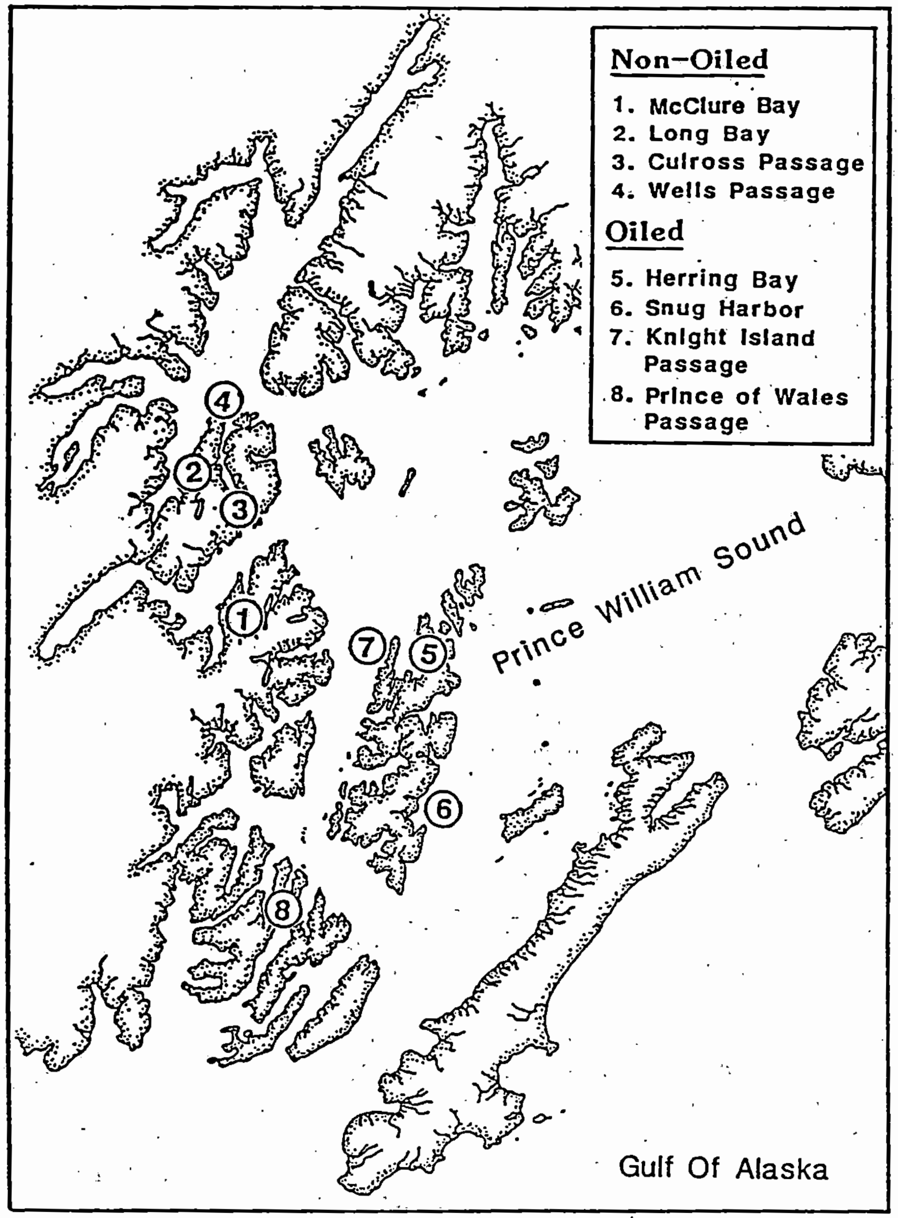


Figure 1. Locations of oiled and non-oiled sampling locations for NMFS component of NRDA study F/S-4. Locations 1, 2, 5, and 6 were classified as embayments; locations 3, 4, 7 and 8 were classified as corridors.

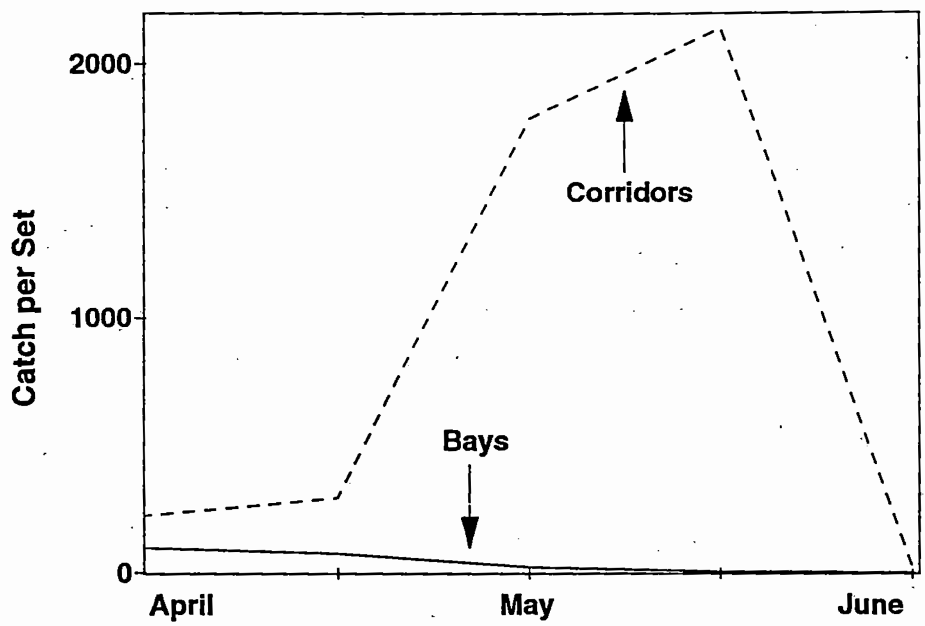


Figure 2. CPUE of juvenile pink salmon caught in beach seines in non-oiled bays and corridors of Prince William Sound, April-June, 1989.

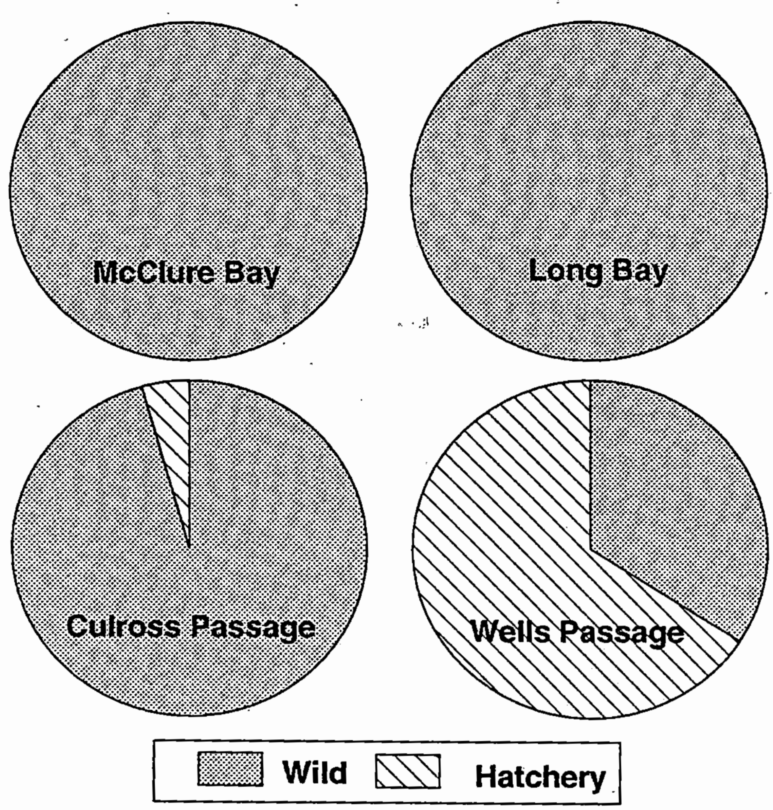


Figure 3. Origin of juvenile pink salmon captured at four non-oiled locations in Prince William Sound, April-June, 1989.

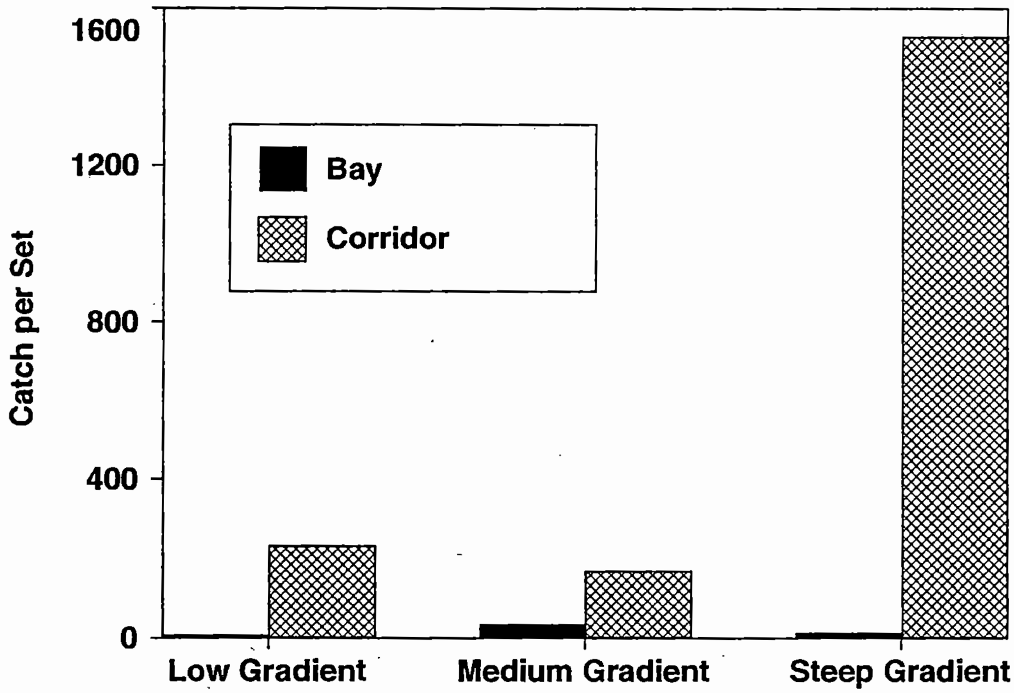


Figure 4. CPUE of juvenile pink salmon by habitat type from non-oiled bays and corridors in Prince William Sound, April-June, 1989.

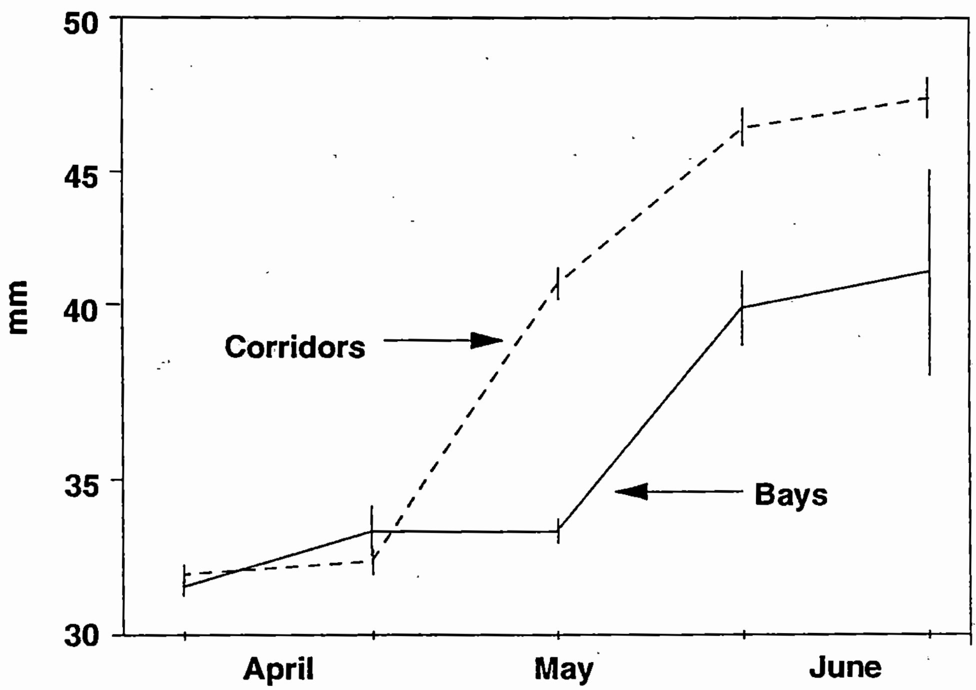


Figure 5. Mean fork lengths of juvenile pink salmon captured in non-oiled bays and corridors in Prince William Sound, April-June, 1989. Vertical bars are 95% Confidence Intervals of the means.

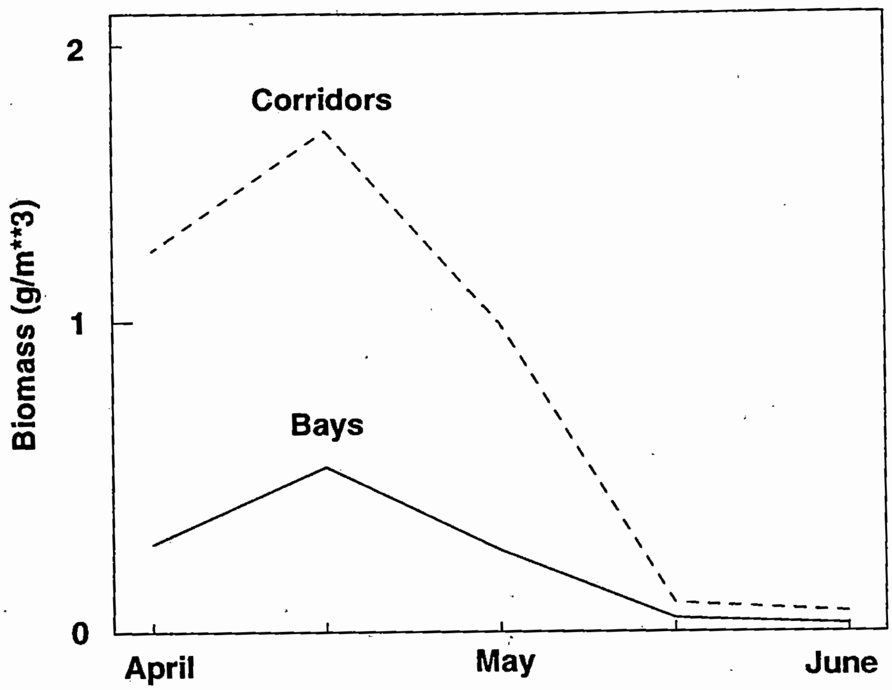


Figure 6. Biomass of pelagic zooplankton in non-oiled bays and corridors of Prince William Sound from April-June, 1989.

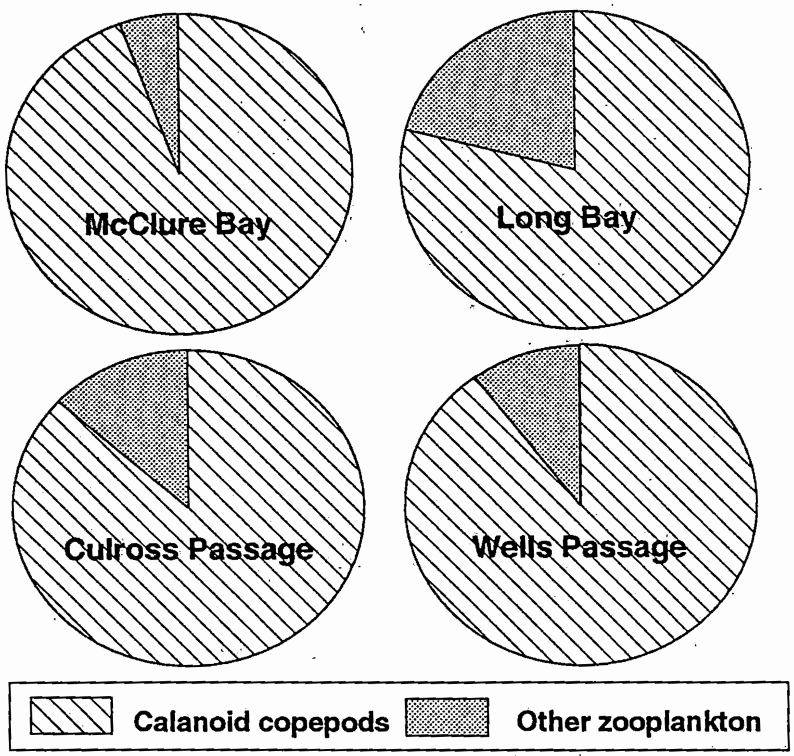


Figure 7. Relative biomass of zooplankton collected in horizontal zooplankton tows in four non-oiled locations in Prince William Sound, April-June, 1989.

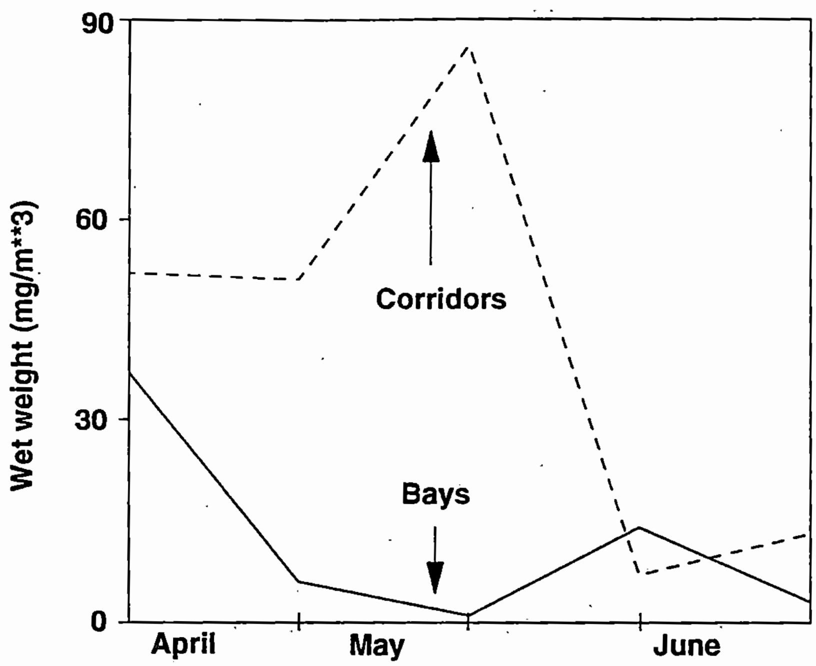


Figure 8. Biomass of epibenthos collected from non-oiled bays and corridors of Prince William Sound, April-June, 1989.

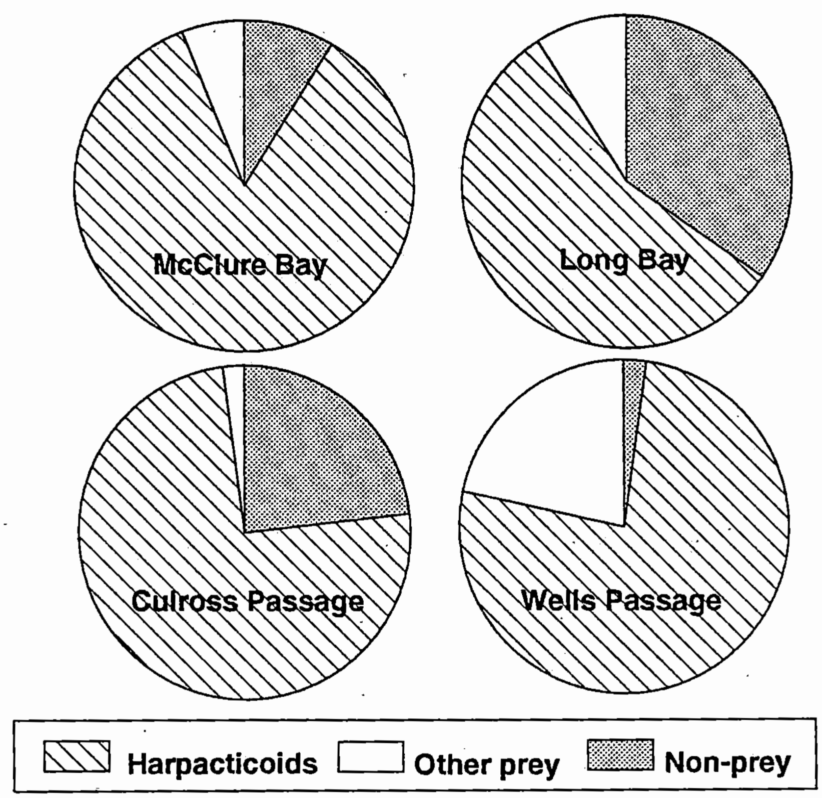


Figure 9. Relative biomass of epibenthos collected in the epibenthic sled at four non-oiled locations in Prince William Sound, April-June, 1989.

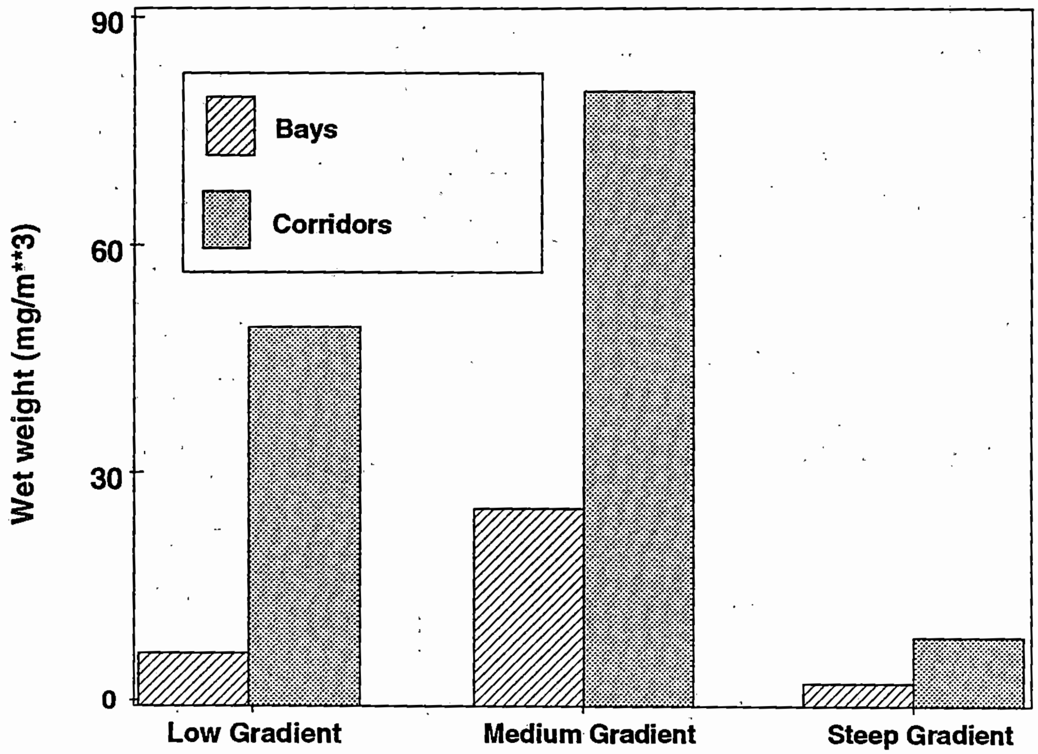


Figure 10. Biomass of epibenthos by habitat from non-oiled bays and corridors in Prince William Sound, April-June, 1989.

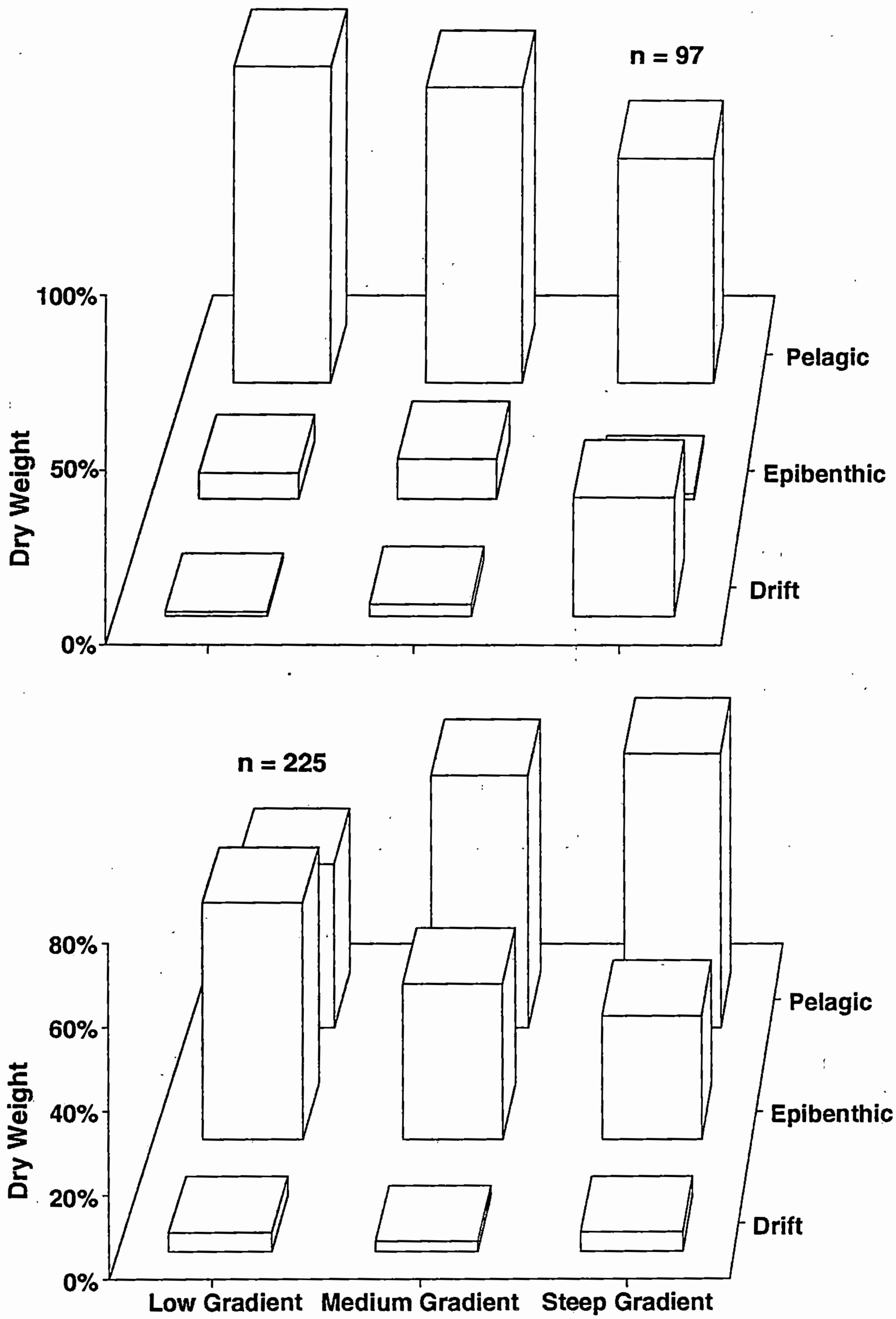


Figure 11. Prey percent dry weight from juvenile pink salmon stomachs collected in three habitat types of non-oiled bays (top) and corridors (bottom) in Prince William Sound, April-June, 1989.

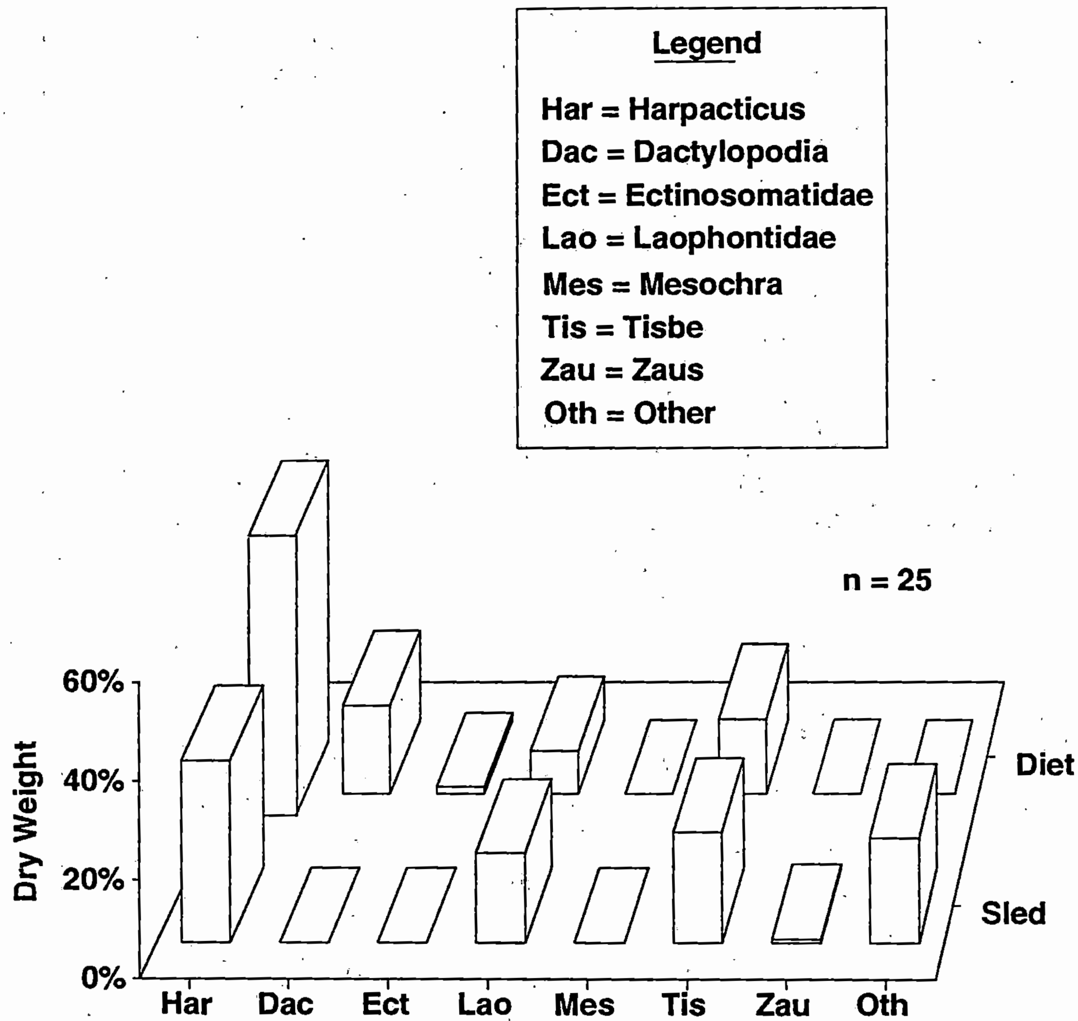


Figure 12. Harpacticoid composition in juvenile pink salmon stomachs and epibenthic sled at low gradient habitats in non-oiled corridors of Prince William Sound, May, 1989.

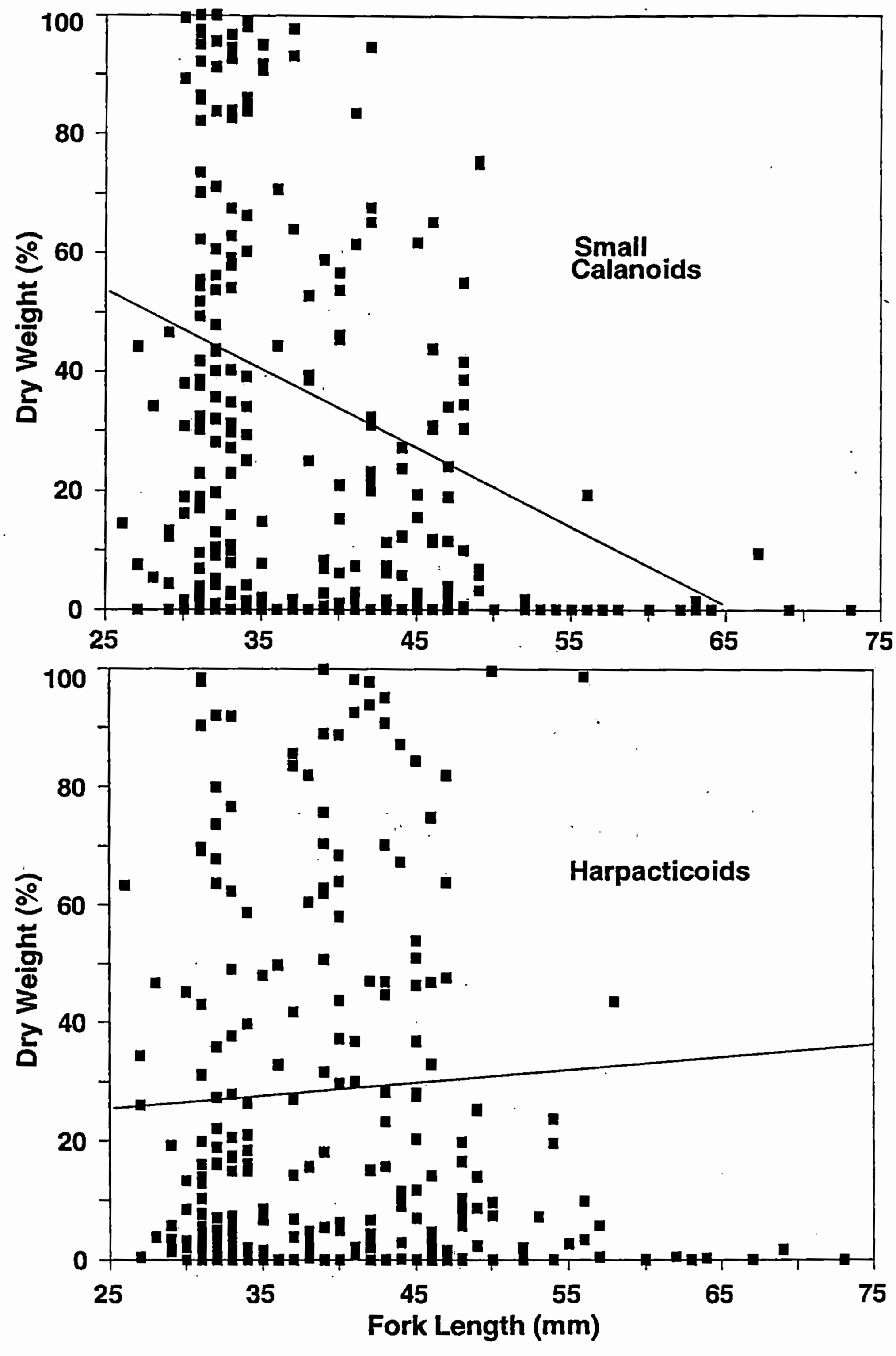


Figure 13. Relationship of percent biomass of small calanoids (top) and harpacticoids (bottom) in stomachs of pink salmon fry to fish length, non-oiled areas of Prince William Sound, 1989.

Streamside Incubation of Chum Salmon Eggs at Two Streams on Kuiu Island, Alaska

Carol Ann Woody

United States Forest Service
Box 309,
Petersburg, Alaska 99833

Steve Reifenstuhl

Northern Southeast Regional Aquaculture Association
1308 Sawmill Creek Rd.,
Sitka, Alaska 99835

Remote streamside incubators on two spring-fed streams on Kuiu Island, Alaska, exceeded 95% green egg to fry survival from 1986 to 1988. The sites were expanded in 1989 and 1990 to increase incubation capacity from 1.25 million to 6 million eggs. Green egg to fry survival decreased to 54% in 1989 due to improper installation of water intakes. Survival for 1990 appears to be greater than 90%. Full production should be realized by 1993.

Costs for this project, including restoration of 400 m^2 of spawning habitat, are shared by four cooperators and are estimated to be $520,000 from 1985 to 2005. Benefits are expected to equal $2,325,000 assuming: 90% green egg to fry survival; 1% marine survival, and an average chum weight of 3.6 kg at $4.00 U.S. per fish. The estimated benefit cost ratio is 4.4:1.

Declining salmon stocks in the 1970's (ADFG 1985) prompted Alaskan fishermen, state and federal agencies to seek enhancement opportunities to reverse the trend. Two streams draining into the head of Port Camden (Figure 1) were selected by a regional enhancement planning team (Northern Southeast Regional Planning Team 1985) as having great potential for immediate development to help increase salmon stocks.

The streams support chum salmon wildstocks that have sustained subsistence use through the millennium and a seine fishery during the 1900's. Annual natural production is about 20,000 adults. The goal of this enhancement project is to add 50,000 harvestable chum salmon to the Port Camden fishery, a four fold increase over the past 20 year period.

Plentiful upwelling ground water, constant water temperature (4°C) and available broodstock in the Port Camden streams, indicated streamside incubation as a suitable means of enhancement. This technique was selected because of its success in other areas of Alaska (Roberson and Holder 1987), low maintenance requirements, low capital investment, and the adaptability of the Camden sites.

In 1985, a pilot project was initiated using a plywood incubator and a simple water intake. Inconclusive results led to modifications and further testing in 1986. Evaluation in 1987 demonstrated a 95% survival of green eggs to fry for the 1986 brood.

Project expansion and site improvements were made in 1989 and 1990, increasing the total incubation capacity to six million eggs. The number of eggs incubated at the sites will continue to increase until 1993, when maximum capacity will be realized. The lag time to realize full production will allow time to evaluate the improvements.

METHODS

The project sites are locally named West Port Camden (WC) and East Port Camden (EC). The streams are listed in Alaska Department of Fish and Game (ADF&G) records as #109-43-08 and #109-43-06, respectively.

EXPANSION OF WEST CAMDEN

Expansion of the WC site took place in 1989. A dam installed in 1986 was removed and replaced with a 30 m long by 2.5 m high sheetpile dam. Pilings were driven to a depth of 1 m by a backhoe. Seven aluminum and three experimental plywood egg boxes were installed. The egg boxes were plumbed to the water source by a series of PVC pipes (10 cm diameter) threaded on flanges to the downstream dam face (Figure 2). Water intake pipes (10 cm diameter) threaded to the upstream face, extend 5 m into the pond and are connected to a headbox. The headbox (91 cm x 38 cm x 15 cm) has two perforated plates for filtration.

Spawning habitat restoration was completed upstream from the egg box site. An abandoned beaver dam complex was removed and 400 m^2 of spawning habitat was restored by loosening compacted gravel and installing log weirs to increase depths. Spawning habitat near the egg boxes was enhanced in two ways: (1) the stream was narrowed with a log and gravel berm to increase water velocity and, (2) cedar weirs were installed to increase stream depths and to retain the limited spawning gravel.

EXPANSION OF EAST PORT CAMDEN

Expansion at the EC site took place in 1990. Six aluminum egg boxes were installed in a 10 m x 15 m area cleared of natural vegetation. A water infiltration gallery was constructed upstream to trap a portion of the abundant ground water. Two trenches were dug (approximately 30 m x 2 m x 2 m and 15 m x 2 m x 2 m) then lined with filter fabric, prior to placing four, (10 cm diameter) perforated, flexible pipes in each. The eight flexible pipes were plumbed into a manifold, wrapped in the filter fabric and covered with cobble. The manifold feeds a 20 cm diameter pipeline. The pipeline delivers water to a downstream headbox where it is distributed to each egg box by individual 5 cm diameter PVC pipes (Figure 3).

A dam of spruce logs, covered with gravel and lined with impermeable fabric, was constructed around the infiltration system to provide suitable head. The head differential is approximately 1 m. This supplies a maximum flow of 0.13 cfs which is valved to about 0.09 cfs for each incubation box.

The three plywood egg boxes, installed in 1987, are supplied with water from a separate headbox and PVC pipe system originating in the impounded spring area.

EGG BOXES

The aluminum boxes used in this project are slightly different than those used in other remote facilities (Figure 4). They are durable and easy to clean. The outer box is approximately 2.4 m x 1.2 m x 0.6 m. The long sides of the box have a lip 10 cm from the bottom to hold cross pieces. The crosspieces hold the inner box (2.2 m x 1.0 m x 0.5 m) above the water inlet. The most important feature of the system is that the water outlet of the inner box is securely bolted and sealed to the outer box outlet. This ensures that water entering the system may exit only by upwelling through the perforated aluminum bottom of the inner box, ensuring an even flow through the 4 cm x 4 cm polyethylene substrate and eggs. The water systems of EC and WC provide about 0.07 to 0.13 cfs to each egg box.

RESULTS AND DISCUSSION

The pilot project in 1985 demonstrated that streamside incubation could work at Port Camden, if better water systems could be developed. In 1986, small water impoundments of sandbags and plastic tarps were constructed at each site. Each impoundment supplied water (0.07 cfs) to a single plywood egg box via a perforated aluminum headbox and PVC pipe. Survival of the 1986 brood was 99%; a 54% increase over the 1985 brood (Table 1).

Development continued in an effort to realize an incubation goal of six million eggs. The number of incubators at each site was increased to three in 1987, thereby increasing the potential egg incubation capacity to 900,000 (300,000 eggs/box). However, significant differences between the potential and actual loading of the egg boxes are evident from 1986 to 1990 for each site (Table 1). The difference in annual eggtake numbers of EC are attributable to the need to evaluate effects of site improvements and egg loading densities on survival. The WC differences are mainly due to human and water system problems:

(1987) only 5,000 eggs were taken because the WC egg take crew missed the spawning run,

(1989) although the incubation capacity had been expanded to three million by the addition of seven egg boxes, a leak in the sheetpile dam made a reduced eggtake logical.

The eggs taken at WC in 1989 were lost, not due to the leak, but due to a clogged water intake and air accumulation in a pipeline. A new headbox and realignment of the pipeline appears to have solved this problem however, the dam leak is still being evaluated. Except for the water system failure in 1989 at WC, overall egg to fry survival has been greater than 95% since 1986. Survival of the 1990 brood will be determined in the spring; as of January 1991 survival appears to be greater than 90%.

Egg takes will increase annually until full production is reached in 1993. At a loading density of 300,000 eggs per incubator, each site can incubate 3 million eggs. If we assume: 90% egg to fry survival and 1% marine survival, then 6 million eggs could produce 54,000 adult chum salmon annually. Approximately 2,400 adult chum pairs will be needed to fill the egg boxes, which would leave about 49,200 fish for harvest. The 400 m^2 of restored spawning habitat at WC could accommodate 235 adult pairs if we assume 1.7 m^2 per pair. This area has the potential to augment commercial harvest by about 1,000 fish assuming 2,500 eggs per female chum, 25% survival of egg to fry, 1% marine survival, and 470 fish for escapement. The project should produce approximately 50,000 harvestable adults at full production.

Benefits to the commercial fishery from 1985 to 2005 equal about $2,325,000 (U.S.). Assumptions of this analysis include: an average chum weight of 3.6 kg at $4.00 per fish, and a realized incubation capacity by 1993.

Costs for the two year pilot project are estimated at $5,000. Aluminum incubators, artificial substrate and plumbing costs were $2,000 per incubator. Plywood incubators cost about $500. Construction costs including engineering, materials, and equipment, were about $80,000. Capital costs over the 20-year period, 1985 to 2005, are estimated at $120,000. Annual operating costs at $20,000 per year for 20 years equal $400,000; yielding a total project cost of $520,000. The benefit cost ratio is estimated at 4.4 to 1.

Streamside incubation of chum salmon is a low cost and low maintenance alternative to hatchery production or fry plants. The following criteria are essential for successful development of a remote site incubation facility:

1. Spring or groundwater, low in dissolved gasses, possessing suitable temperatures for normal embryonic development, and absent of organic debris or iron bacteria.

2. Adequate water and head differential to provide adequate flows during low flow periods. The ability to impound water to create the head differential is also essential. Once eggs are placed in the incubator and the tops are fastened, little work is required until spring. Typically, the incubators are checked periodically during the winter to ascertain adequate water flows. To date, streamside incubation at Port Camden has proven to be a low cost, low maintenance enhancement project, which can make a contribution to the existing user groups.

ACKNOWLEDGEMENTS

This project was made possible by the cooperative efforts of the Alaska Department of Fish and Game, the Alaska Pulp Corporation, the Northern Southeast Regional Aquaculture Association, and the United States Forest Service.

REFERENCES

ADFG. 1985. Alaska Commercial Salmon Catches, 1878-1984. Division of Commercial Fisheries, Alaska Department of Fish and Game, Juneau, AK. p. 19-20.

NORTHERN SOUTHEAST REGIONAL PLANNING TEAM. 1985. Comprehensive Salmon Plan, Phase II: Northern Southeast Alaska. Alaska Department of Fish and Game, Juneau, AK. p. 52-57.

ROBERSON, K., AND R.R. HOLDER. 1987. Development and evaluation of a streamside sockeye salmon (*Oncorhynchus nerka*) incubation facility, Gulkana River, Alaska. p. 191-197. In H.D. Smith., L. Margolis, and C.C. Wood [ed.] Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci.96.

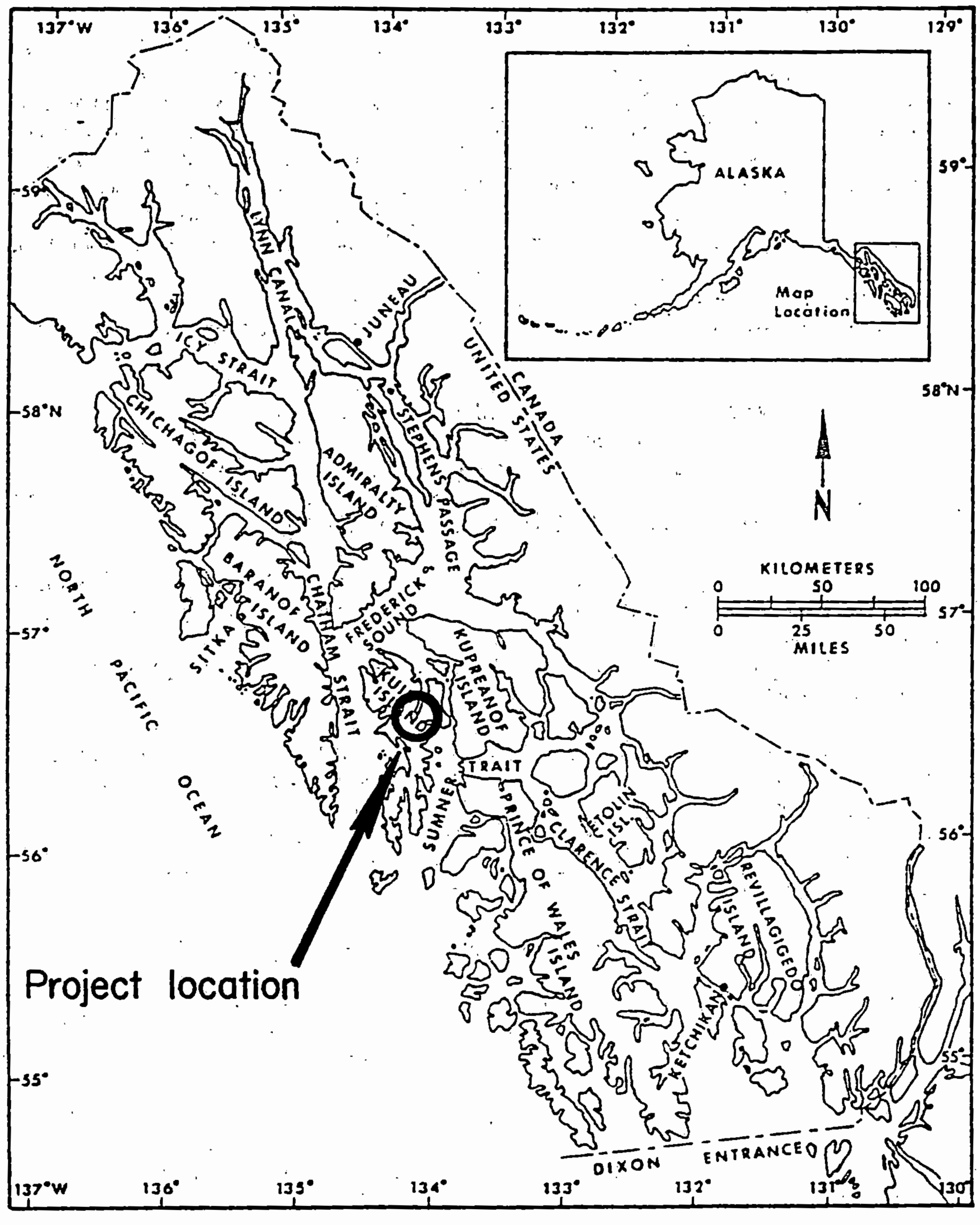


Figure 1. Location of the Port Camden egg incubation project.

Table 1. Annual production summary of the Port Camden chum egg incubation facility.

Port Camden Incubation Boxes (numbers in thousands)							
	East Camden		West Camden		Total		
Brood Year	Eggs Taken	Fry Released	Eggs Taken	Fry Released	Eggs Taken	Fry Released	% Survival
1985	75	34	-	-	75	34	45.3
1986	100	99	100	99.0	200	198	99.0
1987	600	594	5	4.5	605	599	99.0
1988	750	726	600	583.0	1,350	1,309	97.0
1989	750	728	600	0.0	1,350	728	53.9
1990	1,925	N/A 1/	750	N/A	2,675	N/A	N/A
1991	2,500 2/		1,850 2/		4,350 2/	?	?

1/ Not available.
2/ Projected.

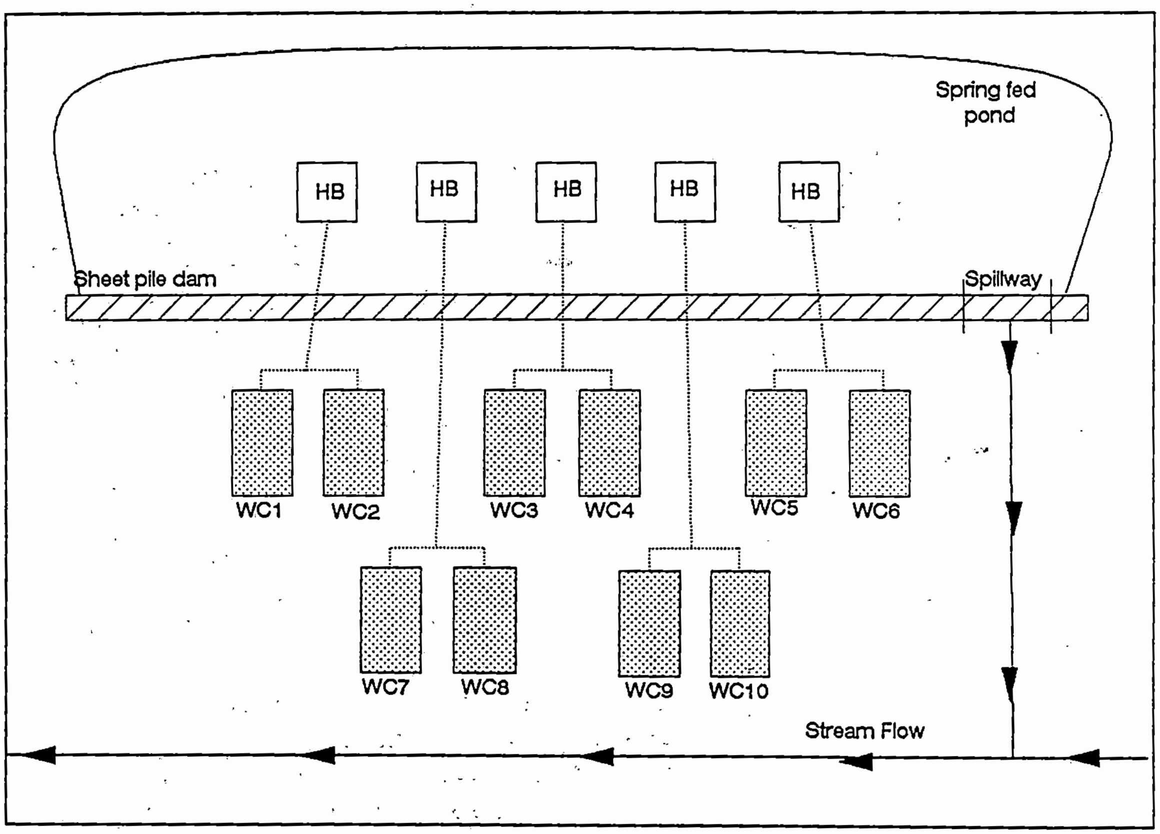


Figure 2. Schematic diagram of the West Camden incubation facility. Perforated headboxes (HB) are connected to 10 cm pvc lines (·:····) that deliver spring water to eggboxes (WC1-10).

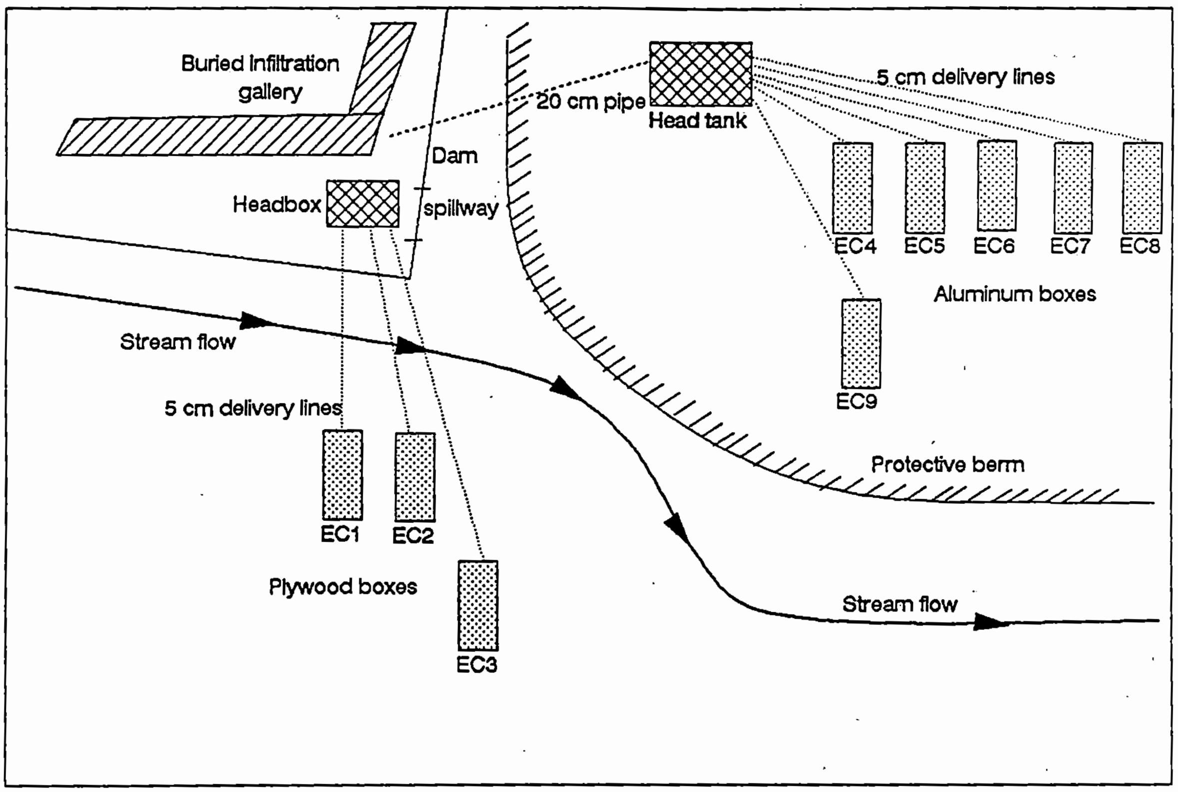


Figure 3. Schematic diagram of the East Camden incubation facility.

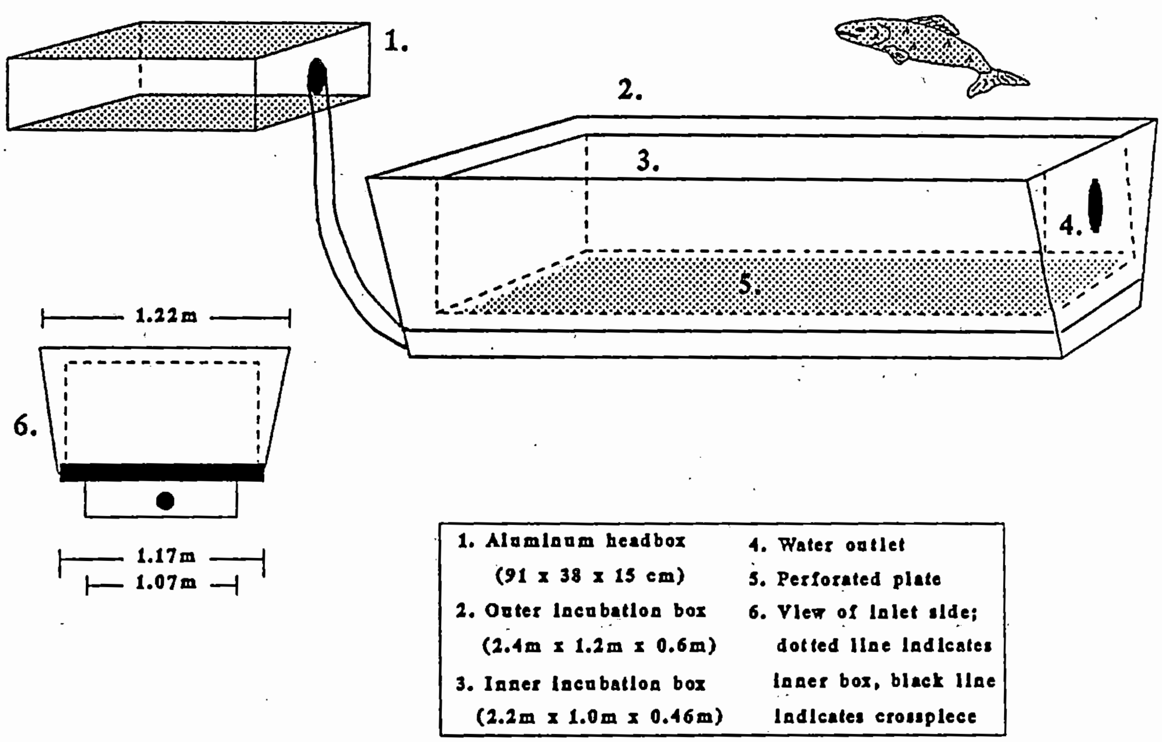


Figure 4. Diagram of aluminum incubation boxes installed at the Port Camden facility, not to scale.

A Ten Year Evaluation and Some Recent Applications of Improved Groundwater-fed Side Channels in British Columbia

R. Gregory Bonnell, Matthew P. Foy and Mel D. Sheng

Resource Restoration Unit, Salmonid Enhancement Program
Department of Fisheries and Oceans, Pacific Region
Suite 400, 555 West Hastings Street
Vancouver, British Columbia, Canada, V6B 5G3

Since 1978, more than 50 groundwater-fed side channels have been constructed in British Columbia totalling over 100,000 m^2 of new or improved salmonid spawning and rearing area. The technique involves grading down, deepening and widening intermittent or relic side channels to intercept subsurface flow. Data collected from 1978 to 1987 from 24 channels showed an annual production of chum salmon (*Oncorhynchus keta*) emergent juveniles of over 290 fry/m^2 of developed spawning area, and a mean survival to emergent of over 16% of potential egg deposition. A conservative benefit/cost ratio calculated for the technique in 1983 was 1.7. Channels constructed using introduced graded spawning gravel (e.g., 0% fines $\leq$ 9.5mm in diameter) did not result in greater survival or production of chum salmon fry than those constructed using existing native gravel (e.g., <15% fines < 1.6mm in diameter), although construction costs for graded gravel channels averaged $4.00(1988 Cdn)/$m^2$ higher. Two recent applications of this technology have been: to aid in a successful transplant of pink salmon (*O. gorbuscha*) to help rehabilitate a depressed stock; and to increase chum salmon fry production using artificial in-channel incubation.

The use of groundwater, seepage or spring fed areas for spawning by chum salmon (*Oncorhynchus keta*) and other salmonids is well known along the northwestern coast of North America. Adults returning to spawn in freshwater will home with precision to locations influenced by groundwater. These streams tend to more moderate temperature, discharge, and hydraulic characteristics than those fed by surface flow alone.

Pioneered by biologist D.E. Marshall and engineer R.J. Finnigan in the late 1970's, the Department of Fisheries an Oceans has constructed over 50 groundwater-fed side channels totalling over 100,000 m^2 of new or improved habitat. The technique has been used on 17 river systems in British Columbia including the Thompson, Fraser, Cowichan, Squamish and Skeena Rivers (Figure 1). A conservative estimate of annual production from these projects is 400,000 adult chum salmon and 20,000 adult coho salmon (*O. kisutch*) together with smaller numbers of other salmon and trout species.

This paper presents a summary of results of chum salmon investigations on 24 channels over a 10 year period following up those of Lister et al. (1980), and describes two recent applications using these channels to further improve productivity of pink and chum salmon stocks. The review of results for chum salmon was based on data collected by several DFO biologists and technicians and was originally prepared for the Fisheries Bioengineering Symposium held in Portland, Oregon in 1988 (Bonnell 1991).

METHODS

PLANNING, DESIGN AND CONSTRUCTION

Side channels are typically developed on medium to large rivers whose bench lands consist of porous gravel-type soils with an adequate supply of ground water near the surface (Marshall 1984). As many as 15 factors may be considered in site selection, with candidates being rejected on biological, engineering or economical grounds (Table 1). Major consideration is given to availability of spawner recruits or donor stock, presence of sufficient flow, and costs of excavation, flood protection and bank armouring.

Details of design and construction have been described in a number of reports (Lister et al. 1980; Marshall 1984; Sheng et al. 1990, and Bonnell 1991). The channels are typically 300 to 1000 m long, 5 to 6 m wide, and 0.2 to 0.4 m deep with discharges of 0.09 to 0.14 m^3/s (Sheng et al. 1990). Mean developed areas are approximately 2300 m^2 for existing gravel channels (n = 12) and 2800 m^2 for graded gravel channels (n = 7).

Table 1. Site selection factors for assessing the feasibility of groundwater-fed side channel projects for chum salmon in British Columbia.

Factors	Criteria
Gradient	Approximately .002 to .005 along center line of the channel
Substrate	Clear firm gravel soil base with low proportion of fines
Water source	Unconfined aquifer with high percolation rate
Water table	Near ground surface with minimal fluctuation
Water quality	General suitability --dissolved oxygen, temperature, total gas pressure, water chemistry suitable for incubation and preferably rearing
Spawner recruitment	Channel should be located within the upstream spawning limit preferably with sufficient population size to recruit channel initially
Flood protection	Location to take advantage of existing protection such as high ground, dike works, road embankments. Low propensity for backwatering during floods
Existing Habitat	Current value should be low or nil
Access	For heavy machinery during construction and for assessment and maintenance later
Sources of siltation	Low potential for siltation from road drainage, intermittent surface flow, or other sources
Availability of materials	Channels should be in close proximity to a rock quarry for bank armoring and natural or graded gravels for substrate if necessary
Approvals	Property ownership (rights of way), interagency approvals, special approvals (e.g., pipeline crossing)
Maintenance	Low potential requirement; e.g., little or no beaver activity
Others	Public relations/interpretation, and local community involvement
Manageability	Potentially few enforcement problems; proposed adult production to be consistent with stock management plans

CHUM SALMON ASSESSMENT

Adult populations and sex ratios were estimated by adjusted Petersen mark-recapture methods (Ricker 1975), by total carcass counts (usually aided by a downstream fence to catch carcasses), of by frequent foot surveys. Fecundities were determined from channel-specific regressions on length or estimated from the literature (Beacham 1982). Egg retention was assumed to be zero. Potential egg deposition was calculated as the number of females spawners multiplied by the mean fecundity.

Hydraulic redd sampling (McNeil 1964) was carried out to estimate embryo survival. Samples were taken in a non-random fashion evenly throughout the channels with minima of 100 eggs per sample and 25 to 30 samples per channel. Mean embryo survival was estimated as the grand mean of the sample results for a given channel. Intragravel dissolved oxygen levels were estimated by drawing 200-500 mL samples from .15 m below the bed surface, transferred to a glass container and measured using an electronic oxygen meter and probe.

Migrating fry were counted at downstream fences. Fry survival was estimated as the number of fry trapped divided by the potential egg deposition. The total developed spawning area of a channel was used to calculate spawner densities, egg deposition and fry production.

An independent bioengineering study team analyzed the economics of our channels in 1983 (D.B. Lister and Associates et al., DFO unpublished consultant report, 1983). The benefit/cost model used was the Salmonid Enhancement Program Production Model - a tool used by DFO planners to evaluate potential projects. Benefits were based on the incremental production from the channels - i.e., total production less that which would have occurred without the construction - and were discounted 10% per annum. Costs included capital and operating costs, administrative costs, contributions of donated time and/or materials at market value, fishing industry harvesting and processing costs, and industry labour.

RESULTS AND DISCUSSION

CHUM SALMON ASSESSMENT

The spawning densities observed for all channels ranged from 0.03 to 2.8 females/m^2 with a mean of 0.8 females/m^2 (SD = 0.6) and a mode of 0.6 females/m^2. The overall mean proportion of females observed was 0.46 (SD = 0.11), with the mean proportion in native gravel channels (0.49) slightly but not significantly higher than that in graded gravel channels (0.44). The mean fecundity was 3240 eggs/female (SD = 242) with a range of 2936 to 3524 eggs/female.

In 1982, mean embryo survival was significantly correlated with intragravel dissolved oxygen over 7 developed and 3 undeveloped groundwater-fed side channels ($r = 0.685$, $P<0.05$) although only 48% of the variability was accounted for (Figure 2). Embryo survival of 50% in individual redds generally occurred at intragravel dissolved oxygen concentrations between 3.5 and 6.0 mg/L.

Using pooled data from native gravel channels, mean embryo survival was significantly correlated with subsequent fry survival ($r = .777$, $P<0.025$ $n = 7$) (Figure 3). No correlation was found using pooled data from graded gravel channels. Two individual channels showed significant correlations: Worth Creek (graded gravel) ($r = .981$, $P<0.01$, $n = 5$) and Mamquam (native gravel) ($r = .953$, $P<0.05$, $n = 4$) (Figure 4). These results suggest that it may be possible to predict fry survival (in a gross way) from hydraulic sampling thus reducing the assessment cost of downstream trapping. However, the correlations observed were based on few sample numbers.

For all channels reviewed at all spawning densities, fry survival averaged 16.3% (Table 2). Mean survival for existing gravel channels was slightly but not significantly higher than that for graded gravel channels. At low spawning densities (<0.5 females/m^2), survival averaged 23% (ranging from 12 to 48%) (Figure 5). The 4 labelled data points in Figure 5 are not representative due to different design in one case, and an unusual state of deterioration in the other. Survival decreased with increasing spawning density to < 10% at over 1.3 females/m^2 and to < 5% at 2.1 females/m^2. At any point below a density of 0.7

Table 2. Chum salmon spawning density, potential egg deposition, survival and annual fry production in groundwater-fed side channels in British Columbia for brood years 1978-1987.

Factor	Channel Type		
	Existing Gravel Substrates	Graded Gravel Substrates	Both
Females Spawners/m^2			
mean	0.8	0.8	0.8
SD	0.6	0.6	0.6
N	19	30	49
Potential Egg Deposition/m^2			
mean	2,558	2,355	2,431
SD	1,934	1,640	1,759
N	18	30	48
Embryo Survival (%) (from redd sampling)			
mean	72	52	62
SD	21	24	25
N	33	34	67
Fry Survival (%)			
mean	17.4	15.8	16.3
SD	11.4	12.5	12.2
N	9	21	30
Annual Fry Production (fry/m^2			
mean	337	280	297
SD	167	177	176
N	9	21	30

females/m^2 (67% of the data), survival was more than twice the 7.9 % average Lister et al. (1980) found for natural streams and well above the 9.0% suggested as a standard for natural production in British Columbia (Enhancement Opportunities Sub-Committee for the SEP, DFO unpublished document, 1983).

For all channels reviewed, the annual production of emergent fry averaged 297 fry/m^2, with the mean for existing gravel channels higher than that for graded gravel channels but not significantly so (Table 2). Fry production increased with spawning density to roughly 400 to 500 fry/m^2 at about 0.8 to 1.0 females/m^2 (2600 to 3200 eggs/m^2), and remained fairly high even at densities in excess of 2.5 females/m^2 (8000 eggs/m^2) (Figure 6). These results are comparable to the production observed at Sashin Creek for pink and chum salmon (McNeil 1969) - a peak of 500 fry/m^2 at about 1.0 females/m^2 (2000 to 3000 eggs/m^2) -

although production from Sashin Creek declined rapidly to about 100 fry/m^2 at 2.2 females/m^2 (5500 eggs/m^2), whereas production from groundwater channels appears to remain higher. West and Mason (1987) advocated an egg deposition ceiling of 3000 to 4000 eggs/m^2 for sockeye (or about 1.0 to 1.3 females/m^2) where production reached maximum levels. For chum salmon in groundwater-fed side channels, 82% of the results were below this ceiling and corresponded to a mean fry survival of 28.4% and a mean annual fry production of 271 fry/m^2.

The assumptions of the SEP Production Model greatly reduce the likelihood of a project achieving a benefit/cost ratio higher 3.0, and ensure excellent benefits from projects with ratios greater than 1.0. The results of the 1983 analysis (D.B. Lister and Associates et al., DFO unpublished consultant report, 1983) showed an overall benefit/cost ratio of 1.7 (ranging from 0.34 to 2.42).

Since that analysis, chum fry and coho yearling production have exceeded its assumptions and the cost has decreased. The overall mean development cost of existing gravel channels was \$24.56/m^2 (in 1987 Canadian dollars), compared with the cost for graded gravel channels of \$28.99/m^2. The mean developmental cost for both types built before 1983 was \$25.90/m^2 compared with \$24.30/m^2 for those built since 1983 (all in 1987 Canadian dollars).

INDIAN RIVER - MAMQUAM CHANNEL PINK TRANSPLANTS

In the 1985 brood year approximately 1.3 million eyed pink salmon eggs were brought to Mamquam Channel, a enhanced groundwater side channel of the Mamquam River, for final incubation. The eyed eggs were spread over the gravel surface (4000 eggs/square meter) and covered with sheets of black plastic to exclude light and predators.

During the spring of 1986 approximately 750000 pink fry were captured in a downstream trap operating at the lower end of Mamquam channel. Predation, primarily by coho smolts , is thought to be the major mortality after the eyed stage for the pink eggs planted in the channel (5500 coho smolts were captured in the trap that year).

In the 1987 and 1989 brood years approximately 1.39 million and 1.0 million eyed pink salmon eggs were planted in the top end of Mamquam Channel. This resulted in 1.33 million and 0.6 million migrating fry respectively. The large difference in survival between the two years was attributed to the numbers of coho smolts in the channel in the respective years. For the 1987 brood only 29 coho smolts were captured migrating from the channel while in the 1989 brood year 7200 coho smolts migrated from Mamquam channel.

MCNAB CREEK CHANNEL CASSETTE INCUBATION -CHEAKAMUS RIVER CHUM TRANSPLANT

McNab Creek spawning channel is a groundwater channel designed for chum salmon. The channel is located 100 meters west of the mouth of McNab creek in Howe Sound and was built in 1986. The channel is 230 meters long, 4.5 meters wide and empties directly into the estuary.

The elevation of the channel bed is level with a 10.5 foot tide. A 12 foot tide is level with the operating water level in the channel.

The water temperature and oxygen level in the channel are stable and average 7.5°C and 11 ppm, respectively. Groundwater discharge is also stable averaging 4 cfs.

Low profile cassette incubators have been operated in the channel since 1987. Each incubator holds 24 cassettes and has a total capacity of approximately 240-290 thousand fry. The incubator shells are made out of 1/8 inch sheet aluminum and are 18 inches high, 4 feet 4 1/2 inches wide and 6 feet long. The cassettes slide into horizontal guides that are six rows high and are spaced 1 inch apart (see Figure 7 and 8). The total water depth required to operate the incubators is 13 inches.

The incubators are situated in the top third of the channel above the influence of saltwater intrusion. The incubators sit flat on the channel bed and are anchored down with rocks. Water velocity through the cassettes is normally 3 to 5 inches per second at low tide. Water velocities change intermittently during rising or receding high tides ranging between .5 to 12 inches per second. Velocities through the incubators are set by placing rock dams either on both sides or in front of the incubators.

Table 3. Chum fry production and survival at McNab Channel using channel cassette incubators.

Brood Year	No. of Eyed Eggs Planted	No. of Fry Released	Percent Sur.
1987	100,000	91,200	91.20
1988	551,052	545,652	99.00
1989	530,706	526,106	99.10
1990	736,760	735,240	99.80

Cheakamus R. eyed chum eggs from Tenderfoot Hatchery are planted in the cassettes late January.. The fry are released early April. No maintenance has been required in the four years of operation and survivals has been above 95%. In the first year of operation, January 1988, a prototype Instream cassette incubator was operated with approximately 100,000 Cheakamus chum eggs. Survival in 8 of the cassettes was 99.5% and zero in two others because of DE-watering during low tide. In the following years, production has increased from 525 to 735 thousand (see Table 3). The first major returns are expect in November 1992.

REFERENCES

Beacham, T.D. 1982. Fecundity of coho salmon (*Oncorhynchus kisutch*) and chum salmon (*O. keta*) in the northeast Pacific Ocean. Canadian Journal of Zoology 60: 1463-1469.

Lister, D.B., D.E. Marshall, and D.G. Hickey. 1980. Chum salmon survival and production at seven improved groundwater-fed spawning areas. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1595, Vancouver, British Columbia.

McNeil, W.J. 1964. A method of measuring mortality of pink salmon eggs and larvae. United States Fish and Wildlife Service Fisheries Bulletin 63: 575-588.

McNeil, W.J. 1969. Survival of pink and chum salmon eggs and alevins. Pages 101-117 in: Northcote, T.G. (editor). Symposium on Salmon and Trout in Streams. H.R. MacMillan lectures on Fisheries, University of British Columbia, Vancouver, Canada.

Marshall, D.E. 1986. Development and assessment of groundwater-fed side channels. Pages 106-109 in: Paterson, J.H. (editor) 1986. Proceedings of the Workshop on Habitat Improvements, Whistler, British Columbia. 8-10 May 1984. Canadian Technical Report of Fisheries and Aquatic Sciences 1483. Vancouver, British Columbia.

Ricker, W.E. 1975. Bulletin 191, Department of the Environment Fisheries and Marine Service, Ottawa, Canada.

West, C.J. and J.C. Mason. 1987. Evaluation of sockeye salmon (*Oncorhynchus nerka*) production from the Babine Lake Development Project. Pages 176-190 in Smith, H.D., L. Margolis, and C.C. Wood (editors). Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences 96, Ottawa, Canada.

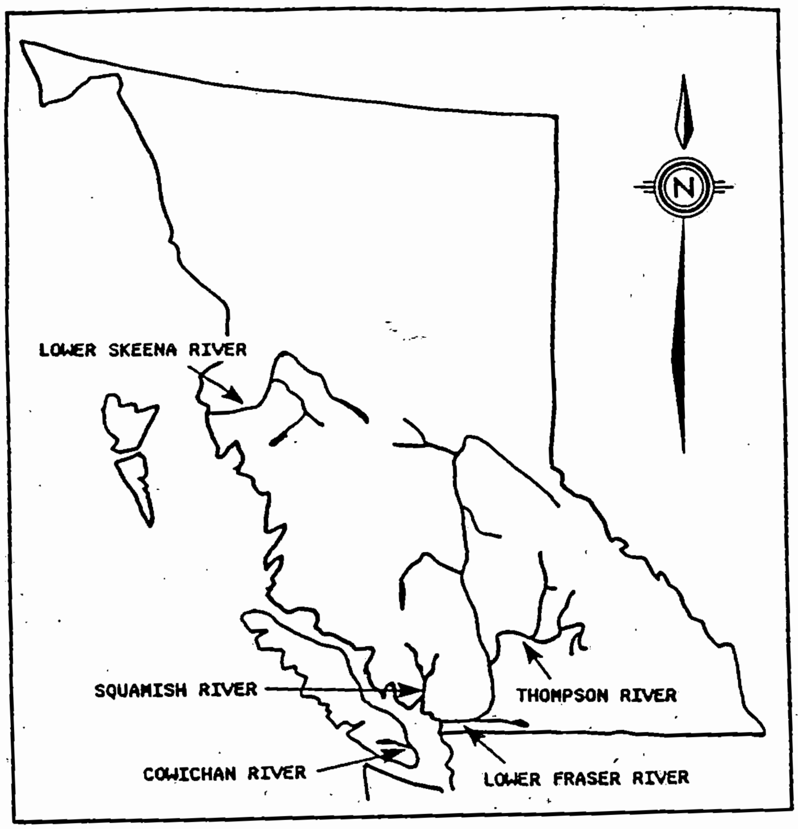


Figure 1. Map of British Columbia showing five of the major watersheds in which groundwater-fed side channels have been constructed for.

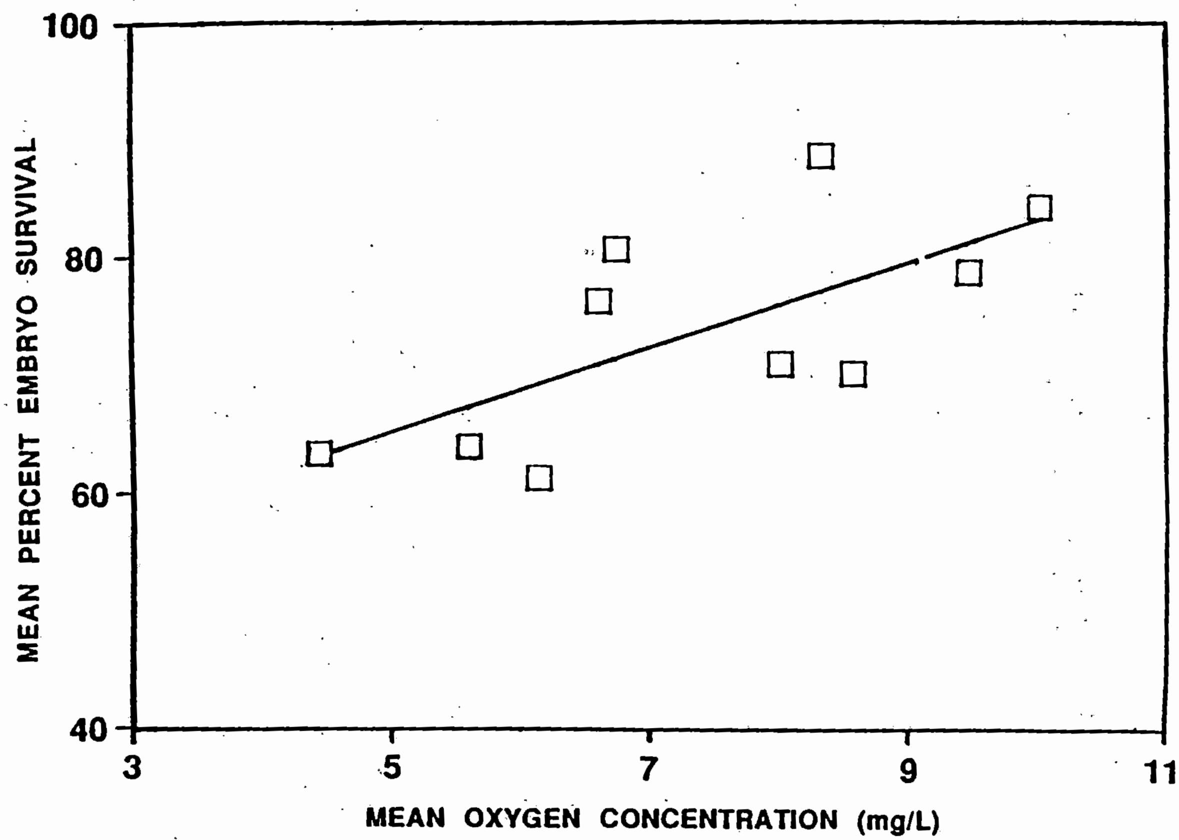


Figure 2. Chum salmon embryo survival as a function of intergravel dissolved oxygen concentration at hatch, from Brood 1981 sampling, all data (correlation; $r=.685$, $P \leq .05$).

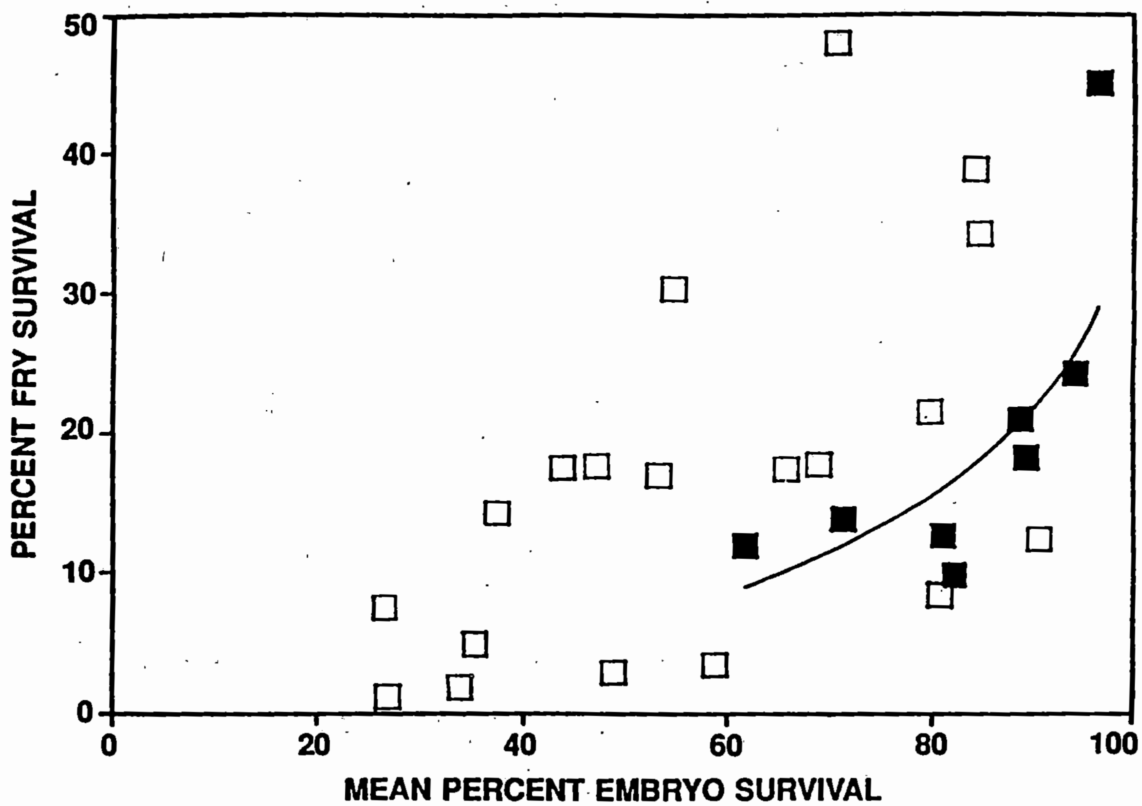


Figure 3. Observed chum salmon fry survival as a function of earlier mean embryo survival. The estimates are from downstream migrant trapping and redd sampling in existing (solid squares) and graded (open squares) gravel channels. The curve is the correlation for existing channels (r=.777, P≤.025).

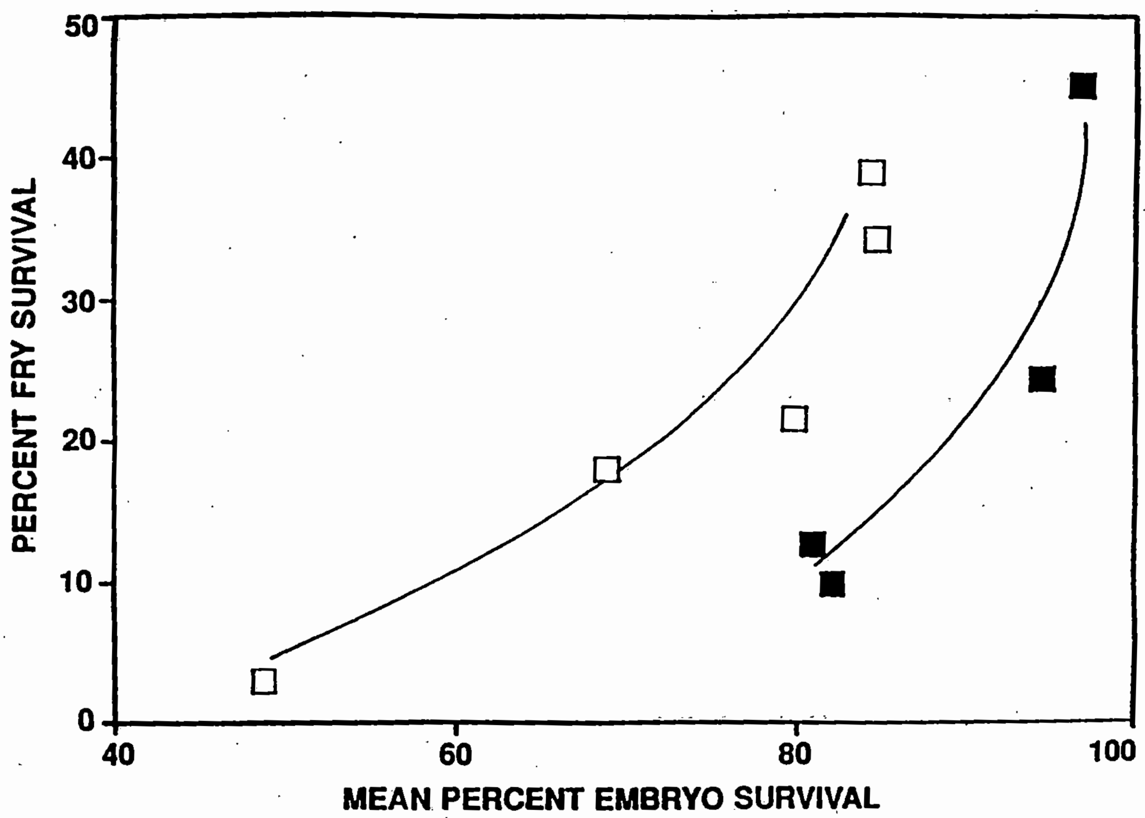


Figure 4. Observed chum salmon fry survival as a function of earlier mean embryo survival. The estimates are from downstream migrant trapping and redd sampling. The curves are the correlation for Manquam Channel (solid squares, r=.953, P≤.01).

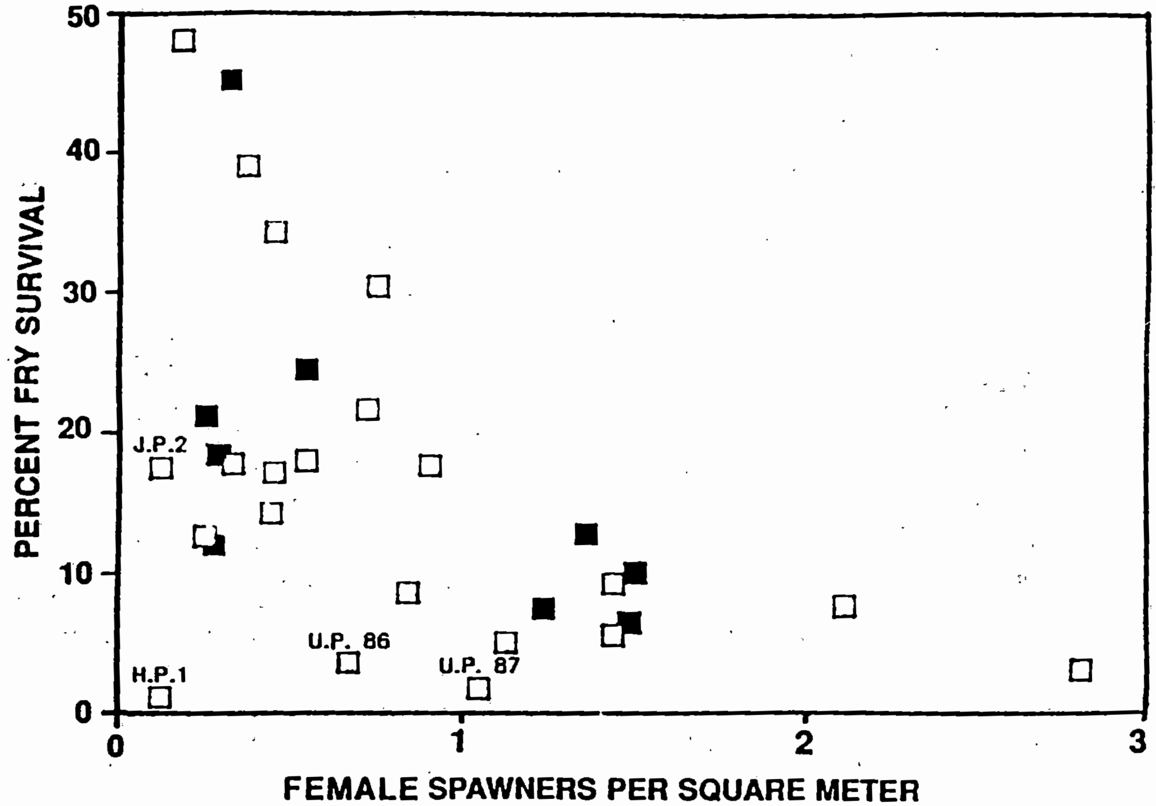


Figure 5. Chum salmon fry survival as a function of female spawner density in existing (solid squares) and graded (open squares) gravel channels.

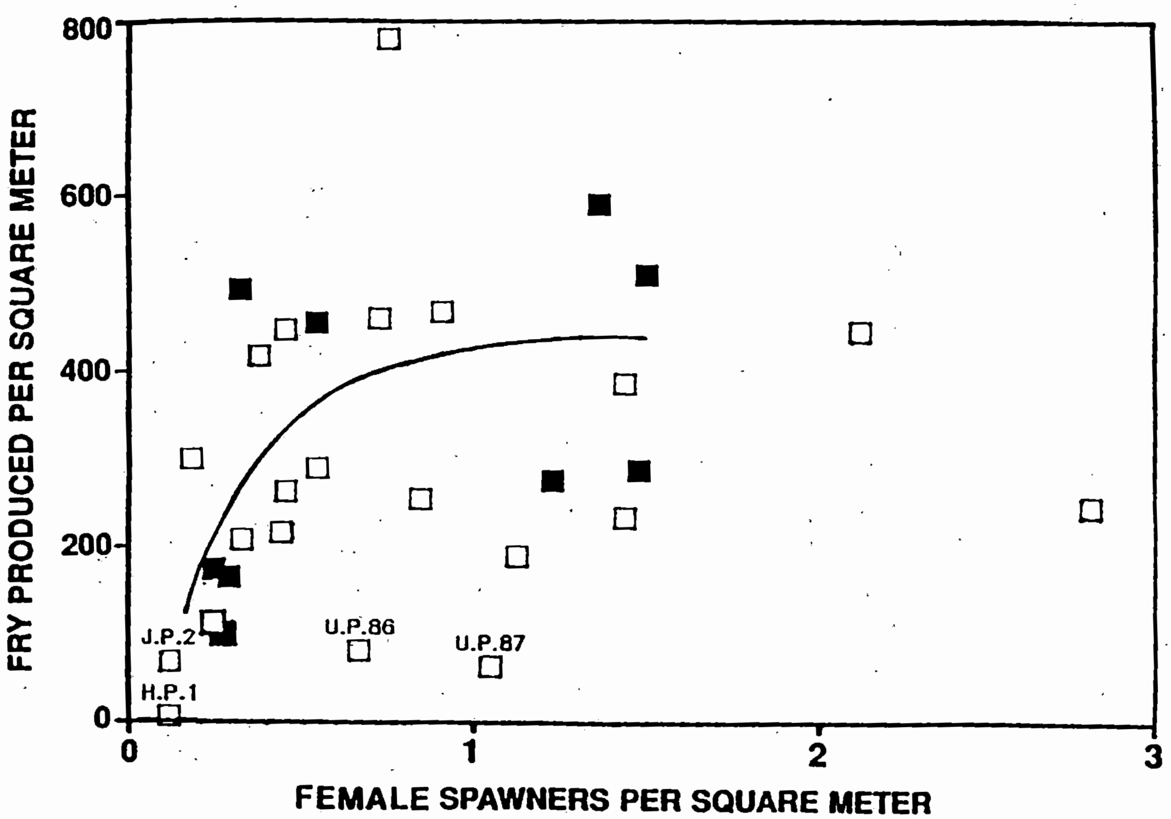


Figure 6. Annual chum salmon fry production as a function of female spawner density in existing (solid squares) and graded (open squares) gravel channels. The curve was drawn by eye.

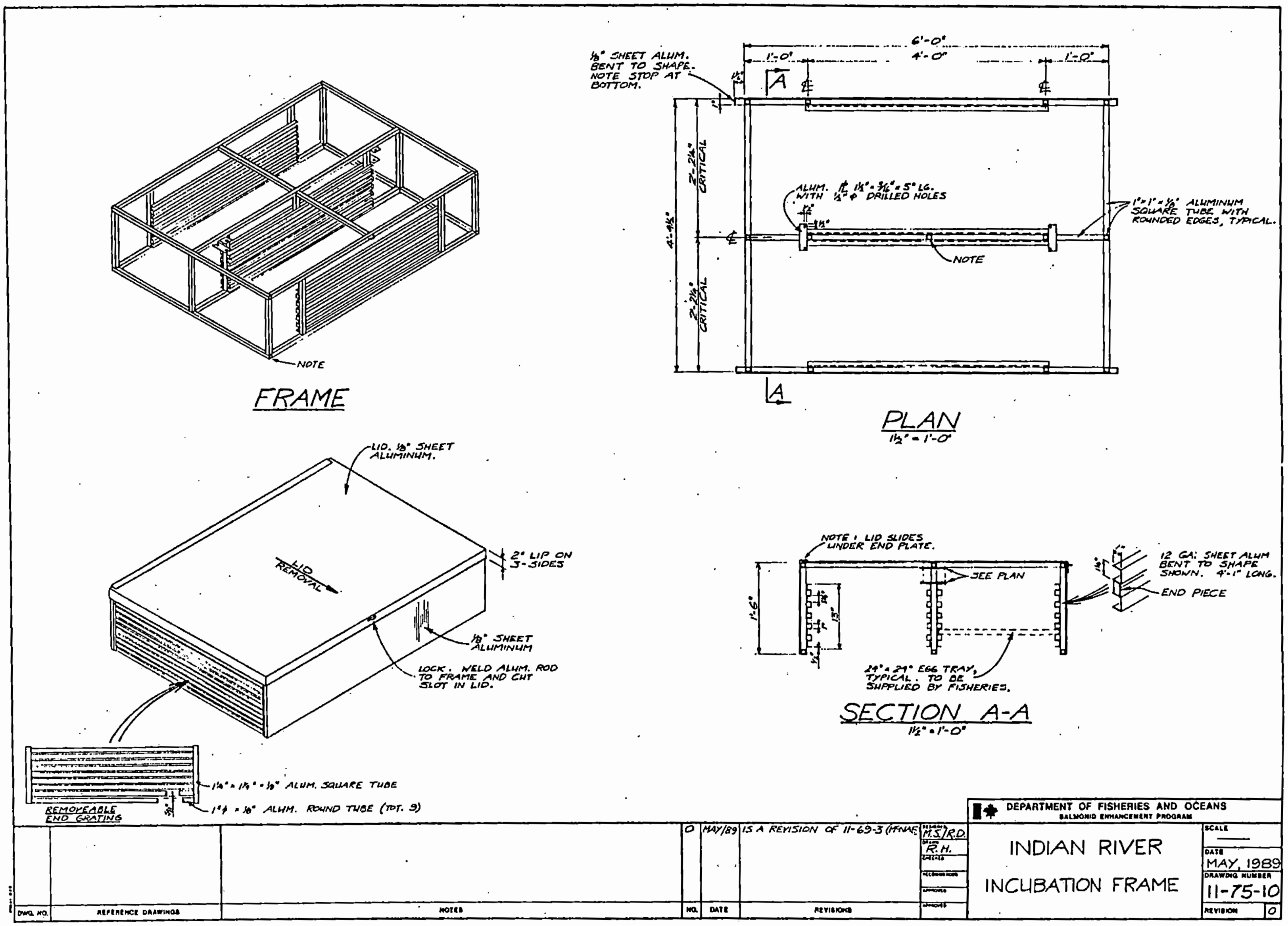


Figure 7. Drawing of an aluminum channel cassette incubator.

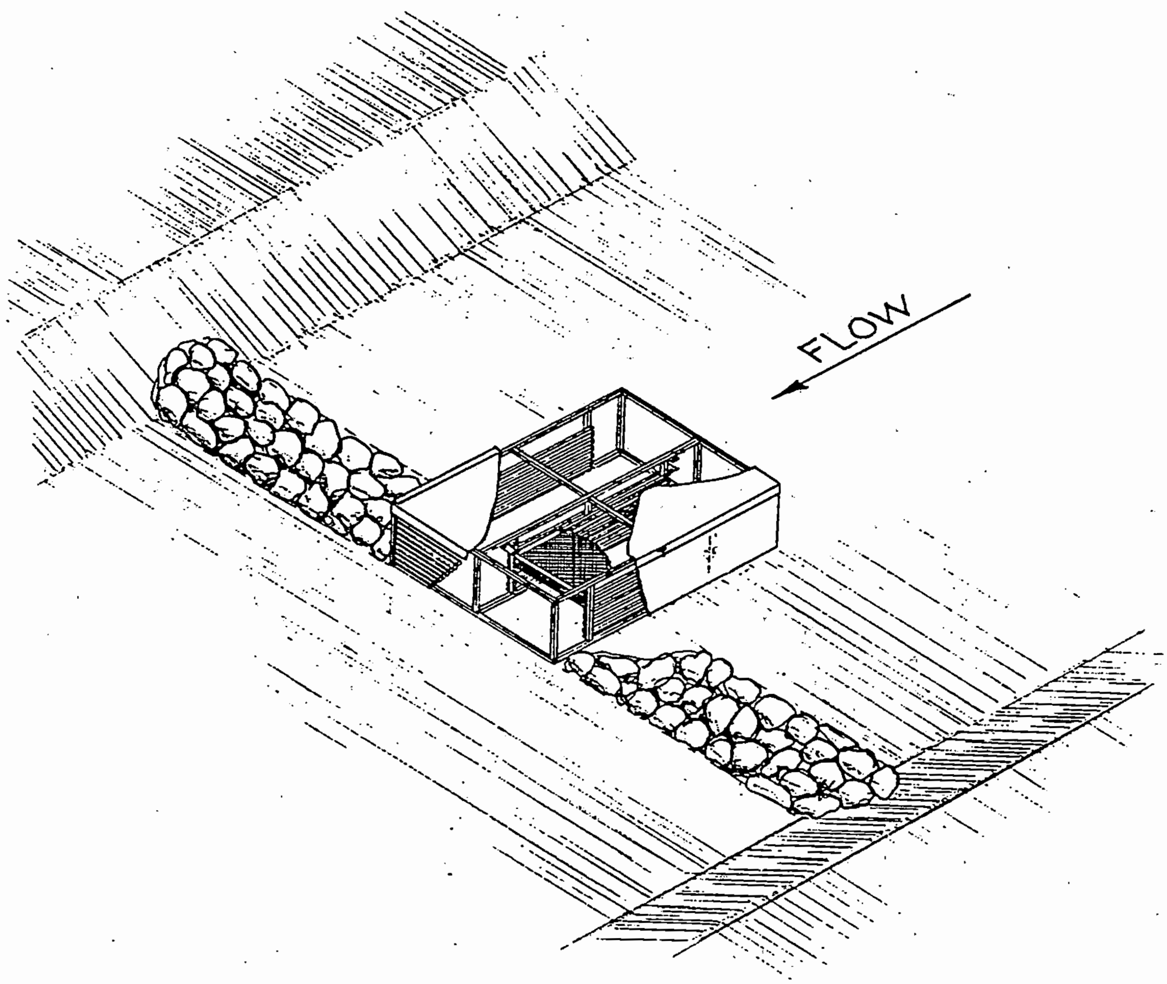


Figure 8. Schematic of an aluminum channel incubator installed in a channel.

Use of Remote Site Incubators to Enhance Pink and Chum Salmon in Hood Canal Streams

Kent R. Dimmitt and Jerry Manuel

Salmon Culture Division
Washington Department of Fisheries
115 General Administration Building
Olympia, Washington 98504

To enhance populations of chum salmon (*Oncorhynchus keta*) in Hood Canal tributaries, the Washington Department of Fisheries (WDF) developed a number of remote incubation sites. The first streamside incubators were boxes made of marine plywood and filled with gravel. By 1984 most of these were deteriorating and were completely replaced by a new system, the Remote Site Incubator (RSI). The RSI is a lightweight polyethylene unit, portable, and easy to clean and disinfect. A cost analysis was done using the Fulton Creek site which uses 8 RSI units to incubate 1 million chum. Amortized over 10 years the total cost for the site was $1090.00 per year. At an average 1990 value of $6.00 per fish, the site would have to contribute 182 fish per year to the commercial fishery to achieve a 1.0 benefit:cost ratio. Using an estimated 95% egg to fry survival rate during incubation, fry to adult survivals of 0.019% would produce the necessary fish. Even at the lowest reported survivals (0.75%), 7125 fish would be produced giving a benefit:cost ratio of 39.22.

Hood Canal (Figure 1), in Washington state, has a large run of chum salmon (*Oncorhynchus keta*). Actual run sizes have ranged from 123,300 to 801,162 over a ten year period. This stock is targeted by Indian and non-Indian commercial fishers. Because of reduced natural escapement, the Washington Department of Fisheries (WDF) developed a number of remote incubation sites to enhance tributary spawning populations.

In the late 1970's most streamside incubators were boxes constructed of marine plywood and filled with gravel. These incubators were easy to construct and inexpensive, however, they were costly to install on site. Because they were heavy, roads had to be built for heavy installation equipment and incubators were unsuitable for moving from one location to another.

By 1984 most of the units were deteriorating. To continue these programs new incubators were required. In 1985 a complete new system, the Remote Site Incubator (RSI), was designed and built by WDF personnel. The polyethylene unit is lightweight, portable, and easy to clean and disinfect (Manuel 1989). Since its inception, the RSI program has expanded to 72 units located on streams in Hood Canal and Puget Sound.

METHODS AND MATERIALS

The incubator is an upwell flow-through system using black, 6.4 mm thick, polyethylene 55 gallon barrels with lids. The dimensions of the barrel are 55.9 cm (OD) with a depth of 91 cm. Inside the unit is a water diffuser, filter screen, plastic sub-strate (bio-saddles), up to five egg screens and a top screen. The unit is designed to operate with a clarifier to clean and stabilize the water pressure of the incubator, and a water collector that will remove objects larger than 6 mm. A 15.2 cm head between the clarifier and incubator is required to provide the 38-45 liter per minute flow rate required to incubate 125,000 alevins (25,000 eggs/tray).

For purposes of illustration, we have chosen the Fulton Creek site. This creek is 9 kilometers long, on the west side of Hood Canal, and originates near the 1,000 meter level of the Olympic Mountains. The creek is accessible to salmon upstream to a falls at kilometer 1.4 where the incubation site is located. One million chum salmon are incubated at this site using spring water at a constant temperature of 9^0 C. Eggs for the site are spawned at Hoodsport hatchery, and incubated to the eyed stage (approximately 33 days) at the George Adams hatchery (see Figure 1). After being shocked and picked, eggs are transported to the site and placed in the incubators. Once fry migration is complete, the barrels are disinfected and stored until the following year. The barrels have an expected life of 25 years.

DISCUSSION

Costs of the program can be broken down into two categories: 1) set up and construction of the barrels and the incubation site and, 2) costs that are accrued each year in spawning and incubating the eggs (includes disease treatments) at the hatcheries, transportation to the site, and maintenance and cleanup during the operation of the site. Total construction cost of the barrels and the site was estimated at $5,268.00 (Table 1). Costs of the second category items are estimated to be $563.00 per year (Table 2).

We could not calculate a benefit:cost ratio because survivals of these fish have not been determined. Therefore, as an alternative we looked at the contribution this program needs to make to the fishery in order to break even. We amortized the costs of initial set up over 10 years (2 brood cycles) and found the cost to be approximately $527.00 per year. Adding the other costs from category 2 ($563.00) the total yearly cost is $1090.00. In 1990 the average size and price of chum salmon caught was 10 pounds and 60 cents per pound, respectively. To achieve a benefit:cost of 1.0, the site would have to contribute approximately 182 fish to the commercial fishery. The egg to fry survival rate in the incubators is estimated to be around 95%. With 950,000 fry migrating to sea, a survival rate of .019% would produce the necessary fish. Survival rates of naturally produced chum vary, and range from .75% to 2.5% (Bakkala 1970). Even at the lowest reported survivals, 7,125 adults would be produced giving a benefit:cost ratio of 39.22.

The barrel incubator (RSI) is durable, lightweight and can be installed or removed with ease. It is easy to construct and provides for volitional release of fry that appear to be high quality. These advantages make the RSI a usable product especially for programs like our Volunteer Resource Program (Kolb *et al.*, Unpubl.) or cooperatives. Benefit:cost analysis showed that even with very low survival rates the system can be cost effective. Further evaluation of production from this site and others should be conducted to better refine the costs of this type of enhancement.

REFERENCES

Manuel, J.L. Remote Site Incubation of Pink and Chum Salmon Eggs. Fourteenth Northeast Pacific Pink and Chum Salmon Workshop; 1989 February 22-24. Port Ludlow Resort, Port Ludlow, Washington. pp.136-139.

Bakkala, R.G. 1970. Synopsis of Biological Data on the Chum Salmon, *Oncorhynchus keta* (Walbaum) 1792. United States Department of the Interior. Fish and Wildlife Service. FAO Fisheries Synopsis No. 41. Circular 315.

Kolb, R.; Manuel, J.L.; Dimmitt, K.R. 1990. Remote Site Salmon Egg Incubation. Unpubl. Draft. Washington Department of Fisheries Volunteer Fisheries Resource Program. 15 pp.

Table 1. Cost of constructing barrels and incubation site.

Materials (4"pipe,2"pipe,valves,couplings)	$600.00
Barrels ($496/barrel x 8 barrels)	$3,968.00
Labor (40 hrs)	$400.00
Miscellaneous (sandbags,lumber,etc.)	$300.00
Total	$5,268.00

Table 2. Costs accrued per year of operation.

Spawn 1 million chum eggs	$145.00
Disinfection and placing eggs in freestyle incubators	$35.00
Care and maintenance of eggs over incubation period	$33.00
Power costs for pumping 20 gpm to eggs over 33 day incubation period	$50.00
Shock and pick 1 million eggs	$60.00
Transportation and placing of eggs into barrels	$80.00
Care and maintenance of eggs until release	$20.00
Cleanup	$40.00
Cost of land (leased/year)	$100.00
Total	$563.00

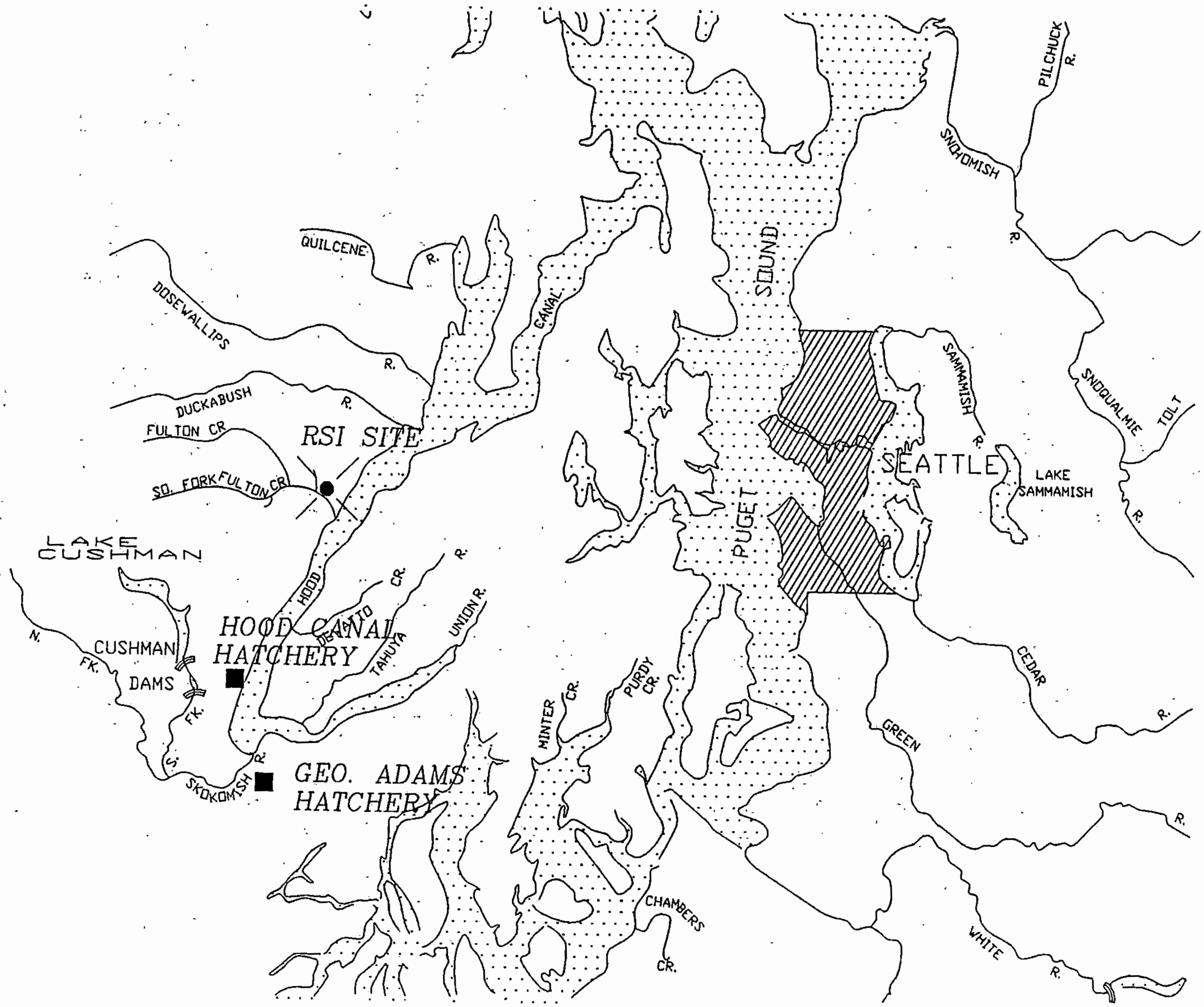


Figure 1. Map of Hood Canal, Washington, showing location of remote site incubator (RSI) and support hatcheries.

Statistical Power Analysis of a Large-Scale Fishing Experiment Designed to Test the Gear Selectivity Hypothesis on British Columbia Pink Salmon (*Oncorhynchus gorbuscha*)

Murdoch K. McAllister [1] and Randall M. Peterman

Natural Resource Management Program
Simon Fraser University, Burnaby, B.C., V5A 1S6 Canada

[1] *School of Fisheries, WH-10, University of Washington, Seattle, Washington, 98195 U.S.A.*

Since the 1950's, several stocks of British Columbia pink salmon (*Oncorhynchus gorbuscha*) have shown as much as a 34% decrease in mean adult body size, causing significant reduction in potential biomass yields of commercial harvests. Previous research suggests that this trend is due to size-selective harvesting of large fish, but recent work presents an alternative: changes in oceanographic conditions. Corrective action by management agencies will require that the true causal mechanism be identified. Therefore, we examined several alternative designs of large-scale fishing experiments that aim to test whether size-selective fishing is the cause of decreased body size (i.e., the gear selectivity hypothesis). In order for this to be the cause of ongoing changes in body size, heritability (h^2) of growth rate must be greater than zero, given the historical selection differentials. Empirically-based Monte Carlo simulation was used to compute the statistical power (i.e., probability of correctly detecting a value of h^2 significantly greater than zero) of several experimental designs. Block designs of five to ten years and three to six spatial replicates could yield high statistical power in tests for the presence of a significant h^2. For example, if h^2 were 0.22, selection differential were 0.25 kg, and there were four spatial replicates, a seven-year experiment would give power = 0.87. We conclude that some experimental designs have good potential to test the possible effects of size-selective fishing on mean adult size of B.C. pink salmon.

Since the 1950's, several stocks of adult pink salmon in British Columbia have shown up to a 34% decrease in mean body weight (Ricker et al. 1978) (Figure 1). This decrease is not attributable to a shift in mean age at maturity because virtually all pink salmon in British Columbia (B.C.) mature at age two years. Almost all B.C. stocks showed a strong decreasing trend between 1959 and 1975 (Ricker et al. 1978). However, since 1975 some of these stocks have shown increases in mean adult weight (Healey 1986), while others have continued to decrease. This has created a controversy about the causes of interannual variation in mean body size of pink salmon. Ricker et al. (1978) hypothesized that the decreasing trends in body size of B.C. pink salmon resulted from removal of larger-than-average-size fish by fishing gear, combined with heritability of growth rate (h^2). However, the trend in mean adult body size could also have resulted from changes in oceanographic conditions (Healey 1986), increased intra- or inter-specific competition (Healey 1986), or selective depletion of stocks with larger mean body size (inter-stock selection) (Nelson and Soule 1987).

Current data do not enable us to eliminate any of the above hypotheses (McAllister, Lockhart, and Peterman, unpublished data) because any estimates of heritability of growth rate from historical catch data (e.g., Ricker et al. 1978) are possibly confounded with selective depletion of larger stocks, or oceanographic and density-dependent effects. Interpretations of past data are further constrained by a lack of spatial controls (no nearby pink salmon stocks fished with non-selective gear such as purse seines) to compare with selectively fished stocks.

Decreased fish body size is a problem for fisheries managers for several reasons. First, decreased mean adult size can result directly in decreased catch biomass (e.g., a 34% decrease in mean adult body weight corresponds to a potential 34% decrease in catch biomass if the number of fish caught remains the same). Second, decreases in mean adult body size may also affect reproductive success. A growing body of evidence suggests that large female body size confers substantial reproductive advantages. Larger female pink salmon carry more and larger eggs (Foerster and Pritchard 1941; Bilton 1973) and may spawn earlier, resulting in increased freshwater survival of offspring (Skud 1973). Furthermore, smaller pink salmon, may be less able to swim long distances or up steep gradients to spawning grounds (Ricker 1989). Thus, there may be a reproductive disadvantage for smaller-than-average-size adults, especially females, and reduced mean adult weight could reduce stock productivity (Foerster and Pritchard 1941).

In this paper, we used statistical power analysis (Dixon and Massey 1983; Toft and Shea 1983; Cohen 1988; Peterman 1990) to evaluate the potential of alternative designs of a proposed large-scale fishing experiment to test the gear selectivity hypothesis on B.C. pink salmon. See McAllister et al. (1991) for further details on the evaluation of the expected statistical performance of the experiment and McAllister and Peterman (1991) for an economic evaluation of the proposed experiment that uses decision analysis and expected biomass yields as the measure of performance.

METHODS

STATISTICAL MODEL

The following model represents the various components of interannual variation in mean adult weight of pink salmon that may be present in a size-selective fishery:

$$(1)\quad W_{i,t}\text{-}W_{i,t\text{-}2} = B_0 + T_t + D_{i,t\text{-}2}h^2 + E_{i,t}$$

where $W_{i,t}$ is the mean adult body weight just prior to fishing of the filial generation of stock i in year t of the experiment. Each stock i consists of either a single even-year or odd-year breeding population of pink salmon and is caught in the same terminal fishery (i.e., a fishery located adjacent to the mouth of a spawning stream). $W_{i,t\text{-}2}$ is the mean adult body weight just prior to fishing of the parental generation of stock i in year t-2 of the experiment. B_0 is the regression constant, which represents the mean intergenerational change in adult body weight. This could be induced by environmental effects, if a time-trend in environmental effects exists, common to all stocks. T_t is the difference in environmental effects between year t and year t-2 common to all stocks in the experiment. T_t represents a common trend in a given two-year span, whereas B_0 represents a common constant trend over the entire time span of the experiment. $D_{i,t\text{-}2}$ is the selection differential from size-selective fishing for stock i in year t-2. This equals the mean body weight of the parental generation just after selective fishing, minus that just prior to selective fishing (Falconer 1989). h^2 is the mean heritability of growth rate averaged over time and across stocks i. $E_{i,t}$ is the residual effect, unique to stock i, of the difference in adult body weight between year t and year t-2.

EXPERIMENTAL DESIGN

Experimental designs were developed to test the null hypothesis that h^2 of growth rate in model (1) was equal to zero at alpha=0.05 when the hypothesized true value was between 0.18 and 0.25 (see below). Terminal fisheries were chosen as spatial replicates in order to reduce interception of fish migrating to nonlocal fisheries. In practice, spatial replicates should contain single breeding populations of pink salmon to ensure intra-stock as opposed to inter-stock selection (Nelson and Soule 1987). Some stocks would be selectively fished by gill net gear. Others would be nonselectively fished by seine gear. Selection differential would be measured in each area and year by sampling mean adult body size with seine nets just prior to and just after fishing. In each spatial replicate, selective gear would be alternated yearly with nonselective gear to control for local effects (Hurlbert 1984). Logistical details of this design and its feasibility are discussed further in McAllister (1990). The simplest form of a controlled, replicated design (i.e., a block design) was evaluated (Figure 2) in terms of statistical power.

POWER ANALYSIS BY EMPIRICALLY-BASED MONTE CARLO SIMULATION

In order to compute power, possible sets of results in each alternative experimental design were simulated 500 times with random variation. Most of the parameters and variances used to simulate mean adult body weight were estimated beforehand from regressions of historical catch data using model (1) above. In each individual simulation of an experiment, we tested the null hypothesis that h^2 is equal to zero and computed P, the probability that the estimate for h^2 could have resulted from chance alone from populations with a true mean h^2 =0. Power was computed as the proportion of times out of all the simulations for a given design that the computed P value was less than alpha (i.e., 0.05); this was because the null hypothesis (i.e., h^2 is equal to 0) was false in all simulated cases. See Figure 3 for a flowchart of the Monte Carlo procedure.

Estimation of Parameters

Parameters include (1) the initial mean adult body weight of each stock in the experiment, (2) the variance in the random effects on adult weight unique to each stock in each generation, (3) the variance in random effects common to all stocks in each generation, (4) heritability of growth rate, (5) the mean selection differential, and (6) the variance of interannual variation in selection differential.

1. Initial weights -- The source of estimates of the initial weights simulated in each year is as follows. Mean adult body weights of pink salmon in 1987 and 1988 were for statistical areas 2W, 3, 4, 5, 6, 7, and 8 for even years and the same excluding 2W for odd years (Figure 4). Mean weights were calculated by dividing the total weight of the seine catch by the total number of pink salmon caught by seine in each of the statistical areas (see McAllister (1990) for details on procedure). Data were obtained from M. Henderson (Canada Department of Fisheries and Oceans (D.F.O.), Vancouver, British Columbia).

2. Heritability of Growth Rate -- h^2 was estimated using historical data and statistical model (1) (McAllister 1990). Historical catch data (by gear type in pieces and weight) and escapement data for statistical areas 4,5,6,7, and 8 for years 1965-1988 (Figure 4) (data provided by M. Henderson, D.F.O., Vancouver, and T. Beacham, D.F.O., Nanaimo, respectively) were used to estimate $W_{i,t}$, $W_{i,t-2}$, and $D_{i,t-2}$ in model (1). Regressions using data from statistical areas 4, 5, and 6 yielded an estimate of h^2 of 0.25; areas 6 and 7, 0.18; and areas 7 and 8, 0.22. These values of h^2 were used in the sensitivity analysis.

Our estimates of h^2 closely match Ricker et al.'s (1978) minimum estimates and suggest minimum values for h^2 that could account for the decreasing trend in mean adult size in some B.C. pink salmon stocks.

3. Stochastic Parameters -- We simulated two forms of random variation in mean adult weight. These were (1) effects common to all stocks in a given year (t_t, where $T_t = t_t - t_{t-2}$), and (2) effects unique to each stock in a given year (called residual effects here) ($e_{i,t}$, where $E_{i,t} = e_{i,t} - e_{i,t-2}$). Variances in $E_{i,t}$ and T_t were estimated from regressions that used the same historical catch data used to estimate h^2 and model (1). Analysis of the residuals of $E_{i,t}$ and T_t from these regressions indicated that it is reasonable to assume that the residuals are normally distributed and not autocorrelated (McAllister 1990). However, we needed estimates of the variance in $e_{i,t}$ and t_t for the simulations.

In order to estimate the variance in t_t and $e_{i,t}$, we divided the estimates of variance for $E_{i,t}$ and T_t each by two. This step follows from (1) the principle of additivity of variances (e.g., $\mathrm{var}(T_t)=\mathrm{var}(t_t) + \mathrm{var}(t_{t-2})$) and (2) the expectation that $\mathrm{var}(t_t)=\mathrm{var}(t_{t-2})$ and $\mathrm{var}(e_{i,t})=\mathrm{var}(e_{i,t-2})$. Thus, for example, $\mathrm{var}(T_t)=2\mathrm{var}(t_t)$ and $\mathrm{var}(t_t)=\mathrm{var}(T_t)/2$.

We defined the baseline estimates of variance in residual effects as the minimum estimates yielded from regressions that used pairs of adjacent statistical areas (see McAllister (1990) for details). Terminal fisheries in the pair that yielded the smallest estimate of residual variance could potentially yield the highest power test and therefore could be the best candidates for experimentation. Data from areas 7 and 8 yielded the lowest SD in $e_{i,t}$. This was 0.046 kg. SD in t_t was estimated to be 0.265 kg. High and low values of SD in $e_{i,t}$ were 0.059 (using data from areas 6,7, and 8) and 0.033 kg (obtained by dividing the residual variance from data from areas 7 and 8 by two and taking the square root), respectively.

4. Selection Differential -- We used a mean selection differential (over stocks and years) of 0.25 kg (from McAllister 1990) with a SD=0.057 kg in the Monte Carlo simulations.

Monte Carlo Procedure

Figure 3 summarizes the Monte Carlo procedure. Simulations were initiated by choosing a mean adult weight randomly without replacement from the historically observed set of six odd-year or seven even-year adult weights, depending on whether the initial year for the replicate was odd or even-numbered (see section on initial weights). A chance variation term ($e_{i,t}$) was randomly chosen from a normal distribution with baseline SD=0.046 kg and mean =0. An effect common to all stocks for this generation (t_t) was chosen randomly from a normal distribution with SD=0.265 kg and mean =0, and added to the adult weight to obtain the weight for stock i in that initial year, $W_{i,t}$. These SDs were estimated from historical data, as described above.

If the stock was selectively fished, the selection differential (mean plus random effect for each stock in each year) was multiplied by the value for heritability to obtain the response ($R_{i,t+2}$) to selection (i.e., $R_{i,t+2}=h^2D_{i,t}$) (Falconer 1989).

In the next simulated generation, the common time effects and stock-specific effects on weight were again drawn randomly from these respective distributions. These values and, if the stock was selectively fished, $R_{i,t}$, were added to the adult weight of the previous generation ($W_{i,t-2}$), less the common time effect (t_{t-2}) and the chance variation effect ($e_{i,t-2}$). The difference in adult weight between one generation and the next was estimated by $W_{i,t}$ -$W_{i,t-2}$.

The above procedure was repeated for the duration of the experiment for each spatial replicate. Next, the simulated data were regressed using model (1). Using a 1-tailed Student's t-test, we tested the null hypothesis that heritability is equal to zero at alpha=0.05 when the true simulated value was 0.18, 0.22, or 0.25.

Using the above procedure, we simulated individual experiments 500 times. Power was estimated as the number of times in which the null hypothesis was rejected, divided by 500. Baseline estimates of heritability (0.22), mean selection differential (0.25 kg), and residual variance in mean adult weight per stock (SD=0.046 kg) were used in all simulations except where stated otherwise.

RESULTS

We found several different designs that could be informative. In such designs, managers would have a >0.8 probability of correctly rejecting the null hypothesis that h^2 is equal to zero when it was either 0.18, 0.22 or 0.25 in nature and alpha was 0.05.

BASELINE CASE AND SENSITIVITY ANALYSES

Baseline results are for a 10-year experimental design with four spatial replicates. Using baseline estimates of parameters, statistical power was 0.97, i.e., a 0.97 probability of correctly rejecting the H_o when h^2 = 0.22 and D = 0.25 kg, at alpha =0.05 (Figure 5).

Unless stated otherwise, all sensitivity analyses below used baseline parameter values.

In the first sensitivity analysis, we varied the number of spatial replicates and experimental duration. Power exceeded 0.8 in five to ten years, depending on the number of spatial replicates (Figure 5). With only three spatial replicates it would take ten years for power to exceed 0.8; with six spatial replicates it would take five years.

In the second sensitivity analysis, we tested the influence of size of the simulated true heritability of growth rate on statistical power (Figure 6). The baseline number of spatial replicates in this and all subsequent analyses was four. Power exceeded 0.8 in six years at the high estimate of heritability (0.25) and in ten years for the low estimate (0.18). This compares with seven years for the baseline case where h^2=0.22.

In the third sensitivity analysis, we evaluated the effect on power of different values for mean selection differential (i.e., the difference in mean adult body weight of a single breeding population just after selective fishing minus that just before selective fishing). Power exceeded 0.8 in four to ten years, provided that mean selection differential was at least 0.20 kg (Figure 7). A mean selection differential of 0.20 kg would require ten years for power to exceed 0.8; one of 0.35 kg would require only four years. However, if mean selection differential was 0.15 kg, it would take 16 yr for power to exceed 0.8.

Fourth, we evaluated the effect on power of high and low variability in the year-to-year deviation in weight unique to each stock of pink salmon, $e_{i,t}$. Power exceeded 0.8 in five years for the minimum amount of variation (SD=0.033 kg) and in ten years for the maximum amount (SD=0.059 kg, Figure 8). Power was insensitive to different values for variance in t_t, the variance in weight common to all stocks, because the corresponding effects, T_t, were estimated and removed from the residual variance in each regression.

DISCUSSION

Our statistical power results suggest that a large-scale fishing experiment on British Columbia pink salmon is a promising method to determine whether growth rate is sufficiently heritable to support the conclusion that size-selective fishing is an important source of change in adult body weight. Sensitivity analyses show that under most conditions examined five to ten year experimental designs would yield power greater than 0.8 to detect a significant h^2. An experiment with only four spatial replicates and a mean selection differential of 0.25 kg would yield power of 0.87 in seven years, if h^2=0.22 (an estimate of h^2 with current data). Thus, if no significant estimate of h^2 was obtained after seven years of experimentation, managers could accept the null hypothesis with only a 0.13 chance of a type II error (i.e., incorrectly accepting the null hypothesis that h^2 is = 0 when it is actually 0.22). At ten years, β (i.e., 1-power) would be 0.03 for the same number of spatial replicates. Figure 5 shows how power (1- β) changes with the number of spatial areas and duration. Managers could thus choose a design that minimized the chance of a type II error to their satisfaction in an acceptable time frame. Then regardless of the outcome of the experiment, they would be confident in their conclusion about the relative importance of size-selective fishing. That conclusion would be relevant to design of remedial measures as well as interpretation of past decreases in body weight.

FACTORS AFFECTING STATISTICAL POWER

Several issues need to be addressed in order to make our proposed experimental design work in the field. Our sensitivity analysis indicates that mean selection differential (*D*) can strongly influence statistical power. For example, only values of *D* of 0.20 kg and greater yielded power >0.8 in less than ten years when there were four spatial replicates (Figure 7).

Reversing size selectivity of gill nets has potential short-term ramifications for economic value of the catch. Nets selective for smaller-than-average-size fish might selectively catch female pink salmon which tend to have smaller girths than males (Todd and Larkin 1971). Thereby, larger abundance of spawners and reduced allowable catches would be required to compensate for the higher gear selectivity for females. Furthermore, regulations that could increase the selectivity of nets for smaller fish would also make the gear less efficient so that it caught fewer fish per unit effort (Riedel 1963) and fewer fish of larger-sized, more valuable species such as sockeye salmon (*O. nerka*) (Wilson and Pearse 1984; Wilson and Andrews 1987). However, nets could be made more efficient and selective for smaller-than-average-size fish by requiring the use of monofilament nets with smaller mesh sizes than nets currently used.

Straying of adult pink salmon from natal streams, especially between areas with contrasting treatments, could also decrease power. Straying between areas with contrasting treatments both before and after selective fishing could produce a negative bias in the measured response to selection (i.e., $W_{i,t}$-$W_{i,t-2}$). For example, in samples of $W_{i,t}$ in selectively fished areas, smaller-sized strays from nonselectively fished areas would replace larger-sized strays from selectively fished areas. Biases in measurements of variables could result in a biased estimate of h^2, increased residual variance, and reduced power. Thus, it is important that managers choose replicates that reduce the effects of straying on the statistical performance of the experiment.

Our estimates of residual variance could be larger than those obtained in an experiment if it took place among stocks in one, rather than two statistical areas (from which baseline variances were estimated). Residual variance tends to increase as the geographic range among spatial replicates increases because as the range increases, fewer spatial and temporal locations are shared by stocks (Walters et al. 1988, 1989). For instance, variance in $e_{i,t}$ was larger when model (1) was regressed with data from statistical areas 6, 7, and 8 (SD=0.059 kg), than with just areas 7 and 8 (SD=0.046 kg) (McAllister 1990).

COMPARISONS WITH OTHER EXPERIMENTAL HARVEST EXAMPLES

Relative to most other analyses of proposed large-scale fishing experiments, the results from this analysis suggest a shorter duration experiment can achieve high power. For example, Allen and Kirkwood (1976) reported that with a 20% coefficient of variation (CV) in an index of abundance of a whale population, it would take 13 years for managers to be able to detect with 0.88 probability a 5% decrease in abundance per year. Furthermore, after 13 years, abundance would be reduced to 54% of the original amount. The authors concluded that such a result would be unacceptable. For an experiment currently under way that tests hypotheses on the effects of different fishing techniques on demersal fish production, Sainsbury (1988) reported that learning periods longer than 12 years would enable good model discrimination. Walters and Collie (1989) reported the results of an evaluation of a proposed experiment that is designed to determine the exploitable stock size of B.C. Pacific ocean perch, which do not recruit until ages 8-12. It would take 20 to 30 years to detect the effects of unrestrained fishing on recruitment if no stock collapse occurred.

Generally, the uniform, two-year age at maturity, large number of separate breeding populations of pink salmon on the B.C. coast, and semelparous and anadramous characteristics of pink salmon facilitate temporal and spatial replication and experimental manipulation. Thus the current proposed experiment on B.C. pink salmon offers more opportunity for learning than is typical for large-scale fishing experiments.

There are a number of practical difficulties for implementation such as finding at least three suitable spatial replicates and developing appropriate gear regulations for them. The practicality of a large-scale experiment can be further assessed by a more detailed study of the terminal fisheries for pink salmon stocks and by small-scale experiments with different types of gill nets to assess their size-selectivity for smaller-than-average-size pink salmon. The results of our sensitivity analyses should provide managers with general guidelines for developing the proposed experimental harvest strategy.

ACKNOWLEDGMENTS

We thank Jeremy Collie, Mike Henderson, Scott Forbes, Mike Lapointe, and Jim Woodey for useful discussions. We are grateful to Mike Henderson and Terry Beacham for providing us with the required data and to Richard Routledge, Mike Lapointe, Scott Forbes, Judith Anderson, and Mike Henderson for very helpful comments on a more detailed version of this manuscript. We also thank Miguel Pascual for helpful comments on the current manuscript.

REFERENCES

Allen, K.R. and G.P. Kirkwood. 1976. Is Experimental management of whale stocks practicable? Comment on ACMRR/MM/SC/ 57,61,82. FAO Scientific Consultations on Marine Mammals. Bergen, Norway. Summarized in K.R. Allen. 1980. Conservation and management of whales. Univ. of Washington Press, Seattle, WA 107 p.

Beacham, T.D. 1984. Catch, escapement and exploitation of pink salmon in British Columbia, 1951-1981. Can. Tech. Rep. Fish. Aquat. Sci. 1276, 215 p.

Bilton, H. 1973. Relationship between egg size and fish size in pink salmon (*Oncorhynchus gorbuscha*) from Lower Babine River in 1966 and 1967. Fish. Res. Bd. Man. Rep. 1235, 5 p.

Cohen, J. 1988. Statistical power analysis for the behavioral sciences. 2nd edn. L. Erlbaum Associates, Hillsdale, New Jersey, 567 p.

Dixon, W.J. and F.J. Massey, Jr. 1983. Introduction to statistical analysis. 4th edition, McGraw Hill Book Co., New York, NY. 678 p.

Falconer, D.S. 1989. Introduction to quantitative genetics. 3rd. edn. Longman Scientific and Technical. New York.

Foerster, R.E. and A.L. Pritchard. 1941. Observations on the weight relation of egg content to total length and weight in the sockeye salmon (*Oncorhynchus nerka*) and the pink salmon (*O. gorbuscha*). Trans. Roy. Soc. Can. 35:51-60.

Healey, M.C. 1986. Optimum size and age at maturity in Pacific salmon and effects of size-selective fisheries, p. 39-52. In D J. Meerburg [ed.] Salmonid age at maturity. Can. Spec. Publ. Fish. Aquat. Sci. 89.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Monogr. 54:184-211.

McAllister, M.K. 1990. Decision and power analysis of large-scale fishing experiments designed to test the gear selectivity hypothesis on British Columbia pink salmon (*Oncorhynchus gorbuscha*). Master's thesis, Natural Resource Management Program, Simon Fraser Univ., Burnaby, B.C. 179 p.

McAllister, M.K. and R.M. Peterman. 1991. Decision analysis of a large-scale fishing experiment designed to test the gear selectivity hypothesis on British Columbia pink salmon. Can. J. Fish. Aquat. Sci. (submitted).

McAllister, M.K., D.M. Gillis, and R.M. Peterman. 1991. Statistical power analysis of a large-scale fishing experiment designed to test the gear selectivity hypothesis on British Columbia pink salmon (*Oncorhynchus gorbuscha*). Can. J. Fish. Aquat. Sci. (submitted).

Nelson, K. and M. Soule. 1987. Genetic Conservation of Exploited Fishes, p. 345-388. In N. Ryman and F. Utter. [ed.] Population genetics and Fishery Management. Sea Grant Program. Univ. of Washington Press. Seattle, WA.

Peterman, R.M. 1990. Statistical power analysis can improve fisheries research and management. Can. J. Fish. Aquat. Sci. 47:2-15.

Ricker, W.E. 1981. Changes in the average size and average age of Pacific salmon. Can. J. Fish. Aquat. Sci. 38:1636-1656.

Ricker, W.E. 1989. History and present state of the odd-year pink salmon of the Fraser River region. Can. Tech. Rep. Fish. Aquat. Sci. 1702.

Ricker, W.E., H.T. Bilton and K.V. Aro. 1978. Causes of the decline in size of pink salmon (*Oncorhynchus gorbuscha*). Fish. Mar. Serv. Tech. Rep. 820, 93 p.

Riedel, D. 1963. Contribution to the experimental determination of the selection parameter of gill nets. Arch. Fischereiwiss 14:85-97.

Sainsbury, K.J. 1988. The ecological basis of multispecies fisheries and management of a demersal fishery in tropical Australia, p. 349-382. In J. A. Gulland. [ed.] Fish Population Dynamics. 2nd. edn. John Wiley and Sons Ltd. New York, NY.

Skud, B.E. 1973. Factors Regulating the production of pink salmon. Rapp. P. -V. Reun. Cons. Perm. Int. Explor. Mer. 164:106-112

Todd, I. and P.A. Larkin. 1971. Gill net selectivity on sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) of the Skeena River system, British Columbia. J. Fish. Res. Board Canada 28:821-842.

Toft, C.A. and P.J. Shea. 1983. Detecting community-wide patterns: estimating power strengthens statistical inference. Am. Nat. 122: 618-625.

Walters, C.J. and J.S. Collie. 1989. An experimental strategy for groundfish management in the face of large uncertainty about stock size and production, p.13-25. In R.J. Beamish and J.A. McFarlane [ed.] Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment. Can. Spec. Publ. Fish. Aquat. Sci. 108.

Wilson, K.H. and J.H. Andrew. 1987. The influence of gill net hang ratio on the catch of salmon in the Fraser River. Can. Tech. Rep. Fish. Aquat. Sci. 1516, 16 p.

Wilson, K.H. and B.C. Pearse. 1984. The relative selection of three mesh sizes of Fraser River sockeye gill nets for chinook salmon. Can. Tech. Rep. Fish. Aquat. Sci. 1250, 71p.

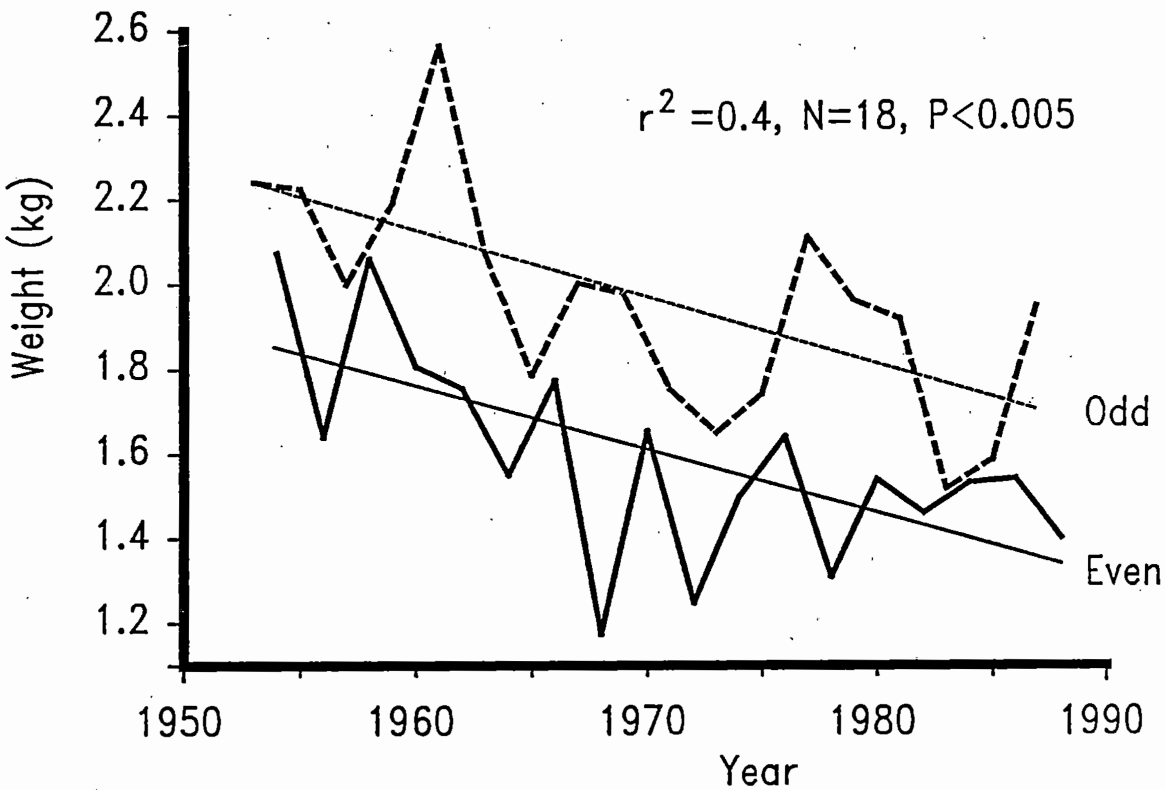


Figure 1. Mean adult weight of pink salmon in even and odd-numbered years in Statistical Area 7 for years 1953-1988. Values shown for r^2, N, and P are the same for each stock.

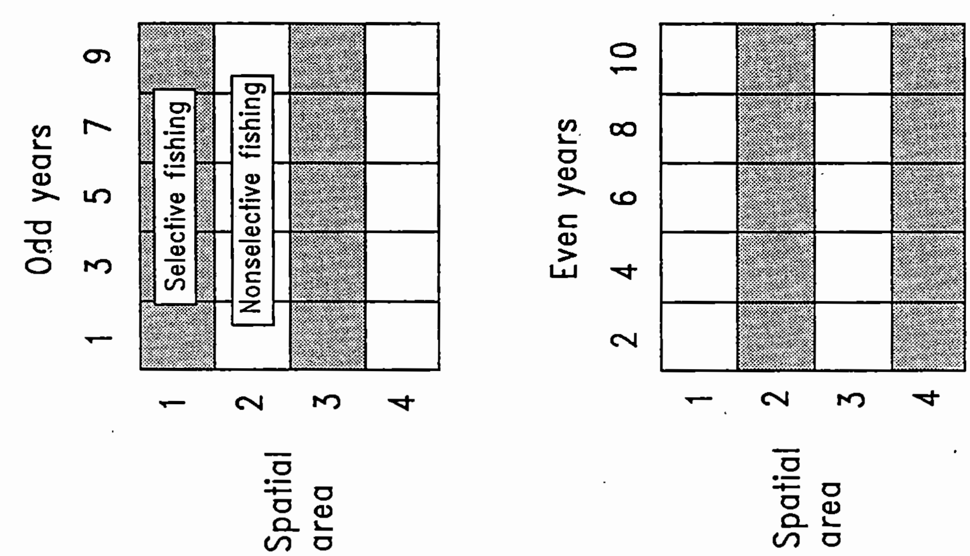


Figure 2. Diagram of a block experimental design. This design has a duration of ten years and four spatial areas containing both even and odd-number year stocks of pink salmon. Selective and nonselective fishing are initiated in years one and two.

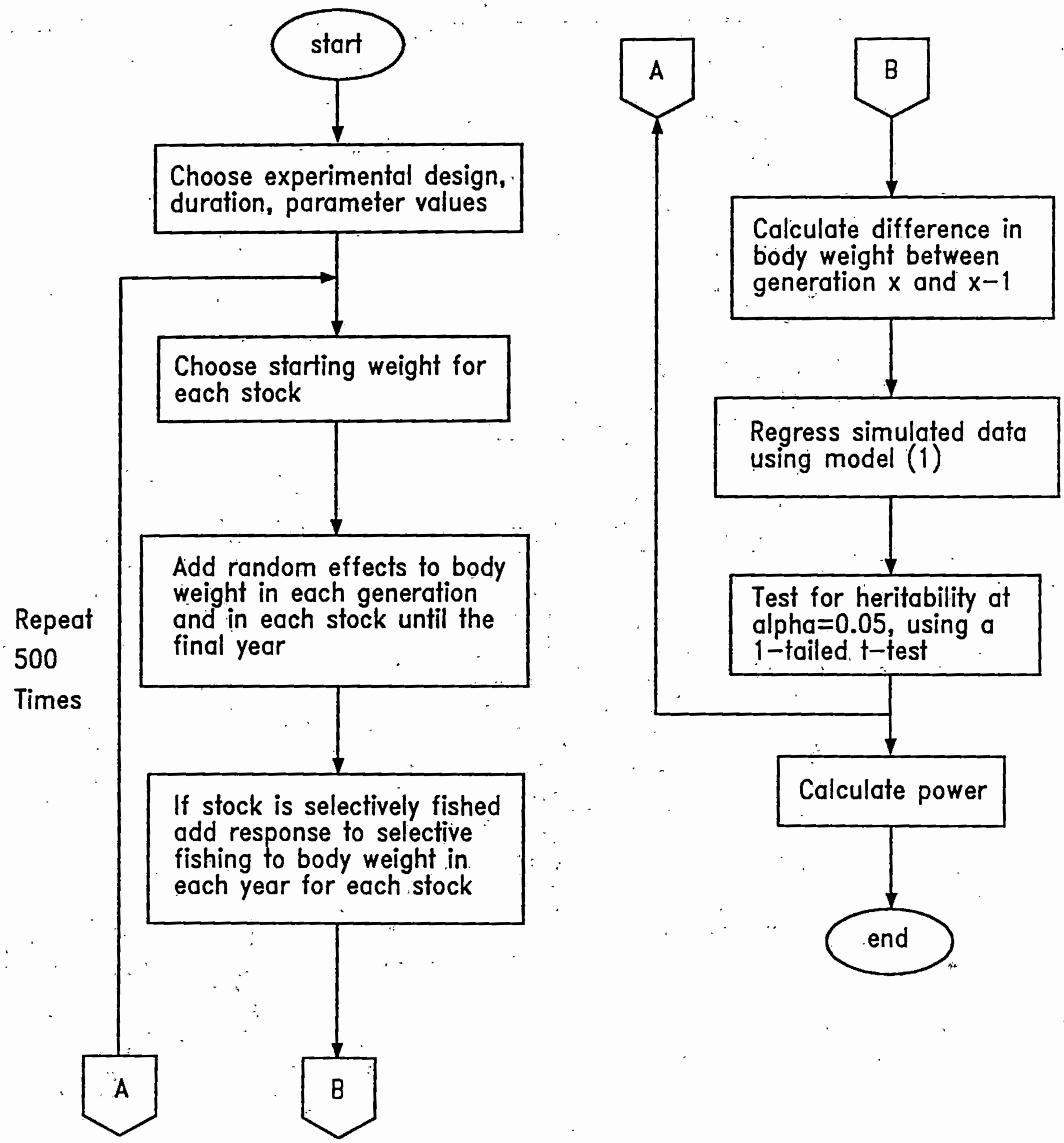


Figure 3. Flow chart showing the basic steps in the empirically-based Monte Carlo procedure that was employed to estimate the statistical power of alternative experimental designs in tests for heritability of growth rate.

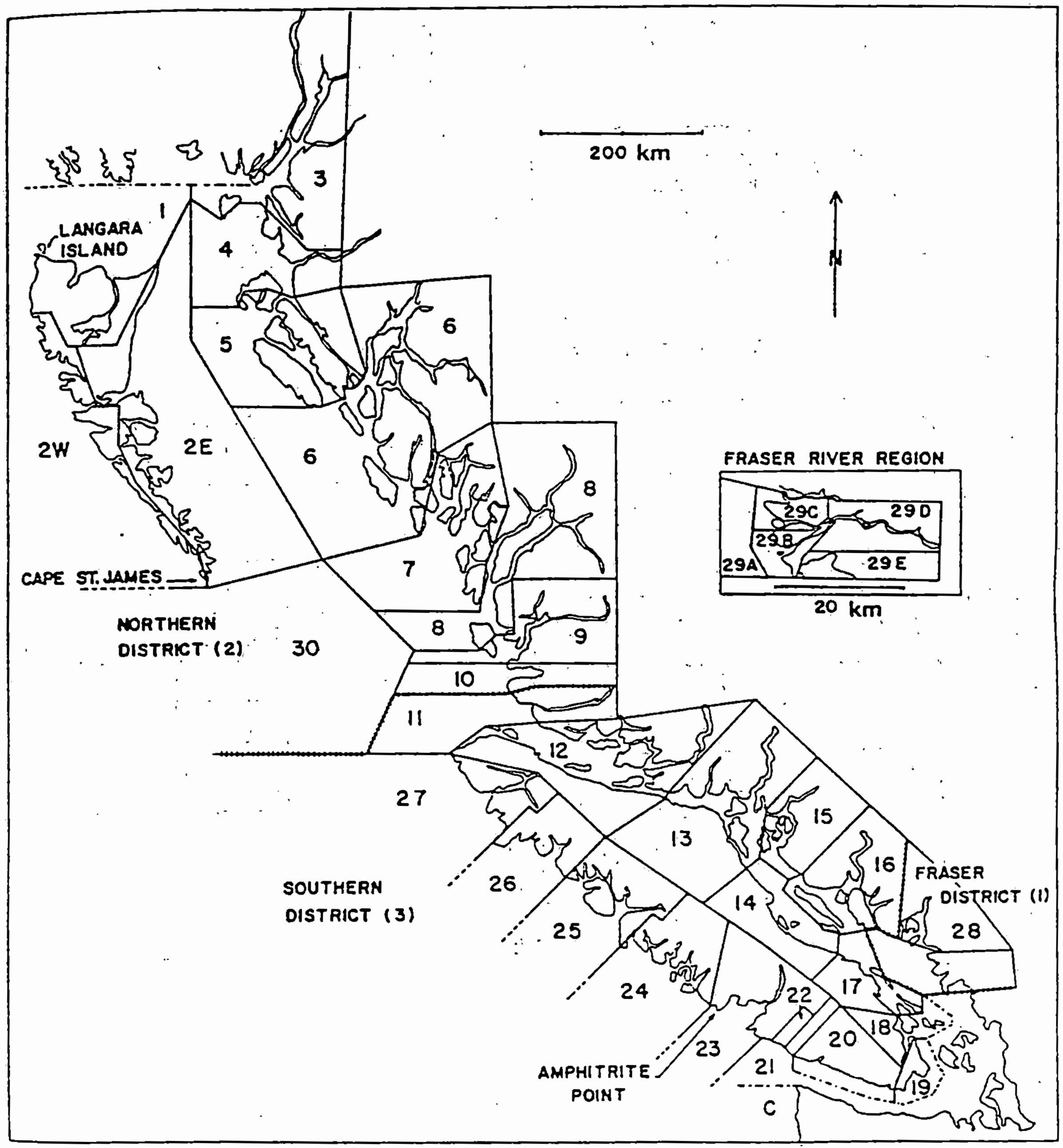


Figure 4. Map showing the Statistical Areas in B.C. (from Ricker 1981).

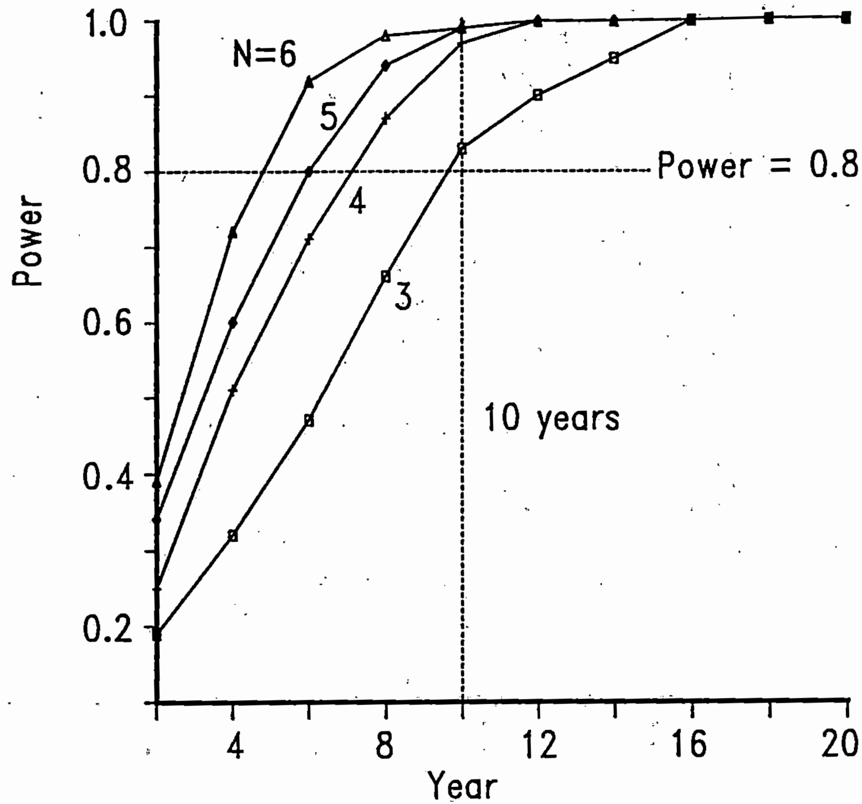


Figure 5. Statistical power versus time for block designs with 3, 4, 5, and 6 spatial replicates. Baseline parameter values were: heritability of growth rate=0.22, mean selection differential=0.25 kg and variation in residual effects (SD=0.046 kg).

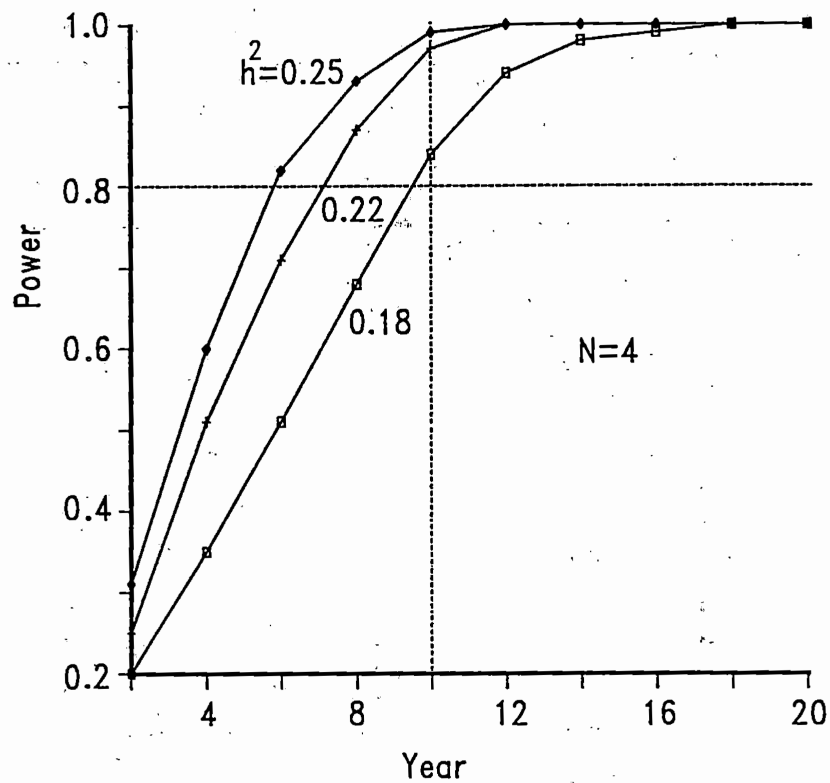


Figure 6. Statistical power versus time for block design with heritability =0.18, 0.22, 0.25. Baseline parameter values were: number of spatial replicates=4, mean selection differential=0.25 kg, and variation (SD) in residual effects =0.046 kg.

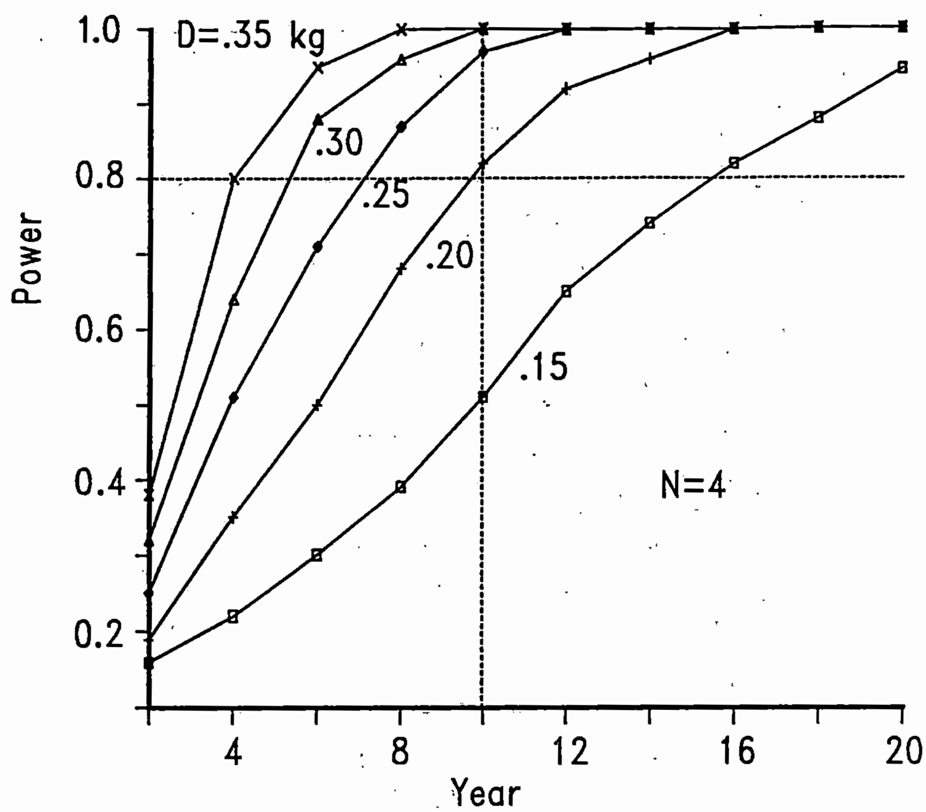


Figure 7. Statistical power vs time for block design with mean selection differential=0.15, 0.20, 0.25, 0.30 and 0.35 kg. Baseline parameter values were: number of spatial replicates=4, heritability of growth rate=0.22 and variation in residual effects (SD=0.046 kg).

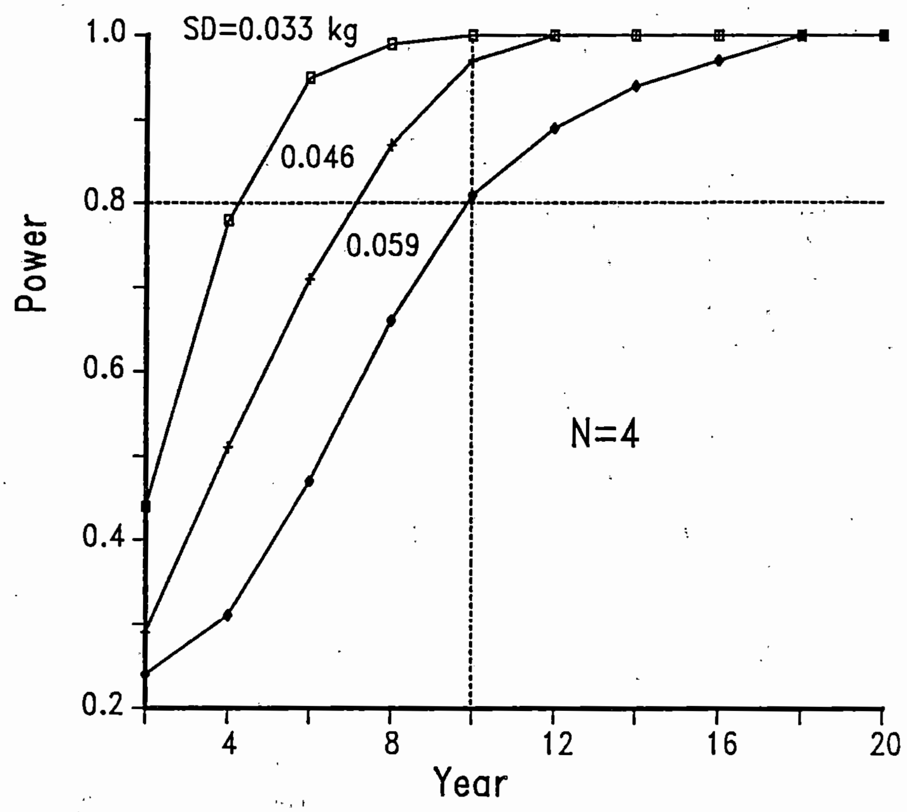


Figure 8. Statistical power versus time for block design with SDs for random effects unique to each stock =0.033, 0.046, 0.059 kg. Baseline parameter values were: number of spatial replicates=4, heritability of growth rate=0.22, and mean selection differential=0.25 kg.

An Empirical Orthogonal Functions Analysis of Sea Surface Temperature Anomalies in the North Pacific Ocean and Cross Correlations with Pink Salmon (*Oncorhynchus gorbuscha*) Returns to Southern Alaska

T. M. Willette and R.T. Cooney

School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
Fairbanks, Alaska 99775

An empirical orthogonal functions analysis of sea surface temperature anomalies (SST) in the North Pacific Ocean (1947-1987) resulted in four significant ($p<.05$) empirical functions describing 58% of the total field variance. The first two significant empirical functions (T1 & T2) describe most of the variability in SST anomalies in the Gulf of Alaska. Spectral analyses of the amplitude time series (ATS) from these empirical functions indicated significant ($p<.05$) cyclicity at periods of 19 and 44 months in T1 and 26 and 66 months in T2. Multiple comparison of variances and dependent means tests indicated that the biennial oscillation in T2 was phase-locked to the annual cycle. This results in significantly greater ($p<.001$) SST during summer in odd- compared with even-numbered years.

An empirical orthogonal functions analysis of pink salmon returns (brood years 1960-1986) to southeast Alaska, Prince William Sound, and Kodiak resulted in significant ($p<.05$) empirical functions accounting for 67% and 60% of the variability in the odd- and even-broodline returns, respectively. The ATS from the empirical functions describing pink salmon returns were cross-correlated with the ATS from T1 and T2. The ATS from the odd broodline was significantly correlated with the ATS from T1 during the spring of the brood year ($p<.01$) and during the spring of the fry outmigration ($p<.05$). The ATS from the odd broodline was also significantly correlated ($p<.05$) with the ATS from T2 during the winter period of egg incubation. The ATS from the even broodline was significantly correlated ($p<.05$) with the ATS from T2 during the spring, summer, and autumn of the fry outmigration.

These investigations indicate that a common factor affects pink salmon population dynamics in these three regions of southern Alaska. This common factor appears to be the effect of large-scale ocean temperature anomalies in the Gulf of Alaska on the marine survival of the fish. Odd- and even-broodline pink salmon returns are related to different patterns of ocean temperature variability at different stages in the lifecycle. These differences may be related to the biennial oscillation in ocean temperatures in the Gulf of Alaska.

Environmental conditions appear to have a strong influence on recruitment success among many fish species and stocks in the northeast Pacific Ocean (Hollowed et al. 1987). Among different regions of Alaska, salmon catches exhibit similar time trends suggesting that underlying biological, environmental, or economic processes drive salmon catch dynamics (Quinn and Marshall 1989). Ocean temperatures have been related to the growth and survival of salmon in several regions (Blackbourn 1978; Helle 1979; Donnelly 1983; Quinn and Marshall 1989). The present study was conducted to determine if large-scale ocean temperature anomaly patterns were related to pink salmon returns (catch plus escapement) to southern Alaska. Empirical orthogonal functions (EOF) analysis (Lorenz 1959) was used to describe variability in sea surface temperature (SST) anomalies in the North Pacific Ocean and variability in pink salmon returns to southern Alaska. EOF analysis is an effective method for extracting a signal from noisy data. The amplitude time series resulting from the EOF analyses of the SST anomalies and pink salmon returns were cross correlated.

METHODS

EMPIRICAL ORTHOGONAL FUNCTIONS ANALYSIS OF SEA SURFACE TEMPERATURE DATA

The data used in this analysis were a 41-year record (1947-1987) of sea surface temperatures on a 5° x 5° grid (35°-55°N,160°E-125°W). Temperature anomalies were calculated by subtracting the monthly mean at each grid point from the raw data. In time series analysis, it is assumed that the data are stationary, i.e., the statistical properties of the series do not change over time (Jenkins and Watts 1968). Sea surface temperature data contains low frequency variability that leads to a violation of this assumption (Davis 1976). To minimize this problem, a recursive 47-lag highpass filter with a half-power point of 86 months was used to remove the low frequency variability in the SST anomaly data.

EOF analysis was performed on the SST anomaly data. The EOFs or principal components are the eigenvectors of a finite-dimensional covariance matrix (Lorenz 1959). Each EOF is uncorrelated with the others at zero lag. The variance in the each EOF is described by its eigenvalue. The temporal variability in each EOF is described by its amplitude time series (ATS). The sampling errors associated with each EOF were estimated as described by North et al. (1982). The effective number of independent observations (N_{eff}) at each grid point was estimated as described by Trenberth (1984). The error bars about the eigenvalues were calculated using the mean N_{eff} for the entire SST anomaly field.

ANALYSES OF THE AMPLITUDE TIME SERIES FROM THE EOFS

Three additional analyses were conducted on the ATS from two EOFs that described most of the temperature variability in the Gulf of Alaska. The power spectra of the ATS were estimated to determine the principal frequencies of variability. The spectra contain 6.0 degrees of freedom at a bandwidth of .0076 cycles $month^{-1}$. A red noise null hypothesis was used to determine the significance of spectral peaks (Trenberth 1975). The first order autoregressive parameter for each ATS was used to calculate the theoretical red noise spectrum for the significance tests (Jenkins and Watts 1968). The lower 95% confidence intervals about the spectral estimates were calculated as described by Jenkins and Watts (1968). Spectral estimates were considered significant only if their lower 95% confidence interval exceeded red noise.

A multiple comparison of variances test (Zar 1984) was conducted on each ATS to determine if the variance within each season was different from the overall variance in the time series. A dependent means test (Johnson 1980) was conducted to determine if the seasonal mean amplitudes in odd and even-numbered years were different. In these analyses, the seasons were defined as follows: winter = January, February, March; spring = April, May, June; and so on.

EMPIRICAL ORTHOGONAL FUNCTIONS ANALYSIS OF PINK SALMON RETURNS AND CROSS CORRELATIONS WITH SEA SURFACE TEMPERATURES

Pink salmon (*Oncorhynchus gorbuscha*) commercial catch and escapement (brood years 1960-1986) from Kodiak, Prince William Sound, and southeast Alaska were used in this analysis. Significant returns of hatchery-produced pink salmon occur in Prince William Sound and to lesser extent in southeast Alaska and Kodiak. The return of wild pink salmon was estimated by subtracting estimates of hatchery returns from the total return.

The return data were standardized by subtracting the mean from each observation and dividing by the standard deviation. The number three was added to each standardized return estimate to eliminate any negative values. The skewness and kurtosis divided by their standard errors, respectively, were estimated for the standardized, natural logarithm and square root transformed return data. These estimates were made using the data from all three regions and both broodlines combined.

EOF analysis was conducted on the return data from the odd and even broodlines, separately. The ATS resulting from these analyses were cross correlated with the ATS from an EOF analysis of unfiltered SST anomalies. The spatial structures of the EOFs from the unfiltered SST anomalies (Davis 1976) are very similar to those from the highpass filtered SST anomalies (Figure 2). Seasonal mean amplitudes from the unfiltered SST EOFs were used in the cross correlations. The N_{eff} for correlations was estimated as described by Trenberth (1984).

RESULTS AND DISCUSSION

EMPIRICAL ORTHOGONAL FUNCTIONS ANALYSIS OF SEA SURFACE TEMPERATURE DATA

The EOF analysis of SST anomalies resulted in four significant EOFs ($p<.05$) describing 58% of the total field variance (Figure 1). The EOFs have been labelled in ascending order (T1 through T4) according to the amount of variance they explain. Several EOF analyses have been performed on SST data from the North Pacific Ocean (Davis 1976; Weare 1976; Davis 1978; Haney et al. 1983). In the present study, the notation used by Davis (1976) was employed. The spatial patterns of T1, T2, and T3 in the present study are the same as in Davis (1976); T4 in the present study is similar to Davis' T6 (Figure 2). T1 and T2 describe most of the variance in SST anomalies in the Gulf of Alaska. The characteristics of the ATS from T1 and T2 are examined in section b.

ANALYSES OF THE AMPLITUDE TIME SERIES FROM THE EOFS

Spectral analyses of the ATS from T1 and T2 indicated significant spectral estimates ($p<.05$) at periods of 19 and 44 months and 26 and 66 months, respectively (Figure 3). Significant spectral estimates also occurred in each of the spectra at higher frequencies, but these involve a small amount of variance.

The multiple comparison of variances test on the ATS from T2 indicated that the variance in winter was significantly lower ($p<.05$) than the overall variance in the time series (Table 1). The variance during summer in the ATS from T2 was nearly significantly greater ($p=.05$) than the overall variance in the time series. The dependent means test indicated that the amplitudes in T2 were significantly greater ($p<.001$) during summer in odd-numbered years compared with even-numbered years (Table 1).

The combined results of these analyses indicate that T2 contains a significant biennial oscillation that is phase-locked to the annual cycle. This oscillation results in warmer ocean temperatures in the Gulf of Alaska during the summers of odd-numbered years compared to even-numbered years on average. The mean temperature difference between odd- and even-numbered years is about 0.3°C during summer in the Gulf of Alaska. This biennial oscillation in ocean temperatures is probably caused by a biennial oscillation in sea level pressure that affects wind velocity over the ocean (Trenberth and Shin 1984). Biennial oscillations in the ocean and atmosphere have been detected in many parts of the world (Reed 1961; Landsberg 1962; Veryard 1961; Landsberg et al. 1963; Angell et al. 1969; Trenberth 1975; Brier 1978; Walsh and Mostek 1980; Trenberth 1980; Rasmusson et al. 1981; White 1985; Rasmusson et al. 1990; Kerr 1990).

EMPIRICAL ORTHOGONAL FUNCTIONS ANALYSIS OF PINK SALMON RETURNS AND CROSS CORRELATIONS WITH SEA SURFACE TEMPERATURES

An examination of skewness and kurtosis indicated that a natural logarithm transformation resulted in a near normal distribution of the return data. All subsequent analyses were conducted on the natural logarithm transformed return data. The EOF analyses of the odd- and even-broodline pink salmon returns each resulted in one significant EOF ($p<.05$) describing 67% and 60% of the variance, respectively (Figure 4). The returns in Prince William Sound were more highly correlated with the EOFs than the returns to the other two regions (Table 2). These results indicate that a common factor causes similar changes in pink salmon population size among these three regions.

Cross correlations between the SST EOFs and pink salmon return EOFs resulted in several significant ($p<.05$) correlations (Figure 5). At the $p=.01$ significance level, the ATS from the odd broodline was correlated with the ATS from T1 during the spring of the brood year. Also, the ATS from the even broodline was correlated with the ATS from T2 during the spring and autumn of the fry outmigration. In a previous study, similar patterns of correlation were found between an index of the marine survival of pink salmon in Prince William Sound and ocean temperatures at standard oceanographic depths near the mouth of Resurrection Bay, Alaska (Willette 1985). These results combined with those from the present study suggest that changes in marine survival from year to year are similar among these three regions of southern Alaska. This may be the common factor causing similar changes in pink salmon population size among these three regions.

An association between pink salmon returns and ocean temperatures during the early marine period is not unexpected (Blackbourn 1978; Helle 1979; Donnelly 1983; Quinn and Marshall 1989). Size-selective predation appears to be the principal cause of mortality among pink salmon during the early marine period (Parker 1971). Water temperature has a strong effect on the growth of juvenile pink salmon (Martin 1966; Kepshire 1976). Higher water temperature may accelerate growth and shorten the period when fry are vulnerable to predators. SST anomalies during spring indicate changes in the timing of the seasonal increase in temperature. Fry outmigrating after the seasonal increase in ocean temperature generally have a higher survival (Taylor 1988). These processes acting on a regional scale appear to account for the correlation between pink salmon returns and SST anomalies in the Gulf of Alaska during the early marine period. This correlation also indicates that large-scale temperature anomalies in the Gulf of Alaska affect temperatures in the coastal zone or that similar processes affect temperatures throughout the region.

An association between odd-broodline returns and SST anomalies during the spawning migration of the parent population is unexpected. Ocean conditions at this time in the life cycle may affect migratory timing or gonad development. Warmer ocean temperatures may result in earlier migratory timing (Burgner 1981) and reduced egg mortality. Eggs from odd-broodline pink salmon are more susceptible to low temperature mortality during early development than eggs from even-broodline fish (Beacham and Murray 1988). Thus, warm ocean temperatures may result in earlier spawning and reduced egg morality, because the eggs pass through the critical early developmental stage before the onset of winter. This mechanism may be more likely to operate near the northern range of odd-broodline pink salmon. Changes in adult migratory timing may also cause changes in fry outmigration timing that affect marine survival. Adult migratory timing is related to fry outmigration timing (Gharrett and Jones 1987; Joyce and Smoker 1987), and fry outmigration timing is related to marine survival (Taylor 1980; Taylor 1988). Warmer ocean temperatures may also cause increased growth of adult pink salmon resulting in larger eggs or eggs with greater caloric content (Yastrebkov 1966; Beacham et al. 1988). Larger eggs result in larger fry with higher growth rates (Yastrebkov 1966). This may confer an advantage to fry during the first few days or weeks of marine residence when mortality is very high (Bax 1983). Further studies are needed to determine if interannual changes in adult migratory timing or egg size are correlated with the survival of progeny.

It is not clear how a biennial oscillation in ocean temperatures in the Gulf of Alaska may affect pink salmon. Age-at-maturity is relatively fixed at two years in pink salmon (Pritchard 1939; Bilton and Ricker 1965), so the two broodlines experience conditions in odd- and even-numbered years at different stages in the lifecycle. On average over many generations, odd-broodline pink salmon experience slightly lower ocean temperatures during the early marine period and slightly higher temperatures during the adult migratory period compared to even-broodline pinks. These differences in ocean temperature between odd- and even-numbered years are small (0.3°C). The effect this may have in maintaining the age-at-maturity at two years requires further study.

CONCLUSIONS

1. There is a significant biennial oscillation ($p<.05$) in sea surface temperatures in the Gulf of Alaska. The cycle results in significantly warmer ($p<.001$) sea surface temperatures during summer in odd-compared with even-numbered years.

2. Pink salmon returns to southeast Alaska, Prince William Sound, and Kodiak exhibit significant common modes of variability ($p<.05$) that appear to be due to similar changes in marine survival from year to year in these three regions.

3. Returns of odd- and even-broodline pink salmon are significantly correlated ($p<.05$) with different sea surface temperature anomaly patterns in the North Pacific Ocean at different stages in the life cycle. These differences may be related to the biennial oscillation in ocean temperatures in this region.

REFERENCES

Angell, J.K., J. Korshover and G.F. Cotten. 1969. Quasi-biennial variations in the "centers of action". Mon. Wea. Rev. 97: 867-872.

Bax, N.J. 1983. Early marine mortality of marked juvenile chum salmon released into Hood Canal, Puget Sound, Washington, in 1980. Can. J. Fish. Aquat. Sci. 40: 426-435.

Beacham, T.D. and C.B. Murray. 1988. Variation in developmental biology of pink salmon (*Oncorhynchus gorbuscha*) in British Columbia. Can. J. Zool. 66: 2634-2648.

Beacham, T.D., R.E. Withler, C.B. Murray, and L.W. Barner. 1988. Variation in body size, morphology, egg size, and biochemical genetics of pink salmon in British Columbia. Trans. Amer. Fish. Soc. 117(2): 109-125.

Bilton, H.T. and W.E. Ricker. 1965. Supplementary checks on the scales of pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*). J. Fish. Res. Board Can. 22: 1477-1489.

Blackbourn, D.J. 1978. An analysis of the factors accounting for variations in the marine survival of Fraser pink and other North American pink and chum stocks. In: J.C. Mason (ed.), Northeast Pacific pink and chum salmon workshop, 488p.

Brier, G.W. 1978. The quasi-biennial oscillation and feedback processes in the atmosphere-ocean-earth system. Mon. Wea. Rev. 106: 938-946.

Burger, R.L. 1981. Predicting sockeye run timing with temperature data. Coast. Ocean. and Climatology News. 2(4): 42-43.

Davis, R.E. 1976. Predictability of sea surface temperature and sea level pressure over the North Pacific Ocean. J. Phys. Oceanogr. 6: 249-266.

Donnelly, R.F. 1983. Factors affecting the abundance of Kodiak archipelago pink salmon (*Oncorhynchus gorbuscha*). Ph.D. dissertation, University of Washington, Seattle, Washington.

Gharrett A.J. and M.S. James. 1987. Discrete emigration times of temporally distinct subpopulations of pink salmon. In: Phil Rigby (ed.), Proceedings of the 1987 Northeast Pacific pink and chum workshop p 121.

Haney, R.L., B.H. Houtman, W.H. Little. 1983. The relationship between wind and sea surface temperature anomalies in the mid-latitude North Pacific Ocean. Atmosphere-Ocean 21(2):168-186.

Helle, J.H. 1979. Influence of marine environment on age and size at maturity, growth, and abundance of chum salmon, *Oncorhynchus keta*, from Olsen Creek, Prince William Sound, Alaska. Ph.D. dissertation, Oregon State University, Corvalis, Oregon, 118 p.

Hollowed, A.B., K.M. Bailey, W.S. Wooster. 1987. Patterns in recruitment of marine fishes in the northeast Pacific Ocean. Biol. Oceanogr. 5: 99-131.

Jenkins, G.M. and D.G. Watts. 1968. Spectral Analysis and its Applications. Holden-Day, San Francisco, California.

Johnson, R.R. 1980. Elementary Statistics. Duxbury Press, Belmont, California.

Joyce, J.E. and W.W. Smoker. 1987. Phenotypic variation in development rate in pink salmon. In: Proceedings of the 1987 Northeast Pacific Pink and Chum Workshop p 122.

Kepshire, G.M. 1976. Bioenergetics and survival of chum (*Oncorhynchus keta*) and pink (*O. gorbuscha*) salmon in heated seawater. Ph.D. dissertation, Oregon State University, Corvalis, Oregon.

Kerr, R.A. 1990. The climate system as a ticking clock. Science 249: 1246-1247.

Landsberg, H.E. 1962. Biennial pulses in the atmosphere. Beitr. Phys. Atmos. 35: 5184-5194.

Landsberg, H.E., J.M. Mitchell, H.L. Crutcher and F.T. Quinlan. 1963. Surface signs of the biennial atmospheric pulse. Mon. Wea. Rev. 91: 549-556.

Lorenz, E.N. 1959. Empirical orthogonal functions and statistical weather prediction: report No. 1, Statistical Forecasting Project, Dept. of Meteorology, MIT.

Martin, J.W. 1966. Early sea life of pink salmon. Alaska Department of Fish and Game Informational Leaflet 87: 111-125.

North, G.R., T.L. Bell, R.F. Cahalan and F.J. Moeng. 1982. Sampling errors in the estimation of empirical orthogonal functions. Mon. Wea. Rev. 110: 699-706.

Parker, R.R. 1971. Size-selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Bd. Can. 28: 1503-1510.

Pritchard, A.L. 1939. Homing tendency and age at maturity of pink salmon (*Oncorhynchus gorbuscha*) in British Columbia. J. Fish. Res. Board Can. 4: 233-251.

Quinn, T.J. and R.P. Marshall. 1989. Time series analysis: quantifying variability and correlation in SE Alaska salmon catches and environmental data, p. 67-80. In: R.J. Beamish and G.A. McFarlane (ed.) Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Pub. Fish. Aquat. Sci. 108.

Rasmusson, E.M., P.A. Arkin, W-Y Chen, and J.B. Jalickee. 1981. Biennial variations in surface temperature over the United States as revealed by singular decomposition. Mon. Wea Rev. 109: 587-598.

Rasmusson, E.M., X. Wang, C.F. Ropelewski. 1990. The biennial component of ENSO variability. J. Mar. Sys. 1: 71.

Reed, R.J., W.C. Campbell, L.A. Rasmussen and D.G. Rodgers. 1961. Evidence of a downward propagating annual wind reversal in the equatorial stratosphere. J. Geophys. Res. 66: 813-818.

Taylor, S.G. 1980. Marine survival of pink salmon fry from early and late spawners. Trans. Am. Fish. Soc. 109: 79-82.

Taylor, S.G. 1988. Inter- and Intra-annual survival of pink salmon (*Oncorhynchus gorbuscha*) returning to Auke Crek, Alaska in 1986 and 1987. In: Vol. I. APPRISE. Annual Report, SFOS APP87-100. School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, pp.545-572.

Trenberth, K.E. 1975. A quasi-biennial standing wave in the Southern Hemisphere and interrelations with sea surface temperature. Quart. J. R. Met. Soc. 101: 55-74.

Trenberth, K.E. 1980. Atmospheric quasi-biennial oscillations. Mon. Wea. Rev. 108: 1370-1377.

Trenberth, K.E. 1984. Some effects of finite sample size and persistence on meteorological statistics. Part I: autocorrelations. Mon. Wea. Rev. 112: 2359-2368.

Trenberth, K.E., and W-T K. Shin. 1984. Quasi-biennial fluctuations in sea level pressures over the northern hemisphere. Mon. Wea. Rev. 112: 761-777.

Veryard, R.G. and R.A. Ebdon. 1961. Fluctuations in equatorial stratospheric winds. Nature 189: 791-793.

Vidal, J. 1980. Physioecology of zooplankton, article 2: Effects of phytoplankton concentration, temperature, and body size on the development and molting rate of *Calanus pacificus* and *Pseudocalanus sp*. Mar. Biol. 56: 135-146.

Walsh, J.E. and A. Mostek. 1980. A quantitative analysis of meteorological anomaly patterns over the United States, 1900-1977. Mon. Wea. Rev. 108: 615-630.

Weare, B.C., A.R. Navato and R.E. Newell. 1976. Empirical orthogonal functions analysis of Pacific sea surface temperatures. J. Phys. Ocn. 6: 671- 678.

White, W.B. 1985. The resonant response of interannual baroclinic Rossby waves to wind forcing in the eastern midlatitude North Pacific. J. Phys. Oceanogr. 15: 403-415.

Willette, T.M. 1985. The effects of ocean temperatures on the survival of the odd- and even-year pink salmon (*Oncorhynchus gorbuscha*) populations originating from Prince William Sound, Alaska. M.S. Thesis, University of Alaska, Fairbanks, Alaska.

Yastrebkov, A.A. 1966. Effect of egg size upon size and growth rate of pink salmon larvae. Tr. Murm. Morsk. Biol. Inst. 12(16): 45-53. Fish. Res. Board Transl. No. 1822.

Zar, J.H. 1984. Biostatistical Analysis. Prentice-Hall, Englewood Cliffs, New Jersey, 718p.

Table 1. Results of the multiple comparison of variances and dependent means tests. Single and double asterisks indicate significance at the p=.05 & .001 levels, respectively.

EOF	Winter	Spring	Summer	Autumn
Variances				
T1	8.33	5.86	8.08	8.18
T2	3.10*	3.96	8.92	6.23
Means				
T1	-.62	-.52	.30	.58
T2	.29	.52	1.66**	.02

Table 2. Correlations between the significant empirical orthogonal functions and pink salmon returns to southern Alaska.

Broodline	SE AK	PWS	KODK
ODD	.769	.943	.728
EVEN	.686	.832	.796

SE AK - southeast Alaska
PWS - Prince William Sound
KODK - Kodiak Island

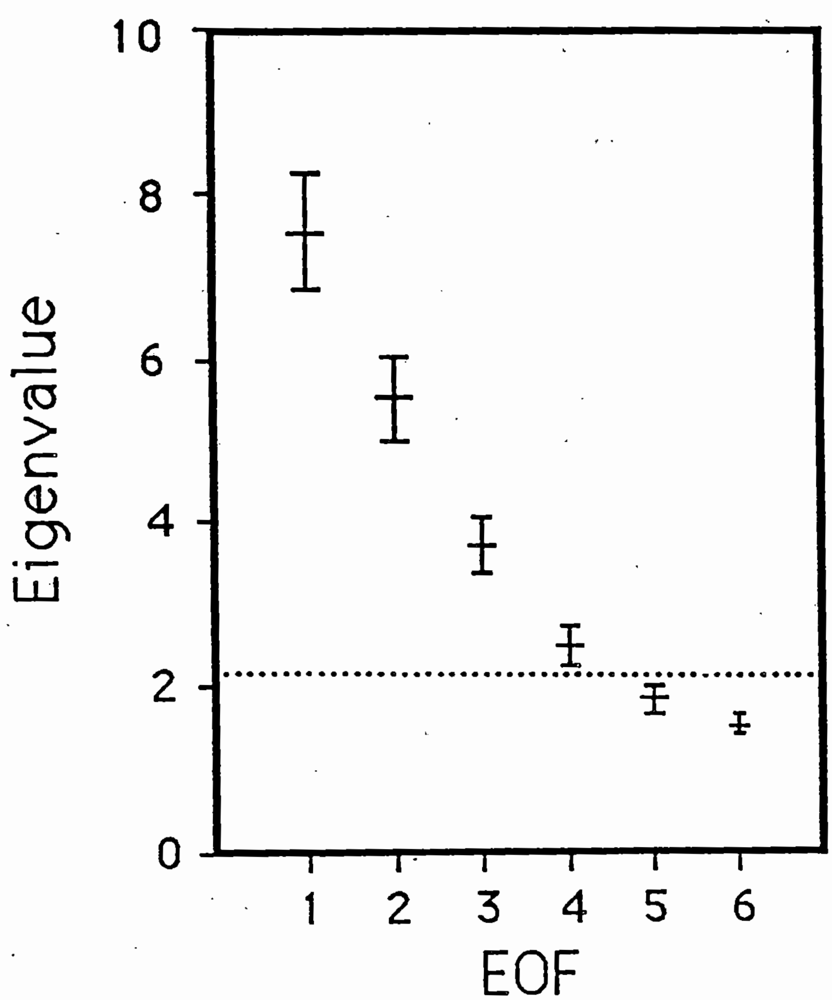


Figure 1. Eigenvalues from the EOF analysis of sea surface temperature anomalies. The error bars indicate the 95% confidence intervals for the eigenvalues. Eigenvalues above the dotted line are significantly different from each other.

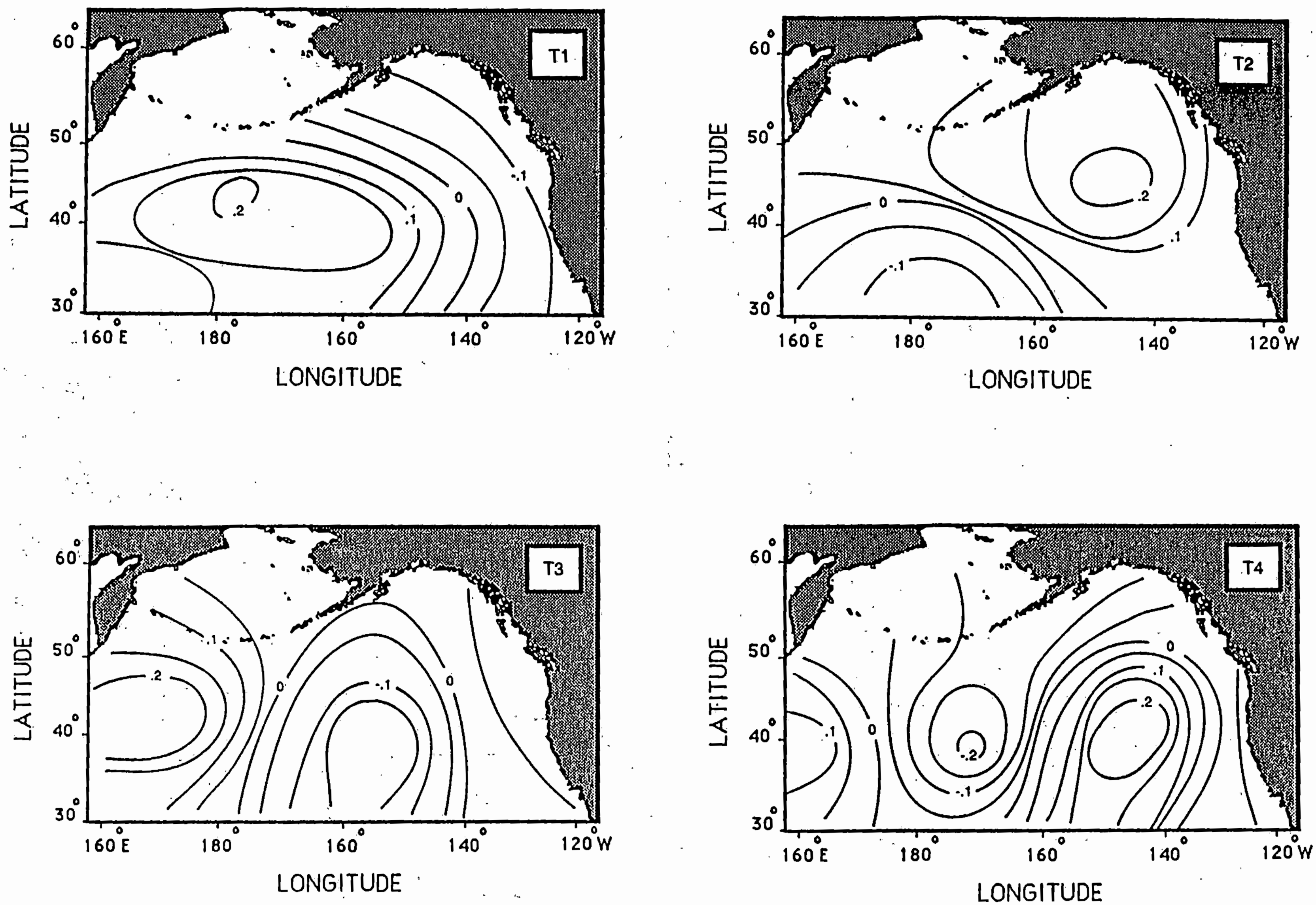


Figure 2. Spatial patterns of the eigenvectors from the four significant EOFs describing sea surface temperature anomalies.

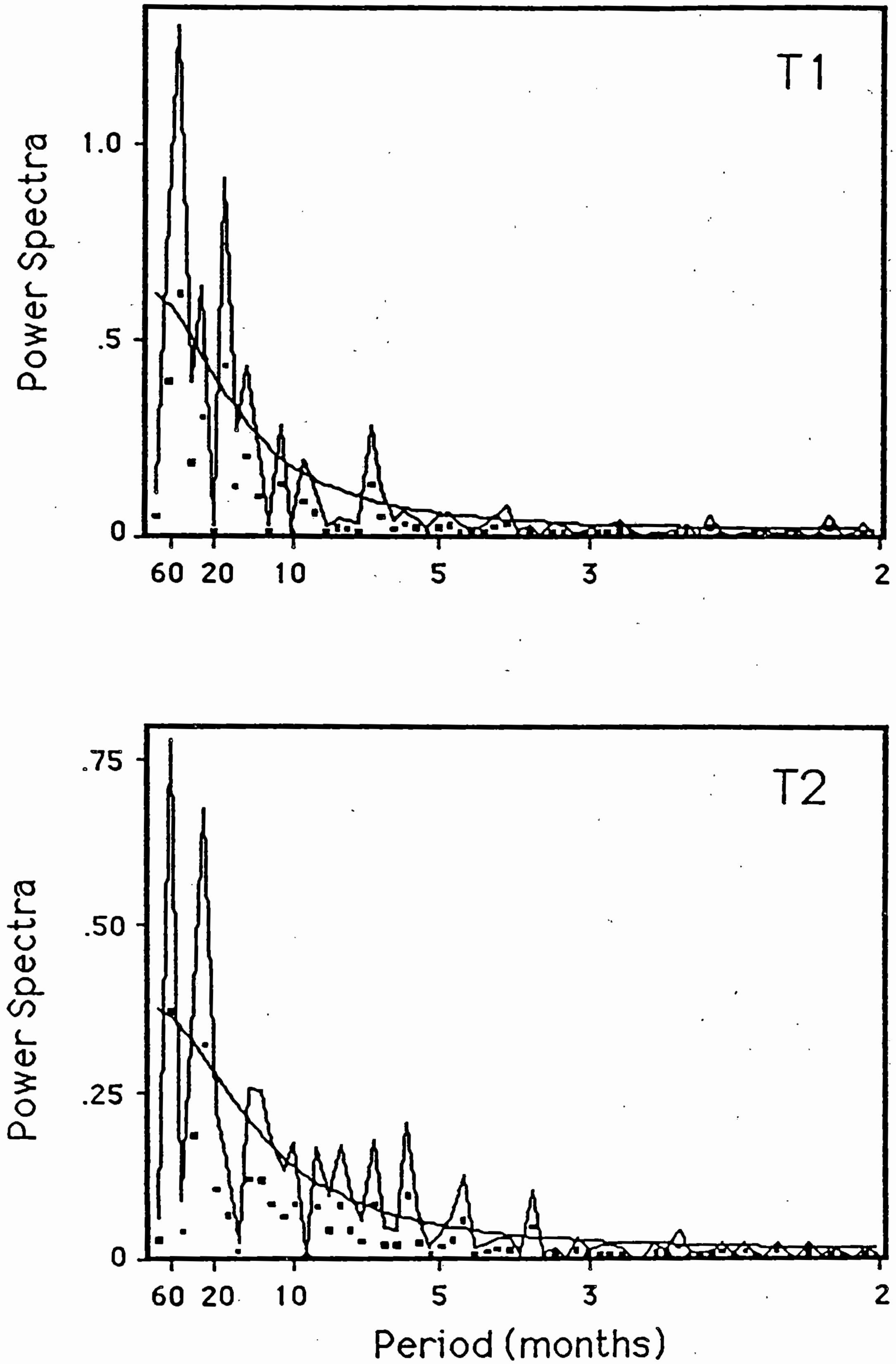


Figure 3. Power spectra of the ATS from T1 and T2. The solid line indicates the theoretical red noise spectrum for each ATS, and the squares indicate the lower 95% confidence interval about the spectral estimates.

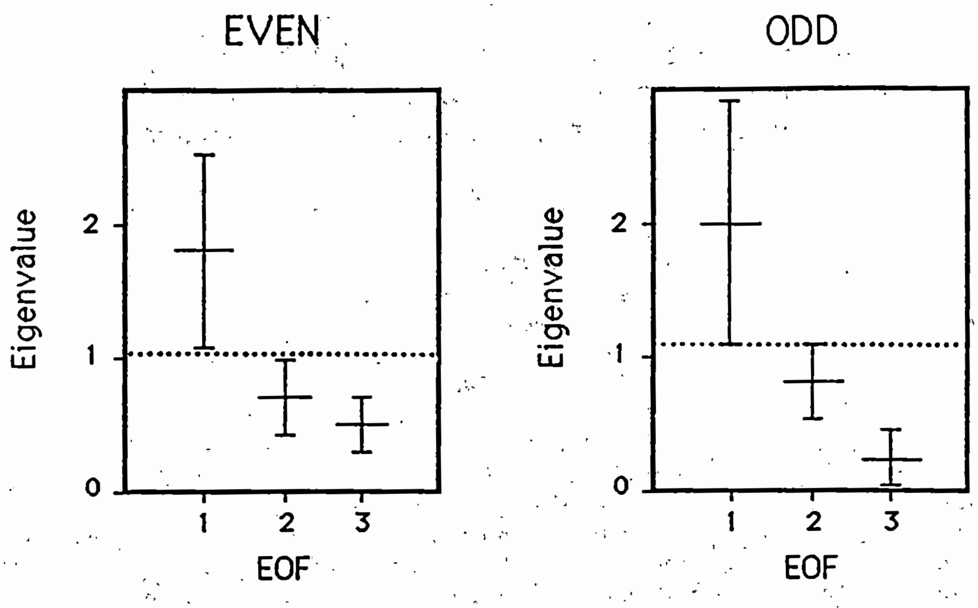


Figure 4. Eigenvalues from the EOF analysis of the odd- and even-broodline pink salmon returns. The error bars indicate the 95% confidence intervals for the eigenvalues. Eigenvalues above the dotted line are significantly different from each other.

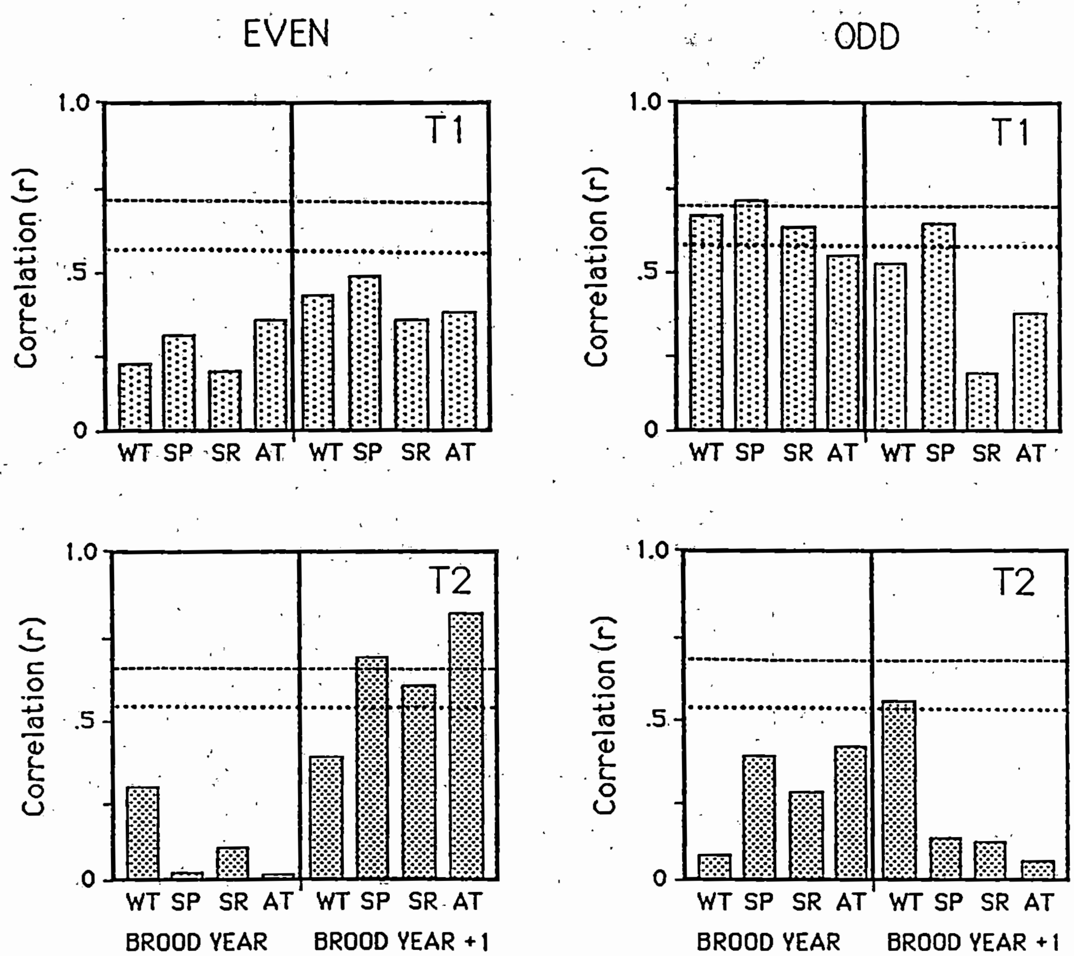


Figure 5. Cross correlations between unfiltered ATS from T1 and T2 and the ATS from the EOF analysis of the odd- and even-broodline pink salmon returns. The dotted and dashed lines indicate the p=.05 and .01 significance levels for the correlations, respectively. WT=winter, SP=spring, SR=summer, AT=autumn.

Brood-year Sea Surface Temperature and the Subsequent Freshwater Survival Rate of Wild and Enhanced Stocks of North American Pink, Chum and Sockeye Salmon

D. J. Blackbourn

Department of Fisheries and Oceans
Biological Sciences Branch
Pacific Biological Station
Nanaimo, British Columbia
Canada V9R 5K6

The association between coastal and oceanic brood-year sea surface temperature (SST) and the subsequent fresh-water survival (FWS) rate of 18 stocks of North American wild and enhanced pink, chum and sockeye salmon is compared to the association of environmental variables operating during the egg-incubation phase, and that of density-dependent variables such as spawner or egg number. In all but 2 stocks (a total of 89%) the SST relationship with FWS rate is significant, and in 15 stocks (83%) SST accounts for more of the variation in FWS rate than does spawner or egg number. In 16 of the stocks (89%) SST from the distant Gulf of Alaska during periods up to 10 months before spawning accounts for more variation in FWS rate than does coastal SST data. In all stocks but one the SST/FWS relationship is negative. When SST and other factors are analyzed together additional variation is accounted for in all cases (13 of 18 or 72%) where both types of factor are significantly related to FWS rates. The areas and times from which Gulf of Alaska SST is most strongly related to FWS rate are more similar among stocks of the same species than stocks of different species but from the same spawning location or time period. In one sockeye stock local and Gulf of Alaska temperatures are strongly related to losses of eggs and fry attributed to IHN. The apparent effect of brood-year ocean temperatures on FWS rate in some salmon stocks has some complex and serious implications for future production and stock management.

The early fresh-water survival rate of many stocks of salmon is highly variable, even when the results of known catastrophes such as severe floods or freezing are excluded from consideration (Salo 1991). It is reasonable that the causes of such variability have been most often sought amongst environmental factors assumed to have their effect at spawning or during the incubation of the eggs. However, some investigators have considered that the mortality of salmon eggs or sperm during the fertilization or incubation of enhanced salmon may be related to anomalous conditions, such as high water temperatures, occurring well before the time of spawning (B. Anderson and J. Jensen, D.F.O., personal communication).

Annual variation in the pre-spawning mortality of salmon has been compared to environmental data during the up-river migration of adults (Gilhousen, 1990), but I am not aware of any previous explicit consideration of the association between events occurring during the marine migratory phase of adults and subsequent egg-to-fry, or early fresh-water survival rate of eggs after spawning.

An earlier analysis of the fresh-water survival (FWS) rate of Fraser pink salmon indicated that this rate was negatively related to the duration of passage of the adults from the outer coastal troll fishery into the outer net fishery (D. Blackbourn, unpublished data). It was also known that this duration of passage was positively related to coastal sea surface temperature (SST) about one month earlier (Blackbourn, 1984). The passage data record of Fraser pinks is shorter than that of the record of FWS rate and is, in any case, no longer obtainable due to changes in the fisheries. Therefore, the large variation of FWS rate in recent years (P.S.C., 1990) can no longer be directly compared to a possible agent of its variation - the duration of passage and the effects this may have on pink salmon gamete maturation and quality. However, a possible index of such variation in maturation is still available in the form of the SST data and this shows some interesting results in comparison with recent FWS rate data for Fraser pinks.

Annual variation in the overall migration timing of the adults of Fraser pinks and other stocks of salmon has been related to SST in the Gulf of Alaska early in the final year (Blackbourn 1984, 1987); but comparisons between FWS rate and adult return timing or prior Gulf of Alaska SST have not been made.

In order to evaluate the generality of the relationship apparent in Fraser pinks, I report here comparisons between FWS rate in stocks of three species of salmon and environmental data from various periods in the brood year: (a) early in the year and far out to sea, (b) from periods within a month or two of spawning and (c) during incubation. A measure of potentially density-dependent factors such as spawner or egg number is also included in the analyses.

Recent trends in nearshore SST and in spawner number for many North American salmon stocks have been similar and increasing (Freeland, 1990; P.S.C. 1990). Therefore in a simple attempt to avoid the confounding effect of autocorrelation between these factors, I also examine the extent to which SST data accounts for significant variation in FWS rate in addition to that accounted for by spawner/egg number and other environmental data. If these relationships prove to be significant, then SST data from periods several months before spawning might have potential use in the setting, or in the in-season adjustment of escapement goals. Data from three 'incubation types' of stocks are used in this paper: (a) from naturally spawning stocks ('wild'), (b) from those using 'spawning channels' and (c) from those stocks whose eggs are incubated in hatcheries or egg boxes ('hatchery'). These types should show a gradient of controlled conditions during incubation, and therefore an opposite gradient of variation in FWS rate. Data from all types is used to investigate the possible existence of a partial, universal brood-year SST effect on egg or sperm quality, without the confounding effects of other potential agents of annual variation in FWS rate such as river discharge during incubation, or inter-gravel particle size.

METHODS

A) DATA SOURCES

(1) Salmon Data

Much of the salmon data in this paper originates from unpublished sources (see acknowledgements). The exceptions are data from: a) Fraser pinks in International Pacific Salmon Fisheries Commission, Annual Report 1985, and Pacific Salmon Commission Fraser Panel Report, 1990; b) Sashin Creek pinks in Vallion et al. (1981) plus data on the 1979 brood year from A. Wertheimer, N.M.F.S. Auke Bay, Alaska; c) Carnation Creek chums in Hartman and Scrivener (1990), and updated by J. C. Scrivener, D.F.O.; and d) Kotzebue Sound chums in Bird (1982).

Fresh-water survival data was chosen from salmon stocks from western Alaska to southern British Columbia and from the early 1960's to the late 1980's. Data from stocks representing the three 'incubation types' (see Introduction) of pink, chum and sockeye were chosen, as I am not aware of data from both wild stocks and from spawning channels for chinook and coho salmon.

The fresh-water survival (FWS) rate data used covers various periods in the life-history of the stocks. Counted eggs, or 'actual' egg deposition (AED) to counted fry ('egg to fry' or 'AED to fry') is the most accurate and complete measure of early FWS rate. Estimates of egg number extrapolated from fecundity estimates (potential egg deposition or PED) to fry is also a common measure. In one case, Atnarko river pinks, the most direct estimate of survival is based on the percentage of live, of the total of live plus dead eggs and fry, still in the gravel in January. FWS rate data covering longer periods is the only kind available in two cases: a) Great Central Lake (GCL) sockeye (PED to lake fingerling number); and b) Shushwap Lake sockeye (number of female spawners to lake fingerling number). Survival rate (PED to adults) for Kotzebue Sound chum from north-western Alaska is not separated into fresh-water and marine phases. However, this stock was included in the analysis as there is little other data from wild chum stocks.

Methods for estimating spawners numbers for Fraser River sockeye and pink salmon are described by Woodey (1984) and Andrew and Webb (1987) respectively. For most other stocks in this paper, the methods of estimating spawner egg and fry number have not been fully described, and so the statistical properties (accuracy, precision, etc.) of the estimates remain unknown.

(2) Environmental data

Some of the British Columbia shore SST data used here have been published in Canadian Data Reports of Hydrography and Ocean Sciences; for example in Giovando (1983). Offshore SST data from the Bering Sea and Gulf of Alaska up to 1982 were obtained from the unpublished records of Dr. D. McLain of the Pacific Environmental Group, N.M.F.S., Monterey, California. Since 1982 most of the offshore SST data originates from reports (the 'Oceanographic Monthly Summary' and the '15-day SST mean') published by the U.S. National Weather Service, N.O.A.A., Washington D.C., U.S.A.

British Columbia rainfall and air temperature data are published in the series 'Monthly Record-meteorological observations in western Canada' by the Canadian Atmospheric Environment Service, 4905 Dufferin St., Downsview, Ontario, and in the 'British Columbia Climate Summary' from the local regional office of the same Service. Carnation Creek physical data were kindly provided by J.C. Scrivener, D.F.O.

3) Analyses

Simple and multiple least squares regression were used to identify associations among environmental data, spawner or egg number, and measures of FWS rate from several stocks of wild or enhanced pink, chum and sockeye salmon. Results are considered significant where $P \leq 0.05$. The percentages of the FWS rates are not transformed as this parameter for stocks of each 'incubation type' has fairly low variance in most cases, with little overlap between types. Thus, the data does not greatly violate the assumption of normality in distribution.

The fresh-water environmental variables in the analyses are the closest available in time and space to the spawning grounds or the hatcheries. The coastal SST data are mean monthly values from stations and periods close to the final marine migration areas of the stocks; and also, where appropriate, from the outer coastal areas, e.g., Kains Is. on northwestern Vancouver Is. for Fraser River sockeye.

The Gulf of Alaska SST data from the brood year are mean monthly values from 'Marsden' squares of 5° latitude by 5° longitude and are included in the analyses as follows:

a) Time: Data from every month from November (adult return year minus one) to June (return year) are considered as potentially appropriate from the inferred location of the stocks according to models of return timing in pink, chum and sockeye salmon (Blackbourn 1984, 1987). Within these limits, those months or combinations of months of SST data with the highest single regression coefficients versus the FWS rate for each stock are shown in the results.

b) Place: The stock-specific distribution of North American salmon at sea early in their last year is unknown, although it has been inferred for some stocks, particularly for Fraser River pinks and sockeye (Blackbourn 1984, 1987; Takagi et al. 1981). From models in the latter papers, it is assumed that pink salmon stocks would be distributed in the south-eastern Gulf of Alaska between 40° and 50° N and between 125 and 150° W. Therefore monthly SST data from within this area are used in primary analyses with pink FWS rate data. Similarly, SST data from within a large area across the central Gulf between 45° and 55° N and between 135 and 160°W are used in initial comparisons with sockeye FWS rate data.

There is even less information on the possible location of North American chum salmon early in their last year than for pink and sockeye. Therefore, the initial choice of monthly SST values is arbitrarily from an area of the west-central Gulf between 45° and 55° N and between 145° and 170° W. It proved necessary to search further afield (i.e., the southern Gulf) for SST data with reasonably strong coefficients in comparison with FWS rate data for some hatchery chum stocks.

The SST data within these areas showing the strongest coefficients when compared to FWS rate data were then used in multiple regression analyses with all other factors, including: coastal SST, fresh-water environmental data just before, during or after spawning, and also spawner or egg number. In some of the time series there are fairly strong time-series trends and thus strong cross-correlations between them, particularly between coastal SST and spawner or egg number in some stocks. In the absence of any model which fits the spawner/egg data with low variance, the best evidence for a real or potential effect of brood-year SST on FWS rate in such cases is taken to be significant additional variation accounted for when SST data is also used. In all analyses the variation is that proportion adjusted for the total degrees of freedom in each combination.

In order to maximize the degree of biological insight gained, no formal protocol for dealing with successive correlation analyses (Walters, 1990) is followed in this study. In such a protocol it is recommended that the degrees of freedom be decreased for each successive "case" (here, stock, month or SST "Area") investigated. To do so here would rapidly exhaust the number of stocks for which it could be used; especially in the case of the "hatchery" stocks, which have relatively short records, with a concomitant loss of information. Within each species the stocks are analyzed in the order shown in Table 1. Therefore, use of the formal protocol would have caused much more stringent tests of significance to have been applied to the "hatchery" stocks than to the other types.

RESULTS

As expected, the variance of FWS rate data declines in general, from the wild stocks through the 'spawning channel' stocks to those from hatcheries or incubation boxes (Table 2). However, even the 'wild' stocks show a low and similar level of variance at or just below 50% of the mean FWS rate. The similarity of the values between the species is remarkable given that the pink and chum stocks in the analyses are from both large and small streams, and that the FWS rate for the sockeye stocks includes parts of the limnetic life-history (Table 2).

The level of variance of the 'spawning channel' type overlaps that of the 'hatchery/incubation' box type due to very low variance in the Seton Creek spawning channel pink data (11%) and the high variance associated with the Puntledge River hatchery pink stock (Table 2). The Quinsam Hatchery pink data show a very low level of variance (6%), which on average is very similar to that of the data from chum 'hatchery/incubation box' stocks.

There are only two of 18 stocks in which the SST effect is non-significant, though stronger than for other factors, and only three of 18 in which SST has a smaller statistical association with FWS rate than does spawner or egg number (Table 1 and 3). These three exceptions are all chum stocks, one of each incubation type. In only one of 18 stocks, Shuswap Lake sockeye, is the relationship between SST and FWS rate positive, an exception which I cannot explain (Table 1). Factors other than SST are significantly related to FWS rate in 13 of 18 stocks (Table 3).

In all stocks but two, the 'early' brood-year SST data from the Gulf of Alaska accounts for more variation in FWS rate than does the later coastal SST data. These exceptions, Fraser River pinks and Nadina River sockeye must be considered as the minimum number, as the comparisons are not balanced, in that SST data from only one or two coastal locations are considered in each case and there is no search for strongest coefficients; whereas only those Gulf of Alaska SST data with the highest coefficients with FWS rate are used in the final comparisons (Tables 1 and 3).

In those 13 of 18 stocks in which both SST data and other factors are significantly related to FWS rate; factor combination from multiple regression analyses results in significant added variation in every case (Table 3). As to whether coastal and Gulf of Alaska SST when taken together account for added variation in FWS rate, the answer seems to be generally negative. There are only seven positive cases of this combination of factors of the total of 18 (39%) (Tables 1 and 3). Contributions to this fraction are very uneven between stocks of the different incubation types. For example, wild stocks show added variation in 4 of 7 cases (57%); and in spawning channel stocks the fraction is similar of two to four (50%); but in only 1 of 7 'hatchery' stocks (14%) is additional variation in FWS rate accounted for using both types of SST data (Table 1 and 3).

In two chum stocks the degree of association of the SST data from the areas of the Gulf of Alaska which have the highest coefficients for a particular stock (the 'best' areas) is compared to the 'best' coefficients of SST from ocean areas more typical of other chum stocks. For example, the SST area (RR and QQ) in Figures 1 and 2 (B) which show the 'best' coefficients for Puntledge River and Conuma River (hatchery) chum is well to the south of the 'best' areas for other chum stocks, e.g., (areas K in Figure 1). For example, SST data from area J in the northwestern Gulf accounts for zero percent of the variance of the FWS rate of Puntledge and Conuma chum compared to 58% and 85% for the SST data from areas RR and QQ (Table 1). However, SST data from area J does account for significant additional variation in the FWS rate of Conuma, but not that of Puntledge chum, when added to egg number in a multiple regression analysis (Table 1). This result, if not from chance, aligns the results for Conuma chum with other chum stocks.

The boundaries of the SST areas with the strongest coefficients with FWS data for pink, chum and sockeye data show some, but certainly not complete separation (Figure 3) and the distribution of best SST areas within each species show an interesting, parallel feature. Despite large differences in period of data record and location of spawning stream, several stocks of the same species have very similar 'best' areas and times in the Gulf of Alaska (Figure 2(a), (b) and (c)). This within-species similarity is particularly marked for 'wild' and 'spawning channel' pink and chum stocks (Figs. 2(a) and (b)).

The results for Fraser pinks confirm the earlier work (see Introduction) in that there is a strong relationship between coastal SST and FWS rate (Table 1(A)). This analysis also confirms that spawner number and other biological and environmental data from the period well before spawning all account for considerable variation in FWS rate. When added to coastal SST data, two or three of these factors account for additional significant variation, but this stock is unusual in that SST data from the Gulf of Alaska earlier in the brood year do not show a relationship with FWS rate (Table 1(a)).

Most of the pink fry which leave Seton Creek, a small interior tributary of the Fraser River, do so from two spawning channels. The Seton Creek channel fry number about 6% of the total fry produced by the Fraser River. Although the same coastal SST data as are used with the Fraser River data account for 27% of the adjusted variance in Seton Channel FWS rate, spring-time SST data from the Gulf of Alaska accounts for the greatest amount of variation in Seton Creek pink FWS rate (Table 1(c)). Thus, Seton Creek spawning channel pink data inexplicably show more similarities to those of the other two wild stocks in Table 1, Atnarko River and Sashin Creek pinks, than to those of wild pinks of its parent river, the Fraser. To an even greater extent than is seen in the data from the three wild pink stocks, almost all the variation in FWS rate of Seton Creek spawning channel pinks is accounted for when egg number, incubation air temperatures, and coastal SST are added to the Gulf of Alaska SST data (Table 1(a)). Perhaps this is because there is less random error in the spawning channel data.

Extremely low temperatures during incubation have been held to be the major cause of low FWS rates and of low overall production of Alaskan salmon during the early 1970's (Rogers, 1984). Thus, the results for Sashin Creek pinks (Southeast Alaska) are particularly surprising. Air temperatures measured at Sitka, less than 100 km from Sashin Creek on the other side of the same island, from November of the brood year to March of the fry year, account for zero % of the variance of FWS rate for Sashin Creek pinks from 1963 to 1979. On the other hand, sea surface temperatures almost twelve months earlier, in November and December of the first marine year are strongly negatively related to FWS rate for this stock and account for 61% of the variance (Table 1A).

Quinsam and Puntledge River pink hatchery data show surprisingly different trends, in that Gulf of Alaska SST, and coastal SST data from two locations account for more than 50% of the variance in FWS rate for Puntledge River pinks, but none of these factors are significant for nearby Quinsam River data, a stock with much less variance in FWS rate (Tables 1 (a) and 2). The 'best' Gulf of Alaska SST (data) for each of Quinsam and Puntledge pink show no relationship with FWS data, when compared to data from the other stock (Table 1(a)).

Although Kotzebue Sound and Carnation Creek are thousands of miles apart the 'best' Gulf of Alaska areas and times are almost the same (Figure 2b). This is also despite the fact that the time-span of FWS data from the two stocks has very little overlap. These two 'wild' chum stocks are also unusual in different ways in that whereas a great deal is known about Carnation Creek chums, (Hartman and Scrivener, 1990), we have little detailed knowledge of Kotzebue Sound chums. Inter-gravel particle size data accounts for

50% of the adjusted variance in FWS rate of Carnation Creek chums, a much larger amount than is accounted for by other fresh-water environmental variables or by egg number (Table 1(b)). However, brood-year SST from the Gulf of Alaska several months before spawning also accounts for up to 41% of the FWS rate. More importantly, when considered in concert with particle size and other fresh-water data, SST accounts for 73% of the total variation in FWS rate, a considerable increase over the effect of particle size alone (Tables 1 and 3).

In a case not summarized in Tables 1 and 3, an analysis is made of the statistical relationship between SST and a known agent of fresh-water mortality in salmon. Many stocks of sockeye are very susceptible to Infectious Haemopoietic Necrosis (IHN), and the incidence and effect of this virus has been studied in spawning sockeye adults, eggs and fry for several years at Babine Lake, British Columbia. The annual egg-to-fry survival rates of sockeye at the No. 1 spawning channel at Fulton River, Babine Lake are shown in Table 4. These estimates include those eggs and fry killed by IHN and other causes, and also that proportion of the fry which from long experience were thought very likely to die soon after enumeration due to a very high incidence of the virus (G. Traxler, DFO, personal communication).

The four variables which are presumed to be independent are: annual numbers of sockeye eggs laid in Fulton Channel No. 1, and water temperatures from three areas known or thought to be traversed by Babine Lake sockeye during their last year; i.e., (a) from the eastern Gulf of Alaska more than nine months before spawning; (b) from Bonilla Island in eastern Hecate Strait near the mouth of the Skeena River in August; and (c) from the Fulton River during sockeye spawning in September. Of these four variables, only Gulf of Alaska and river temperatures are strongly related to FWS rate; negatively for the former and (surprisingly and inexplicably) positively for the latter (Table 4). Combination of the four variables account for almost all the variation in FWS rate from this short data set for the years 1984 to 1989.

DISCUSSION

The gradient of variation in FWS rate generally follows the expected direction from greater variation in wild than in enhanced stocks of salmon. The hypothesis of a previous effect of brood-year SST on FWS rate in all three incubation types is supported by these analyses. However, the additive effect of SST variation on FWS rate is expressed least often in the data from the 'hatchery' stock category when pink and chum stocks are taken together. This difference is entirely due to the situation with the pink stocks, as the hatchery chum stocks show an additive effect of SST on FWS rate which is little different than that shown by wild or spawning channel pink, chum or sockeye stocks.

The overall additive effect of SST on FWS rate in the multiple regression analyses is demonstrated by its occurrence in 100% of those stocks in which more than one factor is related to FWS rate (13 of 18 or 72%). The particular effect of brood-year SST should be further tested by more intensive studies, particularly in those stocks for which detailed data on spawner and egg number and from the incubation environment can be readily measured. The effect of SST could be partially and experimentally investigated on fish held well before spawning at various sites along the migration path or perhaps held at fish farms with laboratory facilities.

A significant added effect of SST is seen in the data for several salmon stocks of great economic importance, e.g., Fraser and Atnarko River pinks, Great Central Lake and Shuswap Lake sockeye, and Little Qualicum chums. Therefore, in addition to more research, some consideration should be given to the application of (a) brood-year oceanic SST data in fisheries management in the setting of pre-season escapement goals for such stocks, and of (b) that of coastal SST data in adjustments to those goals during, or perhaps even before the fishing season. If these effects are real, and whether or not SST is an index for some other environmental effect on gamete quality, the short-term effect of SST may be predictable. For example for the great majority of those stocks in which SST has a strong negative relationship with FWS rate; in a year which is warmer than average, a greater escapement than the average may be necessary to obtain an average number of fry the following spring. However, as the FWS rate for a stock may be also negatively related to spawner or egg number (Table 1) the specific relationship between all these factors must be carefully considered for each stock before changes in escapement goals could be recommended.

Although the results of the multiple regression analyses are statistically the more noteworthy, from an ecological point of view the results of the simple regression analyses of the effect of SST data are extremely interesting. Firstly, in several cases coastal SST data from locations and places thought, or in some cases known, to be appropriate to particular stocks do show strong relationships with FWS rate data for those stocks: e.g., data from Amphitrite Pt. (western Vancouver Island) in July for feeding Fraser pinks and the (very early) GCL sockeye; from Kains Is. (north-western Vancouver Is.) in July for the mid-summer Nadina (Fraser) sockeye; and for the late-summer returning Weaver Creek sockeye, data from Amphitrite Pt. in August and from Chrome Is. (Georgia Strait) data from August to October (Table 1). On the other hand it is puzzling that several stocks show little or no relationship between coastal SST data and FWS rate. These anomalies may be due to the heterogeneity of data and degree of measurement error found in many salmon stocks and which affect our ability to detect such relationships.

The results of simple regression analyses of Gulf of Alaska SST data months before spawning are also intriguing. The areas from which SST data show the strongest relationship with FWS rates of pink and sockeye stocks are generally within the boundaries originally thought likely to show such results, i.e., the south-eastern and central Gulf respectively. More surprisingly, the best results for all but two chum stocks also confirm the original but in this case arbitrary, choice of the north-western Gulf of Alaska. Perhaps the most interesting result of all is that stocks of pinks and chums from widely separated spawning locations and different time-periods have very similar locations and periods for their "best" Gulf of Alaska SST data. These results give some credence to the idea that subtle effects of the ocean environment via gamete development on the fresh-water survival rate of salmon may be real, and in some cases, as or more important than the more obvious local fresh-water environmental factors.

These comparative analyses include data from many diverse physical and biological variables. The underlying precision and accuracy of the methods used to produce these data are mostly unknown. This is an obvious statistical weakness of the study. Paradoxically, it is also a strength in that the expected outcome of analysis of such heterogenous data might be expected to reveal few, if any, significant associations between SST and FWS. It is probable that the consistent statistically significant associations among these data reflect some real underlying connection.

The need to broaden our currently narrow focus on the incubation environment alone, to include oceanic brood year data is emphasized by the surprising importance of the latter in the FWS rate variation of Sashin Creek pinks. The data record for this stock includes the early 1970s a period infamous in Alaska and elsewhere for its anomalously low air and water temperatures (Rogers, 1984), but it is not generally known that the concurrent winter SST in parts of the southern Gulf of Alaska was warm.

The chum salmon of Carnation Creek, Vancouver Island have been intensively studied for nearly twenty years; it is probable that their spawning and incubation environment has been measured in greater detail than has that of any other stock of Pacific Salmon (Hartman and Scrivener 1990; Scrivener, 1991). In particular, it is known that the size of the inter-gravel particles is extremely important in determining the fresh-water survival rate of this stock (Scrivener, 1991). The results of these analyses have shown that even for such a stock about which we know a great deal, a consideration of the subtle annual variation in its environmental 'history' well before spawning may also be useful in understanding past variation in production and for predicting future production.

The only stock in this paper for which brood-year temperatures have been linked with a particular mortality agent, is with the deaths of eggs and fry attributed to the IHN virus in Fulton River sockeye. Correspondingly, this very brief analysis may be the first to specifically link IHN mortalities in sockeye with possible environmental causes. Causal links between the temperature data and the mortalities have not been established. Indeed, it is difficult to do so when temperatures from the two periods have coefficients of opposite sign. Therefore, it will be very interesting to see how well these apparently useful relationships hold in future, given the general importance to the enhancement potential of salmon, particularly sockeye, of susceptibility to IHN.

The possible warming of the ocean and rivers in the next 50 years due to increased amounts of "greenhouse" gases is already of concern to salmon biologists. The potential warming has been considered important to both fresh-water and marine phases of the life-cycle of salmon; and present and potential future fresh-water and ocean temperatures are investigated for each phase respectively, particularly for stocks in the southern part of the range for each species. Consideration of data such as those discussed in this paper add a further concern. The time and place of future changes in ocean climate may prove to be important not only to such salmon parameters as marine survival rates, marine growth rates, fecundity, migration timing and routes etc., but also to the subsequent fresh-water survival rates of the eggs of the returning adults. In this respect, it may be important to remember that in the recent past SST anomalies have been of different strengths and even of the opposite sign in various parts of the north-east Pacific and the Gulf of Alaska. If the future ocean climate contains a similar amount of temporal and spatial heterogeneity, then the future fresh-water survival rate of a particular stock may not be entirely directed by the environmental trends at or near the spawning location. Also, to judge by these results, future trends in fresh-water survival rate of stocks of different species, e.g., pinks and chums, at the same spawning location could be environmentally-mediated to a different degree or even in a different direction.

ACKNOWLEDGMENTS

For the provision of unpublished salmon data I am gratefully indebted to the following people: A) Pink salmon - Seton Creek (Fraser River), D. Hickey, DFO; Atnarko River, R. Hilland, DFO; Quinsam and Puntledge River Hatcheries, D. Bailey, DFO; B) Chum salmon - Little Qualicum River spawning channel, and Snootli Creek, Inch Creek, Puntledge River and Conuma River Hatcheries, D. Bailey, DFO; C) Sockeye Salmon - Great Central Lake, K. Hyatt, DFO; Shushwap Lake, W. Saito, DFO; Weaver Creek and Nadina River (Fraser River) spawning channels, D. Harding, DFO; Fulton River (Babine Lake) spawning channel, S. Barnetson, DFO. I am grateful for useful discussions with all the above individuals and also with other knowledgeable people such as Bryan Anderson, Darryl Hebert and John Jensen. Garth Traxler (DFO) kindly supplied me with the IHN mortality data from the Fulton River spawning channel. I thank L. Giovando and H. Freeland, DFO for recent unpublished sea surface temperature data from B.C. shore stations.

REFERENCES

Andrew, J. H. and T. M. Webb. 1987. Review and assessment of adult pink salmon enumeration programs on the Fraser River. Final Report for DFO by ESSA - Environmental and Social Systems Analysts Ltd., Vancouver, B.C. 62 p.

Bird, F. 1982. Preliminary forecast model for Kotzebue Sound, Alaska chum salmon (*Oncorhynchus keta*). Alaska Fish and Game Dept. Informational Leaflet No. 203. 26 p.

Blackbourn, D. J. 1984. Sea surface temperature and return timing in North American Pacific Salmon pp. 111-119. In K. Fresh and S. Schroeder (ed.) 1983 Northeast Pink and Chum Salmon Workshop, Orcas Island, WA., January 1983.

——————— 1987. Sea surface temperature and the pre-season prediction of return timing in Fraser River sockeye salmon (*Oncorhynchus nerka*), p. 296-306. In H. D. Smith, L. Margolis and C. C. Wood (ed.). Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Freeland, H. J. 1990. Sea surface temperatures and salinities along the coast of British Columbia: Regional evidence for a warming trend. Can. J. Fish. Aquat. Sci. 47(2): 346-350.

Gilhousen, P. 1990. Pre-spawning mortalities of sockeye salmon in the Fraser River system and possible causal factors. Int. Pac. Sal. Comm. Fish. Bull. XXVI. 58 p.

Giovando, L. F. 1983. Observations of seawater temperature and salinity at British Columbia shore stations, 1980. Can. Data Rep. Hydrogr. Ocean Sci. 9: 133 p.

Hartman, G. F. and J. C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Can. Bull. Fish. Aquat. Sci. 223: 148 p.

P.S.C. 1990. Report of the Fraser River panel to the Pacific Salmon Commission on the 1989 Fraser River sockeye and pink salmon fishing season. Pacific Salmon Commission, May 1990.

Rogers, D. E. 1984. Trends in abundance of northeastern Pacific stocks of salmon. pp. 100-127 *In* W. G. Pearcey [ed.] The influence of ocean conditions on the production of salmonids in the North Pacific. Oreg. State Univ. Sea Grant Coll. Program Oresu-W-83-001.

Salo, E. O. 1991. Life history of chum salmon (*Oncorhynchus keta*). *In* C. Groot and L. Margolis [eds.] Pacific Salmon life histories. University of British Columbia Press, Vancouver, British Columbia.

Scrivener, J. C. 1991. An update and application of the production model for Carnation Creek chum salmon. p. __ In I. Guthrie and B. White (ed.) Proc. 15th Northeast Pacific Pink and Chum Salmon Workshop, Parksville, British Columbia, February, 1991.

Takagi, K., K. V. Aro, A. C. Hartt, and M. B. Dell. 1981. Distribution and origin of pink salmon (*Oncorhynchus gorbuscha*) in offshore waters of the North Pacific Ocean. Int. N. Pac. Fish. Comm. Bulletin No. 40.

Vallion, A. C., A. C. Wertheimer, W. R. Heard, and R. M. Martin. 1981. Summary of data and research pertaining to the pink salmon population at Little Port Walter, Alaska, 1964-1980. Northwest and Alaska Fisheries Centre, Auke Bay, Alaska. Processed Report 81-10.

Walters, C. J. 1990. A partial bias correction factor for stock-recruitment parameter estimation in the presence of autocorrelated environmental effects. Can. J. Fish. Aquat. Sci. 47(3): 516-519.

Woodey, J. C. 1984. Escapement estimation in the management of Fraser River sockeye salmon, pp. 121-132. *In* P. E. K. Symons and M. Waldichuk [ed.] Proceedings of the workshop on stream indexing for salmon escapement estimation, West Vancouver, B.C., 2-3 February, 1984. Can. Tech. Rep. Fish. Aquat. Sci. 1326.

Table 1(A). Brood-year (B.Y.) factors which account for variation in fresh-water survival rate of some stocks of wild (W), spawning channel (S), and hatchery (H) pink salmon. Gulf of Alaska (G. AK.) S.S.T. areas as in Figure 1.

STOCK	PERIOD	N	AREA	F.W. SVL RATE	% OF ADJUSTED VARIANCE OF F.W. SVL RATE ACCOUNTED FOR IN: SIMPLE			AND MULTIPLE REGRESSION		
					FACTORS	SIGN	%AR^2	FACTORS	%AR^2	P
Fraser R. (W)	1961-1989	15	Southern B.C.	P.E.D. to down-stream fry	1) No. spawners	neg	43	1) + 4)	60	.002
					2) b.y. scale growth	pos	28	2) + 3) + 4)	66	.002
					3) Fraser R. discharge summer	pos	26			
					4) coastal S.S.T. July (Amp)	neg	55			
					5) G. AK. S.S.T. Jan (Q)	neg	0			
Atnarko R. (W)	1974-1989	10	Central B.C.	P.E.D. to live eggs + fry in January	1) No. spawners	neg	48	1) + 4)	74	.004
					2) incub. air temps.	pos	0	1) + 5)	64	.012
					3) incub. river neg.	pos	0	1) + 4) + 5)	77	.007
					4) coastal S.S.T. July (McInnes)	pos	10	1) + 2) + 5)	59	.040
					5) G. AK. S.S.T. Jan-Mar (R) Feb-Apr (S)	neg	59			
Sashin Cr. (W)	1963-1974 and 1979	12	S.E. Alaska	A.E.D. to fry	1) No. spawners	neg	19	2) + 5)	59	.012
					2) spawn timing	pos	18	1) + 5)	55	.012
					3) incub. air temp	pos	0	1) + 2) + 5)	59	.025
					4) coastal S.S.T. August (SITKA)	neg	0			
					5) G. of AK. S.S.T. Nov-Dec$_{-1}$ (R+S)	neg	61			
Seton Ck. (S) (Fraser R.)	1967-1989	12	South-Central B.C.	P.E.D. to fry	1) No. eggs	--	0	3) + 4)	77	.001
					2) Incub. air temp.	pos	12	2) + 3)	72	.002
					3) Coastal S.S.T. July-Aug (AmP)	neg	27	2) + 3) + 4)	86	.000
					4) G. AK. S.S.T. May-June (R+S)	neg	72	1) + 3) + 4)	85	.000
								1) + 2) + 3) + 4)	91	.000
Quinsam R. (H)	1979-1988	10	E. Vanc Is. B.C.	egg to fry	1) No. eggs	neg	0	1) + 4)	10	.285
					2) coastal S.S.T. July (Kains)	pos	0			
					3) coastal S.S.T. Sept. (Chrome)	neg	0			
					4) G. AK. S.S.T. Feb-Mar (G+U)	neg	14			
					5) G. AK. S.S.T. Nov-Dec$_{-1}$ (x+y) (see Puntledge pinks)	neg	0			
Puntledge R. (H)	1979-1988	10	E. Vanc. Is. B.C.	egg to fry	1) No. eggs	neg	0	2) + 4)	58	.031
					2) coastal S.S.T. July (Kains)	neg	0	3) + 4)	54	.039
					3) coastal S.S.T. Sept. (Chrome)	pos	19	2) + 3) + 4)	61	.055
					4) G. AK. S.S.T. Nov-Dec^{-1} (x+y)	neg	37			
					5) G. AK. S.S.T. Feb-Mar (U) (see Quinsam pinks)	pos	0			

Table 1(B). As for 1(A) but for stocks of wild (W), spawning channel (S), and hatchery or incubation box (H) chum salmon. Gulf of Alaska S.S.T. areas as in Figure 1.

STOCK	PERIOD	N	AREA	F.W. SVL RATE	% OF ADJUSTED VARIANCE OF F.W. SVL RATE ACCOUNTED FOR IN: SIMPLE			AND MULTIPLE REGRESSION		
					FACTORS	SIGN	%AR²	FACTORS	%AR²	P
Carnation Ck. (W)	1971-1989	18	S.W. Vanc. Is. B.C.	P.E.D. to fry	1) No. eggs	pos	6	4) + 6)	70	.001
					2) incub. water temp.	neg	5	3) + 4) + 6)	73	.001
					3) incub. peak flow	pos	3	4) + 5) + 6)	71	.001
					4) size of inter-gravel particles	neg	50			
					5) coastal S.S.T. Sept. (Amp)	neg	13			
					6) G. AK. S.S.T. June-Aug (U)	neg	41			
					7) G. of AK. S.S.T. Mar-May (K)	neg	25			
Kotzebue Sound (W)	1962-1976	15	W. Alaska	P.E.D. to adults	1) No. eggs	neg	35	1) + 4)	49	.007
					2) % 4 yr-olds	pos	0	2) + 4)	44	.024
					3) coastal S.S.T. July (Bering Sea)	neg	0	1) + 3) + 4)	42	.065
					4) G. AK. S.S.T. Mar-Apr (K)	neg	34			
Little Qualicum R. (S)	1979-1988	10	E. Vanc. Is. B.C.	P.E.D. to fry	1) No. eggs	neg	56	1) + 2)	77	.002
					2) % brood 4 yr- olds	pos	5	1) + 5)	66	.010
					3) Incub. air temp	pos	24	1) + 3)	59	.018
					4) incub. riv. disch.	pos	0	1) + 2) + 4)	78	.007
					5) Georgia st. S.S.T. Oct (Chrome)	pos	0	1) + 2) + 6)	78	.007
					6) G. of AK. S.S.T. Jan-Feb (B+C+J)	neg	50	1) + 2) + 4) + 6)	86	.006
Snootli Ck. (H)	1982-1989	8	Central B.C.	egg to fry	1) No. eggs	neg	0	1) + 2)	0	
					2) coastal S.S.T. July (McInnes)	pos	0	1) + 3)	0	
					3) G. AK. S.S.T. Dec-Feb (J)	neg	9			
Inch Ck. (Fraser R.) (H)	1970-1980	11	S.W. B.C.	egg to fry	1) No. eggs	neg	3	1) + 4)	59	.029
					2) coastal S.S.T. Aug. (Kains)	pos	0	1) + 2)	51	.058
					3) coastal S.S.T. Oct. (Chrome)	neg	0	1) + 2) + 4)	55	.036
					4) G. AK. S.S.T. Dec-Feb (B)	neg	35	1) + 3) + 4)	57	.031
								1) + 4)	4	--
								1) + 2)	7	--
Inch Ck. (Japanese style)	1981-1988	8	S.W. B.C.	egg to fry	1) No. eggs	neg	12	1) + 3)	46	.092
					2) coastal S.S.T. Aug. (Kains)	neg	0	1) + 2) + 3)	52	.130
					3) coastal S.S.T. Oct. (Chrome)	neg	0	1) + 3) + 4)	33	.237
					4) G. AK. S.S.T. Dec-Feb (B)	neg	6			
Puntledge R. (H)	1979-1988	10	E. Vanc. Is. B.C.	egg to fry	1) No. eggs	pos	7	2) + 3)	54	.027
					2) coastal S.S.T. Oct. (Chrome)	pos	0	1) + 3)	52	.031
					3) G. AK. S.S.T. Dec-Jan (RR+QQ)	neg	58	3) + 4)	52	.031
					4) G. AK. S.S.T. Dec-Feb (J) (See Carn. & Kotz. chum)	neg	0	2) + 3) + 4)	47	.083
								1) + 3) + 4)	45	--
Conuma R. (H)	1978-1988	11	N.W. Vanc. Is. B.C.	egg to fry	1) No. eggs	pos	12	1) + 3)	84	.000
					2) coastal S.S.T. Aug. (Kains)	neg	0	1) + 4)	65	.006
					3) G. AK. S.S.T. Dec-Jan (y+2+RR+QQ)	neg	85	3) + 4)	85	.000
					4) G. AK. S.S.T. Dec-Feb (J) (See Carn. & Kotz. chum)	neg	0	1) + 3) + 4)	82	.001
								1) + 2) + 4)	60	--

Table 1(C). As for 1A, but for stocks of wild (W), and spawning channel (S) sockeye salmon. Gulf of Alaska areas as in Figure 1.

STOCK	PERIOD	N	AREA	F.W. SVL. RATE	% OF ADJUSTED VARIANCE OF F.W. SVL RATE ACCOUNTED FOR IN: SIMPLE			AND MULTIPLE REGRESSION		
					FACTORS	SIGN	%AR²	FACTORS	%AR²	P
Great central Lake (W)	1978-1988	11	S.W. Vanc. Is. B.C.	P.E.D. to fingerling	1) No. spawners	neg	21	4) + 5)	51	.023
					2) incub. air temps.	neg	0	3) + 5)	49	.029
					3) near-coastal S.S.T. June (V)	neg	38	2) + 4) + 5)	58	.028
					4) coastal S.S.T. July (Amp)	neg	36	3) + 4) + 5)	53	.043
					5) G. AK. S.S.T. Mar-Apr (I+J)	neg	38			
Shuswap Lake (W)	1970-1987	10	S. Central B.C.	female sp. to fingerling	1) No. females	neg	14	1) + 6)	62	.014
					2) Fraser R. disch. Sept-Oct	neg	28	1) + 2) + 6)	58	.042
					3) Fraser R. water temp. (sept)	pos	0	1) + 4) + 6)	68	.019
					4) Georgia St. S.S.T. Sept (chrome)	pos	8			
					5) coastal S.S.T. Aug (Kains)	pos	0			
					6) G. AK. S.S.T. Dec-Feb (G+H)	pos	35			
Weaver Ck. (Fraser R.) (S)	1965-1989	25	S.W. B.C.	P.E.D. to fry	1) No. eggs	neg	46	5) + 6)	74	.000
					2) female length	--	0	1) + 6)	72	.000
					3) incub. air temp.	neg	0	1) + 5) + 6)	83	.000
					4) Georgia St. S.S.T. Aug-Oct) chrome	neg	15	1) + 4) + 5) + 6)	82	
					5) coastal S.S.T. August (amp)	neg	47			
					6) G. AK. S.S.T. Jan-Feb (S+T+V)	neg	61			
Nadina R. (Fraser R.) (S)	1973-1989	16	W. Central B.C.	P.E.D. to fry	1) No. eggs	neg	3	2) + 5)	51	.006
					2) return timing early Fraser sox	neg	14	4) + 5)	38	.027
					3) Fraser disch. (July)	pos	13	2) + 4) + 5)	51	.012
					4) Georgia St. S.S.T. July (chrome)	neg	1	1) + 2) + 4) + 5)	46	.031
					5) coastal S.S.T. July (Kains)	neg	41			
					6) G. AK. S.S.T. June (S)	neg	27			
					7) G. AK. S.S.T. Mar-Apr (J)	neg	7			

Table 2. Standard deviation of the mean as a percentage of the mean value of the fresh-water survival rate of salmon stocks in Table 1 averaged by incubation type. (N) = Number of stocks.

Species	Incubation Type		
	Wild	Spawning channel	Hatchery/Inc. Box
Pinks	47(3)	11(1)	20(2)**
Chum	51*(1)	39(1)	8(5)
Sockeye	45(2)	31(2)	-

* Excludes Kotzebue chum, as data for this stock includes the marine phase.
** Quinsam River = 6%
Puntledge River = 33%

Table 3. Relative strength of regression coefficients of spawner/egg no. and/or brood year sea surface temperature (from Table 1).

Stock	SST > Spawner/egg no.	G. AK. SST > coastal SST	Added variation acctd. for by	
			SST + other factors	G. AK. SST + Coastal SST
Pinks				
Fraser (W)	Yes	No	Yes	No
Atnarko (W)	Yes	Yes	Yes	Yes
Sashin (W)	Yes	Yes	OFI	No
Seton (S)	Yes	Yes	Yes	Yes
Quinsam (H)	Yes*	Yes	AFI	No
Puntledge (H)	Yes	Yes	OFI	Yes
Chum				
Carnation (W)	Yes	Yes	Yes	Yes
Kotzebue (W)	No	Yes	Yes	No
L. Qualicum (S)	No	Yes	Yes	No
Snootli (H)	Yes*	Yes	AFI	No
Inch (1) (H)	Yes	Yes	Yes	No
Inch (2) (H)	No	Yes	Yes	No
Puntledge (H)	Yes	Yes	OFI	No
Conuma (H)	Yes	Yes	Yes	No
Sockeye				
G.C.L. (W)	Yes	Yes	Yes	Yes
Shuswap (W)	Yes**	Yes**	Yes	Yes
Weaver (S)	Yes	Yes	Yes	Yes
Nadina (S)	Yes	No	Yes	No

* SST Non-sign at P<.05
** SST Relationship positive
AFI - All Factors Insignificant
OFI - Other Factors Insignificant

Table 4. Brood-year temperature and fry production from No. 1 spawning channel on Fulton R. (Babine Lake, Central B.C.). The egg to fry survival rates include estimated potential fry losses due to infection with IHN. The SST area from Figure 1.

Brood yr.	Egg-to-fry survival rate %	No eggs ($x10^6$)	Water temp. Fulton R. fence Sept. (°C)	SST Bonilla Is. Hecate St. August (°F)	SST G. of AK. Nov-Jan (Area T.) (°C)	
		(1)	(2)	(3)	(4)	
1984	33	23.7	15.4	56.5	9.66	
1985	18	20.3	-	52.0	9.44	
1986	15	23.6	14.8	53.6	9.88	
1987	4	25.3	14.6	53.8	10.70	
1988	6	23.9	14.4	54.9	10.07	
1989	52	22.6	15.7	54.5	9.24	
(B) Correlation coefficients versus E/F SVL rate						Excl 1985
% AR^2		0	94	0	54	80
P		.515	.004	.530	.059	-
Sign		Neg.	Pos.	Pos.	Neg.	Neg.

Multiple regression

(1) + (3)	(1) + (4)	(2) + (4)
98	75	97
.012	.059	.017

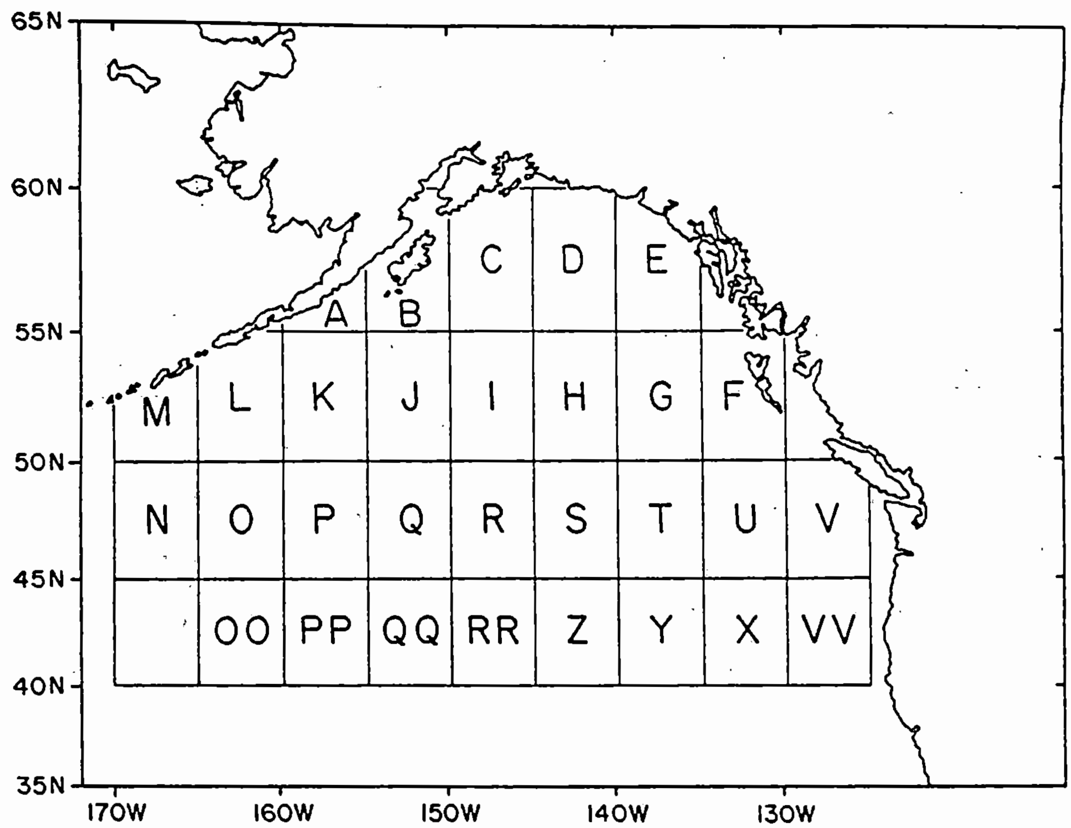


Figure 1. Designation of 5° squares of latitude and longitude in the Gulf of Alaska.

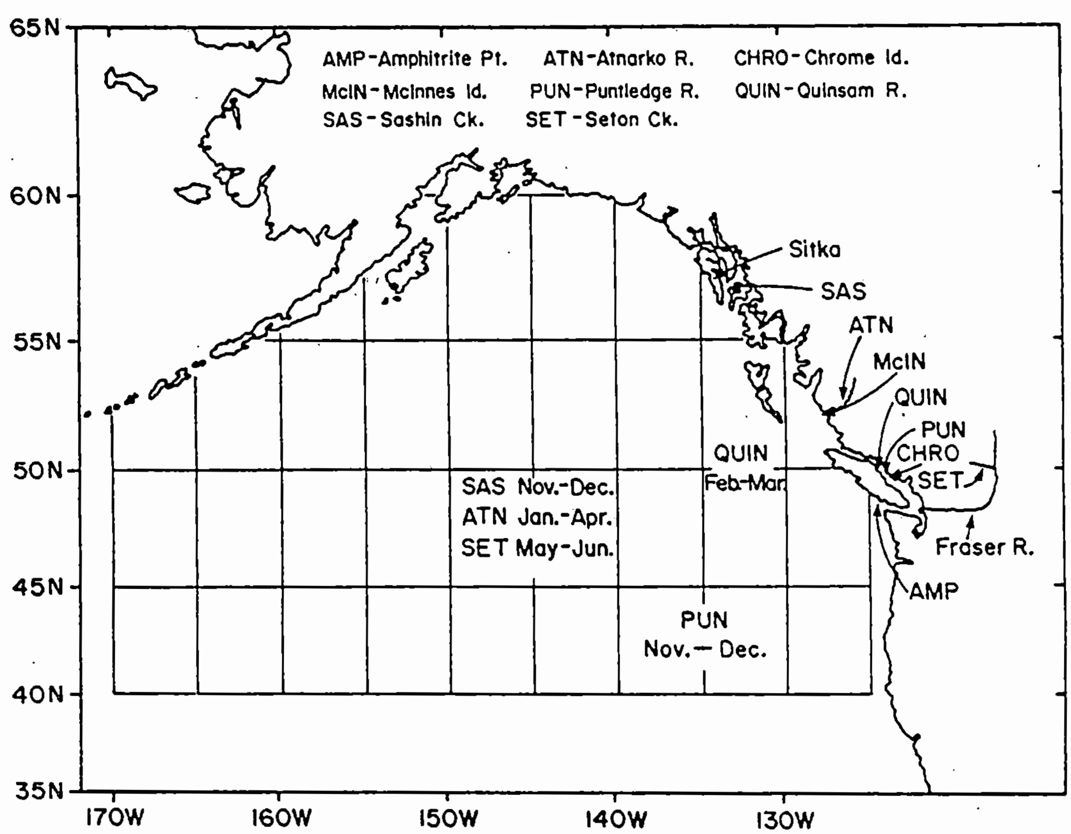


Figure 2(A). Areas and times of strongest correlation between SST in brood year and FWS rate in pink salmon [Table 1(A)].

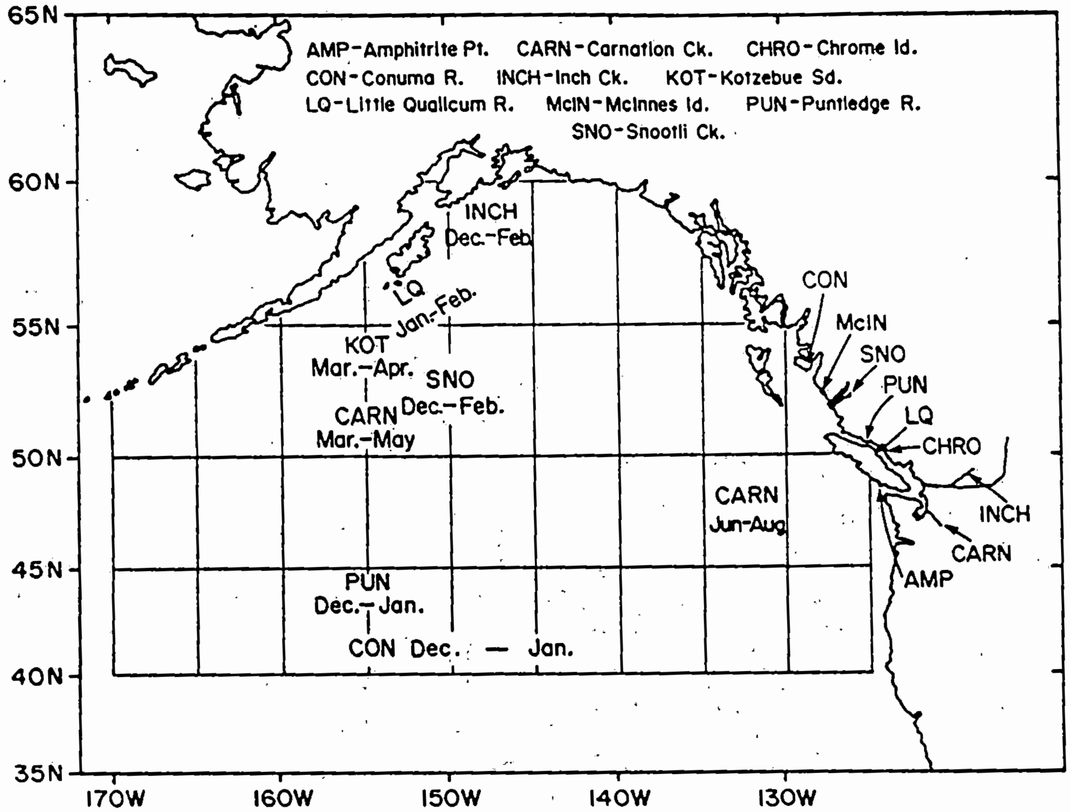


Figure 2(B). Areas and times of strongest correlation between SST in brood year and FWS rate in chum salmon [Table 1(B)].

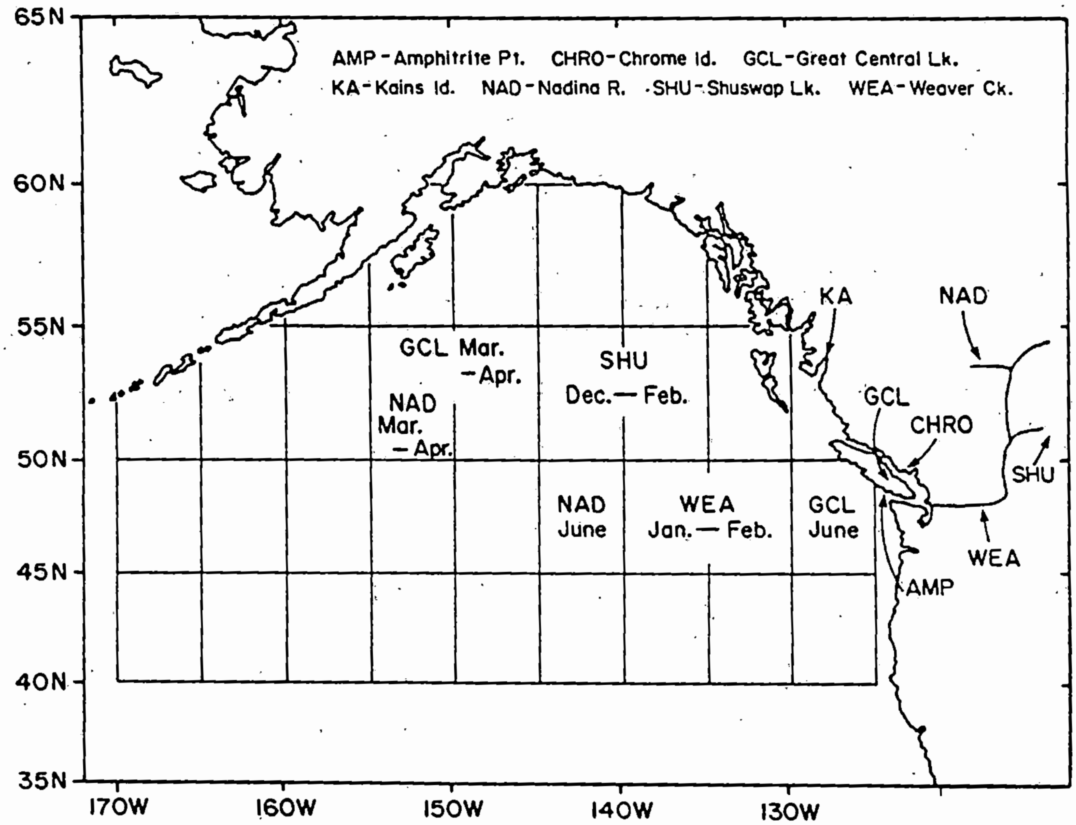


Figure 2(C). Areas and times of strongest correlation between SST in brood year and FWS rate in sockeye salmon [Table 1(C)].

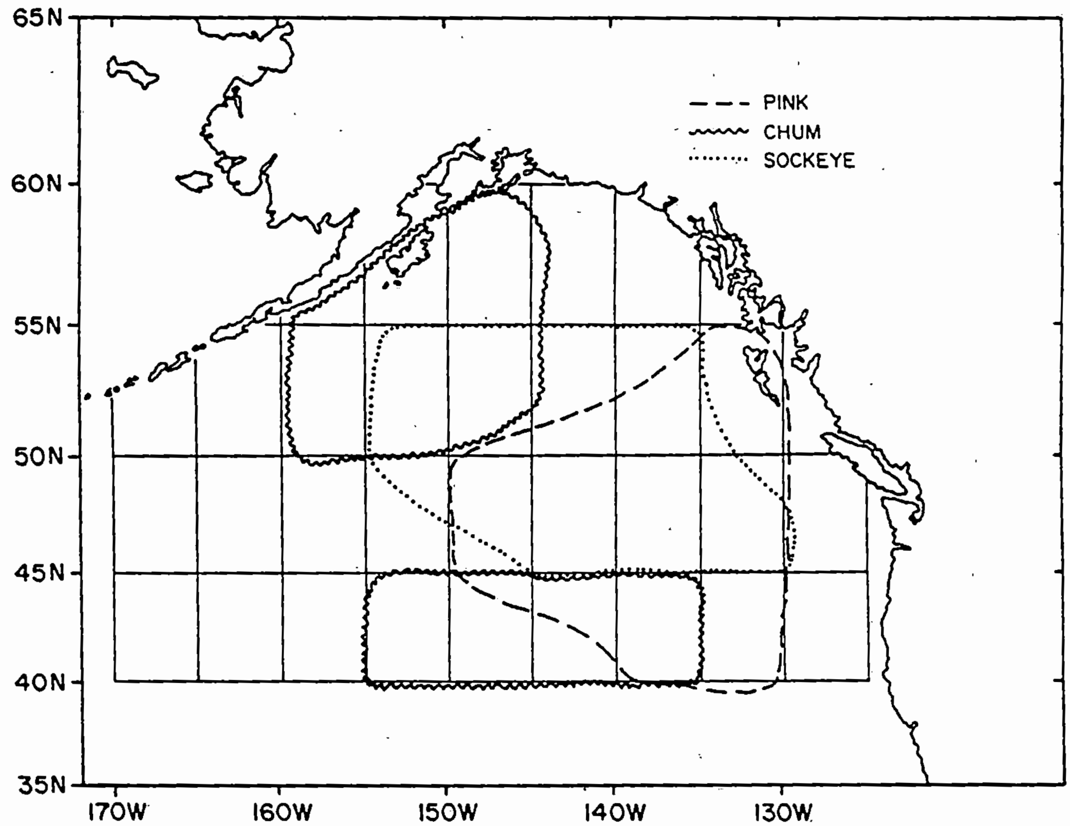


Figure 3. Boundaries of areas of strongest correlation between SST in brood year and FWS rate for pink, chum, and sockeye salmon (Figure 2).

Bottom Distribution of Chum Salmon (*Oncorhynchus keta*) Along the Pacific Coast of Northern Honshu

Yasuhiro Ueno

National Research Institute of Far Seas Fisheries
7-1, 5 Cho-Me Orido, Shimizu 424, Japan

A large number of chum salmon (*Oncorhynchus keta*) (4,337 fish) were caught incidentally by five trawlers along the Pacific coasts of northern Honshu during September through December, 1986. The depth at which chum salmon were caught ranged from 150 to 460 m and most chum salmon occurred near the bottom at 200 to 350 m deep. This bottom distribution of chum salmon appears to extend north and south along the coast of Iwate to the Chiba Prefecture. One hundred chum salmon caught by a trawler at depths between 260 and 280 m in November, 1989 were examined for gonad condition. The results showed that all fish were mature and close to spawning.

It is possible that chum salmon avoid the high surface water temperature of 12 to 20 °C and migrate to depths between 200 to 350 m, where the water temperatures are relatively low at 3 - 11 °C. This seems to be a specific adaptation of chum salmon in this area, which is at the southern most extent of their range.

Trawlers fishing the coasts of Iwate Prefecture situated in the northern part of Honshu generally catch cod, squid and other species but not salmonids. I informally received information on by-catch of chum salmon (*Oncorhynchus keta*) from fishermen in Miyako, Iwate Prefecture (pers. comm.). According to the fishermen, the trawlers incidentally caught chum salmon at depth over 200 m in autumn.

There are many salmon rivers in the Pacific coast of northern Honshu (Okazaki 1988). Ueno et al. (1985) reported that mature chum salmon were caught in the coastal belt (within 9 km width or shallower than 200 m in depth) off Iwate Prefecture from the experimental operations of longlines. However, the migration route of mature chum salmon in the offshore waters of Pacific coast of northern Honshu was not well known. It is commonly considered that chum salmon only occur in the surface waters throughout their oceanic life stage (Manzer et al. 1965). It is worth reconsidering the vertical distribution and migration of chum salmon in the light of this new information.

The purpose of this report is to clarify the catch distribution by trawlers in coastal waters off Iwate Prefecture and the life stage of the salmon caught by the trawlers.

MATERIALS AND METHODS

Trawlers conducted their operations in the coastal waters of Iwate Prefecture but trawl fishing was prohibited within 9 km of the coastline (shallower than about 150 m in depth) by fisheries regulations. One trawler cruise generally lasts two or three days and they mainly catch cod, squid and other bottom-living species. Trawling operations usually take two to three hours and they fish 24 hours a day.

I requested the vessel captains to record the location, day, time, trawling depth and number of chum salmon caught by the trawl operation. The captains of five trawlers agreed and cooperated in recording the chum salmon catch in autumn, 1986 (Table 1). The request to record location and day of the trawl operation in which chum salmon were not caught was denied because the captains did not want the locations of their fishing ground known. Two trawlers used a pair trawl system while the other three trawlers used a single trawl system.

One hundred chum salmon caught by the trawler (F-maru, 60 GRT, pair trawl system) in November, 1989 were used to investigate the life stage of the chum salmon.

RESULTS

A total of 4,337 chum salmon was caught by five trawlers from September to December. The trawlers' catches gradually increased from October to November and decreased in December (Table 1, Figure 1). Catches of chum salmon occurred along the 200 m depth contour along the coast of Iwate Prefecture and chum salmon were more abundant in the northern area. There was little change in pattern of the horizontal distribution of catch during the four month fishing period.

Pair trawlers fished at depths between 200 m to 460 m and chum salmon were most abundant at depths of 250 m to 350 m. Single trawlers fished at depths between 150 m to 350 m and chum salmon were most abundant between 200 and 300 m (Figure 2). There was also little change in pattern of the vertical distribution of the catch during the four month fishing period (Figure 2).

Significant catches of chum salmon occurred during daylight while catches made during daybreak and evening were relatively small. Catches were few in darkness as the salmon moved towards the upper layers (Figure 3). There was little change in daily pattern of the catch during the four month fishing period.

The life stage of 100 chum salmon caught by the pair trawler F-maru 60 GRT were examined (Table 2). The mean fork length was 66.8 cm with a standard deviation of 5.2 cm for females, and 65.8 cm with a standard deviation of 5.2 cm for males. Mean gonad weight was 536 g with a standard deviation of 165 g for females, and 176 g with a standard deviation of 56 g for males. Scale annuli readings indicated a female mean age of 4.2 years and 4.1 years for males. Gonad weights indicated that the chum salmon were mature and close to spawning (Ishida et al. 1961).

DISCUSSION

I investigated the condition of the catch on board of the trawler, F-maru and observed that chum salmon were mingled with other benthic fish. Moreover, I found mud from the sea bottom in the mouth and among the gill rakers of chum salmon. The captains stated that most of the fish caught by trawlers were usually benthic fish and squid and that there were very few non-bethnic species (pers. comm.). Accordingly, chum salmon were considered to be caught near the sea bottom. In the present study, a large catch of chum salmon was frequently caught in depths of 200 m to 350 m. This indicates that chum salmon migrate near the bottom of 200 m to 350 m in depth.

In the North Pacific Ocean, chum salmon were generally considered to occur in upper surface layer between 0 m to 50 m (Manzer 1964; Machidori 1967). However, recent studies on biotelemetry for salmonids revealed that salmonids could submerge to a depth of over 100 m (Soeda et al. 1985; Ogura 1990).

Quinn et al. (1989) reported that mature sockeye salmon avoided warm surface layers and swam down to the depths under the thermocline. The Tsugaru Warm Current (12 - 21 °C) is usually distributed within the coastal belt of Iwate prefecture (19 km wide or shallower than about 200 m in depth, Ueno et al. 1987). In addition, it is known that the water temperature in the upper depths between 0 m to 100 m in offshore waters (20 - 90 km offshore) of Iwate Prefecture range between 12 and 20 °C and the water temperature at depths of 150 m to 300 m is 3 to 11 °C (Ueno et. al 1987). Manzer et al. (1965) concluded that chum salmon have a "preferred range" from 2 or 3° to 11 °C. Accordingly, it is considered that chum salmon avoid the warm surface layers and coastal waters (Tsugaru Warm Current) and submerge to depths over 200 m. This seems to be a specific adaptation of chum salmon at the southern extension of its range (Neave et al. 1976).

The maturity of the gonads show that chum salmon would soon enter their natal river for spawning. This suggests that chum salmon move to near shore areas and move upwards towards the surface to find their natal river using the olfactory sense (Hasler et al. 1983) after leaving the 200 m bottom depth contour (Figure 4).

The five trawlers conducted their operations off Iwate Prefecture. The distribution of chum salmon catch appears to extend north and south. It has been reported that trawlers often caught mature chum salmon near the bottom at depths between 50 m to 250 m off Chiba Prefecture, which was situated 450 km south of Iwate Prefecture (The Fisheries Department of Chiba Prefecture 1988). Accordingly, chum salmon bottom distribution seemed to extend north and south from Iwate to Chiba Prefecture.

The daily pattern of the catch of chum salmon in the present study seems to be that chum salmon stay near the bottom at daytime and leave the bottom at nighttime. However, this conclusion is not firm, since the locations of the operations by the trawlers were unclear in nighttime.

ACKNOWLEDGEMENTS

I wish to thank the owners and captains of the trawlers. I would like to express grateful thanks to Dr. H. Kajimura of National Marine Fisheries Service, Dr. M. Kato of Fisheries Agency, Dr. T. Sasaki and Dr. Y. Ishida of National Research Institute of National Research Institute of Far Seas Fisheries, who extend me their kind advice and assistance.

REFERENCES

Fisheries Department of Chiba Prefecture. 1988. Report on the Project to Promote Salmon Propagation in 1987. Chiba. Japan. p.25.

Isada, R., K. Takagi and S. Arita. 1961. Criteria for the Differentiation of Mature and Immature Forms of Chum and Sockeye Salmon in Northern Seas. Bull. Int. North Pacific Fish. Comm. 5:27-48.

Hasler, A.D. and A.T. Scholz. 1983. Olfactory Imprinting and Homing in Salmon. Zoophysiology. 14: 134p. Spring-Verlag, Berlin.

MacHidori, S. 1968. Vertical Distribution of Salmon (*Genus Oncorhynchus*) on the North-western Pacific. II. Bull. Hokkaido Reg. Fish. Res. Lab. 32: 13-20.

Manzer, J.I. 1964. Preliminary Observations on the Vertical Distribution of Pacific Salmon (*Genus Oncorhynchus*) in the Gulf of Alaska. J. Fish. Res. Bd. Canada, 21(5): 891-903.

Manzer, J.I., T. Ishida, A.E. Peterson and M.G. Hanavan. 1965. Salmon of the North Pacific Ocean Part V. Bull. Int. North Pacific Fish. Comm. 15:1-449.

Neave, F., T. Yonemori and R.G. Bakkala. 1976. Distribution and Origin of Chum Salmon in Offshore Waters of the North Pacific Ocean. Bull. Int. North Pacific Fish. Comm. 35:1-79.

Ogura, M. 1989. Outline of Biotelemetry Study for Salmon by Shin-Riasu-maru, 1989. (Document Submitted to the Annual Meeting of the International North Pacific Fisheries Commission, Vancouver, Canada, 1990 October.) 20 p. Fisheries Agency of Japan, National Research Institute of Far Seas Fisheries, Shimizu-shi, Japan.

Okazaki, T. 1988. Distribution and Origin of Salmon. p. 30 - 38. In T. KUBO [ed.] Salmonids in Japan. Takugin-Sogo- kenkyujo, Sapporo, Japan.

Soeda, H., K. Yoza, T. Shimamura, E. Hasegawa and K. Yoshiwara. 1985. On the Vertical Moving Behavior of Chum Salmon Early Migratory Seasons off the Coast of Shiretoko Peninsula. Bull. Japan. Soci. Sci. Fish. 51(9):1425-1429.

Quinn, T.P., B.A. Terhart and C. Groot. 1989. Migratory Orientation and Vertical Movements of Homing Adult Sockeye Salmon (*Oncorhynchus nerka*) in Coastal Waters. Anim. Behav. 37:587-599.

Ueno, Y., M. Yamazaki. 1987. Some Features of Seasonal Changes in the Tsugaru Warm Current along the Sanriku Coast. Bull. Tohoku Reg. Fish. Res. Lab. 49:111-123.

Ueno, Y., S. Nagahora, K. Oikawa, N. Yamazaki and M. Yamane. 1986. Annual Report on the Experimental Fisheries of Autumn Chum salmon in 1989. Fisheries Experimental Station of Iwate Prefecture, Kamaishi, Japan, p.1-46.

Table 1. Numbers of salmon caught in the Pacific coast of northern Honshu by vessel and by month, 1986. Numbers of operations in which salmon was caught are given in parentheses.

Ship Name	Gross Tonnage	Fishing Implements	September	October	November	December	Total
A-maru	59	Pair trawl	106	533	805	183	1627
			(16)	(58)	(48)	(29)	(151)
B-maru	59	Pair trawl	77	674	977	200	1928
			(13)	(49)	(62)	(40)	(164)
C-maru	59	Single trawl	31	68	106	42	247
			(19)	(30)	(34)	(17)	(100)
D-maru	59	Single trawl	41	37	63	19	160
			(23)	(21)	(34)	(12)	(90)
E-maru	58	Single trawl	3	41	302	29	375
			(3)	(19)	(48)	(20)	(90)
Total	--	--	258	1353	2253	473	4337
			(74)	(177)	(226)	(118)	(595)
Percentage in	(%)	-	5.9	31.2	51.9	10.9	100.0
each month	(%)	-	(12.4)	(29.7)	(38.0)	(19.8)	(100.0)

Table 2. Mean value of fork length, body weight, gonad weight and age of chum salmon caught by a pair trawl (F-maru, 60 GRT) in the coastal waters of northern Iwate Prefecture in November, 1989. Standard deviations are given in parenthesis.

Date	Location	Depth (m)	Sex	Number of Samples	Fork Length (cm)	Body Weight (g)	Gonad Weight (g)	Age (year)
Nov. 10	40°07'N	260	female	24	66.7	3567	546	4.3
	142°13'E				(4.8)	(972)	(158)	(0.6)
			male	41	65.3	3287	173	4.2
					(5.2)	(1003)	(54)	(0.7)
Nov. 11	40°07'N	280	female	14	67.1	3467	520	4.1
	142°14'E				(5.7)	(960)	(175)	(1.0)
			male	21	66.7	3454	181	3.9
					(5.2)	(913)	(59)	(0.6)
Total	--	--	female	38	66.8	3530	536	4.2
					(5.2)	(969)	(165)	(0.8)
			male	62	65.8	3344	176	4.1
					(5.2)	(977)	(56)	(0.7)

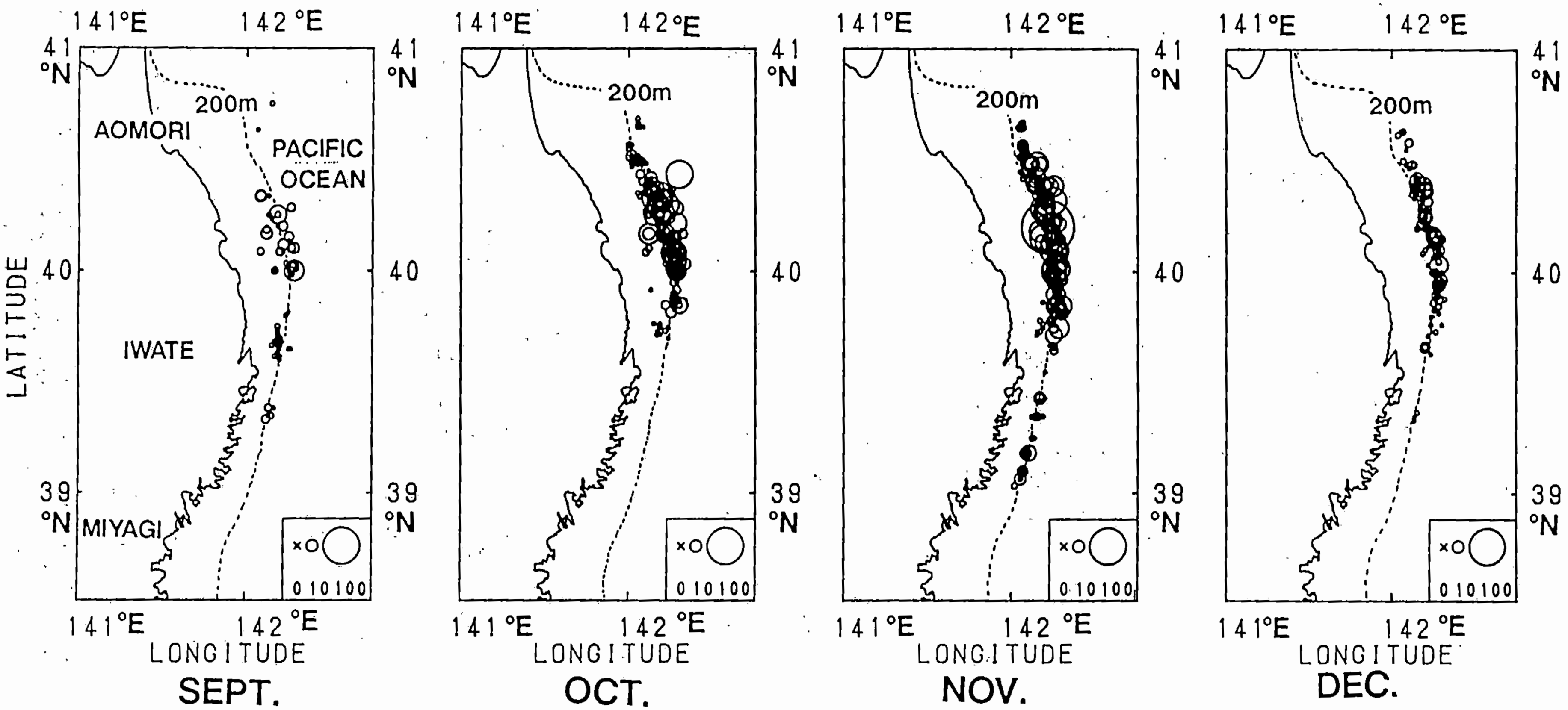


Figure 1. Monthly distribution of chum salmon caught by one operation of trawlers off Iwate Prefecture, 1986. Size of circle proportionally corresponds to the numbers of chum salmon caught.

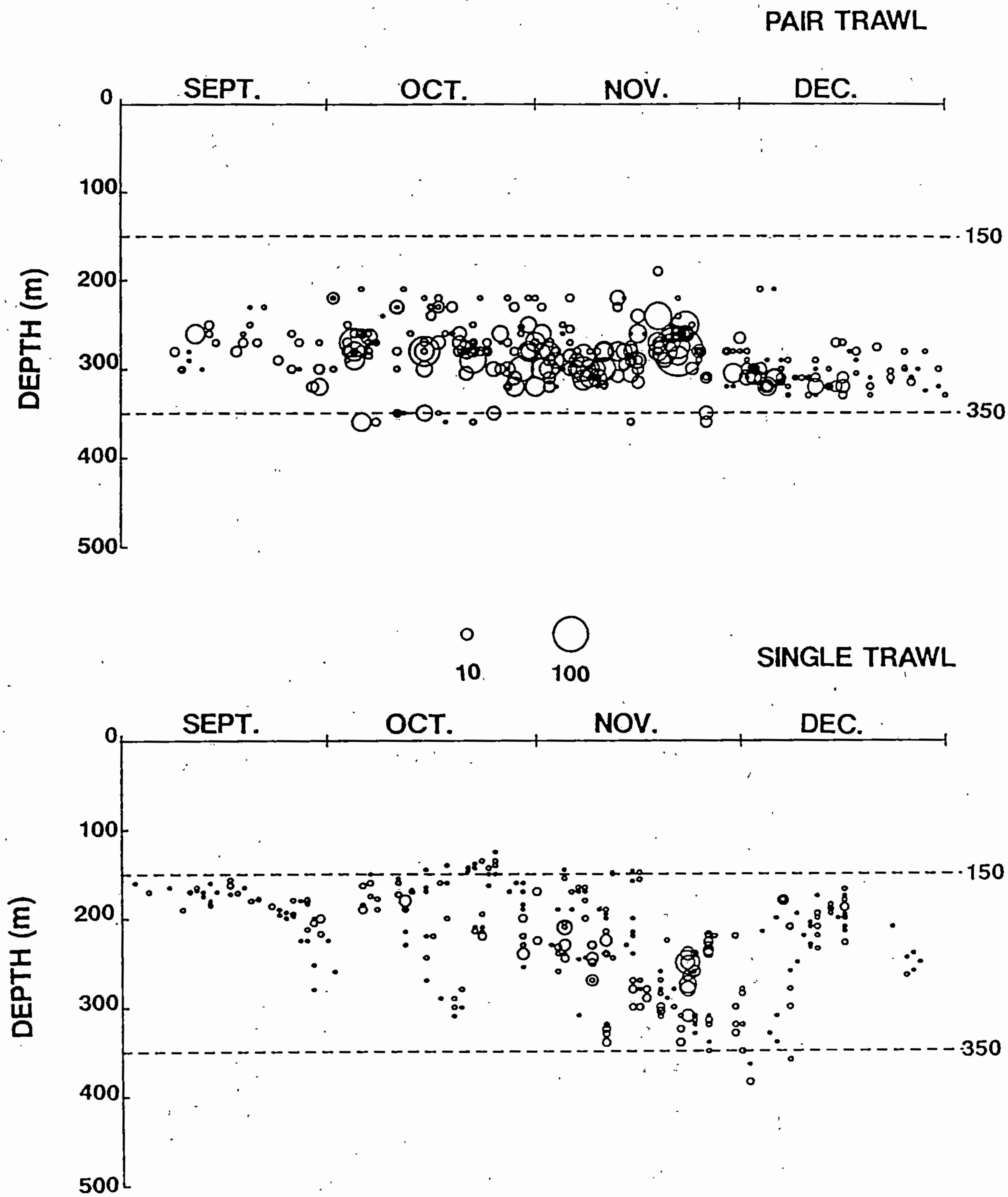
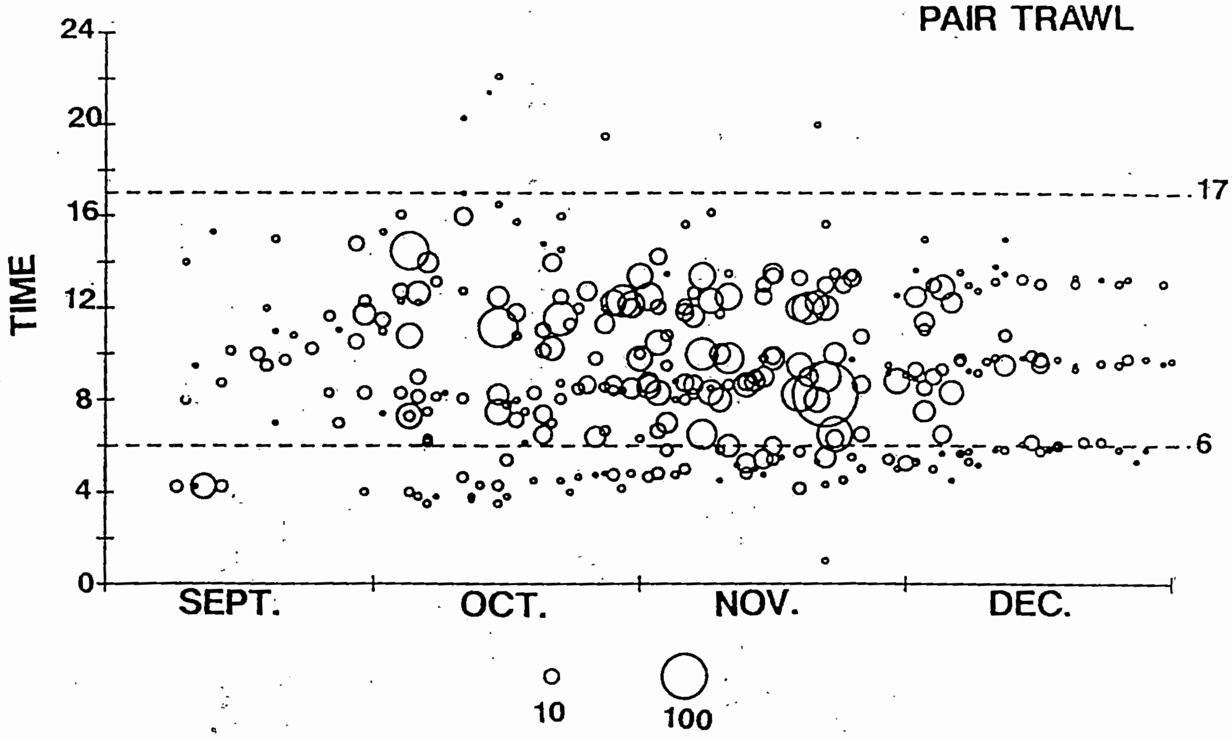


Figure 2. Relationship between depth and date of chum salmon caught by trawlers. Size of circle proportionally corresponds to the numbers of chum salmon caught.



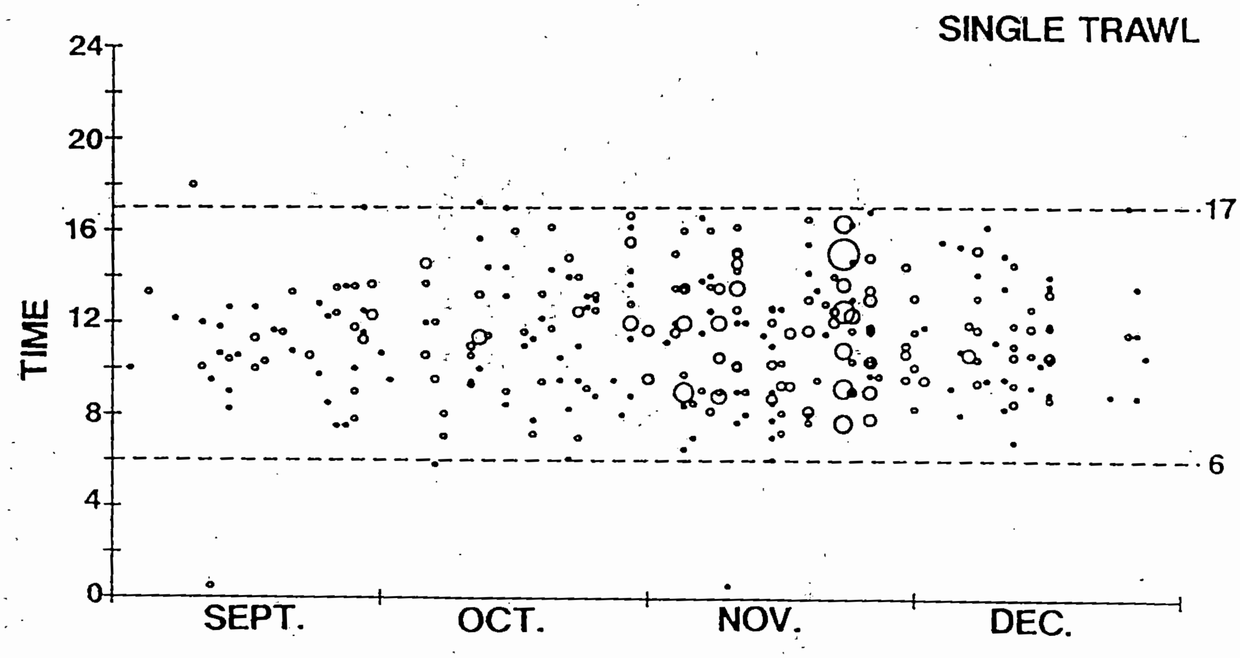


Figure 3. Relationship between time and date of chum salmon caught by trawlers. Size of circle proportionally corresponds to the numbers of chum salmon caught.

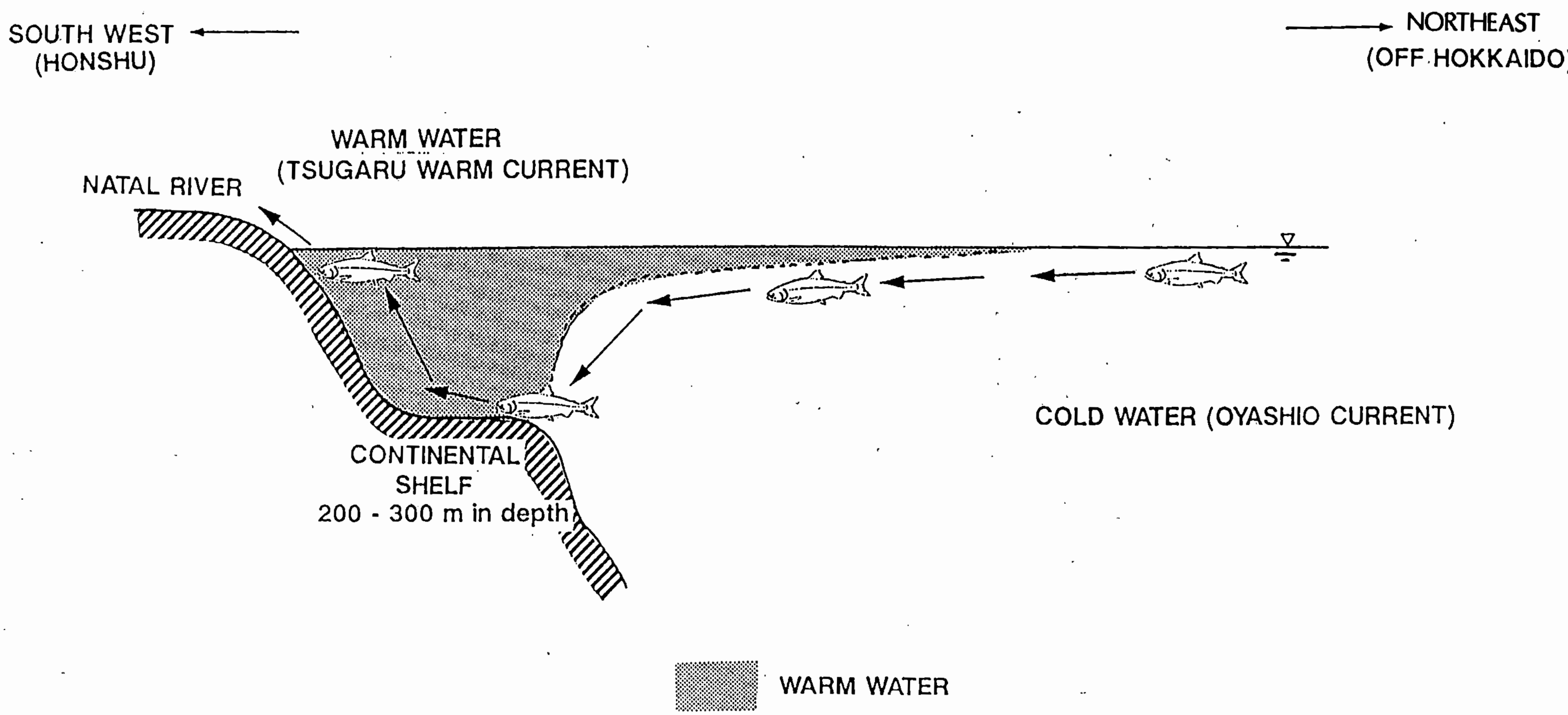


Figure 4. A schematic diagram of behavior of chum salmon on the basis of the results of the trawler catches.

Management of the 1989 Prince William Sound Commercial Pink Salmon Fisheries During the *Exxon Valdez* Oil Spill

Dennis G. Haanpaa

Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, AK 99518

On March 24, 1989, the oil tanker *Exxon Valdez* ran aground on Bligh Reef, spilling 260,000 barrels (11 million gallons) of north slope crude oil into the waters of Prince William Sound. The Alaska Department of Fish and Game along with the Alaska Department of Environmental Conservation were faced with the task of harvesting a forecasted return of 39.3 million pink salmon and ensuring that seafood quality and wholesomeness was maintained. The Department of Fish and Game, under strict guidelines and agreements developed to prevent any tainted fish from entering the market, proceeded with the intent to harvest surplus pink salmon that were of good quality and free of oil contamination. As a result of these efforts, 21.7 million wholesome pink salmon were finally harvested. The value of this fishery to the fishermen was estimated at $16.7 million with an additional $16.1 million to the hatcheries of Prince William Sound.

MANAGEMENT AREA DESCRIPTION

The Prince William Sound (PWS) management area, encompassing all coastal waters and inland drainages entering the northcentral Gulf of Alaska between Cape Suckling and Cape Fairfield, is divided into 11 salmon management districts (Figure 1).

The management goal for all districts is to allow for the orderly harvest of all salmon surplus to predetermined spawning requirements. In addition, regulatory management plans have been developed directing the department to manage enhanced fisheries so that private non-profit (PNP) hatcheries achieve cost recovery and brood stock requirements.

1989 PRE-SEASON COMMERCIAL PINK SALMON MANAGEMENT OUTLOOK

The 1989 pink salmon harvest was forecasted to be 39.3 million fish (Brady 1989). This estimate included 18.8 million pinks from the wild stocks and 20.5 million from four pink salmon hatcheries. The wild stock pink forecast was the largest on record. Average total return of pink salmon between 1965 and 1987 is 13.6 million. Of the forecasted 28.8 million pink salmon returning to the hatcheries, 20.5 million were anticipated to be available for the common property fishery while the remaining 8.3 million were to be used for cost recovery sales and brood stock.

The general waters of all districts are managed on wild stock strength. Escapement performance for wild stock pink salmon is monitored by aerial surveys of 200 established index spawning streams. While wild stock escapement performance determines openings in the general districts of PWS, specific management of hatchery returns is restricted to terminal areas in front of facilities.

OIL SPILL IMPACTS ON PINK SALMON MANAGEMENT

At 12:04 a.m. on March 24, 1989, the tanker *Exxon Valdez* ran aground on Bligh Reef, spilling 260,000 barrels (11 million gallons) of north slope crude oil into the waters of Prince William Sound. Directed by strong north winds and prevailing water currents, oil from the spill moved southwestward from the site of the grounding, impacting many of the Sound's islands and portions of the mainland.

With a forecasted harvest of 39.3 million pink salmon and the potential impact the oil spill could have on seafood quality, the Department of Fish and Game (ADF&G) and the Department of Environmental Conservation (ADEC) agreed to develop a cooperative program in an attempt to conduct an orderly fishery and ensure that seafood quality and wholesomeness was maintained.

Following an April meeting between ADF&G, ADEC, and Alaska Seafood Marketing Institute (ASMI), in which all available information was considered, ADEC finalized a set of emergency regulations pertaining to fishermen, tendermen, and processors. These regulations required all vessels that worked on the spill to be inspected prior to participation in the commercial fishery and all fishermen, tender operators, and processors to inspect their boats, gear, and catch for any indication of contamination from oil during the fishery.

In early May, the Prince William Sound Salmon Harvest Task Force, a working committee made up of leaders and head personnel from State and Federal agencies and the commercial fishing industry, was organized to develop recommendations to preserve the quality of the 1989 salmon harvest. The Task Force proposed that the State adopt a policy that recommended closure of any area or subdistrict where the shoreline has been impacted by oil or where free floating oil was observed.

On June 8, the ADF&G and ADEC signed a "Memorandum of Understanding" (MOU) addressing oil contamination concerns with the salmon fisheries. This document outlined the responsibilities of the two agencies and specified guidelines for evaluating fisheries. As the first line of defense to prevent contaminated salmon from entering the marketplace, ADF&G agreed to keep fishing areas closed "if there was an appreciable likelihood that gear will be fouled, fish harvest adulterated, or such that the conduct of an orderly fishery could not take place" (ADF&G and ADEC MOU 1989). In addition, ADF&G was required to conduct test fisheries prior to district openings to evaluate the presences of oil and the likelihood of contamination occurring.

No major problems from oil contamination were anticipated in the Eastern, Southeastern, and inner waters of the Northern and Coghill Districts. Aerial surveys, beach walks, and test fisheries were conducted to further evaluate these areas. The Southwestern District suffered the most extensive oil impacts from the March 24 oil spill, while both the Montague District and the Eshamy District were also heavily impacted. All three of these districts were closed to commercial fishing during the entire 1989 season.

PRINCE WILLIAM SOUND GENERAL SEINE SEASON

From June 15 through July 11, six purse seine vessels were used in Prince William Sound under a test fishing charter to evaluate the likelihood of encountering oil in areas planned for commercial fishery openings (Schultz 1989). These boats were dispatched to predesignated areas covering the main waters of the Southeastern, Eastern, Northern, Coghill, and Northwestern Districts. A total of 10,566 salmon were harvested by the test fish program. Of these, 4,984 salmon, representing samples from all areas fished, were examined by ADEC seafood inspectors. Examination techniques included organoleptic evaluation of the fish in Cordova and laboratory analysis at the ADEC Palmer laboratory. No oil contamination was detected on any of the salmon inspected by ADEC. The chartered fishing vessels and gear were also inspected following the test fishery, but were found to have no evidence of oil contamination.

The first commercial purse seine fishery, a 12-hour period, occurred in the Eastern and Northern Districts on June 28. The harvest from this seine opening was 461,000 pink salmon.

The second seine fishery opening was scheduled for July 5 and was again of 12-hour duration, and encompassed the same areas of Eastern and Northern Districts as the first period. The harvest was 472,900 pink salmon. Most pink salmon catches continued to come from lower Valdez Arm and were attributed to Solomon Gulch Hatchery production. Wild stock pink salmon were clearly contributing little to the harvest. The same fishing strategy was used the following week, with a 12-hour period on July 12. This period resulted in a harvest of an additional 1.37 million pink salmon. Most of the pink salmon harvest was again attributed to Solomon Gulch Hatchery production.

During these early openings, only a few fishing vessels reported encountering oil sheens during the fishery. The ADF&G responded by conducting aerial surveys of areas where sheens were reported and by interviewing crews on fishing vessels reporting sheens. The ADEC inspections were intensified for tenders bringing in deliveries from these areas. All reported sheens in this area were found to be diesel fuel or bilge oil, and in no case was any contamination of fish or gear detected.

By mid-July pink salmon were starting to return to the Prince William Sound Aquaculture Corporation (PWSAC) hatcheries. Due to the "oil closure" of the Southwestern District and the plans for PWSAC to shift as much of its sales harvest requirements as possible to the Armin F. Koernig (AFK) facility, it was anticipated that most of the 10.7 million pink salmon expected to return to the Esther Hatchery and the 5.0 million pink salmon forecasted to return to the Cannery Creek hatchery would be surplus to hatchery needs and available for harvest in the common property fishery. To ensure the harvest of bright, unmarked, high quality salmon, the Esther Subdistrict and eastern waters of Unakwik Inlet were opened to continuous fishing on July 26.

With Cannery Creek and Esther hatchery terminal harvest areas open to continuous fishing the seine harvest of pink salmon was developing in an orderly and effective manner. From July 26 through 28, the harvest averaged about 600,000 pink salmon each day, indicating that hatchery returns to Esther and Cannery Creek would come in at forecasted levels.

On Friday, July 28, the Department received a number of reports from fishermen and spotter pilots that an oil sheen had moved into the Esther Subdistrict. The sheen was described as 1/2 to 3/4 miles in length and 300 yards wide. Further reports were compiled Saturday morning through radio communications with seine vessels that had encountered oil which contaminated their fishing gear. Consistent with the MOU, an immediate closure of the Esther Subdistrict was announced at 12:00 noon on July 29.

Later that same day, Saturday, July 29, the Department received reports that a seine vessel had encountered an oil sheen at Payday Point in Unakwik Inlet and contaminated its fishing gear. Inspection of that vessel on Saturday evening revealed that the cork line and chaffing gear of the seine as well as the hatch cover on the vessel were spotted with oil. Other vessels in the area also reported seeing an oil sheen at Payday Point. On Sunday morning a second vessel reported encountering an oil sheen near Payday Point that had stained the corks of his seine. Consistent with the MOU, an immediate closure of the open waters in Unakwik Inlet was announced at 12:00 noon on July 30.

As a result of this emergency closure of the fishery, seafood inspection effort was concentrated on fish coming from this area. A number of deliveries were delayed when fishermen requested inspections of their catch, and while tenders carrying salmon from areas where the closures occurred were inspected. Because of the inspection process some fish was lost due to the delays in reaching the processing plants. The inspection program and stiff quality standards resulted in one tender forfeiting a load of fish that was contaminated with oil from a hydraulic system leak.

Following the fishery closures on July 29 and 30, a major effort was mobilized to further evaluate the affected areas to determine whether fish could still be harvested without contamination of fishing gear or fish. The ADF&G research vessel Pandalus was stationed on the grounds to serve as a base for the assessment effort. On August 5, it was estimated that 2 million surplus hatchery fish were present within the Unakwik Inlet area. This large concentration of fish provided an opportunity for a controlled common property harvest. The fleet was placed on 24-hour advance notice, and a course of action was set to attempt to harvest these fish.

A coordinated aerial survey effort involving NOAA, ADEC, Exxon and ADF&G, was conducted daily of the areas around the Esther and Cannery Creek hatcheries to record oil sheens. ADF&G also received numerous reports of oil sheens in this area from spotter pilots and fishermen. Many of these were traced to vessels in the area that had pumped out bilge oil or diesel. To eliminate this source of oil sheens during the critical assessment period, all tenders and fishing vessels were requested to stay outside of the proposed fishing area in Unakwik Inlet.

Four test fishing boats started surveys on August 3. These vessels collected water samples and searched for oil and tar balls by systematically towing purse seines through the water at prescribed locations throughout the area being considered for the Unakwik fishery opening. Test seines had absorbent pads sewn in panels throughout the web so that any encounter with oil would be detected. The vessels observed no oil sheens and no signs of oil contamination were found on any of the seines or absorbent pads.

With the increased potential for a commercial harvest being allowed, the fleet was placed on one hour notice effective 8:00 a.m., August 10. An early morning aerial survey of the proposed fishing area was flown prior to making the final decision on the opening. At 8:00 a.m., the announcement was made to proceed with a fishery of 12-hour duration commencing at 9:00 a.m.

More than 2 million pink salmon were harvested during this 12-hour opening. Although a number of boats reported observed oil sheens, ADF&G biologist and ADEC personnel responding to reports did not observe sheens that threatened the harvest.

The surveillance program was continued and test fishing efforts were redirected in the Esther Subdistrict. By the morning of August 14, with the fleet again on one-hour notice, sufficient evidence had been collected to assure ADF&G that the Esther Subdistrict and surrounding areas, as well as the Unakwik Inlet area, were free of oil. Following a morning survey of the proposed fishing area, a 12-hour opening was announced.

The harvest from this opening totalled about 2.3 million pink salmon. ADF&G and ADEC personnel again responded to a number of reports of oil sheens in the area open to fishing, but these were again attributed to bilge oil and diesel from the tenders and fishing boats of the fleet. No fouled nets or contaminated fish were observed.

The fishery continued through August 29 using the format outlined above; daily aerial surveys, on ground surveillance, and field announcements for short fishing periods. A total of 12 fishery openings were conducted during this time period. Although boundaries were modified on a daily basis, the area opened generally included Unakwik Inlet, the Esther Subdistrict.

On August 30, with most of the pink salmon runs over and fishing effort drastically reduced, the fishery was placed on a schedule of daily 12-hour openings in the Esther Subdistrict. On September 30 the 1989 PWS salmon fishing season was officially closed.

CONCLUSION

Outside of the Esther Island and Cannery Creek Hatchery areas, few openings were scheduled in the Eastern and Southeastern Districts to harvest wild stock production. Overall, wild stock pink salmon contributed little to the final common property commercial catch of 13.8 million. Of this total harvest, it was estimated that 90% of the pink salmon were of hatchery origin. An additional 7.8 million pink salmon, the highest sales harvest on record, were harvested for cost recovery by the hatcheries. The total 1989 pink salmon harvest was 21.7 million. The 13.1 million purse seine harvest was worth $16.0 million to 243 permit holders. An additional 0.7 million pink salmon worth $0.9 million were harvested by the gill net fleet (Brady 1991).

In those districts where commercial harvests were conducted (Eastern, Northern, Coghill, Northwestern and Southeastern), wild stock pink salmon escapements were at or below the lower end of desired ranges. In those districts where there were no commercial harvest (Eshamy, Southwestern, and Montague), the escapement indices exceeded the upper end of the desired ranges by only 40% to 60%.

REFERENCES

Alaska Department of Fish and Game and Alaska Department of Environmental Conservation, Memorandum of Understanding, 1989 Commercial Fishery Season.

Brady, James, Steve Morstad, Ellen Simpson, Evelyn Biggs. 1991. Prince William Sound Area Annual Finfish Management Report 1989, Alaska Department of fish and Game, Cordova, Alaska.

Brady, James. 1989. Commercial Salmon Management Outlook 1989, Alaska Department of Fish and Game, Cordova, Alaska.

Schultz, Keith. 1989. Memorandum to James Brady dated July 28, 1989 regarding Purse Seine Test Fishery. Alaska Department of Fish and Game, Cordova, Alaska.

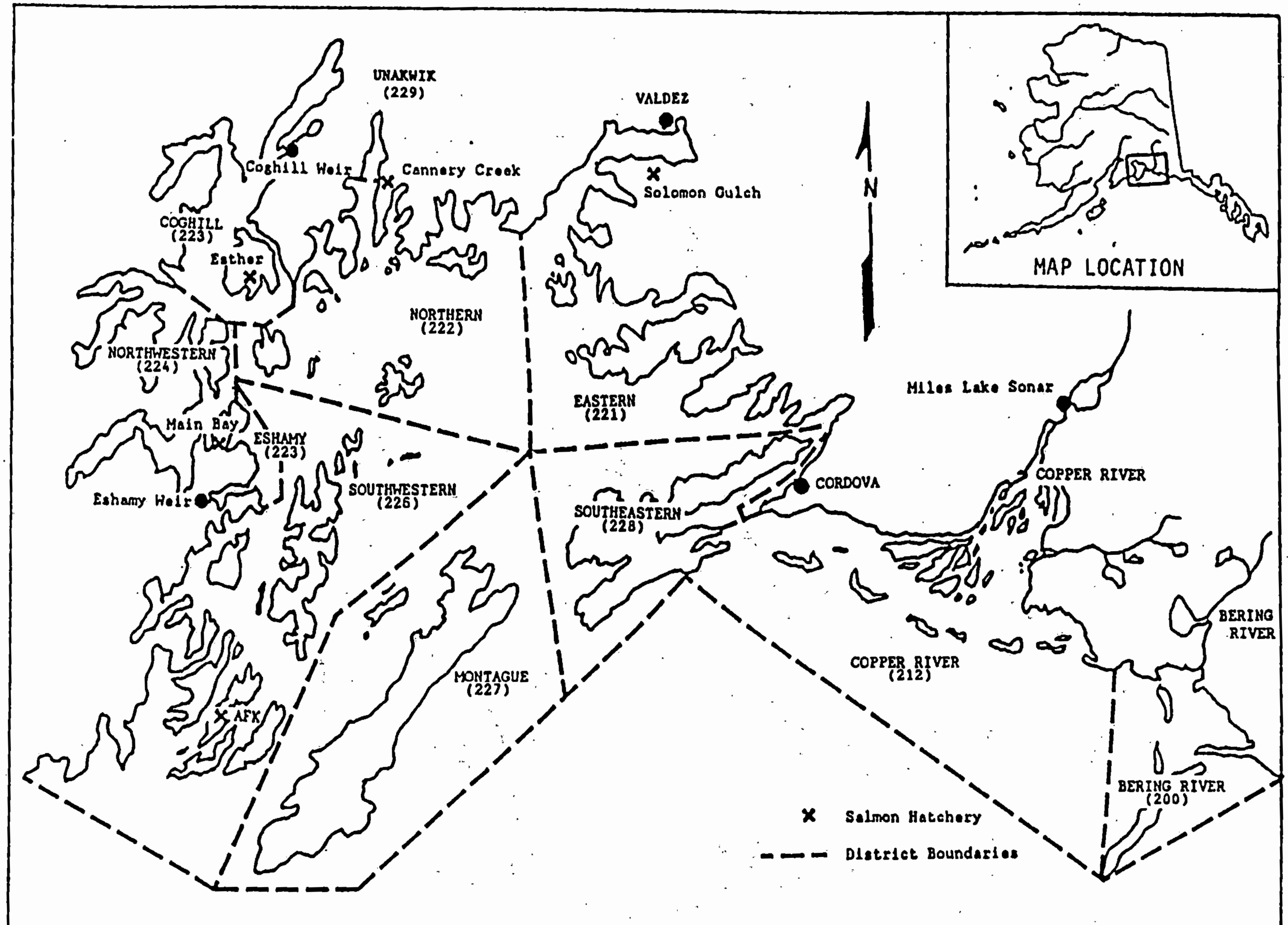


Figure 1. Map of Prince William Sound Area, showing commercial fishing districts, salmon hatcheries, weir locations and the Miles Lake Sonar.

Hatchery Response in Prince William Sound, Cook Inlet and Kodiak to the *Exxon Valdez* Oil Spill

Thomas M. Kron

Alaska Department of Fish and Game
Division of Fisheries Rehabilitation and Enhancement and Development
333 Raspberry Road
Anchorage, Alaska 99518

The March 24, 1989 *Exxon Valdez* oil spill threatened salmon hatchery programs in the Prince William Sound, Cook Inlet and Kodiak areas. Maintenance of hatchery facilities and continued viability of their fish production programs was of utmost concern. Hatchery contribution to the common property fishery the year prior to the spill was valued at $31.9 million in Prince William Sound alone. It was necessary to protect juvenile salmon in saltwater net pens at the hatcheries as well as to protect the adjacent bay such that fisheries could occur in the future without fear of oil contamination.

Deflection boom material was deployed at six hatcheries to exclude oil from the immediate hatchery vicinity. Of these six, the deflection booms at three (AFK, Main Bay and Kitoi) were hit by floating oil. The AFK Hatchery deflection boom was hit by oil starting 8 days after the spill. Large quantities of floating oil moved passed the AFK facility and represented a very serious threat. The Main Bay Hatchery deflection boom was hit by oil starting 11 days after the spill. The Kitoi Hatchery deflection boom was hit by oil starting 30 days after the spill. Though the Kitoi Hatchery was almost 300 miles away from where the *Exxon Valdez* went aground, deflection boom there was hit by up to 1500 gallons/day of oil and oiled debris. All three of these facilities were in serious jeopardy through the spring and summer of 1989 as a result of floating oil. Two other hatcheries (Wally Noerenberg and Tutka) were threatened by oil in the immediate vicinity. The deflection boom at neither of these two facilities was ultimately hit by floating oil.

The hatchery protection response program necessitated intense cooperation and support from State and Private Nonprofit hatchery operators. The fishermen, U.S. Coast Guard, Borough governments and Exxon all made substantial contributors to hatchery protection efforts. Though many said it could not be done, all hatcheries were ultimately protected. This is a credit to many dedicated individuals as well as lack of south easterly storms during the first weeks after the spill.

Traditional fisheries at the impacted hatcheries were closed in 1989 forcing operators to initiate emergency harvest programs for returning salmon. These harvests were tightly controlled to prevent any possibility of oil contamination and were successful in harvesting returns that year. Studies are underway to assess the impact of the oil spill on the survival of fish released from the hatcheries in Prince William Sound.

Humpies and Hydrocarbons: Relating Laboratory Effects Studies to Potential Effects from the *Exxon Valdez* Oil Spill

Stanley D. Rice and Adam Moles

National Marine Fisheries Service
Auke Bay Laboratory
P.O. Box 210155
Auke Bay, Alaska 99821

The potential effects from the *Exxon Valdez* oil spill on the pink salmon, *Oncorhynchus gorbuscha*, are examined in light of controlled laboratory studies. Eggs and alevins are tolerant of short term water-borne oil exposures, but are especially vulnerable in Prince William Sound where whole oil could contaminate the intertidal redds. Out migrant fry in seawater are about twice as sensitive as fry in freshwater, but exposure to high levels of hydrocarbons in seawater from a spill is unlikely. If spilled oil affects out migrant fry, laboratory studies suggest that decreased growth will be the most likely effect. Returning adults have declining abilities to metabolize hydrocarbons, but their exposures are likely to be minimal.

Fishery resource managers have been concerned for some time that a major spill, like the *Exxon Valdez* oil spill, could damage major habitats and populations of salmon in Alaska. Over 20% of the U.S. domestic production of oil flows through the Trans- Alaska pipeline and is carried via tankers through Prince William Sound. This tanker traffic is predicted to continue for another three plus decades as predicted Alaskan oil production comes on line. This perceived threat to the abundant salmon resources of Prince William Sound was recognized in 1970, stimulating a series of laboratory studies to determine life stages and processes of salmon sensitive to oil exposure. Much of this information has been useful in designing field studies to assess the damages from the *Exxon Valdez* oil spill, and will be combined with field observations to support current litigative efforts. Litigation efforts preclude open disclosure of results from State and Federal damage assessment studies of the *Exxon Valdez* at this time. The objective of the following review is to relate laboratory studies to the *Exxon Valdez* oil spill.

The March 1989 grounding of the tanker *Exxon Valdez* was the beginning of a large scale and long term pollution event. Oiling of surface waters lasted for several months; cleaning shores was a large effort in the first two summers after the spill. Several life stages of pink salmon from several year classes were exposed to oil during the multi-year event.

EGGS, ALEVINS IN REDDS: SENSITIVITY VERSUS VULNERABILITY

Eggs of pink salmon are relatively tolerant of short term exposures to water borne oil (Moles et al. 1979). As the development proceeds, yolk is used up, and sensitivity increases (Rice et al. 1975; Moles et al. 1987). The most sensitive freshwater life stage are emergent fry, which have consumed most of their yolk reserves, but have not begun feeding. Eggs are so tolerant to water soluble fractions of oil, that the tests comparing sensitivities had to be with benzene, an aromatic hydrocarbon with a solubility that allows high concentrations to mix into the water. The tolerance of eggs is associated with the slow uptake rates of the hydrocarbons and the large lipid mass of the yolk. Eggs accumulate 14C-hydrocarbons very slowly compared to alevins or fry (Korn and Rice 1981). Eggs are surrounded by membranes, and do not have gills for the efficient transfer of hydrocarbons into the tissues. Furthermore, eggs have a large quantity of lipid rich yolk, that can sequester large quantities of accumulated hydrocarbons. Lipids isolate hydrocarbons away from the actively growing tissues. Although the short term tolerance of eggs is extreme, eggs do slowly accumulate hydrocarbons and can be killed in long term exposures to low concentrations of hydrocarbons (Korn and Rice 1981). Depuration of hydrocarbons out of the eggs is much slower than for alevins or fry.

Eggs and alevins in intertidal redds are both more sensitive and more vulnerable than in freshwater redds. In Prince William Sound, Alaska, up to 75% of the pink salmon production may come from the upper intertidal zone of small streams (Helle 1970). Eggs and alevins in this environment usually have increased survival in most years, but after an oil spill, this zone is particularly vulnerable to oil impact. There are two factors that will impact survival. First, periodic tidal seawater exposures increases the sensitivity of egg/alevins to oil. The combination of oil and periodic saltwater exposure reduced the time to death of 5 day old alevins from 16 days (FW) to 6 days (Moles et al. 1987), apparently as a result of increased accumulation. Alevins exposed to a combination of oil and seawater accumulated 13 times the amount for similar aged alevins exposed to oil in freshwater (Moles et al. 1987). The combination of low concentrations of oil in tidal seawater for 30 days resulted in alevins with virtually no yolk reserves available for the subsequent 60 days in the gravel (Moles et al. 1987).

The second major factor affecting survival is vulnerability. Spilled oil is deposited in the upper intertidal zone, and coats rocks and contaminates habitat. Although streams with a freshwater flow at low tide have more protection from coating than the adjacent shoreline, some stream flows are low and oil can be mixed into the redds by waves and water movements. Evidence of oil in redds has been found. This would change the mode of exposure from water borne oil (light end fraction of oil like substituted benzenes and naphthalenes) to a contact mode, where the spectrum of compounds includes large and toxic multi-ring aromatic hydrocarbons. In 1989, alevins emerged from gravels within weeks of the *Exxon Valdez* grounding; exposure was limited but the oil was fresh and very mobile. In the 1990 brood year, the oil was weathered, less mobile to some extent, but the contamination in Prince William Sound was very pervasive. The eggs/alevins were in the intertidal gravels for approximately 8-9 months before emergence. The chances for exposure to water borne oil were small in 1990, but the chances for direct contact with oil droplets was significant given the length of intragravel incubation.

The laboratory studies on eggs and alevins were water borne exposures; there were no experiments that examined the effectiveness of oil exposures through direct contact on toxicity or uptake. The Alaska Department of Fish and Game had studies in the field to determine survival of eggs and alevins in redds during both 1989 and 1990 in Prince William Sound.

SENSITIVITY OF OUT MIGRANT FRY

The biggest change in sensitivity occurs upon entry to seawater. Several species of salmonid smolts, including pink salmon, were twice as sensitive in seawater as in freshwater when exposed to benzene and the WSF of Prudhoe Bay crude oil (Moles et al. 1979). Even after 42 days of acclimation to seawater, salmon are twice as sensitive to aromatic hydrocarbons as they had been in freshwater, despite a 25% increase in body weight during the 42 day period (Stickle et al. 1982). The increase in sensitivity is probably caused by two factors: increased uptake, and decreased hydrocarbon metabolism, as a result of the physiological adjustments to be made on entry into seawater (renal shut down, drinking seawater and excretion of excess salts, etc.). Thomas and Rice (1981) found that Dolly Varden char exposed in seawater accumulate consistently higher concentrations of toluene and naphthalene (and lower percentages of metabolites) in their tissues than fish exposed in freshwater.

The low temperature of Alaskan waters has two effects on the toxicity of aromatic hydrocarbons, effects that are difficult to separate. Low temperature increases the toxicity of oil by increasing the persistence of aromatic hydrocarbons in water and modifies the physiological sensitivity of test animals (Rice et al. 1977b). Pink salmon fry in seawater showed increased sensitivity at lower test temperatures. Sensitivities ranges from 1.5 ppm at 4C to 1.8 ppm at 12C (Korn et al. 1979).

Salmon readily take up hydrocarbons in their tissues after water exposure, but have the capacity to rid their tissues of the hydrocarbons even while remaining in the exposure solutions (Rice et al. 1977a). Hydrocarbon depuration can be passive via the gills, the primary excretion pathway of smaller aromatic hydrocarbons, or through metabolism and bile excretion (Thomas and Rice 1981, 1982). Hydrocarbon concentrations are difficult to detect in pink salmon juveniles, because of active hydrocarbon metabolism, and because these juveniles are actively growing and do not have lipid rich stores for accumulation reservoirs, like herring (Rice et al. 1987). Pink salmon juveniles have the capacity to adapt to sublethal oil exposures: tolerance to petroleum hydrocarbon increased after sublethal exposures because of the salmon's ability to induce hydrocarbon degrading enzymes after sublethal exposures (Rice and Thomas 1989).

Several studies have shown harmful sublethal effects from petroleum hydrocarbon exposures to pink salmon fry. Pink salmon exposed to sublethal levels of crude oil have increased coughing (Rice et al. 1977a) and increased respiration (Thomas and Rice 1979). Swimming stamina performance was decreased in sublethal hydrocarbon exposures to juvenile coho, suggesting that predator avoidance could be affected (Thomas and Rice 1987). Pink salmon fry can detect and avoid concentrations of oil that are about 1% of the LC50 (Rice 1973). While laboratory tests can define the physiological ability to detect oil, these test provide little insight into the behavioral decisions salmon would make when confronted with oil contaminated water, especially near natal streams or estuaries.

Decreased growth in out migrant pink salmon fry can be caused by hydrocarbon exposures in lab tests, and decreased growth from an oil spill may have a critical impact on marine survival. Decreased growth in pink salmon in seawater occurs at 33% of the LC50 (about 0.4 ppm) after 40 days of exposure. The higher the concentration of oil, the less observed growth. Juvenile pink salmon exposed to nearly lethal levels of crude oil do not grow (Moles and Rice 1983). The concentration that affects growth in pink salmon is the same concentration that increases respiration rates (Moles and Rice 1983; Thomas and Rice 1979), suggesting the energy for growth is diverted to hydrocarbon metabolism and excretion.

Oil contaminated prey may be an important route of hydrocarbon entry into pink salmon fry. In lab tests with *Artemia nauplii* contaminated with the water soluble fraction of oil, pink salmon fry feeding rates and growth were decreased with sublethal exposures (Schwartz 1985). Hydrocarbons were detectable in fry tissue after 10 days, but not after 23 days - even though fry continued to consume oil contaminated prey (Schwartz 1985). The impact of prey, such as harpacticoid copepods, contaminated with whole oil may be far more negative than the light end fraction of oil used in lab studies as the hydrocarbon source. Little is known about the availability, palatability, and vulnerability of oil contaminated prey after an oil spill. Exposure and contamination of epibenthic prey may be substantial.

RETURNING ADULTS

Studies exposing returning adults to oil are rare. Returning adults have less ability to metabolize petroleum hydrocarbons than juveniles, because the ability to induce hydrocarbon metabolizing enzymes is decreased (Thomas et al. 1988). However, exposure to water borne hydrocarbons at harmful levels is unlikely given the short time in the estuary and the lack of feeding - in contrast to juveniles.

There is concern that a spill may interfere with homing to natal streams. Salmon have the ability to detect low levels of organics, including oil (Rice 1974), but the level that will cause avoidance is likely to be high, and not easily attained. Returning adults are motivated, and are likely to pass through sublethal exposures of oil (Weber et al. 1981).

EXXON VALDEZ DAMAGE ASSESSMENT STUDIES

The Natural Resource Damage Assessment process is a complicated suite of studies ranging from studies of environmental contamination, to impacts on fish, birds, marine mammals, and terrestrial species. Alaska Department of Fish and Game and the National Marine Fisheries Services have led several studies that examine the impacts of the *Exxon Valdez* oil spill on eggs/alevins, out migrant fry, and returning adults of pink salmon. The potential for litigation precludes open disclosure of the results of these studies at this time.

REFERENCES

Babcock, M.M. 1985. Morphology of olfactory epithelium of pink salmon, *Oncorhynchus gorbuscha*, and changes following exposure to benzene: A scanning electron microscopy study. Pp. 259-267 in Gray, J.S. and M.E. Christiansen (eds.), Marine Biology of Polar Regions and Effects of Stress on Marine Organisms. Proceedings of the 18th European Marine Biology Symposium, University of Oslo, Norway, 14-20 August 1983. John Wiley & Sons. Chichester, England.

Collier, T.K., L.C. Thomas, and D.C. Malins. 1978. Influence of environmental temperature on disposition of dietary naphthalene in coho salmon (*Oncorhynchus kisutch*): isolation and identification of individual metabolites. Comp. Biochem. Physiol. 61C:23-8.

Coull, B.C. 1973. Estuarine meiofauna: A review: trophic relationships and microbial interactions. In: Stevenson, L.H., Colwel, R.R. (ed.) Estuarine microbial ecology. University of South Carolina Press, Columbia, South Carolina, p. 499-511.

Engelhardt, F.R., M.P. Wong, and M.E. Duey. 1981. Hydromineral balance and gill morphology in rainbow trout *Salmo gairdneri* acclimated to fresh and seawater, as affected by petroleum exposure. Aquat. Toxicol. 1: 175-86.

Gruger, E.H., Jr., M.M. Wekell, P.T. Numoto, and D.R. Craddock. 1977. Induction of hepatic aryl hydrocarbon hydroxylase in salmon exposed to petroleum dissolved in seawater and to petroleum and polychlorinated biphenyls, separate and together, in food. Bull. Environ. Contam. Toxicol. 17: 512-20.

Helle, J.H. 1970. Biological characteristics of intertidal and freshwater spawning pink salmon at Olsen Creek, Prince William Sound, Alaska, 1962-63. United States Fish and Wildlife Service Special Scientific Report Fisheries 602.

Helle, J.H., Richard S. Williamson, and Jack E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. United States Fish and Wildlife Service Special Scientific Report Fisheries 483.

Korn, S., D.A. Moles, and S.D. Rice. 1979. Effects of temperature on the median tolerance limit of pink salmon and shrimp exposed to toluene, naphthalene, and Cook Inlet crude oil. Bull. Environ. Contam. Toxicol. 21(4-5):521-525.

Korn, S. and S. Rice. 1981. Sensitivity to, and accumulation and depuration of, aromatic petroleum components by early life stages of coho salmon (*Oncorhynchus kisutch*). Rapp. P. -V. Reun. Cons. Int. Explor. Mer. 178:87-22.

Moles, A. and S.D. Rice. 1983. Effects of crude oil and naphthalene on growth, caloric content, and fat content of pink salmon juveniles in seawater. Trans. Am. Fish. Soc. 112(2A):205-211.

Moles, A., S.D. Rice, and S. Korn. 1979. Sensitivity of Alaskan freshwater and anadromous fishes to Prudhoe Bay crude oil and benzene. Trans. Am. Fish. Soc. 108(4):408-414.

Moles, Adam, Malin M. Babcock, and Stanley D. Rice. 1987. Effects of oil exposure on pink salmon, *Oncorhynchus gorbuscha*, alevins in a simulated intertidal environment. Mar. Environ. Res. 21(1):49-58.

Rice, S.D. 1974. Toxicity and avoidance tests with Prudhoe Bay oil and pink salmon fry. Pp. 667-670 in 1973 Joint Conference on Prevention and Control of Oil Spills. American Petroleum Institute, Environmental Protection Agency and U.S. Coast Guard. Washington, D.C.

Rice, S.D., M.M. Babcock, C.C. Brodersen, J.A. Gharrett, and S. Korn. 1987. Uptake and depuration of aromatic hydrocarbons by reproductively ripe Pacific herring and the subsequent effect of resides on egg hatching and survival. Pp. 139-154 in Vernberg, W.B., A. Calabrese, F.P. Thurberg, and F.J. Vernberg (eds.), Pollution Physiology of Estuarine Organisms. Belle W. Baruch Libr. Mar. Sci. 17. Univ. S.C. Press. Columbia, S. C.

Rice, S.D., A. Moles, and J.W. Short. 1975. The effect of Prudhoe Bay crude oil on survival and growth of eggs, alevins, and fry of pink salmon, *Oncorhynchus gorbuscha*. Pp. 503-507 in 1975 Conference on Prevention of Oil Pollution. American Petroleum Institute, Environmental Protection Agency, and U.S.

Rice, S.D., J.W. Short, and J.F. Karinen. 1977b. Comparative oil toxicity and comparative animal sensitivity. Pp. 78-94 in Wolfe, D.A. (ed.), Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. Pergamon Press. New York.

Rice, S.D., R.E. Thomas, and J.W. Short. 1977a. Effect of petroleum hydrocarbons on breathing and coughing rates and hydrocarbon uptake-depuration in pink salmon fry. Pp. 259-277 in Vernberg, F.J., A. Calbrese, F.P. Thurberg, and W.B. Vernberg (eds.), Physiological Responses of Marine Biota to Pollutants. Academic Press. New York.

Rice, Stanley D. and Robert E. Thomas. 1989. Effect of pre-treatment exposures of toluene or naphthalene on the tolerance of pink salmon *Oncorhynchus gorbuscha* and kelp shrimp *Eualus suckleyi.* Comp. Biochem. Physiol. 94C:289-293.

Schwartz, J.P. 1985. Effect of oil-contaminated prey on the feeding and growth rate of pink salmon fry (*Oncorhynchus gorbuscha*). Pp. 459-476 in Vernberg, F.J., F.P. Thurberg, A. Calabrese, and W. Vernberg (eds.), Marine Pollution and Physiology: Recent Advances. Belle W. Baruch Libr. Mar. Sci. 13. University of South Carolina Press. Columbia, S.C.

Stickle, W.B., T.D. Sabourin, and S.D. Rice. 1982. Sensitivity and osmoregulation of coho salmon, *Oncorhynchus kisutch*, exposed to toluene and naphthalene at different salinities. Pp. 331-348 in Vernberg, W.B., A. Calabrese, F.P. Thurberg, and F.J. Vernberg (eds.), Physiological Mechanisms of Marine Pollutant Toxicity. Academic Press. New York.

Thomas, R.E. and S.D. Rice. 1979. The effect of exposure temperature on oxygen consumption and opercular breathing rates of pink salmon fry exposed to toluene, naphthalene, and water-soluble fractions of Cook Inlet crude oil and no. 2 fuel oil. Pp. 39-52 in Vernberg, W.B., A. Calabrese, F.P. Thurberg, and F.J. Vernberg (eds.), Marine Pollution: Function Responses. Academic Press. New York.

Thomas, R.E., and S.D. Rice. 1981. Excretion of aromatic hydrocarbons and their metabolites by freshwater and seawater Dolly Varden char. Pp. 425-448 in Vernberg, F. John, Anthony Calabrese, Frederick P. Thurberg, and Winona B. Vernberg (eds.), Biological Monitoring of Marine Pollutants. Academic Press. New York. 559 pp.

Thomas, R.E. and S.D. Rice. 1982. Metabolism and clearance of phenolic and mono-, di-, and polynuclear aromatic hydrocarbons by Dolly Varden char. Pp. 161-176 in Vernberg, W.B., A. Calabrese, F.P. Thurberg, and F.J. Vernberg (eds.), Physiological Mechanisms of Marine Pollutant Toxicity. Academic Press. New York.

Thomas, Robert E. and Stanley D. Rice. 1987. Effect of water-soluble fraction of Cook Inlet crude oil on swimming performance and plasma cortisol in juvenile coho salmon (*Oncorhynchus kisutch*). Comp. Biochem. Physiol. 87C(1):177-180.

Thomas, R.E., S.D. Rice, M.M. Babcock, and A. Moles. 1988. Differences in hydrocarbon uptake and mixed function oxidase activity between juvenile and spawning adult coho salmon exposed to Cook Inlet crude oil. Amer. Zool. 28(4):104A.

Weber, D.D., D.J. Maynard, W.D. Gronlund and V. Konchin. 1981. Avoidance reactions of migrating adult salmon to petroleum hydrocarbons. Can. J. Fish. Aquat. Sci. 38: 779-781.

Methodology for Assessment of Injury to Pink Salmon Eggs and Fry

Brian G. Bue

Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, Ak. 99518, USA

Samuel Sharr, and Steve E. Moffit

Alaska Department of Fish and Game, P.O. Box 669, Cordova, Ak. 99574, USA

This paper describes methodologies used to assess pink salmon (*Oncorhynchus gorbuscha*) egg and pre-emergent fry mortalities due to spawning ground oiling by the *T/V Exxon Valdez* oil spill. Live and dead pink salmon eggs and pre-emergent fry were flushed from the spawning gravel and enumerated for both oiled and unoiled streams. A nested analysis of variance was used to test for differences in egg and fry mortality and egg to fry survival among oiled and unoiled streams. Samples of eggs and fry were collected for histopathological and mixed-function oxidase analysis to tie increases in mortality to oiling. Methods for study site selection, data collection, data analysis, and documenting oil contamination are presented.

Over 900 anadromous fish streams are located in Prince William Sound, Alaska (PWS). The vast majority of these streams support pink salmon (*Oncorhynchus gorbuscha*), many of which spawn intertidally (up to 75% in some years [Helle et al. 1964; Helle 1970]). Much of the intertidal spawning area was contaminated with north slope crude oil from the *T/V Exxon Valdez* spill just prior to fry emergence in late March and early April, 1989. Moles et al. (1987) demonstrated that pink salmon alevins exposed to simulated intertidal oiling had reduced survival, greater uptake of hydrocarbons, and impaired condition compared to alevins in fresh water exposed to the same concentrations of oil.

This study was designed to compare egg and fry mortality as well as egg to fry survival among oiled and unoiled areas using sampling technology developed for past egg and fry density estimation projects (Pirtle and McCurdy 1977). While it is important to show differences in mortality among oiled and unoiled areas, it is also critical to determine whether these differences could be attributed to oiling. Hydrocarbon impact was assessed for each stream and histopathological and mixed-function oxidase data were collected from eggs and fry to examine this link.

This examination is part of the joint Federal-State of Alaska Damage Assessment Program. Results of these studies are considered litigation sensitive; consequently, only methodologies are presented. The results will be presented in a future paper.

METHODS

STUDY SITES

The plume of crude oil from the *T/V Exxon Valdez* flowed in a counter clockwise direction around Prince William Sound and exited through the southwest corner. Most of the 31 streams examined for pink salmon egg and fry density were in the southwest portion of PWS; although, streams in eastern PWS and on Montague Island were included to ensure the availability of sites uncontaminated by oil (Figure 1). The streams on Montague Island and from eastern PWS were latter dropped from the analysis.

No experimental control over treatment of streams with oil (oiled or not oiled) was possible. This problem is common to many designed experiments using observational data. Ideally, level of oiling would have been randomized among streams to account for inherent variability in pink salmon populations and environmental conditions. Control streams (not oiled) possessing similar characteristics (pink salmon abundance, hydrology, and climatic conditions) and in close proximity to oiled streams were selected to balance these differences (Figure 2). All heavily oiled streams in southwest PWS with sufficient numbers of adult pink salmon spawners to support egg and fry sampling were included in the study.

DATA COLLECTION

Egg deposition surveys were performed from late September to mid-October in 1989 and 1990 and are also scheduled in 1991. Pre-emergent fry sampling was conducted from mid-March to mid-April in 1989 and 1990 and are also scheduled in 1991 and 1992. Sampling methods were identical for both surveys and were modeled after procedures described by Pirtle and McCurdy (1977).

Four stream zones, three intertidal and one above tidal inundation were sampled for each study stream. The three intertidal zones were 1.8-2.4 m, 2.4-3.0 m, and 3.0-3.7 m above mean low water. All zones were surveyed and staked using a handheld tide computer, hand level, and stadia rod.

Separate 30.5 m linear transects were established for each zone for egg and pre-emergent fry studies. Shorter transects were used when stream gradients were steep. Fry transects started downstream against the right stream bank and moved upstream to the left bank. Egg transects started downstream against the left stream bank and moved upstream to the right bank. This design reduced sampling overlap between egg and fry transects so that removal of eggs in the fall did not affect spring fry abundance. For each stream a map was drawn showing tide zones and transect locations in relation to major landmarks. Each egg transect was marked with surveyors flagging to help assure that egg and fry plots did not overlap.

Fourteen circular plots, each 0.3 m^2 in diameter, were systematically sampled along each transect. This sample size was a compromise between reducing variance and practical restraints. Fewer plots were sampled on narrow stream channels to avoid excessive removal of eggs and fry. Streams which split into two or more channels within a zone were sampled by allocating plots among the channels based on the either observed spawner distribution or, where spawner distribution was unknown, by equal allocation. A high pressure hose was used to flush eggs and fry from the gravel within plots. These eggs and fry where then captured in a specially designed net. Data on numbers and condition (live or dead) of fry and eggs by species were collected for each plot.

DATA ANALYSIS

Numbers of live and dead eggs and fry were summarized by stream and stream zone. Egg mortality ($\hat{M}ij$) at the time of the egg survey was estimated for each stream (i) and zone (j) as:

$$\hat{M}_{ij} = \frac{\Sigma(DE_{eijk} + DF_{eijk})}{\Sigma(LE_{eijk} + DE_{eijk} + LF_{eijk} + DF_{eijk})} ,$$

where LE_{eijk}, LF_{eijk}, DE_{eijk}, and DF_{eijk} were the number of live eggs, live fry, dead eggs, and dead fry, respectively, from the egg survey (e) for the k^{th} plot from zone j, and stream i. Fry mortality at the time of the fry survey was also estimated using data from the fry survey.

The logit transform of mortality [ln(live/dead)] was also examined:

$$Logit_{ij} = \ln\left[\frac{\Sigma(DE_{eijk} + DF_{eijk})}{\Sigma(LE_{eijk} + LF_{eijk})}\right] .$$

Logits are appropriate for dichotomous data (dead or alive), often transforming the dependent variable to better meet the assumptions of the analysis (Neter et al. 1989).

Egg to pre-emergent fry survival ($\hat{S}_{ij}$) was estimated by:

$$\hat{S}_{ij} = \frac{(\Sigma LF_{fijk}) / n_{fij}}{\Sigma (LE_{eijk} + DE_{eijk} + LF_{eijk} + DF_{eijk}) / n_{eij}} \quad ,$$

where LF_{fijk} was the number of live fry found during the fry survey (f) for the k^{th} plot from zone j, and stream i; n_e and n_f were the number of plots for the egg and fry surveys in zone j, stream i.

Differences in egg and fry mortality and egg to fry survival ($Y_{ijk} = \hat{M}$, Logit, or $\hat{S}$) were examined using a fixed effects, two-factor experiment with repeated measures on one factor (Neter et al. 1985):

$$Y_{ijk} = \mu_{...} + O_i + Z_j + (OZ)_{ij} + S_{k(i)} + \epsilon_{(ijk)} \quad .$$

The two treatments examined were oiling (O_i: 2 levels, oiled and unoiled), and height in the intertidal zone (Z_j; 4 levels, 2.1, 2.7, and 3.4 m above mean low water, and upstream). Both were fixed effects. Data were blocked by stream ($S_{k(i)}$, a fixed effect nested within oiling). The interaction of oiling and height in the intertidal zone was also examined. Equality of variances was tested using the F_{max}-test (Sokal and Rohlf 1969), while normality was visually assessed using box plots (Chambers et al. 1983). Data transformations were examined if non-normality was suspected. If a significant difference due to oiling was detected ($\alpha = 0.05$), four contrasts were examined (oil versus unoiled for the four stream zones) using the Bonferroni method of multiple comparisons ($\Sigma_j \alpha_j = 0.10$) (Neter et al. 1985).

DOCUMENTING CONTAMINATION BY OIL

The intertidal zone of all streams in the study were surveyed on foot, mapped, and photographed within one month of the oil spill to document extent of oiling. Mussels (*Mytilus edulis*) were collected from the intertidal zone in close proximity to each stream during July and August of 1989 and 1990. This sessile species has been shown to bioaccumulate hydrocarbons and was thus considered a good indicator species of hydrocarbon pollution (Karinen 1983).

A random sample of all live eggs and fry sampled from each stream and zone will be examined for histopathological aberrations and presence of mixed-function oxidases. Carls and Rice (1990) found an increase in morphological abnormalities due to crude oil exposure in pollock (*Theragra chalcogramma*) embryos, while Spies et al. (1982) were able to detect pollutants in California flatfishes using test for hepatic mixed-function oxidases.

REFERENCES

Carls, M.G. and S.D. Rice. 1990. Abnormal development and growth reductions of pollock *Theragra chalcogramma* embryos exposed to water-soluble fractions of oil. Fish. Bull., U.S. 88:29-37.

Chambers, J.M., W.S. Cleveland, B. Kleiner, and P.A. Tukey. 1983. Graphical methods for data analysis. Duxbury Press, Boston, Massachusetts.

Helle, J.H. 1970. Biological characteristics of intertidal and freshwater spawning pink salmon at Olsen Creek, Prince William Sound, Alaska, 1962-63. U.S. Fish and Wildl. Serv., Spec. Sci. Rep.-Fish., No. 602, p 19.

Helle, J.H., R.S. Williamson, and J.E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. U.S. Fish and Wildl. Spec. Sci. Rep. Fish. No. 483: 1-26.

Karinen, J.F. 1983. Distribution of heavy metals and hydrocarbons in Auke Bay sediments and in biota near active marinas. Final Report to State of Alaska Department of Transportation and Public Facilities, Project No. K78180, Northwest and Alaska Fisheries Center Auke Bay Laboratory, Auke Bay, Alaska.

Moles, A., M.M. Babcock, and S.D. Rice. 1987. Effects of oil exposure on pink salmon, *O. gorbuscha*, alevins in a simulated intertidal environment. Marine Environment Research, 21:49-58.

Neter, J., W. Wasserman, and M.H. Kutner. 1985. Applied linear statistical models. Second Edition. Irwin, Homewood, Illinois.

Neter, J., W. Wasserman, and M.H. Kutner. 1989. Applied linear regression models. Second Edition. Irwin, Homewood, Illinois.

Pirtle, R.B. and M.L. McCurdy. 1977. Prince William Sound general districts 1976 pink and chum salmon aerial and ground escapement surveys and consequent brood year egg deposition and pre-emergent fry index programs. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 9, Juneau.

Spies, R.B., J.S. Felton, and L. Dillard. 1982. Hepatic mixed-function oxidases in California flatfishes are increased in contaminated environments and by oil and PCB ingestion. Marine Biology 70:117-127.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco, California.

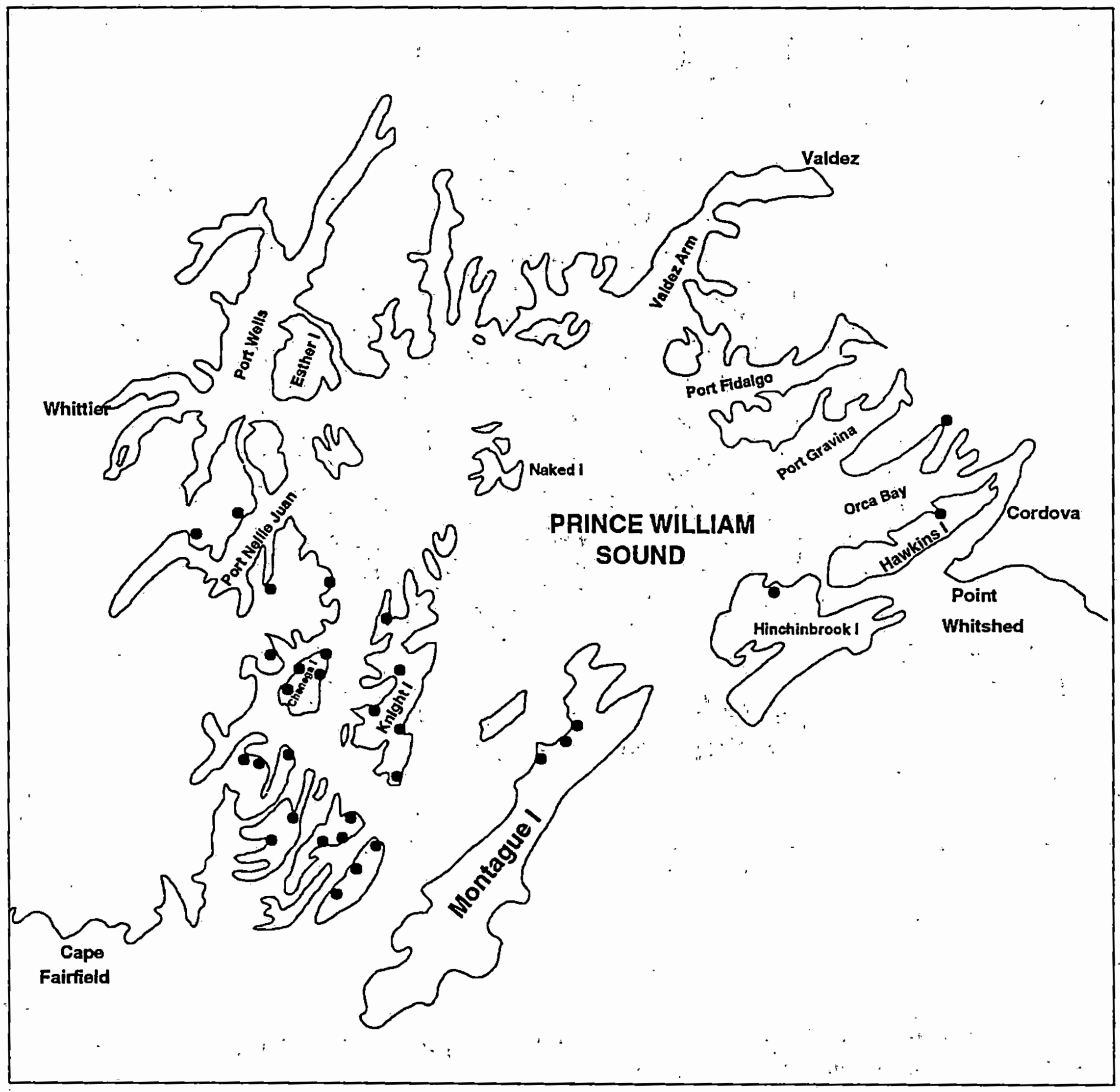


Figure 1. Location of streams examined by the 1989 and 1990 egg and fry studies, Prince William Sound, Alaska.

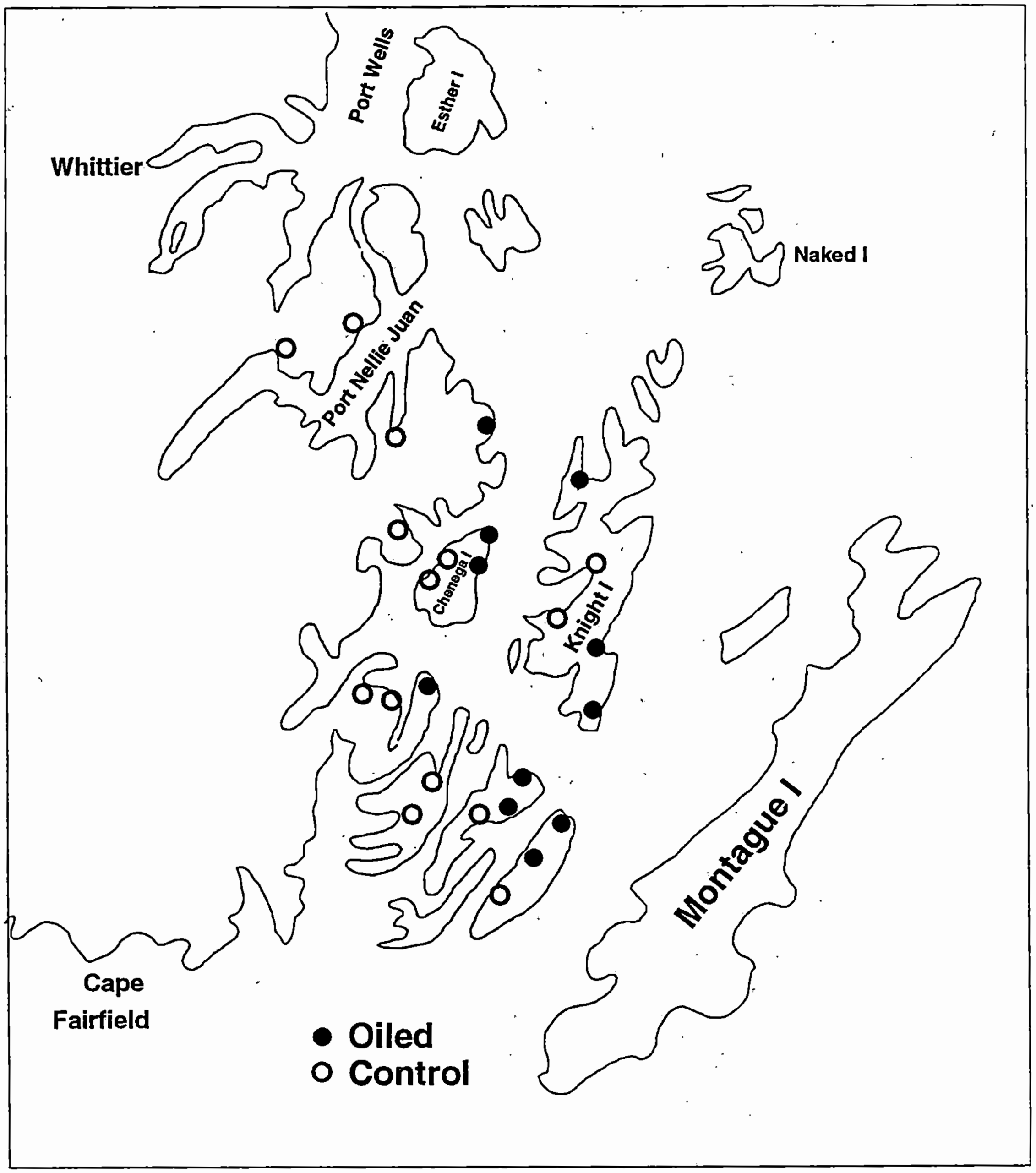


Figure 2. Location and preliminary treatment designation (Oiled or Not Oiled) for the 1989 and 1990 egg and fry analysis, Prince William Sound, Alaska.

Juvenile Pink Salmon Damage Assessment Studies in Prince William Sound

Alex Wertheimer

National Marine Fisheries Service
Auke Bay Laboratory, P. O. Box 210155
Auke Bay, Alaska 99821

Mark Willette

Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, Alaska 99501

R. Ted Cooney

University of Alaska Fairbanks
Institute of Marine Science
Fairbanks, Alaska 99775

The *Exxon Valdez* oil spill occurred in early spring, just prior to the movement of hundreds of millions of juvenile salmon from streams and hatcheries into Prince William Sound. Over 1000 miles of shoreline in Prince William Sound and south-central Alaska were contaminated, all potential rearing habitat for pink and chum salmon fry. The early marine residency is a period of high and variable mortality which can determine year-class strength (Parker 1968; Walters et al. 1978; Bax 1983; Nichelson 1986). Growth of pink and chum salmon during their early marine phase is extremely rapid (LeBrasseur and Parker 1964; Healey 1980; Mortensen and Wertheimer 1980), and is important to escape size-selective predation (Parker 1971; Hargreaves and LeBrasseur 1985). To attain rapid growth, standing crops of food organisms must be high (Bailey et al. 1975) or delivered to rearing areas at a high rate by currents (Cooney et al. 1978).

Oil in the marine environment can affect juvenile salmon in a variety of ways. Oil can be directly toxic to salmon; juvenile salmon are especially susceptible when first in seawater (Rice et al. 1975; Rice et al. 1984). Sublethal levels of hydrocarbons can affect metabolism and reduce growth of juvenile salmon (Rice et al. 1975). Sublethal levels of hydrocarbons can damage olfactory lamellar surfaces, conceivably impacting migratory behavior and feeding patterns (Babcock 1985). Oil can also be toxic to meiofauna and zooplankton (Caldwell et al. 1977; Bonsdorff 1981; Bodin 1988). Mortality, reduction of reproductive potential, or growth inhibition of prey populations could result in reduced growth of juvenile salmon, and thus increase their exposure to predation. Contamination of prey with hydrocarbons has also been shown to reduce feeding behavior and growth of juvenile salmon (Schwartz 1985).

Because of the concern that such effects could greatly reduce the marine survival of pink salmon, a Natural Resources Damage Assessment study was initiated to determine the impact of the spill on pink salmon during their initial marine residency. This research was a cooperative project involving three organizations: the University of Alaska Fairbanks (UAF), the Alaska Department of Fish and Game (ADFG), and the National Marine Fisheries Service (NMFS). Each agency was responsible for a particular component study.

The UAF component focused on comparisons between the spill year and historical data on juvenile salmon early marine residency in and near Sawmill Bay in southwestern Prince William Sound (Figure 1). This site was directly in the spill path as the oil exited Prince William Sound. It is the location of the Armin Koening Hatchery, one of the Prince William Sound Aquaculture Association's major pink salmon enhancement facilities. Prior research at this hatchery had documented fry feeding behavior, growth, and prey abundance and preferences (Urquhart 1979; Barnard 1981; Cooney et al. 1981). A university research team returned to Sawmill Bay from May and June of 1989 to collect similar data in the year of the spill. Juvenile salmon were collected by dip net and beach seine both within the portion of Sawmill Bay that was protected from oil contamination by booms, and in the adjacent, contaminated Elrington Passage. Zooplankton samples were also taken within Sawmill Bay and in Elrington Passage.

The ADFG component focused on the recovery of coded-wire tagged pink salmon to determine growth rates and migratory behavior. Over one million tagged pink salmon were released in Prince William Sound in 1989 and again in 1990. Juvenile pink salmon were captured by beach seining and purse seining in May-July in six general areas in western Prince William Sound (Figure 1). Recovery of tagged fish allowed computation of growth rates and examination of migration patterns. Growth rates were then compared between oiled and non-oiled recovery areas for specific groups. Growth was also compared between tagged fish from Armin Koening hatchery, released into a heavily contaminated area, and those from the Wally Noerenberg Hatchery on Esther Island, released into an uncontaminated area. In order to document exposure to hydrocarbons, coded-wire tagged pink salmon were frozen when captured for hydrocarbon body-burden analysis, and untagged fish from the same seine sets were preserved in formalin for later examination for mixed-function oxidase (MFO) induction.

The NMFS component focused on paired comparisons between oiled and non-oiled locations in Prince William Sound. Four pairs of locations were selected in the western portion of the Sound (Figure 2). These locations were sampled from April through June in 1989 and 1990. Water, sediment, and mussels were sampled at each location to quantify the degree of hydrocarbon contamination in the environment. Three nearshore habitat types, classified by beach gradient, were sampled by beach seining at each site to describe the distribution, abundance, size and apparent growth, and feeding habits of pink and chum salmon fry in these habitats. Samples of pink salmon were taken at each site for hydrocarbon tissue analysis, and samples of both pink and chum salmon were preserved for MFO analysis. Coded-wire tagged juveniles were sorted from the catches to contribute to the ADFG analysis. Epibenthic and zooplankton prey communities were also sampled at each location. The sampling design allowed biological parameters to be compared between the oiled and non-oiled locations using either a repeated-measures analysis of variance or a Wilcoxin signed-rank test.

Because of the restrictions placed on these studies as litigative-sensitive material, no results can be presented at this time. The extent of damage to juvenile salmon will have to be interpreted in the context of the record return of pink salmon to Prince William Sound in 1990, survivors of juvenile fish entering the Sound during the spring of the spill. The record return to the Sound is an indication that there was not a catastrophic impact on the total productivity of the Sound for salmon in the marine environment. However, the large return does not preclude actual and documentable damage to the resource. Overall marine survival could have been incrementally reduced by direct or indirect impacts of oil in the marine environment. Also, particular populations of fish in areas of the Sound that were more heavily contaminated could be severely impacted, while other populations of hatchery or wild fish experience excellent survival. Completion of the NRDA studies on salmon in Prince William Sound, and release of their findings, will hopefully provide a comprehensive picture of the specific effects of the spill on both a regional and site-specific level.

REFERENCES

Bailey, J.E., B.L. Wing, and C.R. Mattson. 1975. Zooplankton abundance and feeding habits of fry of pink salmon and chum salmon in Traitor's Cove, Alaska, with speculations on the carrying capacity of the area. Fish. Bull. 73:946-961.

Babcock, M.M. 1985. Morphology of olfactory epithelium of pink salmon, *Oncorhynchus gorbuscha*, and changes following exposure to benzene: a scanning electron microscope study,p. 259-267, In J.S. Gray and M.E. Christiansen (eds), Marine biology of polar regions and stress on marine organisms. John Wiley & Sons.

Barnard, D.R. 1981. Prey relationships between juvenile pink (*Oncorhychus gorbuscha*) and chum (*O. keta*) salmon in Prince William Sound, Alaska. M.S. Thesis, University of Alaska Fairbanks. 72 p.

Bax, N.J. 1983. Early marine mortality of marked juvenile chum salmon released into Hood Canal, Puget Sound, Washington, in 1980. Can. J. Fish. Aquat. Sci. 40:426- 435.

Bodin, P. 1988. Results of ecological monitoring of three beaches polluted by the 'Amoco Cadiz' oil spill: development of meiofauna from 1978 to 1984. Mar. Eco. Prog. Ser. 42: 105-123.

Bonsdorff, E. 1981. The 'Antonio Gramsci' oil spill impact on the littoral and benthic ecosystems. Mar. Poll. Bull. 12: 301-305.

Caldwell, R.S., E.M. Caldarone, and M.H. Mallon. 1977. Effects of a seawater-soluble fraction of Cook Inlet crude oil and its major aromatic components on larval stages of the Dungeness crab, *Cancer magister* Dana. p. 210-220 in D.A. Wolfe (ed), Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Pergamon Press, Oxford.

Cooney, R.T., D. Urquhart, R. Neve, J. Hilsinger, R. Clasby, and D. Barnard. 1978. Some aspects of the carrying capacity of Prince William Sound, Alaska, for hatchery released pink and chum salmon fry. Univ. Alaska, Sea Grant Rep. 78-4. 102 p.

Cooney, R.T., D. Uruquat, and D. Barnard. 1981. The behavior, feeding biology, and growth of hatchery released pink and chum salmon fry in Prince William Sound, Alaska. Univ. Alaska, Sea Grant Rep. 81-5. 114 p.

Hargreaves, N.B. and R.J. LeBrasseur. 1985. Species selective predation on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) by coho salmon (*O. kisutch*). Can. J. Fish. Aquat. Sci. 42:659-668.

Healey, M.C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. In W.J. McNeil and D.C. Himsworth (editors), Salmonid Ecosystems of the North Pacific, p 203-230. Oregon State Univ. Press, Corvallis.

LeBrasseur, R.J. and R.R. Parker. 1964. Growth rate of central British Columbia pink salmon (*Oncorhynchus gorbuscha*). J. Fish. Res. Board Can. 21:1101-1128.

Mortensen, D.G., and A.C. Wertheimer. 1988. Residency and growth of juvenile pink salmon in Auke Bay, Alaska. Pages 501-544 in APPRISE Annual Report, Vol. 1. SFOS APP 87-100, University Alaska Fairbanks.

Nichelson, T.E. 1986. Influences of upwelling, ocean temperature, and smolt abundance on marine survival of coho salmon (*Oncorhynchus kisutch*) in the Oregon production area. Can. J. Fish. Aquat. Sci. 43:527-535.

Parker, R.R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. J. Fish. Res. Board Can. 25:757-794.

Parker, R.R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28:1503-1510.

Rice, S.D., D.A. Moles, J.F. Karinen, S. Korn, M.G. Carls, C.C. Brodersen, J.A. Gharrett, and M.M. Babcock. 1984. Effects of petroleum hydrocarbons on Alaskan aquatic organisms. NOAA Tech. Mem. NMFS F/NWC-67. 128 p.

Rice, S.D., D.A. Moles, and J.W. Short. 1975. The effect of Prudhoe Bay crude oil on survival and growth of eggs, alevins, and fry of pink salmon, *Oncorhynchus gorbuscha*. p. 503-507, In 1975 Conference on prevention and control of oil pollution. American Petroleum Institute, Washington, D.C.

Schwartz, J.P. 1985. Effects of oil-contaminated prey on the feeding and growth rate of pink salmon fry *Oncorhynchus gorbuscha*. pp 459-476 In F.J. Vernberg, F. Thurberg, A. Calabrese, and W. Vernberg (eds.), Pollution and Physiology of Marine Organisms. U. South Carolina Press, Columbia, S.C.

Urquhart, D.L. 1979. The feeding, movement, and growth of pink salmon, *Oncorhynchus gorbuscha*, fry released from a hatchery in Prince William Sound, Alaska. M.S. Thesis, Univ. Alaska Fairbanks. 111 p.

Walters, C.J., R. Hillborn, R.M. Peterman, and M.M. Staley. 1978. Model for examining early ocean limitation of Pacific salmon production. J. Fish. Res. Bd. Can. 35: 1303-1315.

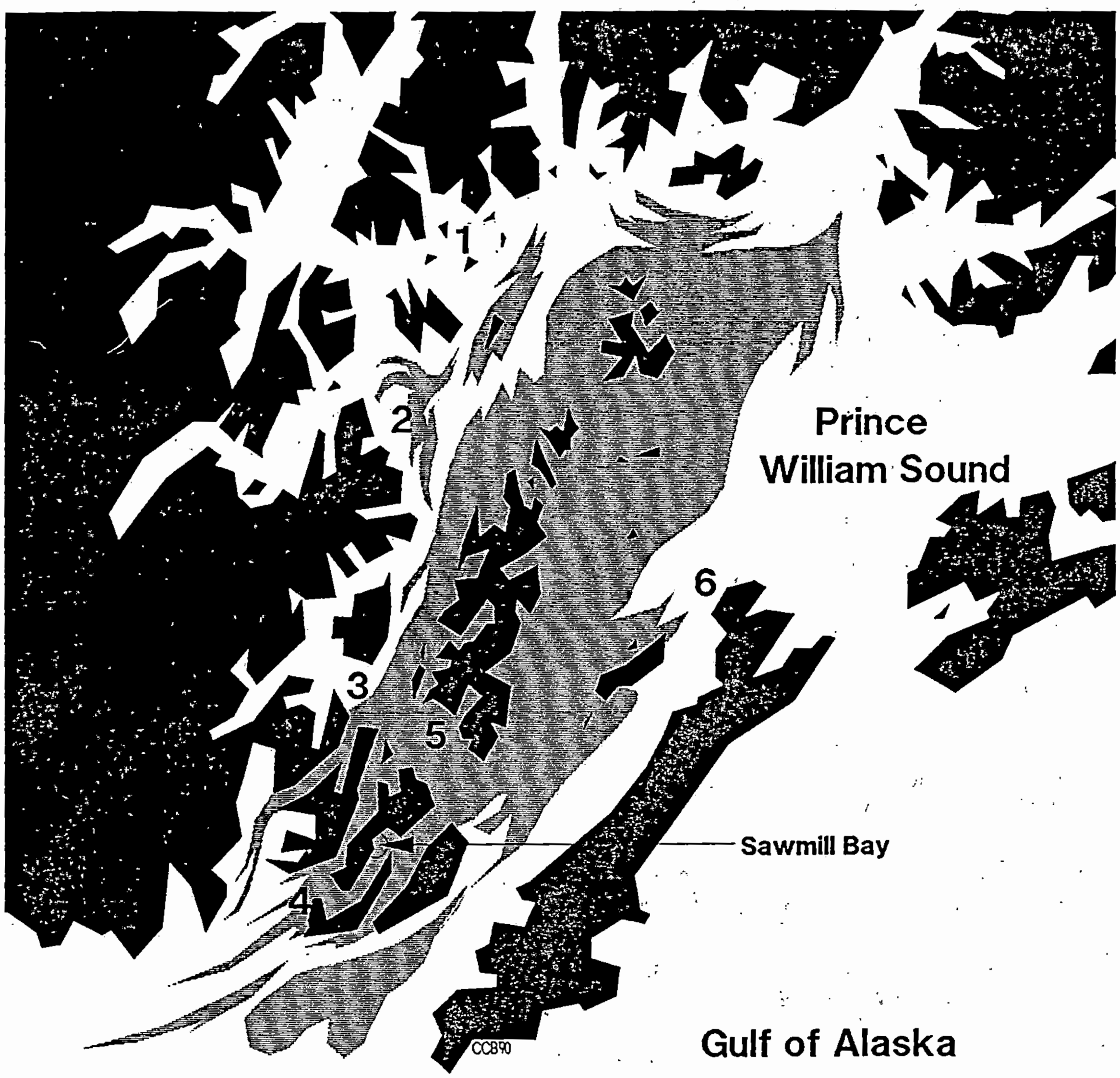


Figure 1. Stippled area represents the general spread of the oil slick through Prince William Sound. Numbers are general locales sampled for juvenile salmon by ADFG. Sawmill Bay was the location of the UAF research effort.

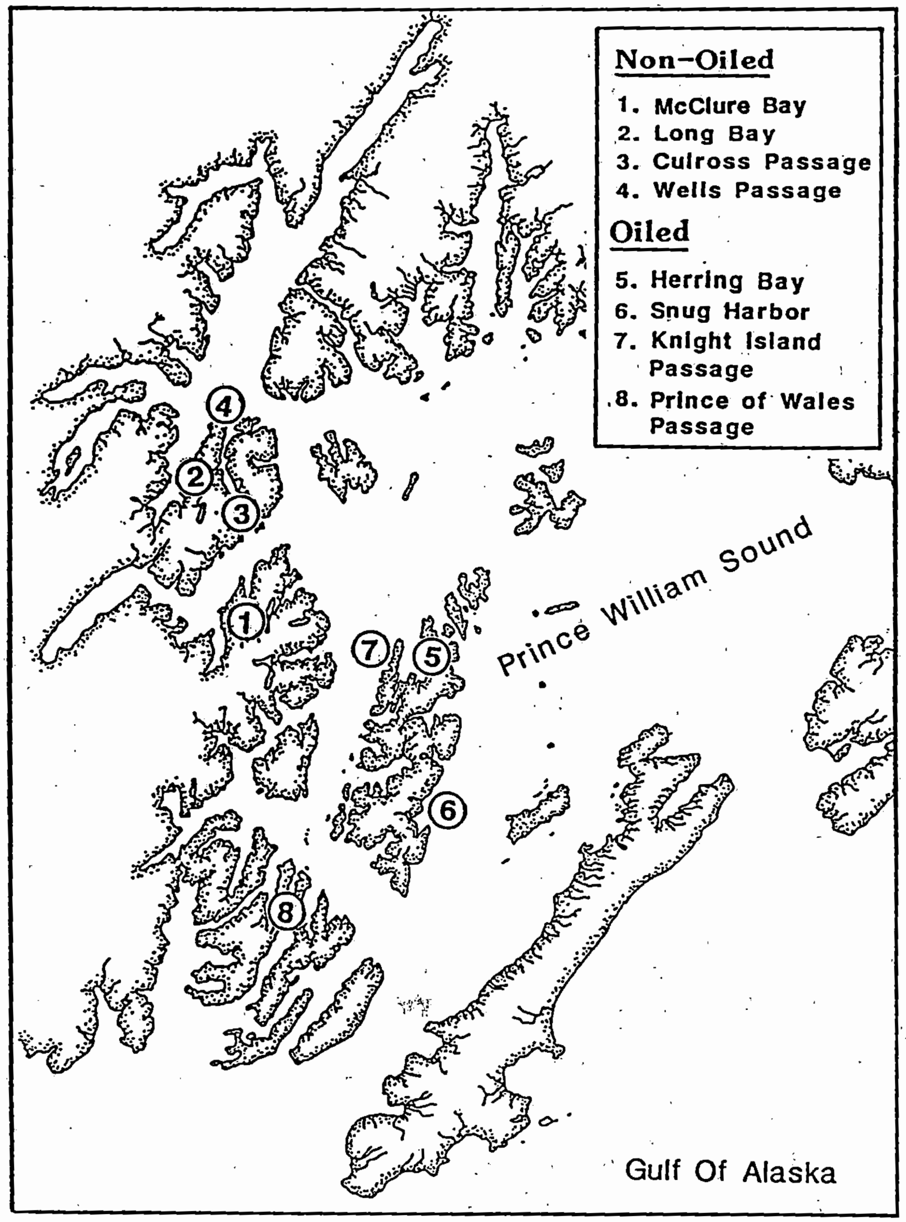


Figure 2. Western Prince William Sound. Numbers indicate locations of study areas for NMFS component of Early Marine Salmon Damage Assessment Study.

Methodology for Assessing Injury to Wild Pink Salmon Using Coded Wire Tagging

Daniel Sharp

Alaska Department of Fish and Game
P.O. Box 669,
Cordova, Alaska 99574

In response to the *Exxon Valdez* oil spill, the Alaska Department of Fish and Game initiated a study in March of 1990 to measure losses in production of representative wild stocks of pink salmon affected by the spill. The study focused on streams with predominantly intertidal spawning populations. Winged fyke nets measuring 3.0 meters in height with 3.12 mm mesh openings (1/8th inch) were placed in the intertidal zone of three streams with oiled estuaries and three streams in unoiled areas in western Prince William Sound. Emergent pink salmon fry emigrating from these streams were captured at the 1.8 meter (six foot) tide level, enumerated and a sample tagged with half-length coded-wire tags at each site. Fry were captured in the intertidal zone and then anaesthetized and tagged using fresh water without any apparent negative affects. Twenty four hour survival rates of tagged fish were 99%. Longer term survival appears good since many tagged wild fry were captured as part of an early marine life history study.

The *Exxon Valdez* oil spill in Prince William Sound may have adversely affected the marine and estuarine survival of wild pink salmon (*Oncorhynchus gorbuscha*). Many intertidal spawning areas along with nearshore and offshore rearing areas were heavily exposed to crude oil. The Alaska Department of Fish and Game initiated a study in March of 1990 to document and measure losses in production of wild stocks of pink salmon. The goal of the study was to enumerate and mark (with half-length coded-wire tags) stocks of pink salmon from streams with predominantly intertidal spawning populations in both oiled and unoiled areas of Prince William Sound. Initially, the presence of marked fish has allowed researchers to document stock specific exposure of juvenile pink salmon to contaminated waters in their early marine life. In 1991, the objectives of the study are to recover a sufficient number of marked adult salmon in the commercial fishery and in streams to allow investigators to assess the marine survival rates, harvests, escapements, and the extent of straying from natal streams for each tagged stock.

Prior to the initiation of this oil spill study, experimental attempts to tag wild pink fry with coded-wire tags have been limited (Johnson and Longwill 1988). In hatchery situations, half-length coded-wire tags (HLCWT) have been successfully used to tag emergent pink fry as small as 0.2 g and emergent sockeye fry weighing as little as 0.13 g (Kaill et al. 1986; Thrower and Smoker 1984). Studies using CWTs in wild salmonid stocks (Shaul et al. 1983, 1984, 1985; Holland 1983) have been conducted to better understand migrating behavior, survival rates, and harvest patterns.

Generally, tagging of wild salmonids is performed in freshwater environments using smolt weirs, traps, or seines to collect fish. In Prince William Sound, it is the intertidal areas used by spawning pink salmon that contribute a majority of the wild pink salmon production (Helle et al. 1964; Helle 1970). These intertidally spawned fish are also the ones most likely to be affected by exposure to crude oil. To demonstrate reduced marine survival of juvenile pink salmon or to determine damages to adult production caused by this exposure, requires an accurate assessment of the outmigration, catch and escapement for each tagged stock. This paper details the methods used in the enumeration and tagging of emergent fry from within the intertidal areas of the study streams. These areas are continually subjected to fluctuating tides, currents and salinity levels.

STUDY AREA

In April of 1990, winged fyke nets 3 meters in height were set at the 1.8 m (six foot) tide level in the following streams in western Prince William Sound (Figure 1):

<u>Oiled Areas</u>

Herring Creek . . . . . Knight Island
Loomis Creek . . . . . .Outer Eshamy Bay
Hayden Creek . . . . . .LaTouche Island

<u>Controls</u>

Totemoff Creek . . . . .Chenega Island
Cathead Creek . . . . . Knight Island
O'Brian Creek . . . . . Evans Island

Depending on the strength and duration of the outmigrations, tagging camps remained operational between six and nine weeks from April until early June. All captured outmigrating pink salmon fry were enumerated and a sample were tagged with half-length coded-wire tags at each site.

MATERIALS AND METHODS

FYKE NETS

Pink salmon spawning success below the 1.8 m (six foot) tide level is extremely limited (Helle et al. 1964). Therefore, fyke nets were anchored at the 1.8 m tide level to capture outmigrating fry including those fry emerging from gravel within the intertidal zone. A modified fyke net capable of fishing at a location subjected to three meter tidal fluctuations and able to capture fry as small as 27 mm was designed and installed.

The trap design was similar to typical winged fyke net designs. However, the throat of the trap did not contain hoops or internal funnels and a closed cod end was replaced by a floating live box. The trap portion of the weir had a 3.2 m x 3.2 m opening that led back 7.6 m to a .15 m circular opening and attached to a floating live box. The outer trap opening was supported by either 1 inch, galvanized schedule 40 pipe or, when that proved inadequate, three inch channel aluminum. The dimensions of the wings were 3 m x 15 m and included an additional 'T' shaped panel attached to the base for placement of sandbags (Figure 2). The wings were stretched taught to their full three meter height by suspending them from tripods made from long spruce poles or by securing them to trees along the banks. The net material was a treated 1/8th inch woven nylon mesh and was assembled by James T. Willis Net Maker of Atlantic Beach, North Carolina.

Floating live boxes were designed to lift the cod end up with a rising tide allowing access to captured fry at all tide stages. The boxes were constructed of light weight angle aluminum covered by 1/8th inch vexar mesh along the sides, a solid plastic bottom and rear panels, and a tight fitting door. The inside of the live box was fitted with a single center baffle to reduce water velocity inside. Flotation was achieved by attaching two 6" diameter sealed PVC pipes to either side of the livebox. The pipes were filled with spray urethane foam prior to sealing to displace water in the event of leaks. D-ring attachments for securing pipes to the live-boxes were moveable and allowed for adjustments to be made to compensate for water conditions at each stream.

FRY ENUMERATION

To most accurately measure future losses in production due to the oil spill, a total enumeration of outmigrating pink fry was attempted at each site. To accomplish this, all captured fry were individually tallied using thumb counters or tagging machines. Untagged fry were counted individually by placing a net-full of fry into a bucket and then slowly decanting the bucket over the stream and counting fry as they left the bucket. This method eliminated questionable measurement errors associated with using average weights. Fry used for tagging were tallied separately during the tagging procedure.

The timing and magnitude of daily fry outmigrations determined the frequency of trap checks. At each check, the number of live and dead fry was recorded. Outmigration counts were totalled every 24 hours. Periodically, a sample of 150 fry was measured for length frequencies and average weights.

TAGGING

The coded-wire tagging machine and the process of applying coded wire tags have been extensively reported by Koerner (1977), Peltz and Miller (1988) and Peltz and Haddix (1989). Northwest Marine Technology's Mark IV tagging machines were used for this study. This most recent model differs from earlier models in that many adjustments to the tagging machine and Quality Control Device (QCD) are made with electronic controls rather than mechanical manipulations. In addition, the tag injector contains a counter that keeps a daily tally of fish successfully tagged along with the number of untagged rejects.

Working adjacent to the intertidal zone precluded the use of a submersible pump to provide water to the tagging site. Changing tides would put the source of water more than 70 meters away at low tide. In addition, tidal fluctuations would result in fry being anaesthetized and recovering in water with constantly changing salinities. To minimize osmoregulatory distress during the already stressful process of fin clipping and tag injection, a recirculating fresh water system was established. This closed system consisted of plastic trash barrels, fish totes and buckets with a capacity of approximately sixty gallons of water. The continuous movement of water through this system produced sufficient aeration and water temperature was kept constant by placing snow and ice into a zip-lock bags which were floated in the water. Numerous hose filters were employed to keep organic material from clogging the water pump and solenoids in the QCD.

When preparing to tag fish each day, a sample of fry would be removed from the live box and set aside in a five gallon bucket. These fish were removed from the live box at varying tide stages and salinity levels. However, the stream discharge usually created a visible fresh water lens in the intertidal zone so that salinity levels at the live box were less than that of pure seawater. These fry were taken to the tagging tent where they were transferred to fresh water and anaesthetized in a buffered solution of Tricane Methanesulfonate (MS-222). Anaesthetized fry were adipose clipped, tagged with a half length tag and then allowed to recover in fresh water. At the end of a tagging shift after all fry had visibly recovered from the anaesthetic, all but approximately 200 were transferred to floating .5 m x .5 m x .5 m net pens anchored out in salt water. These tagged fry were held for 24 hours to obtain a count of short term tagging mortality and then released. The 200 or so fry held in fresh water for 24 hours were tested for tag retention and short term mortality prior to their also being released.

RESULTS AND DISCUSSION

Outmigrating emergent pink fry were detected in early April and were still present in the creeks in early June. During this time, six four-person crews were able to successfully apply over 240,000 valid tags to wild pink salmon as well as provide an estimate of the outmigration for each creek's pink salmon stock. When individually enumerating captured fry, it was possible for a crew of four to count more than 40,000 fry and successfully tag over 2,500 fry in a single day.

The design of the fyke nets for this study allowed us to successfully capture newly emergent pink salmon fry from the intertidal area. Mortalities caused solely by the fyke net's operation, anticipated to be high, were in fact extremely low, especially in comparison to sockeye smolt weirs where weir mortalities in high water can sometimes range from 3% to 8%. The large volumes of water impounded upstream of the fyke nets during the flow tide lessened the velocity of the stream discharge at the live box and probably reduced fry mortality. On the ebb tide, this same volume of water would decrease very gradually and not cause the net to sink or cause a large increase in the stream velocity at the live box. Water velocities at the live box were always greatest during the periods surrounding the low tide when there was no tidal influence at the net while the periods following the high tide consistently had the highest numbers of outmigrating fry. Therefore, the optimal time to empty the live box was when the receding tide level was between 2.4 m and 1.8 m. Thereafter, more frequent checks during low tide kept the live box emptied and minimized the time fry were kept in faster moving water.

Overall, outmigrating fry averaged .22 grams in weight and 31 millimeters in length. Beyond April, almost all captured fry had completely absorbed their yolk sac and were buttoned up. The removal of these newly emergent fry from the intertidal area, their transfer into fresh water for tagging and then back into salt water net pens for 24 hours did not result in detectable harm to the fry. Although fry were removed from the trap's live box at varying tide stages and salinity levels, the stream discharge usually created a visible fresh water lens in the intertidal zone so that salinity levels at the live box were always less than that of pure seawater. For all six study streams, twenty-four hour survival rates of tagged fry were 99%. Smaller groups of tagged and untagged fry held for up to seventy-two hours exhibited similarly high survival rates. Twenty-four hour tag retention was also consistently above 90% at each site. These 24 hour survival and retention percentages compare very favorably with groups of pink salmon tagged at hatcheries. Tagged fry from oiled and unoiled areas were also captured many weeks after their release by crews investigating the early marine survival and habitat utilization of pink salmon and provides some indication of the short term survival of tagged wild pink salmon fry.

The efficacy of coded-wire tagging wild pink salmon fry will ultimately be determined by the successful return and recovery of tagged adults in 1991. Analysis of tag return data will follow the methodology outlined by Geiger (1988), Geiger and Sharr (1989) and Peltz and Geiger (1988). Sufficient adult recoveries of marked adults will allow investigators to assess the marine survival rates, harvests and escapements of the adult returns as well as document the extent of straying from natal streams for each tagged stock. Until then, the initial results indicate the efforts to capture and tag intertidally spawned pink salmon can be considered successful.

REFERENCES

Geiger, H.J. 1988. Parametric bootstrap confidence intervals for estimates of fisheries contribution in salmon marking studies. Proceedings of the international symposium and educational workshop on fish-marking techniques. University of Washington Press, Seattle. In press.

Geiger, H.J., and S. Sharr. 1989. A tag study of pink salmon from the Solomon Gulch Hatchery in the Prince William Sound fishery, 1988. Alaska Department of Fish and Game, Division of Commercial Fisheries. In press.

Helle, J.H., R.S. Williamson, J.E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries. Special Scientific Report-Fisheries No.483. Washington D.C.

Holland, J. 1983. A synopsis of Southeastern Alaska FRED Division tagging operations for 1981. Alaska Department of Fish and Game, FRED Report Series 16. 40 p.

Johnson, J., and J. Longwill. 1988. Pacific Salmonid Coded Wire Tag Releases Through 1987. Regional Mark Processing Center. Pacific Marine Fisheries Commission. Portland, Oregon.

Kaill, W.M., K. Rawson, T.L. Joyce. 1986. Retention rates of half length coded wire tags implanted in emergent pink salmon. MS in preparation.

Koerner, J.F. 1977. The use of the coded wire tag injector under remote field conditions. Alaska Department of Fish and Game, Information Leaflet No. 172. 24p.

Peltz, L. and H.J. Geiger. 1988. A study of the effect of the hatcheries on the 1987 pink salmon fishery in Prince William Sound, Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries. In Press.

Peltz, L., and J. Miller. 1988. Performance of half-length coded-wire tags in a pink salmon hatchery marking program. Proceedings of the international symposium and educational workshop on fish-marking techniques. University of Washington Press, Seattle. In press.

Peltz, L., and M. Haddix. 1989. Coded-wire tagging of wild sockeye salmon smolts at Hugh Smith Lake, Alaska. Alaska Department of Fish and Game, FRED Division Report No. 91. 22 p.

Shaul, L.D., Gray, P.L., and J.F. Koerner. 1983. Coded wire tagging of wild coho salmon, *O. kisutch*, stocks in Southeastern Alaska. Alaska Department of Fish and Game, Technical Report 1981-1982, Project AFC-67-1. 114p.

Shaul, L.D., Gray, P.L., and J.F. Koerner. 1984. Migratory patterns and timing of Stikine River coho salmon, O. kisutch, based on coded-wire tagging studies 1978-1982. Alaska Department of Fish and Game, Informational Leaflet No. 232. 42p.

Shaul, L.D., Gray, P.L., and J.F. Koerner. 1985. Coded-wire tagging of wild coho salmon, *O. kisutch*, stocks in Southeastern Alaska, 1982-1983. Alaska Department of Fish and Game, Technical Report No. 140. 105p.

Thrower, R.P., and W.W. Smoker. 1984. First adult return of pink salmon tagged as emergents with binary-coded wire tags. Transactions of the American Fisheries Society 113:803-804.

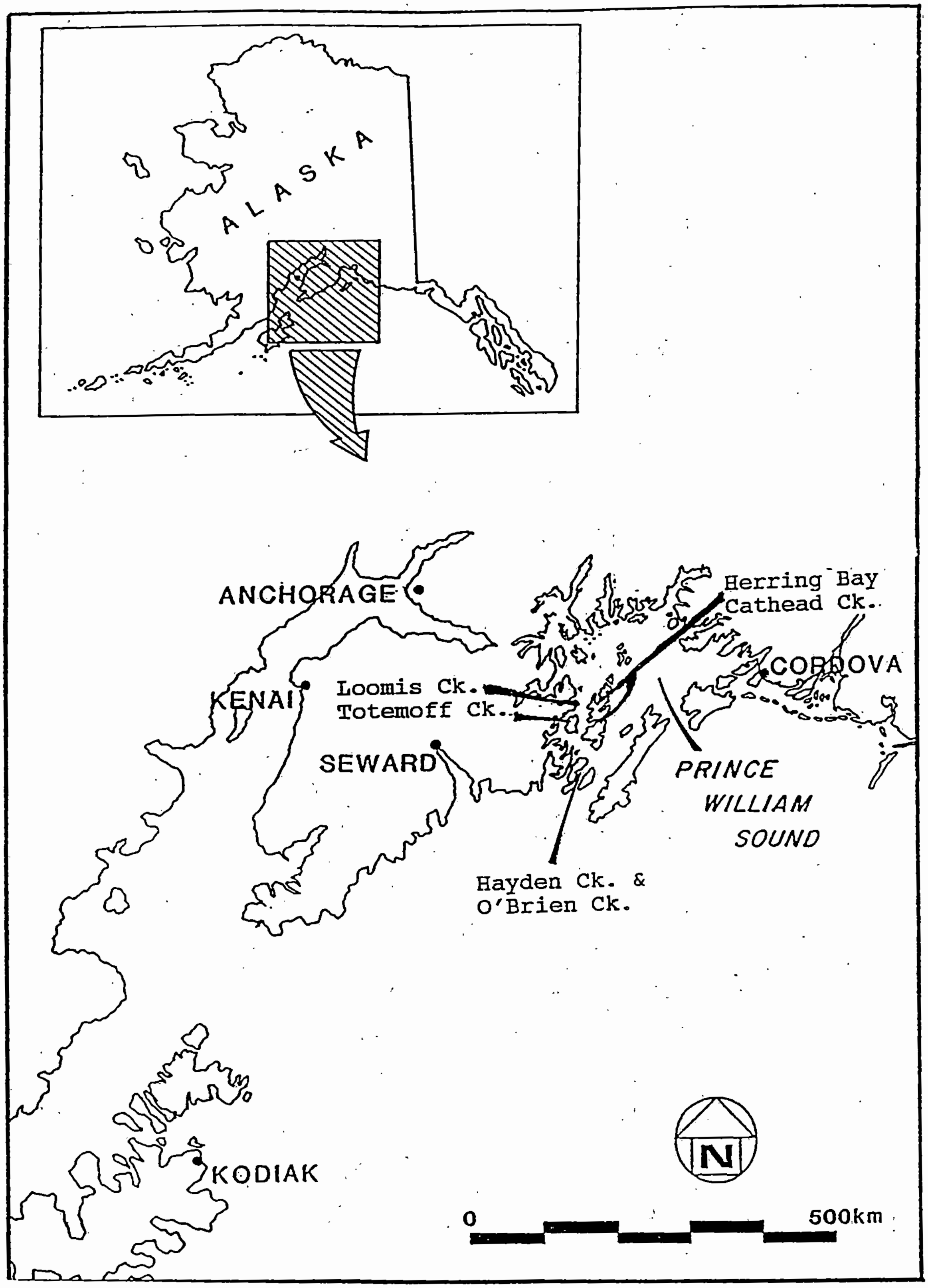


Figure 1: Approximate locations of wild pink salmon coded-wire tagging camps.

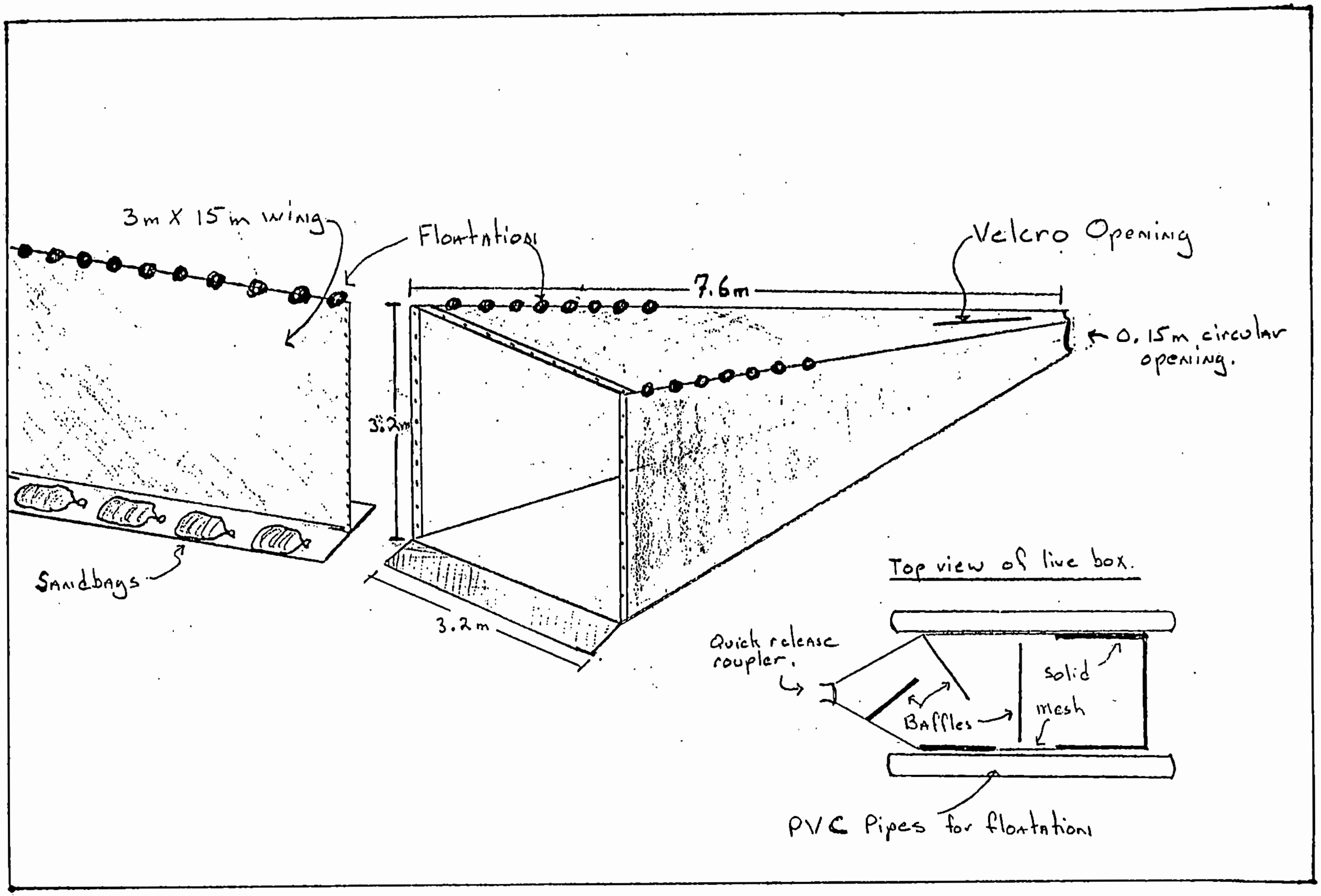


Figure 2: Pink salmon fry trap net and floating live box.

Genetic Stock Identification of Chum Salmon: Status of the Allozyme Baseline in Asia

Gary A. Winans and Paul B. Aebersold

National Marine Fisheries Service
Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, WA 98112

Shigehiko Urawa

Fisheries Agency of Japan
Hokkaido Salmon Hatchery
2-2 Nakanoshima
Toyohira-ku, Sapporo
062 Japan

Since the late 1970's, there has been an expanding high seas driftnet fishery for flying squid in the North Pacific Ocean, involving driftnetters from Japan, South Korea, and Taiwan. The National Marine Fisheries Service is concerned about the incidental bycatch of salmonids in these driftnet fisheries because of potentially serious ecological consequences. Developing a species-wide allozyme baseline for determining the continent-of-origin of chum salmon in high seas catches is the objective of a genetic stock identification project at the Northwest Fisheries Science Center. In cooperation with the Hokkaido Salmon Hatchery, Sapporo, genetic data were obtained from fifteen new collections of chum salmon in Japan and one from the Soviet Union and added to a Pacific Basin baseline. A new 12-locus baseline was assembled from the Basin data set with representative stock groups. In analyses of computer-simulated mixtures, accuracy and precision of stock estimates were improved over the previous 5-locus data set. Efforts continue in 1991 to gather more baseline data for chum salmon from Japan and the Soviet Union. The level of population differentiation revealed with allozymes is sufficient for adequate resolution of stocks to continent of origin in high seas fisheries. DNA research at the Center is aimed at finding more diagnostic marks for genetic stock identification applications.

The flying squid *Ommastrephes bartrami* occurs in subtropical and temperate waters of the Pacific, Atlantic, and Indian Oceans. It undergoes diurnal vertical migration in the open ocean, rising in the water column at night from 300-600 m to surface waters to feed on pelagic fish, crustaceans, and other squid. Large fish and marine mammals, in turn, eat flying squid. Flying squid reach 50 cm in mantle length and about 4 kg in weight (Yatsu 1990). With a declining squid jigging fishery in nearshore Japan, a high seas driftnet fishery developed for this species in the late 1970's. The present-day driftnet fleet in the Pacific Ocean consists of about 750 ships from Japan, Taiwan and Korea. The fleet's annual catch is estimated to be about 200,000 to 300,000 tons of squid (Yatsu 1990).

Driftnets are effective fishing gear. Typically, the monofilament nets have a 110-mm mesh and are suspended vertically from the ocean surface to 10 m. A driftnet ship will normally lay out 50-90 km of net that is fished throughout a night (Yatsu 1990). Because of its size and position in the water column, incidental catch of nontargeted species (bycatch), such as seabirds, sharks, tuna, and marine mammals, is a serious problem. Although the Japanese squid driftnet fishery is regulated to minimize incidental take of salmonids through monthly changes in the northern boundary, salmonid bycatch is also a contentious issue in this fishery. To evaluate the ecological impact of this fishery on the pelagic community, information on the numbers, age, and origin of the bycatch is critical.

Chum salmon *Oncorhynchus keta* can be an important bycatch in driftnet fisheries. For example, in August 1989, two Taiwanese driftnet vessels were seized for illegally catching salmon on the high seas. The holds of both ships were completely filled with frozen salmon. Scientists from the National Marine Fisheries Service determined that 50% of the fish were coho salmon and 29% were chum salmon. Given that an allozyme baseline for chum salmon could be assembled, a genetic stock identification (GSI) analysis of the chum collection conducted at the Center gave results that were used in the prosecution's case.

Chum salmon are amenable to GSI analysis: they harbor moderate to high levels of genetic variability, and regional population differentiation is the rule rather than the exception (see references in Table 1). These observations have led several agencies in North America to establish protein electrophoresis laboratories to develop regional baselines for GSI applications to specific mixed-stock fisheries. Two papers in this workshop (Phelps and Tweit, and Hop Wo and Luedke) summarize the use of GSI analyses in regional management issues.

In 1989, in response to NMFS Enforcement's needs, information was gathered from the literature and through personal contacts to construct the first species-wide data set of allozyme characters for chum salmon (Winans et al. in press; Winans et al. 1990). Our goal was to evaluate the feasibility of using a Pacific Basin baseline for determining the continent-of-origin of chum salmon caught in high seas fisheries. Hypothetically, GSI data can be used not only to evaluate the continent of origin of high seas bycatch of chum salmon for allocation purposes, but also in forensic issues dealing with illegally caught and marketed fish. Since constructing this first Pacific Basin baseline, geneticists at the Center have worked with the Fisheries Agency of Japan to collect new genetic data from Japanese chum salmon. We report on the status of this cooperative work here.

RESULTS OF CURRENT BASELINE RESEARCH

A summary of pertinent allozyme studies of chum salmon is presented in Table 1. Data from approximately 167 collections for 7 to 70 loci (basic genetic characters) are available. Since a GSI analysis requires that all populations in a baseline data set have data for the same loci, this incomplete baseline has limited utility. Because of the minimum number of loci reported in the Japanese and Soviet studies, the baseline is weak in this portion of the species distribution.

In 1989, we examined the discriminatory capability of the largest common data set using computer simulations (Winans et al. in press). We constructed a 5-locus/93-population data set covering five regions--Japan, U.S.S.R., Alaska, Canada, and Washington. The populations referred to here (as elsewhere in baseline references) were either the allele frequencies from individual collections or a weighted average of allele frequencies from two or more collections that were statistically indistinguishable in a within-region comparison (as agreed upon for coastwide GSI work). Using an allocate/sum procedure, estimates to the five regions were generally 80% correct in these simulations. The stocks from the Soviet Union were under-allocated. Based on these results, we felt there was sufficient allozyme differentiation among Asian and North American chum salmon to warrant further development of a Pacific Basin data set for use in GSI.

The weakest part of the Pacific Basin data set is in Asia. Although studies covered extensive geographic portions of Japan and the Soviet Far East (e.g., Salmenkova et al. 1986; Okasaki 1982), few loci were investigated. In 1989-90, our primary goal was to update the Japanese baseline. Under a sanction from the International North Pacific Fisheries Commission, 15 Japanese collections were made by biologists at the Hokkaido Salmon Hatchery, Sapporo. A single Soviet sample was also taken in the northeast region of the Sea of Okhotsk by Japanese and Soviet scientists. Allozyme data were subsequently collected at the Center.

Locales sampled in Japan in 1989-90 are illustrated in Figure 1. Data were collected from 80 to 100 chum salmon from each locale for approximately 70 loci according to procedures outlined in Aebersold et al. (1987). Twenty-five loci were polymorphic; 15 of these were not scored in previous Japanese investigations and thus represent new data in this portion of chum salmon distribution. Technical details of within-sample variability are presented in Winans et al. (1990).

The pattern of genetic similarity among these samples discerned in a multilocus analysis is germane here. Based on a clustering of Nei's genetic distance values (Nei 1978), three genetic groups were indicated (Figure 1). For example, on Hokkaido, the samples on the Pacific Ocean side in the north and northeast form one group, and the three samples on the Sea of Japan formed a second. The remaining samples on both islands were genetically similar and formed a third group. An outlier to this pattern was the sample from Ohkawa River. The Soviet sample was genetically distinct from the Japanese samples.

Our experience in GSI analyses is that the more polymorphic loci used the more accurate and precise the GSI estimates. With the addition of these new Asian data, we are not as confined to the number of loci used to construct a Basin data set. We therefore formed a new baseline using 12 polymorphic loci from stocks or stock groups from each of the North American regions (21 from Alaska, 6 from Canada, and 14 from Washington), as well as the 1 new sample from the U.S.S.R. and 15 new Japanese samples. To assess the 12-locus data set versus the 5-locus data set, we analyzed 100 computer-simulated mixtures (with 500 fish each) in which there was equal representation in each mixture from each of the regions (i.e., the correct mixture estimate was 20% from each region). Estimates were calculated using the 5-locus and the 12-locus baselines. As can be seen in Table 2, the 12-locus baseline provided more accurate and precise estimates. Namely, the 12-locus estimates were closer to 20% and the standard errors were smaller than with the 5-locus baseline.

It is hard to pinpoint the locus or set of loci that effect these improvements in GSI estimates in the new 12-locus data set. Estimates are best-fit solutions in a multilocus genotype space (Winans 1987). Two loci, however, are especially noticeable: *EST-1** and *TAPEP-1**. F_{ST} values for these loci, 0.455 and 0.333, are substantially greater than the F_{ST} values reported for the 5-locus/93-population data set where values ranged from 0.004 to 0.058 (Winans et al. 1990). Wright's F_{ST} values are a measure of population differentiation, ranging from 0 for no differences to 1.0 for complete fixation (Wright 1965). To illustrate differences at these loci, we plotted mean frequency of the common allele (Figure 2). Clearly, the Japanese, Soviet, and Alaskan samples occupy distinctive positions in this 2-locus space. Note the overlap of the Washington and Canadian stocks. Although the addition of more stock points may create greater stock overlap in some cases, the multilocus baseline will continue to show stock differences and be effective in sorting out regional mixtures of chum salmon.

FUTURE RESEARCH

The enhanced discrimination among stock groups of chum salmon afforded by the addition of the new Japanese populations buoys our efforts to expand and modify the Basin-wide data set. In 1991, we are continuing our collaboration with the Fisheries Agency of Japan. Further baseline collections are being made on both Honshu and Hokkaido, and about five new locales are expected. In addition, a protein electrophoresis laboratory will be operational this year at the Hokkaido Salmon Hatchery, Sapporo, and we will work together in standardizing electrophoresis procedures and data scoring.

We also have plans to expand the Soviet baseline in 1991. Similar to the arrangements in Japan, we have tentatively arranged with TINRO-Kamchatka an exchange for baseline sampling and professional training. We expect nine samples from Kamchatka and along the northern coast of the Sea of Okhotsk for study at the Center.

The overall objective of our high seas project at the Center is to provide accurate stock discriminating technology for use in regulating and enforcing high seas fisheries management. Allozyme characters work well for chum salmon in this regard. Still, a portion of our project is involved in examining DNA-based variability in the salmon genome for more diagnostic marks. Protein electrophoresis examines expressed portions of protein genes (extrons), portions known to be evolutionarily conserved. DNA technologies--like restriction fragment analysis and base sequence analysis--examine portions of genes not expressed (introns) that may experience higher rates of evolutionary change yet are still neutral markers of phylogeny. Where allozyme polymorphisms are scarce, e.g., in coho salmon and sockeye salmon, or where allozyme differences among stock groups are marginal, e.g., in chum salmon stocks in northern Puget Sound, DNA-based characters may provide useful GSI markers in the future.

ACKNOWLEDGMENTS

We acknowledge the following people for assisting in this collaborative study: Conrad Mahnken, National Marine Fisheries Service, Seattle; Yukimasa Ishida, Far Seas Research Laboratory, Shimizu; and

Mamoru Kato, Fisheries Agency of Japan, Tokyo. Cindy Shiflett, Thomas Thornton, and Frederick Welch assisted in the laboratory work; David Teel assisted in data management and analyses.

REFERENCES

Aebersold, P.B., G.A. Winans, D.J. Teel, G.B. Milner, and F.M. Utter. 1987. Manual for starch gel electrophoresis: a method for the detection of genetic variation. U.S. National Marine Fisheries Service Tech. Rep. 61: 19p.

Beacham, T.D., A.P. Gould, R.E. Withler, C.B. Murray, and L.W. Barner. 1987. Biochemical genetic survey and stock identification of chum salmon (*Oncorhynchus keta*) in British Columbia. Can. J. Fish. Aquat. Sci. 44:1702-1713.

Beacham, T.D., R.E. Withler, and A.P. Gould. 1985. Biochemical genetic stock identification of chum salmon (*Oncorhynchus keta*) in southern British Columbia. Can. J. Fish. Aquat. Sci. 42:437-448.

Kondzela, C.M., C.M. Guthrie III, R.B. Wilson, H.R. Carlson, and A.J. Gharrett. 1989. Preliminary report on genetic diversity of southern Southeast Alaska chum salmon populations. (INPFC Doc. 3462) 63p. U.S. Department of Commerce, NMFS/NOAA, NWAFC Proc. Rep. 89-12. Seattle.

Okazaki, T. 1981. Geographic distribution of allelic variation of enzymes in chum salmon, *Oncorhynchus keta*, populations of North America. Bull. Japan. Soc. Sci. Fish. 47(4):507-514.

Okazaki, T. 1982. Geographical distribution of allelic variations of enzymes in chum salmon, *Oncorhynchus keta*, river populations of Japan and the effects of transplantation. Bull. Japan. Soc. Sci. Fish. 48(11):1525-1535.

Nei, M. 1978. Estimation of average heterozygosity and genetic distance from a small number of individuals. Genetics 89:583-590.

Salmenkova, E.A., Y.P. Altakhov, R.M. Victorovsky, V.T. Omelchenko, L.T. Botchevskaya, L.N. Yermalenko, E.A. Rudminaitis, and B.A. Semenov. 1986. Genetic structure of chum salmon populations spawning in rivers of the far east and the northeast of the USSR. J. Gen. Biol., 4:529-549.

Utter, F.M. 1978. Genetic variants of proteins in chum and chinook salmon from the Bering Sea and the Yukon and Kuskokwim Rivers. (INPFC Doc. 2066) National Marine Fisheries Service, Seattle, 11 pages.

Winans, G.A. 1987. Using morphometric and meristic characters for identifying stocks of fish. p. 25-62. *In* H.E. Kumpf, R.N. Vaught, C.B. Grimes, A.G. Johnson, and E.L. Nakamura, (eds.) Proceedings Stock Identification Workshop NOAA Tech. Mem. NMFS-SEFC-199.

Winans, G.A., P.A. Aebersold, S. Urawa, and V.G. Markovtsev. 1990. Genetic stock identification of chum salmon: new data for 16 populations in Asia. (INPFC Doc. 3604) National Marine Fisheries Service, Northwest Fisheries Center, 23 p.

Winans, G.A., P.A. Aebersold, and R.S. Waples. In press. Genetic stock identification of chum salmon in high seas fisheries using allozyme data from stocks in the Pacific Basin. Proc. Pacific Salmon International Symposium, Yuzhno-Sakhalinsk, USSR, Sept. 1989.

Wright, S. 1965. The interpretation of population structure by F-statistics with special regard to systems of mating. Evolution 19:395-420.

Yatsu, A. 1990. A review of the Japanese squid driftnet fishery. (INPFC Doc. 3598). National Research Institute Far Seas Fisheries, Shizuoka, Japan, 25 p.

Table 1. Sources for a species-wide baseline of allozyme data for chum salmon.

Region	Number of stocks	Number of loci	Reference*
Japan	26	10	Okazaki 1982
	15	70	This study
USSR	20	6-8	Salmenkova et al. 1986
	1	70	This study
Alaska	17	12	USFWS, unpublished
	8	20	Kondzela et al. 1989
	20	11	NMFS-Seattle, unpublished
	4	11	Okazaki 1981
	1	6	Utter 1978
Canada	23	8	Beacham et al. 1985, 1987
	17	21	WDF, unpublished
Washington	19	21	WDF, unpublished

*NMFS = National Marine Fisheries Service (USA)
USFWS = U.S. Fish and Wildlife Service
WDF = Washington Department of Fisheries

Table 2. Results of mixture analyses with the computer-simulated mixtures consisting of 20% each from the five regions, using two different baselines. The first baseline was composed of 5 loci; *IDH-1**, *IDH-3**, *LDH-1**, *MDH-3,4**, and *PGDH**. The second was composed of 12 loci; *IDH-1**, *IDH-3**, *LDH-1**, *MDH-3,4**, *PGDH**, *AAT-1,2**, *EST-1**, *G3PDH-2**, *LDH-4**, *MDHp-2**, *MPI**, and *TAPEP-1**. Means (and standard errors) of estimated stock composition for 100 replicates are given in percent.

Baseline	Japan	USSR	Alaska	Canada	Washington
5 Loci	21 (6)	18 (8)	23 (9)	15 (10)	24 (9)
12 Loci	20 (2)	19 (4)	20 (5)	19 (6)	22 (5)

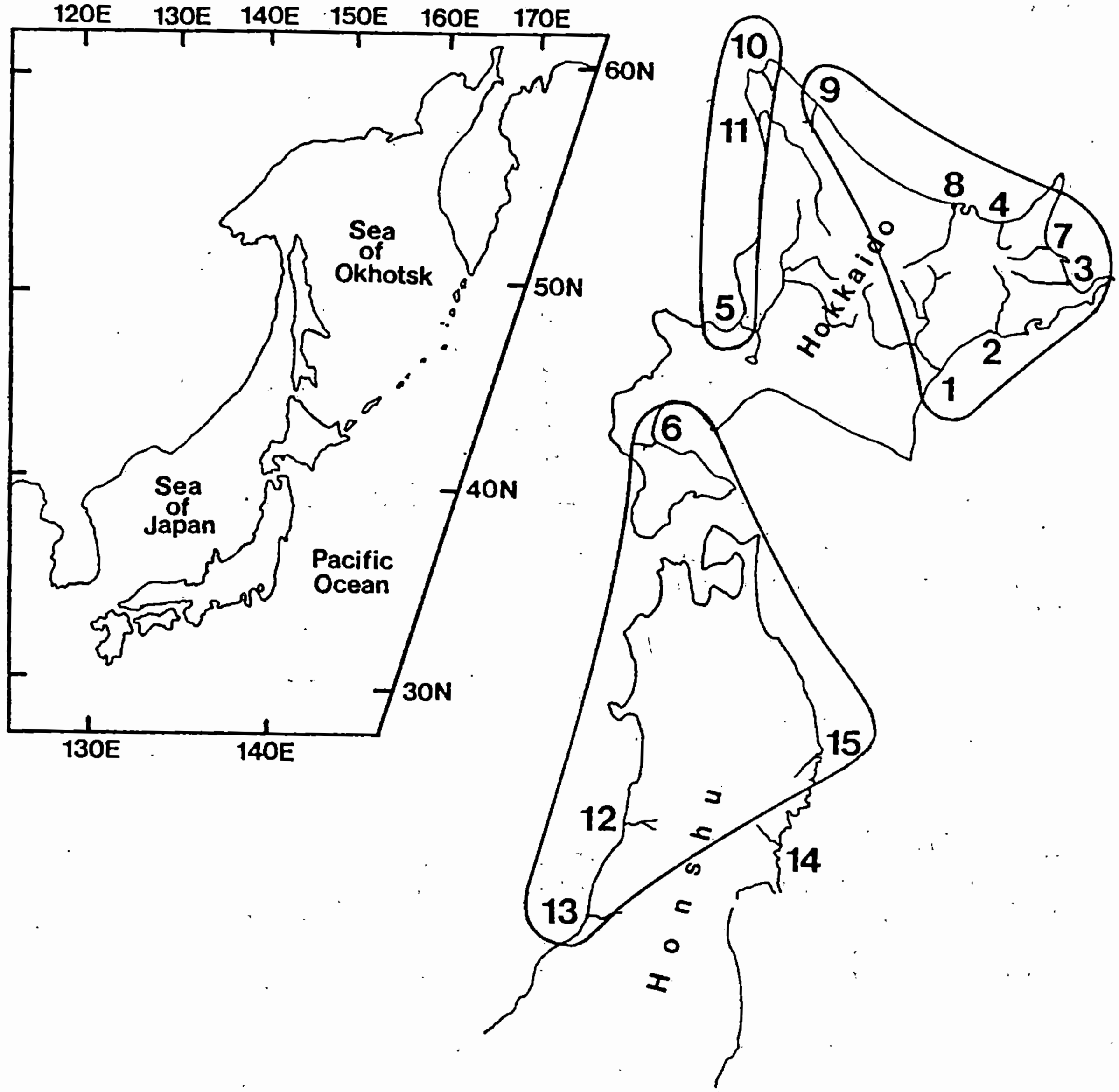


Figure 1. Locations of samples of adult chum salmon in Japan: 1) Tokachi River, 2) Kushiro River, 3) Nishibetsu River, 4) Shari River, 5) Chitose River, 6) Yurrapu River, 7) Shibetsu River, 8) Tokoro River, 9) Tokushibetsu River, 10) Masuhoro River, 11) Teshio River, 12) Gakko River, 13) Miomote River, 14) Ohkawa River, 15) Tsugaruishi River. Adult chum salmon from the U.S.S.R. were gill netted in the northeast corner of the Sea of Okhotsk (approximately 60 N x 165 E). The ellipses enclose samples that are genetically similar (see text).

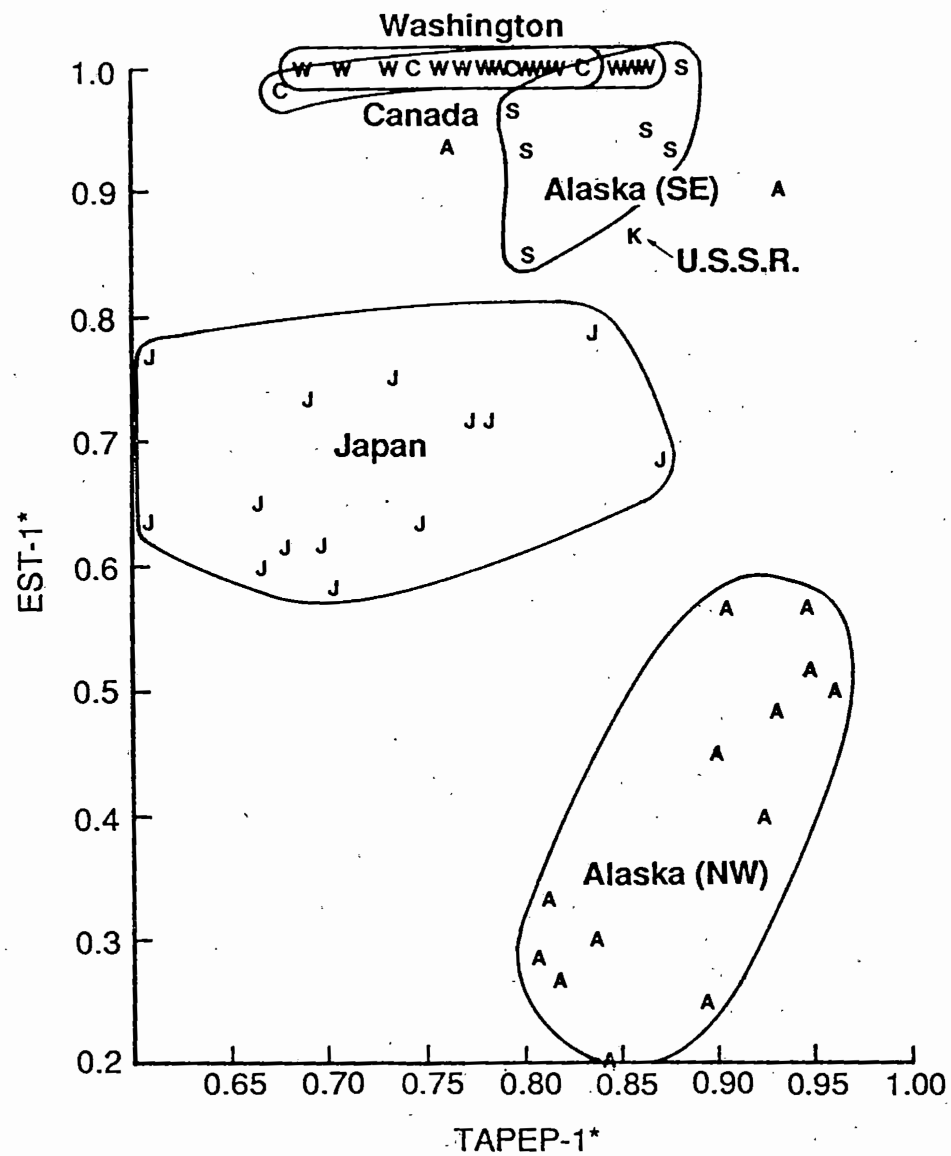


Figure 2. Scatterplot of mean allele frequencies of the common allele at *EST-1** and *TAPEP-1** for chum salmon samples. Ellipses enclose samples to highlight the among-region differences.

Potential Uses of GSI to Lessen Management Conflicts Between Hatchery and Wild Chum Stocks

Stevan Phelps and Bill Tweit

Washington Department of Fisheries
Room 115, General Administration Bldg.
Olympia, WA, 98504, USA

Susan Bishop

Northwest Indian Fisheries Commission
6730 Martin Way E.
Olympia, WA, 98506, USA

We discuss the use and potential of genetic tools to lessen the management conflicts between hatchery and wild chum stocks in Washington. We found substantial differences in the abundance and timing of wild and hatchery chum during four years of the genetic stock identification (GSI) analysis of a South Puget Sound test fishery. At times, hatchery chum from Hood Canal dominated the catch, although the patterns of stock contribution were not consistent from year to year. We also determined the genetic origin of chum stocks to identify chum gene pools from Hood Canal in other management regions. Past stock transfers complicate fisheries management and pose risk to the genetic diversity of chum in Washington. At the Minter Creek Hatchery in South Puget Sound, the Hood Canal origin chum stock is being replaced with the Elson stock from South Puget Sound. At the Tulalip Hatchery in North Puget Sound, managers chose to genetically mark the chum stock to allow GSI to be used to estimate the contribution of this stock to mixed-stock fisheries.

In most of Puget Sound, both natural and hatchery production of chum salmon (*Oncorhynchus keta*) are important to fisheries managers. The managers strive to maximize harvest and production from both the natural and hatchery components of the chum populations. Without some knowledge of the interactions between hatchery and natural chum salmon, the managers risk not realizing their management goals and the fish populations risk genetic conflict. Many of the Puget Sound salmon fisheries occur in areas where the hatchery and wild stocks are mixed, and as a result, the escapement and harvest goals for each of the stocks must be balanced in those fisheries. Errors in applying harvest rates produce over- or under-exploitation, failure to meet allocation goals, and in the worst cases, loss of the weaker (wild) salmon stocks. The genetic conflicts that can arise include loss of among-stock diversity through interbreeding between hatchery and wild salmon, loss of within-stock genetic variation through overfishing, and again, in the worst case, extinction of some wild stocks.

In this paper, we discuss how genetic stock identification (GSI) can be used to decrease the risk of these management and genetic conflicts, enabling fisheries managers to manage a mixture of wild and hatchery stocks effectively. GSI is a tool fisheries managers can use to study a broad range of interactions among hatchery and wild salmon. Most GSI studies with chum salmon have focused on estimating interceptions in mixed stock areas and resulting harvest allocations (Beacham et al. 1985, 1987; Vreeling et al. 1987; Naylor et al. 1988; Hop Wo et al. 1989; Phelps et al. 1989, 1990, 1991). However, other fisheries applications are possible. Seeb et al. (1986) used GSI to estimate the contribution to the escapement of chum produced in streamside egg boxes in Kennedy Creek, a small South Puget Sound stream. Altukhov and Salmenkova (1987) used allele frequency data to determine the success of transplanted chum stocks in the Soviet Union. GSI estimates have also been used to help target a fishery on a more abundant hatchery stock (Beacham et al. 1987). Skaala et al. (1990) recently summarized some genetic studies on the interactions between natural and cultured fish populations of a variety of species. Washington fisheries managers currently use GSI in three areas to understand management and genetic conflicts between hatchery and wild chum stocks:

1) to determine the patterns of stock contribution in some of the mixed-stock fisheries;
2) to identify the origin of chum populations (whether they are native or transplanted);

3) to design a genetic mark for a hatchery stock and later use that mark to discriminate among stocks.

We examine three case studies of the use of GSI to improve management of commercial fisheries in Puget Sound. One is the potential role of GSI in a test fishery used in management of a fishery harvesting both natural and hatchery chum in South Puget Sound. The other two are changes in broodstock at two different hatcheries in Puget Sound, located in areas of major natural production of chum salmon.

GSI USE IN THE MANAGEMENT OF THE SOUTH PUGET SOUND CHUM FISHERY

The chum salmon run returning to South Puget Sound is comprised of many separate stocks originating from the streams, rivers and hatcheries in the region (Figure 1). In order to simplify management, these stocks are classified by their return run-timing: early, normal or late. The normal portion, with a peak of spawning activity in November and December, is by far the largest component of the run. Although the normal portion, is primarily of natural origin and is managed for natural stock harvest rates, it includes a hatchery component.

Typically, almost all of the non-treaty fleet's allocation and a portion of the treaty fleet's allocation of South Puget Sound chum are harvested in net fisheries in Areas 10 and 11 (Figure 1). Much of the remainder of the treaty fleet harvest occurs in the rivers and inlets on relatively discrete stocks or stock groups. The area 10 and 11 fishery is managed to provide sufficient natural escapement and to meet allocation objectives using in-season estimates of run strength. These estimates of run strength are based on catch data from the commercial fisheries and from a purse seine test fishery operating weekly at Apple Cove Point, on the northern edge of Area 10 (Figure 1) (Washington Department of Fisheries, Puget Sound Treaty Tribes, and Northwest Indian Fisheries Commission 1990). The Northwest Indian Fisheries Commission (NWIFC) and the Washington Department of Fisheries (WDF) began obtaining weekly GSI samples from the test fishery in 1987 to estimate the stock composition of the test fishery catch and provide data on the run timing of chum stocks entering Area 10.

Four years of GSI analyses indicate that, at times when South Sound chum run strength is being assessed, the stock composition in northern Area 10 is dominated by non-local stocks, primarily from Hood Canal. The Hood Canal runs are managed primarily for hatchery production and in aggregate average 67% larger than the South Sound runs. The in-season estimates of the run strength of South Sound normal-timed chum are calculated from data from weeks 44 - 46, the time period when, on the average, Hood Canal genetic stocks predominate in the test fishery[1] (Figure 2). However, there is a large amount of annual variation in the timing of both the Hood Canal (Figure 3) and the South Sound runs. The peak of the Hood Canal abundance in the test fishery catch has occurred as early as week 42 in 1987 and 1990 and as late as week 45 in 1988 and week 46 in 1989. The abundance has also varied: from minimal presence in 1990 to very abundant in 1988. The South Sound chum run also has shown considerable annual variation (Figure 4) both in abundance and timing in the test fishery. As with the Hood Canal run, the 1987 and 1990 peaks occurred earlier than the 1988 and 1989 peaks. South Sound chum showed the highest abundance peak in 1988 and the lowest abundance peak in 1989.

The unpredictability in the timing and abundance of both South Sound and Hood Canal chum in a fishing area that is managed for South Sound wild chum is a complicating factor that can lead to all of the types of risks described earlier. Weekly GSI analyses of the test fishery catch are currently the only information available that will allow weekly stock composition estimates of Hood Canal, South Sound and North Sound chum in the South Sound fishing area. With four years of GSI analyses of test fishery catches, we can begin investigating correlations between the weekly catch of South Sound chum in the test fishery and the South Sound chum population size. This should lessen the hatchery-wild management conflict in South Sound fisheries by providing more accurate estimates of the contribution and timing of both hatchery and wild stock management.

---

[1] Some of the Hood Canal genetic stocks that appear in Area 10 originate from South Sound and North Sound hatcheries. This will be discussed in greater detail in a following section. The presence of these stocks does inflate the estimate of Hood Canal abundance in Area 10 to an unknown degree, but does not impact the estimate of abundance of South Sound natural stocks.

Another means of lessening the hatchery-wild conflict arises from our ability to identify the hatchery component of the south Sound run that is of South Sound genetic origin as it passes through the South Sound fishing area. These South Sound hatchery chum of South Sound genetic origin are not present in large numbers (averaging less than ten percent of the aggregate) prior to week 45, when they peak sharply (Figure 5). As the estimates of stock composition in the South Sound fishery become more accurate, through GSI analyses, the population size databases will be refined. These databases are strongly confounded between the Hood Canal stocks and the South Sound stocks because all the Hood Canal chum caught in South Sound are incorporated in the South Sound run size. This complicates management by over-estimating South Sound chum productivity.

CHUM POPULATION ORIGINS

As managers realized the potential for deleterious effects resulting from stocking nonlocal fish into wild populations, chum transplants (which were primarily from Hood Canal to South Sound) decreased. Now, a few generations later, in some streams there is uncertainty whether the present population is a remnant wild stock, a naturalized hatchery population, or a mixture of wild and hatchery gene pools. In addition, several South Sound chum hatcheries use a broodstock that originated in Hood Canal. Through the development of the baseline database for mixed-stock fishery analysis, we have identified several populations comprised of nonlocal origin chum (Table 1) (also see Klaybor and Phelps 1989). We suspect, based on hatchery planting records, that other locations throughout Puget Sound may also have nonlocal chum populations. We plan to continue the electrophoretic examination of additional chum populations in South Sound and Hood Canal to determine their stock origins. This will provide managers with information on stock origin for enhancement planning.

CHANGES IN CHUM BROODSTOCK AT TWO PUGET SOUND HATCHERIES

BROODSTOCK REPLACEMENT

The presence of Hood Canal origin chum in other regions interferes with the use of GSI for run size updates and allocations. GSI analysis identifies chum to the region of genetic origin, not to the area to which they return. The Minter Creek hatchery chum were derived from Hood Canal origin chum, and electrophoretic analysis in 1985 determined that Minter Creek chum were not significantly different from other Hood Canal origin chum (Klaybor and Phelps 1989). Therefore, in 1988, WDF and the South Sound tribes considered several plans to replace the non-local chum stock at the Minter Creek Hatchery. The managers chose to eradicate the Hood Canal origin stock and replace it with a South Puget Sound stock from Elson Creek. The managers chose this option because of a strong desire to use a chum stock from South Puget Sound and because a reliable egg source was available from the Elson Hatchery. Also, the current run timing could be maintained, and it was the least expensive option.

The stock replacement has had little impact on fishery management in South Puget Sound. The Medicine Creek tribes have conducted a wipe-out fishery since the fall of 1988. Several closures in and near the Elson Hatchery have been necessary to reach the egg take goals for both hatcheries (Symma Ebbin, pers. comm.). This fall three-year-olds from the 1988 Elson strain brood will return and by the fall of 1992 the Hood Canal origin chum will be eliminated from this hatchery.

GENETIC MARKING OF A HATCHERY STOCK

The power of genetic analyses depends on the amount of detectable genetic differentiation among populations. Naturally occurring genetic diversity has been the basis for the application of GSI for estimating stock group harvest in mixed-stock fisheries. In some cases, not enough genetic diversity exists among the populations that we want to separate with GSI, for example between two populations derived from the same source stock (as with hatchery transfers). In addition, the natural genetic differentiation among chum from Washington and southern British Columbia is often insufficient to produce significant stock composition estimates (GSI estimate minus the standard deviation is greater than zero) for minor stocks.

As with the Minter Creek Hatchery chum, the Tulalip Hatchery chum stock was derived from Hood Canal origin chum (Figure 1) and thus is indistinguishable in mixed-stock areas from chum returning to Hood Canal. Faced with the same problem as at Minter Creek, the Tulalip managers chose a different option. They decided to artificially increase the genetic distance between this chum stock and other chum populations by selecting broodstock based on electrophoretic characters, i.e., producing genetically marked offspring (see Utter and Seeb 1990 and Seeb et al. 1990 for reviews of the genetic marking process).

Adult chum were trapped in two streams near the Tulalip Hatchery and each chum was tagged with a numbered anchor tag, muscle biopsied, and released into presorting pens. Electrophoretic analysis was performed on the muscle biopsies and adults with the desired genotypes (males homozygous for the mIDHP-1*60 allele and mMEP-2*100, and females homozygous or heterozygous for the mIDHP-1*60 allele) were identified. The next day, the adults were sorted to find the selected broodstock and those selected were spawned. Approximately 5% of the males and 45% of the females carried the desired genotypes. Adults without the desired genotypes were not used for spawning. Except, all the available females, regardless of genotype, were used for spawning on several days during the 1990 genetic mark spawning in order to reach egg-take goals.

During the 1990 spawning season, approximately 180 males and 2000 females were used for spawning. The effective population size from this number of adults is 660, so the amount of inbreeding generated by this genetic marking was very small (F=0.00076). The frequency of the mIDHP-1*60 and mMEP-2*100 alleles in the approximately 4 million offspring produced is markedly different from that of the original parental population (Table 2). This marking process has to occur for an entire generation cycle, 4-5 years, to mark the total hatchery population. When the marking process is completed, Tulalip Hatchery chum will be genetically distinct from other chum populations (Table 2).

Genetic marks can be useful for managing hatchery-wild stock interactions. The increase in accuracy and precision of harvest estimates due to the greater genetic distance between the marked population and others can be used to regulate the time and location of fisheries to reflect differential contribution rates to fisheries. The genetically marked population can act as an indicator stock to estimate harvest when the stock group contribution to a fishery is small, but the harvest is large.

Run size forecasting can also benefit from the combined use of GSI and genetically marked populations. Wild juvenile chum production could be estimated from the abundance ratio of a genetically marked stock in marine areas (essentially a mark-recapture study). For example, chum releases from the Tulalip Hatchery could be tailored to estimate chum productivity from Area 8 streams. Wild productivity estimates, especially during years when flooding has occurred, would benefit fishery planning. Harvest of genetically marked adults in mixed stock areas could also be used as an indicator of wild chum marine survival, assuming similar migration timing and patterns.

Conservation genetic concerns such as the straying of hatchery fish into wild fish spawning areas, subsequent interbreeding, and the potential for fitness reduction can also be studied through the use of genetically marked populations (Chilcote et al. 1986).

ACKNOWLEDGEMENTS

A large number of people, from GSI samplers to fisheries managers, have contributed to this summary of genetic applications to chum management in Washington, and we are grateful to all of them. A special thanks goes to Ann Blakley, Chris Marlowe and Jim Shaklee for reviewing a draft of this manuscript. These studies have been funded by the Washington Department of Fisheries, the Northwest Indian Fisheries Commission, the Tulalip Tribes, and the Squaxin Island Tribe.

REFERENCES

Altukhov, Y.P., and E.A. Salmenkova. 1987. Stock transfer relative to natural organization, management, and conservation of fish populations. In Population Genetics and Fisheries Management (N. Ryman and F. Utter, eds.), pp. 333-343. Washington Sea Grant Program. University of Washington Press, Seattle, Wa.

Beacham, T.D., A.P. Gould, R.E. Withler, C.B. Murray, and L.W. Barner. 1987. Biochemical genetic survey and stock identification of chum salmon (*Oncorhynchus keta*) in British Columbia. Can. J. Fish Aquat. Sci. 44:1702-1713.

Beacham, T.D., R.E. Withler, and A.P. Gould. 1985. Biochemical genetic stock identification of chum salmon (*Oncorhynchus keta*) in southern British Columbia. Can. J. Fish. Aquat. Sci. 44:1702-1713.

Chilcote, M.W., S.A. Leider, and J.J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Trans. Amer. Fish. Soc. 115:726-735.

Hop Wo, L., L.S. Naylor, W.H. Luedke, A.P. Gould, and S.R. Heizer. 1989. Biochemical genetic stock identification of chum salmon in Southern British Columbia 1988, and update 1985-87. Can. Data Rep. Fish. Aquat. Sci. No. 749: 22p.

Klaybor, D.C., and S.R. Phelps. 1989. Patterns of genetic diversity of chum salmon in Southern British Columbia and Washington. In 14th Northeast Pacific Pink and Chum Salmon Workshop (P.A. Knudsen, ed.) pp 14-20. Washington Department of Fisheries, Olympia, Wa.

Naylor, L.S., L. Hop Wo, and A.P. Gould. 1988. Biochemical Genetic Stock Identification of chum salmon in Southern British Columbia, 1987. Can. Data Rep. Fish. Aquat. Sci. No. 700: 17p.

Phelps, S.R., S. Bishop, and D. Klaybor. 1989b. Genetic stock estimates of chum salmon stocks contributing to 1988 weekly test fisheries at Apple Cove Point, Washington - area 9/10. WDF unpublished report.

Phelps, S.R., D. Klaybor, B. Tweit, S. Young, J. Scott, and K. Doughty. 1989. Genetic stock identification estimates of chum salmon stocks contributing to 1988 Washington state fisheries in Areas 5, 7, and 7A. WDF unpublished report.

Phelps, S.R., L. LeClair, C. CdeBaca, and W. Beattie. 1991. Genetic stock identification estimates of 1990 Washington commercial chum fisheries in the Straits of Juan De Fuca and North Puget Sound. WDF unpublished report.

Phelps, S.R., M. Miller, and K. Doughty. 1990. Genetic stock identification estimates of 1989 Washington chum fisheries in areas 5, 7, and 7A and evaluation of test fisheries. WDF unpublished report.

Seeb, L.W., J.E. Seeb, and A.J. Gharrett. 1990. Genetic marking of fish populations. In Electrophoretic and Isoelectric Focusing Techniques in Fisheries Management (D.H. Whitmore, ed.) pp. 223-239. CRC Press Inc., Boca Raton, Fl.

Seeb, L.W., J.E. Seeb, and F.M. Utter. 1986. Use of genetic marks to assess stock dynamics and management programs for chum salmon. Trans. Am. Fish. Soc. 115: 448-454.

Skaala, O., G. Dahle, K.E. Jorstad, and G. Naevdal. 1990. Interactions between natural and farmed fish populations: information from genetic markers. J. Fish. Bio. No. 36: 49-460p.

Utter, F.M., and J.E. Seeb. 1990. Genetic marking of fishes: overview focusing on protein variation. Am. Fish. Soc. Symp. 7:426-438.

Vreeling, M.C., L. Hop Wo, A.P. Gould, W. Luedke, S.R. Heizer, and T.D. Beacham. 1987. Biochemical Genetic Stock Identification of Chum Salmon in Southern B.C., 1986. Can. Data Rep. Fish. Aquat. Sci. No. 634: 19p.

WDF. 1988. Stock composition estimates for the 1987 Apple Cove Point (Areas 9, 10) test fisheries Washington Department of Fisheries GSI Summary Report 88-6. unpublished.

WDF, Puget Sound Treaty Tribes, and NWIFC. 1990. Methods for the updating of chinook, coho and chum salmon runs entering Puget Sound in 1990. Joint Report. 177p.

Table 1. Electrophoretically identified occurrences of Washington chum populations originating from nonlocal regions.

Present Location	Origin
South Sound, Minter Creek Hatchery	Hood Canal
South Sound, Keta Creek Hatchery	Hood Canal
South Sound, Johns Creek[1]	Hood Canal
North Sound, Tulalip Hatchery	Hood Canal
North Sound, Samish Hatchery	Hood Canal
Strait of Juan de Fuca, Elwha River	Hood Canal

[1] Most likely a mixture of native and Hood Canal gene pools

Table 2. Expected genotype frequencies at mIDHP-1* and mMEP-2* in Tulalip Hatchery chum after genetic marking compared to other stock groups.

	mIDHP-1			mMEP-2		
Stock or Group	100/100	100/ 60	60/ 60	100/100	122/100	122/122
Tulalip Hat. '94-'98[1]	0.000	0.410	0.590	0.786	0.191	0.023
Tulalip Hat. past '98	0.042	0.326	0.632	0.777	0.209	0.014
Hood Canal	0.473	0.429	0.097	0.618	0.336	0.046
S. Puget Sound	0.689	0.282	0.029	0.449	0.442	0.109
N. Puget Sound	0.740	0.241	0.020	0.486	0.421	0.091
Fraser River	0.792	0.196	0.012	0.706	0.269	0.026
Georgia Strait	0.893	0.104	0.003	0.585	0.360	0.055
W. Vancouver Is.	0.931	0.068	0.001	0.548	0.385	0.068

[1] The progeny from the genetic marking will not be in Hardy-Weinberg equilibrium until after 1998.

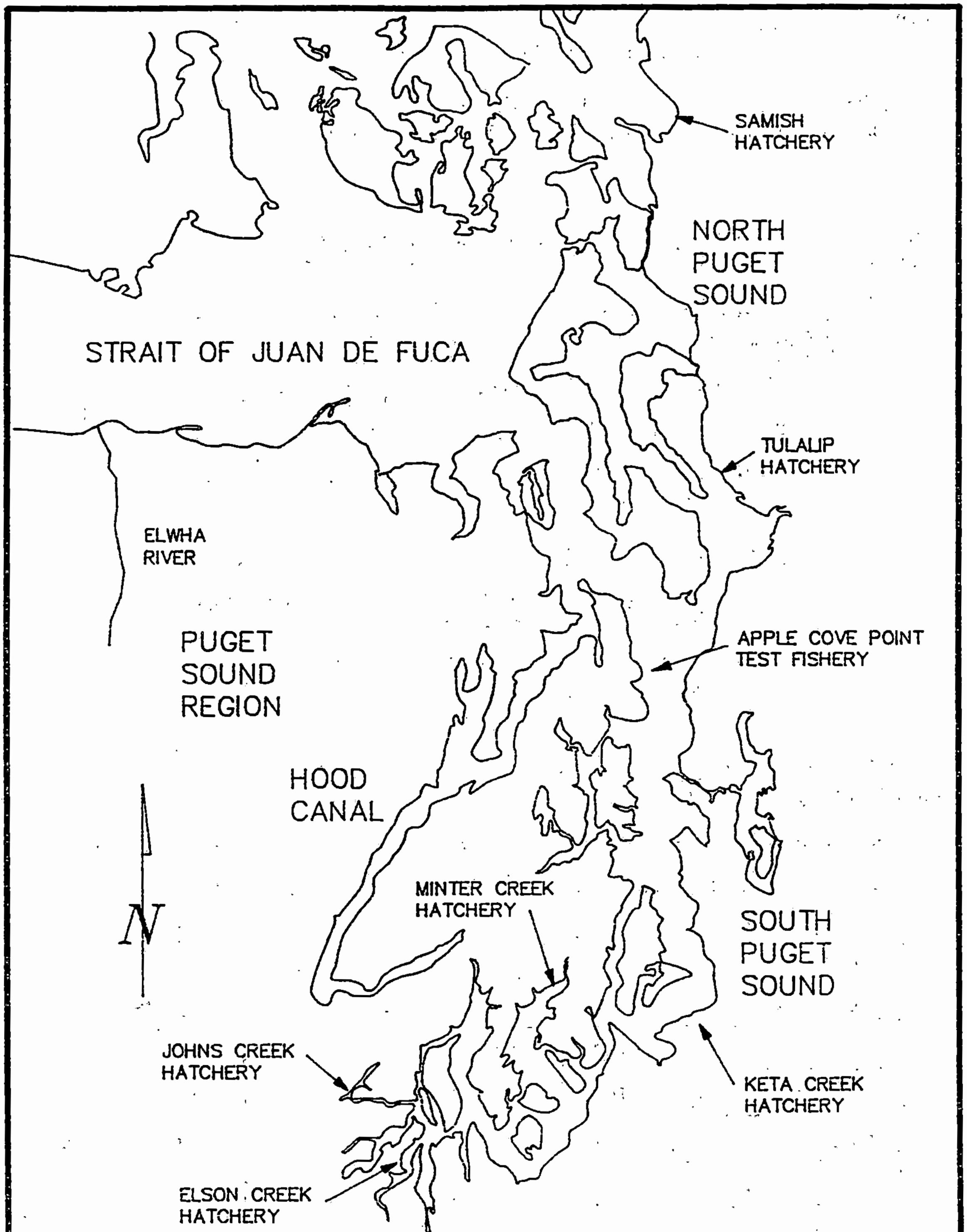


FIGURE 1: MAP OF PUGET SOUND SHOWING CATCH AREAS, SOME HATCHERIES, AND THE TEST FISHING SITE.

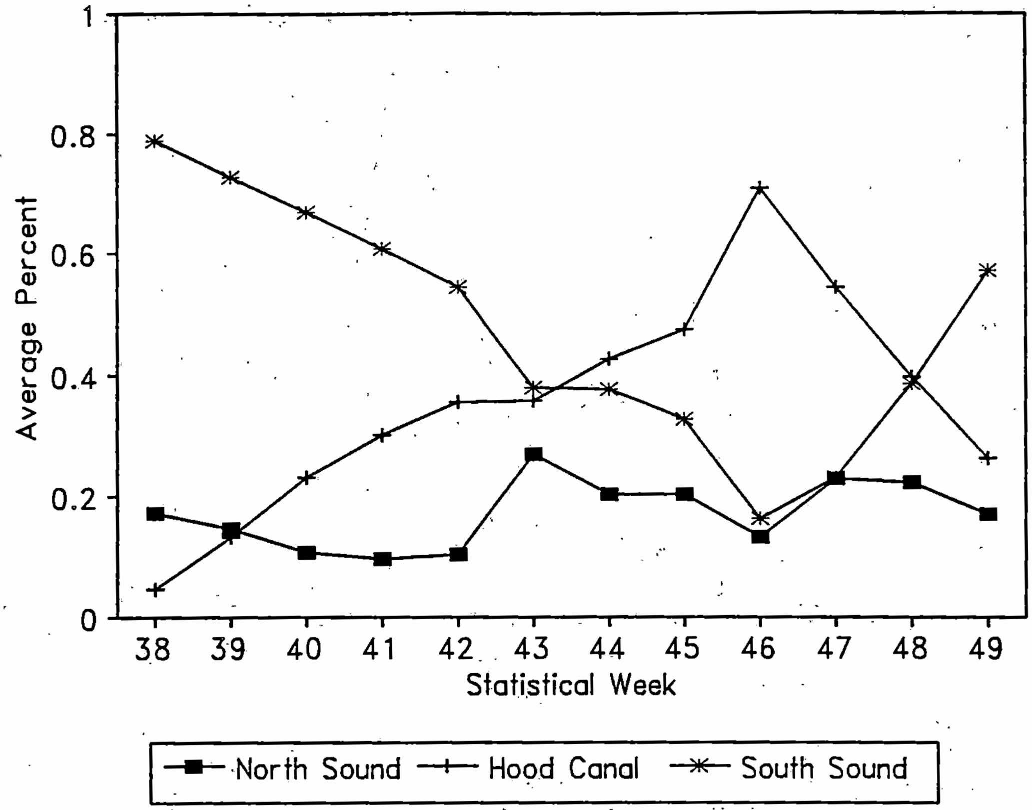


Figure 2. Percent composition of three regional chum salmon stock groups contributing to weekly test fisheries at Apple Cove Point, Washington (1987-1990 average).

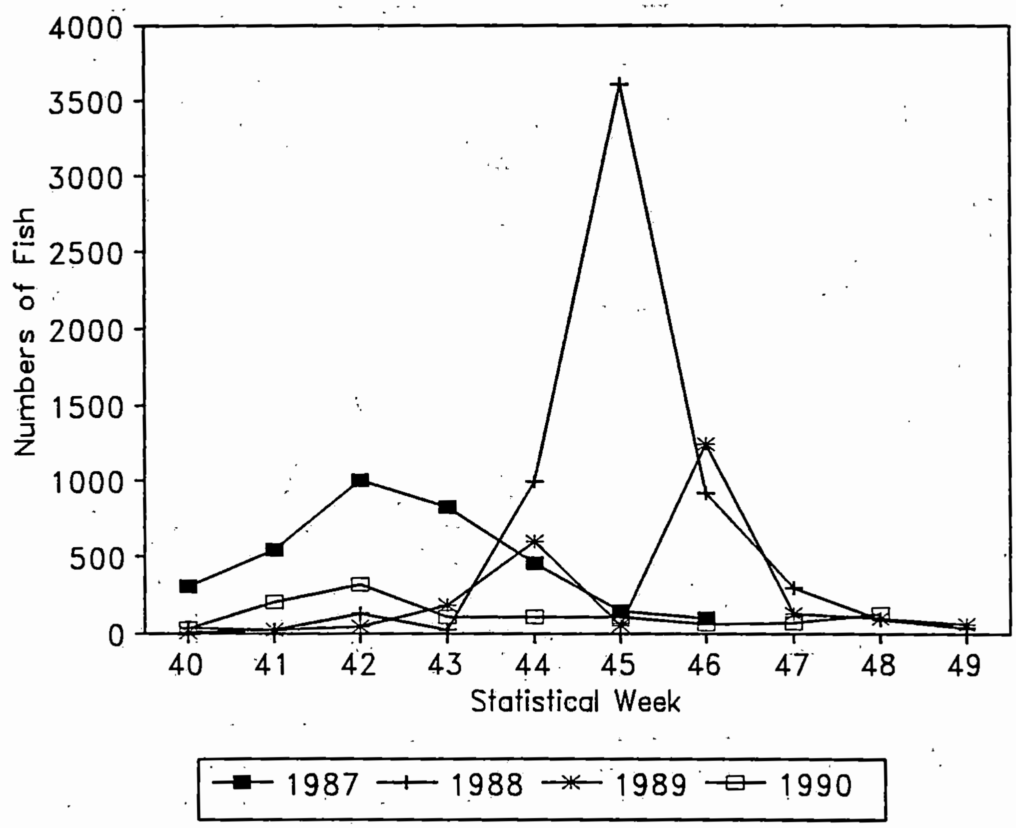


Figure 3. Yearly changes in the estimated abundance of Hood Canal origin chum salmon stock groups contributing to weekly test fisheries at Apple Cove Point, Washington (1987-1990 average).

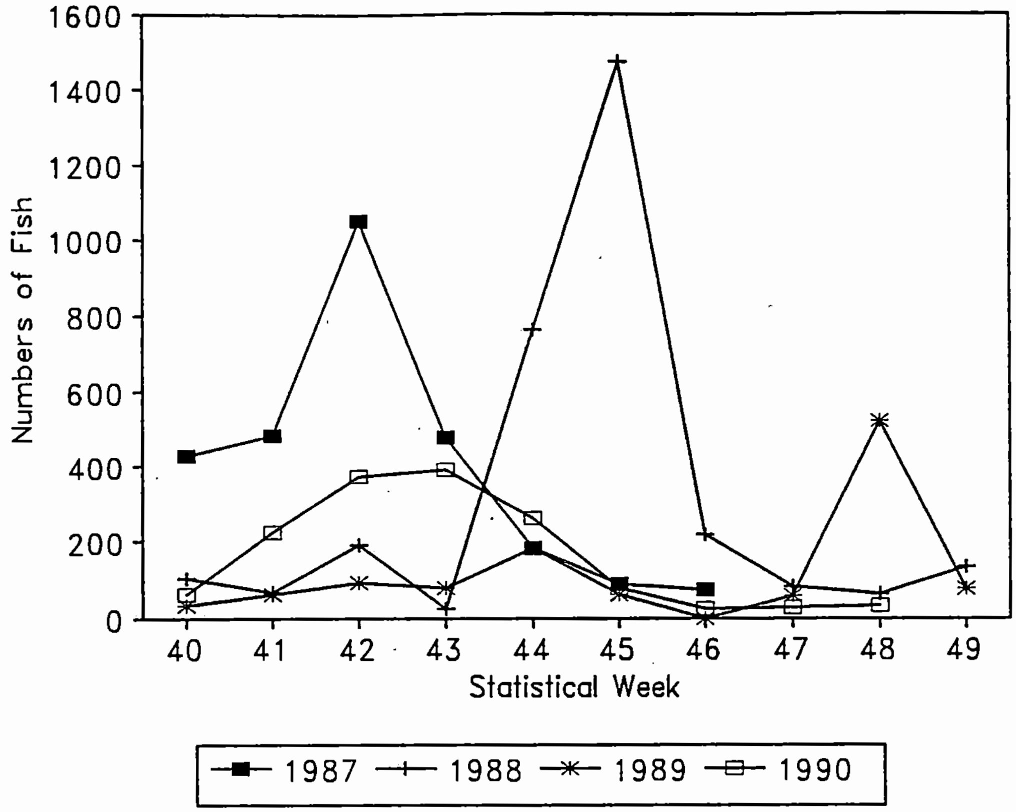


Figure 4. Yearly changes in the estimated abundance of South Puget Sound origin chum salmon stock groups contributing to weekly test fisheries at Apple Cove Point, Washington (1987-1990 average).

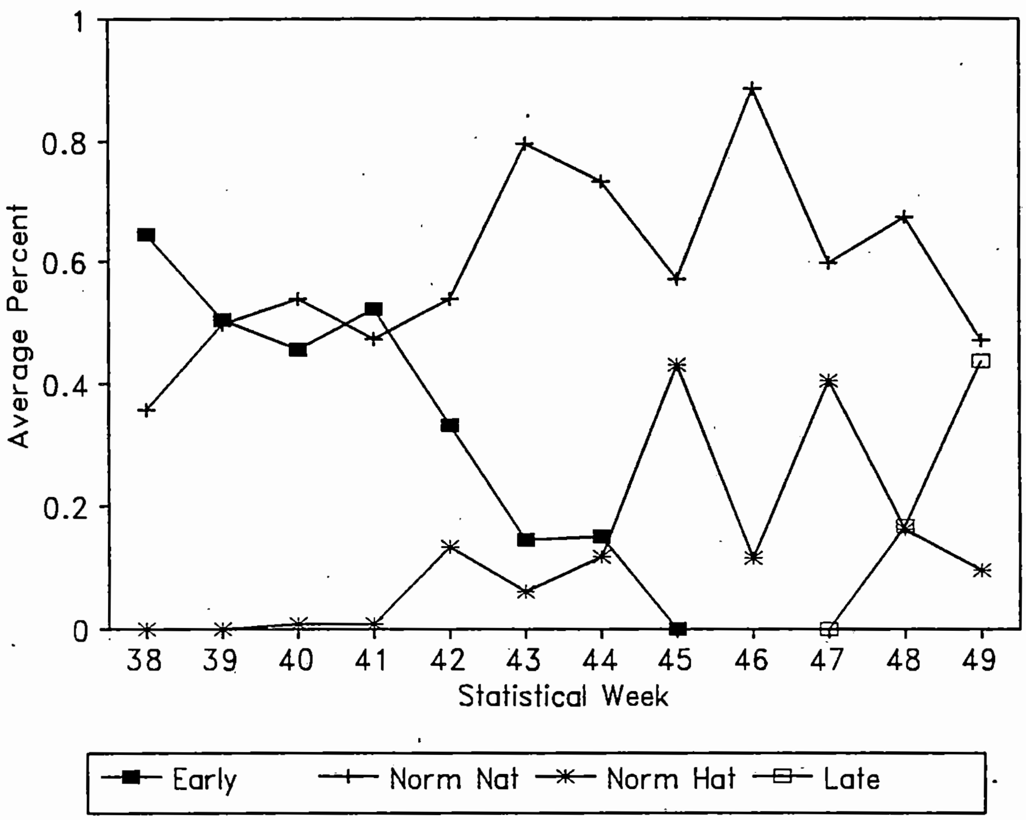


Figure 5. Percent composition of South Puget Sound chum salmon stock groups (of the total South Puget Sound component) contributing to weekly test fisheries at Apple Cove Point, Washington (1987-1990 average).

GSI and Canadian In-season Chum Management

Leroy Hop Wo and Wilf Luedke

Canada Department of Fisheries and Oceans
Fisheries Branch, South Coast Division
3225 Stephenson Point Road
Nanaimo, B.C., V9T 1K3

GSI APPLICATION BACKGROUND

Stock Identification using electrophoretic techniques has occurred in Canadian commercial chum fisheries since 1981. Major chum fishing areas which have undergone Genetic Stock Identification (GSI) are Johnstone Strait, mid Vancouver Island (Qualicum) and Nitinat (Figure 1). The GSI technique has allowed managers to quickly determine the stock composition within specific fisheries. This information becomes valuable in allowing the harvest of more productive stocks while protecting weaker stocks. This strategy becomes very desirable in mixed stock fisheries with high exploitation rates. In addition to selective harvesting, GSI estimates have provided stock timing and migration information as well as estimates of catch contribution from interception fisheries.

PAST GSI APPLICATION

In the past, protection of weaker stocks using GSI have been employed on an in-season basis. For example, in 1984 and 1985, weekly area closures occurred in the Qualicum fishery to protect weaker Fraser bound fish. Closures were determined by testing specific areas prior to openings. If the stock composition results were high in Fraser fish, the specific area was closed.

The identification of catch by origin has in more recent years become a primary concern. Interception catch estimates have help determine the stock returning to terminal areas such as Qualicum and the Fraser River. Catch by stock origin has also provided estimations of harvest by country, an obligation outlined by the Pacific Salmon Treaty.

GSI has also provided important information on migration routes and timing, as well as assist in stock abundance estimates. These average annual results form the basis for stock estimates employed during the fishing season (Figure 2). In-season weekly GSI results have provided confirmation of trends (based on past studies) which have contributed to the overall fishing plan.

CURRENT GSI APPLICATION

Currently, GSI information is used in-season to alert managers to trends not seen in the past and to determine post-season catch by origin.

In Qualicum, weekly interception estimates from Johnstone Strait are compared using past interception results. Any large differences seen in-season are used to alert managers to potential problems. Similarly, in Johnstone Strait, weekly GSI stock composition results are not solely used to determine the next week harvest action. They are used to confirm stock composition estimates derived from past results. In a rigid sense, information provided by GSI are currently not used to manage commercial fisheries on a week by week basis. Instead, decisions rely more on stock composition estimates derived from long term trends. The reasons for not using GSI results to manage on a weekly basis are: (1) historical averages are more readily available for both pre-season and in-season planning; (2) weekly processing deadlines are difficult to achieve; and (3) abnormal results may not reflect accurate stock compositions on an individual weekly basis. However, these in-season weekly results serve more to signal managers to be aware of possible stock composition abnormalities.

FUTURE USE OF GSI

GSI is necessary to provide interception estimates on a post-season basis and provide annual trends to assist in harvest planning. Where stock identification information is completely absent, GSI can be used on a weekly basis as previously demonstrated in Qualicum. However, before more emphasis is put on weekly GSI results, variability between weekly estimates (Figure 3) should be understood and reduced.

In the past, steps have been taken to analyze and reduce this variability. These have include larger sample sizes, expansion of sampling areas and fishery types, investigation of fish behaviour and testing of estimation procedures. In addition, work by the Chum Technical Committee of the Pacific Salmon Commission will hopefully provide information on variability through computer modelling simulations (e.g., differences between 7 and 21 loci, increases in sample size, modelling different populations and analyzing fish schooling behaviour).

SUMMARY OF GSI APPLICATION

GSI has provided valuable long term information on stock composition, timing and interception catch estimates. In the past GSI has provided managers with a stock assessment technique to effectively manage specific fisheries. However, managers are not using GSI to determine harvesting on a week to week basis because of variability concerns. These, along with other concerns are currently being addressed.

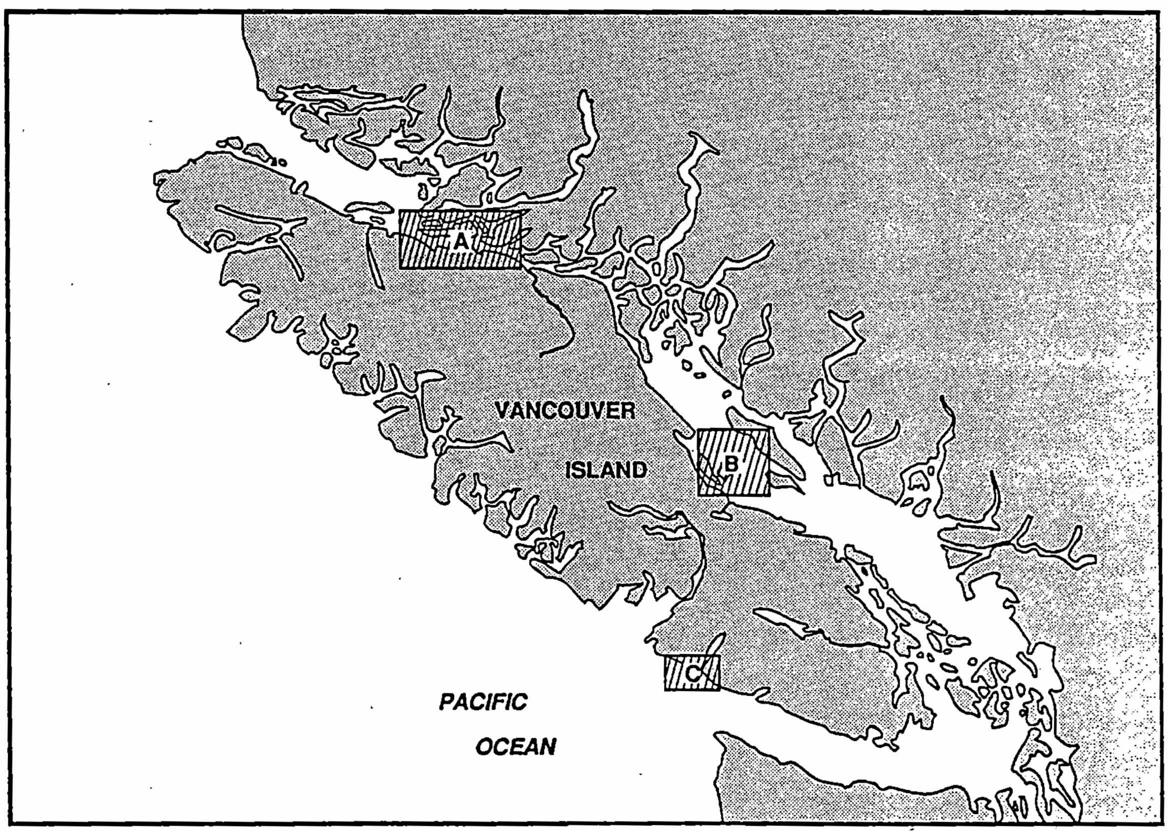


Figure 1. Regions of Chum Sampling
(A) Johnstone Strait (B) Mid Vancouver Island (C) Nitinat

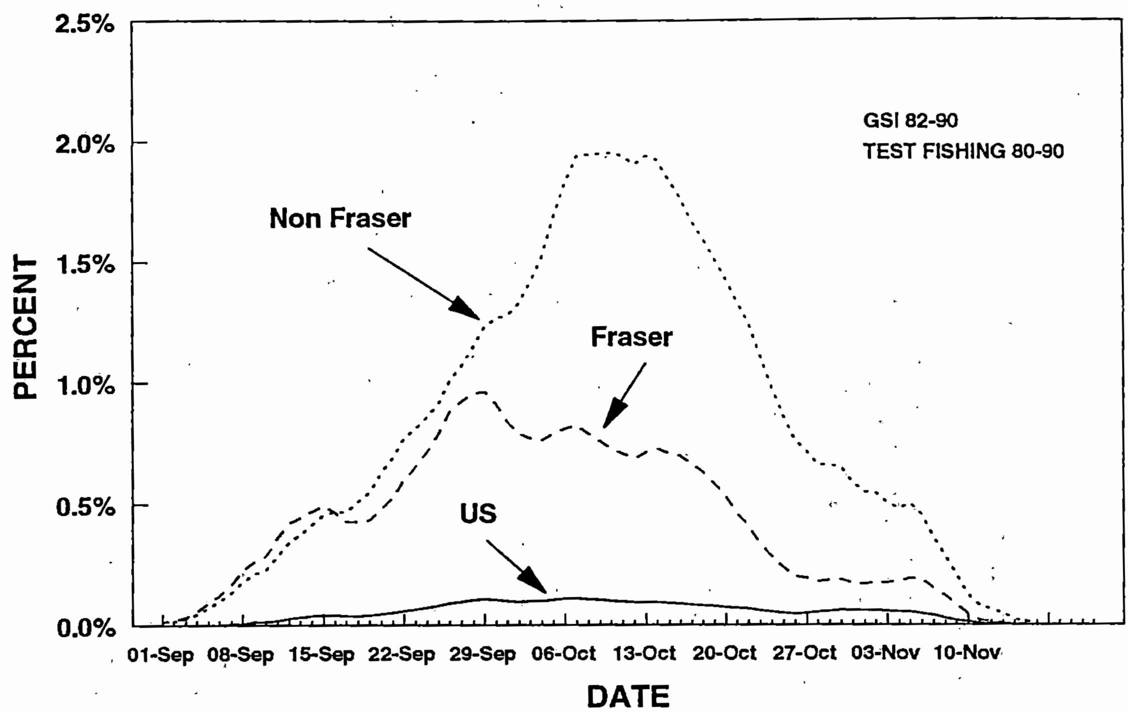


Figure 2. Johnstone Strait Average Chum Timing and Stock Composition.

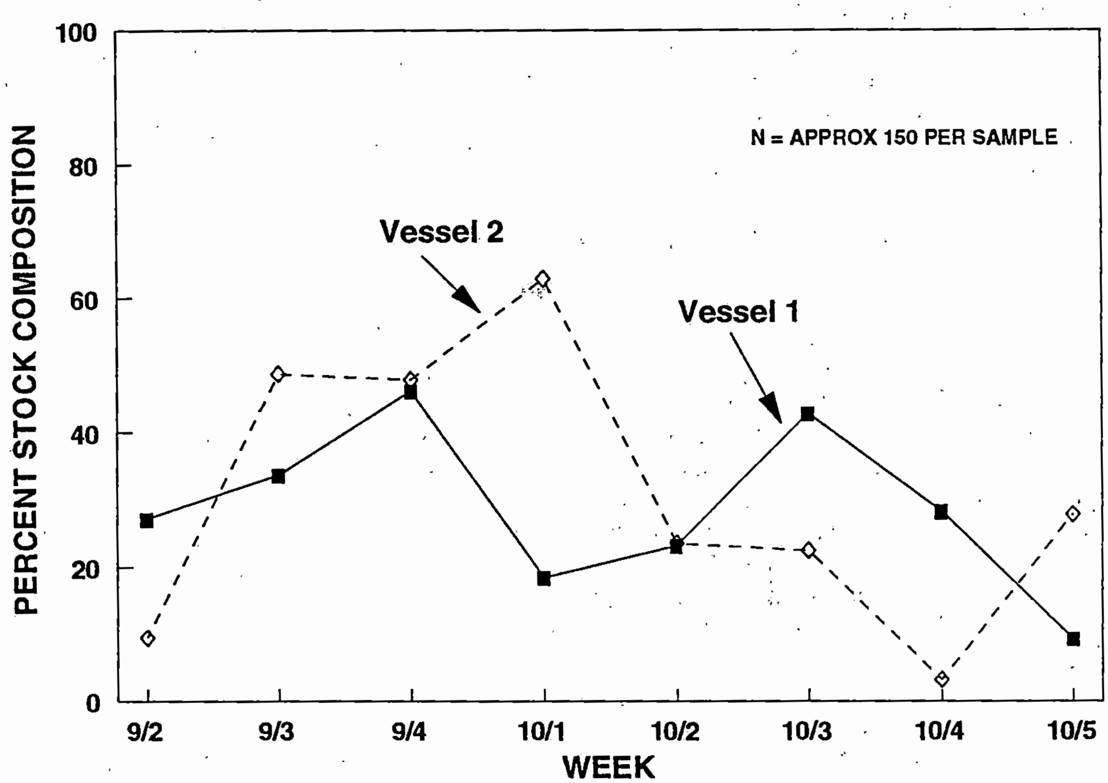


Figure 3. Fraser Stock Composition from Johnstone Strait Test Fishing Vessels, 1990.

In-Season Management of Fraser River Pink Salmon Using GSI Techniques

Bruce White and Jim Gable

Pacific Salmon Commission
600 - 1155 Robson Street
Vancouver, B.C., Canada, V6E 1B5

Genetic stock identification (GSI) techniques are used by the Pacific Salmon Commission (PSC) to estimate stock group contributions in commercial and test fishing catches for in-season management of Fraser River pink salmon (*Oncorhynchus gorbuscha*). Three areas of management activities benefit from the stock group estimates: (1) allocation of Fraser River pink salmon catches among user groups, (2) determination of migratory patterns, and (3) estimation of run size. GSI helped the Fraser River Panel of the Commission to achieve their international and domestic allocation objectives for Fraser River pink salmon in 1989. The international allocation of Fraser pinks between Canadian and United States fishermen was within 295,000 fish (12% of the United States share) of the in-season allocation goal. Domestic allocation goals for catch by user group and/or gear type for each country were also very close to being met. Additionally, GSI information assisted in determining the run timing and migratory pattern of Fraser pinks through various areas (e.g., Johnstone Strait and Juan de Fuca Strait) so that appropriate regulations for their harvest could be developed. Finally, GSI data were used to confirm the presence of high proportions of Fraser pinks in specific fisheries so that several run-size estimators could be employed. These three uses of GSI information helped the Fraser River Panel to achieve escapement and catch allocation objectives (as stated by the Parties) for Fraser River pink salmon in 1989.

The Pacific Salmon Commission (PSC) was established in 1985 with the signing of the Pacific Salmon Treaty by the governments of Canada and the United States. Under the Treaty, the Fraser River Panel of the PSC has two principal mandates involving Fraser River pink salmon (*Oncorhynchus gorbuscha*): (1) accounting for these fish wherever they may be harvested, (2) and managing fisheries targeting on these stocks within the Fraser River Panel Area of jurisdiction (Figure 1). Prior to 1985, there was no reliable method of accurately identifying Fraser River pink salmon during the period of active in-season management. In order to fulfil its mandate under the Pacific Salmon Treaty, the staff of the PSC initiated a pilot program of in-season stock composition analysis of pink salmon in 1985 using protein electrophoresis. The genetic stock identification (GSI) program was expanded and refined during the 1987 and 1989 management seasons and is now an important part of the PSC's in-season management operation.

GSI was selected over other methods of identifying stocks contributing to mixed-stock fisheries, (e.g., run reconstruction, analysis of morphometric characters and scale patterns), because preliminary testing of the technique in 1985 and 1987 showed that it had potential for providing accurate and timely estimates of stock composition on an in-season basis (White and Shaklee 1991, Beacham et al. 1985). Currently, there are about forty stocks in the overall baseline from four stock groups: (1) Fraser River, (2) Puget Sound, (3) Canada South Coast, and (4) Canada North Coast (Figure 1). Two different baselines are used in the fishery analyses. For fisheries occurring north of Cape Caution, the baseline includes all of the stock groups. Fisheries which occur south of Cape Caution are analyzed with a baseline comprised of stocks from the Fraser River, Puget Sound, and Canada South Coast stock groups. Stocks that spawn in central and northern British Columbia are excluded from this baseline because they are not likely to contribute to south coast fisheries.

The Fraser River Panel manages Fraser River pink salmon based on three main objectives: (1) to achieve escapement goals by stock or stock grouping; (2) to allocate the catch internationally and domestically among the user groups; and (3) to conserve other species of salmon and stocks that may be harvested in fisheries directed at Fraser pinks (PSC 1989). GSI analyses assist in achieving these objectives in several ways. Currently, the main use of the GSI estimates is for determining the catch-to-date of Fraser pinks by user group so that the accounting and international and domestic allocation objectives of the PSC can be achieved. GSI information is also used in determining the migratory pattern and timing of Fraser stocks in numerous fisheries where they may occur; from the Canadian Areas 1 and 101 fisheries in the north, to the Oregon troll fishery in the south. Confirming the presence of high proportions of Fraser pinks in specific fisheries so that various methods of run size estimation can be employed is a third application of the GSI estimates. These three uses of the GSI data assist in the development of regulations for harvesting Fraser pinks so that the Panel objectives can be met. The primary purpose of this paper is to describe and demonstrate how each of these uses of the GSI data are computed and applied during the in-season management process.

METHODS AND RESULTS

The three uses of the GSI data outlined above (catch allocation, migration analysis, run size estimation) are examined below. We also discuss the objectives of the Fraser Panel that are affected by these fisheries management applications of the GSI information (Table 1).

ALLOCATION OF CATCHES AMONG USER GROUPS

Achieving the international catch allocation specified in the Pacific Salmon Treaty is the second most important management goal of the Fraser River Panel (meeting the gross escapement goal is the primary objective). Determining the catch-to-date of Fraser River pink salmon by each user group on a "real-time" basis throughout the fishing season provides the PSC staff and the Fraser River Panel with information necessary to achieve the annual international and domestic catch allocation objectives. This process involves multiplying the GSI estimate of the proportion of Fraser pinks present in a particular fishery by the total number of pink salmon caught by a user group (e.g., Canadian purse seine fishermen) for that fishery. Estimates of catches of Fraser pinks by fishery and user group are calculated weekly over the fishing season and provide a basis for modifying fishery openings so that appropriate catch allocations are achieved. Estimates of the total catch of Fraser pinks by user group for the entire season are also generated and compared to the allocation goals by user group. Shortfalls or overages in allocation to the user groups are remedied in future years in the form of catch paybacks. In Table 2 we identify the user groups to whom Fraser pinks are allocated, both internationally and domestically, and the estimates of GSI stock groupings that are required to meet the allocation objectives.

GSI analyses along with 1989 catch data from numerous fisheries indicated that most of the Canadian catch of Fraser pinks occurred in late August and early September. Catches by United States fishermen were concentrated in the period from early to mid-September.

The in-season GSI estimates of Fraser River pink salmon catches showed that the international allocation objectives were very close to being achieved. However, subsequent post-season accounting, which includes a bias correction procedure for the maximum likelihood estimates, which was not available during the 1989 management season, revealed that the United States fishermen actually caught 2,233,000 pink salmon which was 295,000 fish (12%) below their catch goal of 2,528,000. This catch shortfall will be made up in future years.

The domestic allocation objectives were nearly met in the United States. Treaty Indian fishermen caught 1,195,000 fish, exceeding their share by 78,500 fish. Non-Indian fishermen harvested 1,038,000 fish, 3.5% below their share. In Canada, the catches of pink salmon diverged somewhat from the original goals. The deviations were primarily in the gillnet and purse seine sectors, with the gillnet fleet falling short of their allocation and the purse seine fleet exceeding their allocation. GSI estimates provided the basic data used by the Fraser River Panel to achieve or approach the international and domestic allocation goals in each country.

DETERMINING MIGRATORY PATTERNS AND TIMING

Information on the run timing and migration patterns of Fraser pinks in the various fisheries is required for developing regulations for their harvest and allocation among the different user groups. It is also critical for achieving the three main objectives of the Panel. To illustrate this, we give an example from data recorded on the Area 12 and 20 purse seine fisheries during the 1989 fishing season.

One of the primary uses of monitoring the migratory pattern of Fraser pinks is to determine the proportion of these fish diverting via the "northern" approach (through Johnstone Strait, Area 12) versus those taking the "southern" approach (through Juan de Fuca Strait, Area 20). Information on the diversion rate must be considered for two primary reasons when harvest regulations are developed. First there is a different exploitation rate on pink salmon intercepted in the Johnstone Strait purse seine fishery versus those harvested in the Juan de Fuca Strait purse seine fishery. The Johnstone Strait fishery harvests a much higher percentage of the weekly abundance of available pinks in one day of fishing because of the much larger geographic size and greater number of vessels that typically fish this area during an opening. This has an effect on the number of fish escaping into the Strait of Georgia and may compromise escapement goals if not considered. Second, in years where a large percentage of the available pinks migrate through Johnstone Strait, there are proportionally fewer available for harvest in United States Panel Area waters. Consequently, international allocation goals may not be achieved unless pre-season fishing plans are modified in response to changes in diversion rate.

Calculation of the diversion rate requires weekly GSI estimates of the proportion of Fraser pinks in several mixed-stock fisheries. These estimates are important data inputs for a cumulative normal distribution (CND) model used by PSC staff to forecast run size. The model utilizes estimates of catches of Fraser pinks to date, test fishing catch per unit effort (CPUE) data, and historic exploitation rates to "reconstruct" daily abundances of the total run migrating through specific areas (PSC 1990). Output from the model is used to guide decisions on the structure of weekly fisheries in order to achieve escapement goals and harvest objectives.

Without accurate GSI data inputs to the CND model from commercial and test fishing catches, outputs from the model could be misleading and harvest regulations could be established which could potentially undermine management goals. For example, large catches of pink salmon in Johnstone Straits fisheries could falsely signal high Fraser River diversion rates if large proportions of non-Fraser River pinks were present in the area, and were assumed to be of Fraser River origin. In 1989, large catches of pink salmon were made in Johnstone Straits during the period from August 13 to August 26. The combined catches of pink salmon for those two weeks were approximately 1.33 million. The proportion of Fraser pink salmon in the catch during this period was between 46 and 66 percent. If the non-Fraser component had not been identified, the CND model could have greatly overestimated the diversion rate during this period and inappropriate regulations may have been developed.

ESTIMATION OF RUN SIZE

The estimation of total run size of Fraser pinks provides important information for achieving the escapement and catch allocation objectives of the Fraser River Panel. GSI data are used to confirm the presence of high proportions of Fraser pinks in specific mixed-stock fisheries so that a number of run size estimators can be employed. The run-size forecasting models could be adversely affected by the presence of large proportions of non-Fraser pinks in these fisheries. The peak catch per unit effort (CPUE) of pink salmon from the Area 20 purse seine fishery is the first run size estimator we will review.

Assessments of the Fraser River pink salmon run using CPUE data from the Area 20 commercial purse seine fishery began in late August and continued through the period of peak fishing in September. The Fraser River pink salmon component of the total pink salmon catch was estimated using GSI analyses, which were available approximately one week after the closure of each fishery. Moderate CPUE's in both northern and southern approach fisheries in late August suggested a run smaller than the pre-season forecast. Consequently, the in-season projection of total Fraser pink salmon run size was reduced from 17 to 13 million. Peak catches occurred during fisheries on September 3 - 5 and analyses of CPUE data, along with other data, resulted in the run size being increased to 15 million. This was close to the final calculated total return of 16.6 million. Without estimates of Fraser pink salmon contribution rates from the GSI program, there would have been a larger degree of uncertainty around point estimates of Fraser River pink salmon run size generated from CPUE catch data.

The second technique for forecasting run size that relies on GSI to confirm the presence of high proportions of Fraser pinks in mixed-stock fisheries is the distance to the annulus on scales of pink salmon taken in commercial and test fisheries (Blackbourn and Tasaka 1989). In 1989 the results of this assessment technique were variable, with projections of Fraser River pink salmon run size ranging from 7.0 million to 14.6 million fish. However, in weeks where the percentage of Fraser pink salmon identified in the sample was high, the results were less variable. For example, the scale data from the Area 20 purse seine sample from week-ending September 5 (82% Fraser) forecasted a total return of 14.1 million, and the scale data from the Area 123 troll sample from week-ending August 26 (89% Fraser) forecasted a total return of 14.6 million.

The final method employed by the Commission to estimate run size using GSI estimates is the CND model. Accurate GSI data provides critical inputs to the CND model. If the proportion of non-Fraser pink salmon in coastal catches are not identified, serious errors in estimating the total run of Fraser pink salmon escaping to the Strait of Georgia could occur. Based on the catches of Fraser pinks in particular fisheries and the cumulative escapement to date, the CND model can be used to forecast total run size at specific points during the season. As the season progresses and a greater amount of catch and escapement data is accumulated, the accuracy of run size estimates generally improves (PSC 1990). In 1989, late-season run size estimates using this method produced estimates ranging from 13 to 15 million Fraser pink salmon. These estimates were slightly below the post-season (final) estimate of 16.6 million.

DISCUSSION

The Pacific Salmon Commission developed a GSI program for assisting in the management of Fraser River pink salmon because of increasing demands created by the Treaty and for use by the Fraser River Panel for in-season management of these stocks. Prior to 1987 the Commission relied on run-reconstruction techniques (applied post-season) to account for catches of Fraser pinks. Beginning in 1985 with a pilot study, and continuing in 1987 and 1989, GSI methodologies were used to help the Fraser River Panel achieve its two mandates of accounting for Fraser pinks wherever they are harvested and managing fisheries targeting on these stocks within the Panel area of jurisdiction. GSI data has become critical in achieving escapement and international and domestic catch allocation to Canadian and United States fishermen. In addition, it is now an integral part of the weekly data input into the CND model throughout the period of in-season management. The use of GSI estimates for migrational analysis and in the run size estimation process will likely increase in importance in the future as the Fraser River Panel requires information on an increasingly rapid basis, and as the GSI data base grows with successive years of Fraser River pink salmon catch information.

In reviewing the 1989 management season, we examined specific examples of how the GSI program helped the PSC staff and the Fraser Panel achieve escapement goals and harvest allocation objectives. In fisheries occurring south of Cape Caution, the catch component of Fraser River pinks followed a broad trend of increasing from approximately 40% of the catch in mid-August to over 80% by mid-September. By closely monitoring the stock composition each week, particularly in Canadian fisheries occurring in Johnstone Strait and Juan de Fuca Strait, and in United States fisheries in Puget Sound, PSC staff provided the Fraser River Panel with reasonably accurate estimates of the number of Fraser pinks escaping those fisheries and migrating into the Strait of Georgia. The uncertainty surrounding terminal area escapement estimates would have been much higher if GSI estimates of commercial catch had not been available.

GSI analyses of pink salmon catches in Alaska District 104 fisheries showed little evidence of Fraser River pink salmon catches in this area, although catches of Fraser River were identified in Canadian fisheries in northern British Columbia. The largest weekly contribution of the Fraser River stock group in fisheries occurring north of Cape Caution was in the Area 142 troll fishery during the period August 20 to 26. During this time Fraser pink salmon accounted for approximately 53% of the catch. Accurate assessments of Fraser pink catches in all fisheries where they may be caught, including distant fisheries such as Area 142 is important for meeting catch allocation goals.

Tracking of northern area interceptions of Fraser pinks could eventually provide useful information to managers, in addition to their current catch accounting function. Once a sequence of years of GSI data are available from northern area interceptions, trends in Fraser River pink salmon abundance may become apparent. These data may have value for forecasting probable return strength and run timing of Fraser River pinks. The accuracy of such forecasts could potentially be enhanced by stocks that have a high degree of genetic distinctiveness between and within specific stock groups.

It is probable that GSI will prove useful in additional applications to fisheries management. One important use may be in helping to develop fishing regulations to minimize over-harvest of weak or endangered stocks of salmon in mixed-stock fisheries so that the genetic variability of such stocks is maintained (Waples et al. 1990; Allendorf et al. 1987).

Many of the run size estimation relationships currently utilize data which includes both Fraser River and non-Fraser stocks. Quantification of these relationships would likely be improved if the non-Fraser component of the historical data could be removed. As the GSI data base expands, these historic relationships may be replaced by data resulting from assessment techniques using "pure" Fraser stock catch data.

In summary, the GSI program has proven to be a useful tool for assisting in the in-season management of Fraser River pink salmon. Its value will increase as successive years of data are added to the 1987 and 1989 base years.

ACKNOWLEDGMENTS

We thank Jim Woodey of the Pacific Salmon Commission for his comments on a draft of this paper. We would also like to acknowledge Ian Guthrie, Jim Cave, and Steve Cox-Rogers of the Pacific Salmon Commission for providing data included in this paper.

REFERENCES

Allendorf, F.W., N. Ryman, and F.M. Utter. 1987. Genetics and fishery management: past, present, and future, p. 1-19. *In* N. Ryman and F. Utter [ed.] Population genetics and fishery management. Washington Sea Grant Program, University of Washington Press, Seattle, Washington.

Beacham, T.D., R.E. Withler, and A.P. Gould. 1985. Biochemical genetic stock identification of pink salmon (*Oncorhynchus gorbuscha*) in southern British Columbia and Puget Sound. Can. J. Fish. Aquat. Sci. 42: 1474-1483.

Blackbourn, D.J. and M.B. Tasaka. 1989. Marine scale growth in Fraser River pink salmon: a comparison with sockeye salmon marine growth and other biological parameters, p. 58-63. *In* P.A. Knudsen [ed.] Proceedings of the 14th Northeast Pacific Pink and Chum Salmon Workshop.Washington Dept. of Fisheries, Tumwater, WA.

Pacific Salmon Commission (PSC). 1989. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1988 Fraser River sockeye salmon fishing season. 600-1155 Robson Street, Vancouver, B.C. 38 p.

1990. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1989 Fraser River Sockeye and Pink Salmon Fishing Season. 600-1155 Robson Street, Vancouver, B.C. 51 p.

Waples, R.S., G.A. Winans, F.M. Utter, and C. Mahnken. 1990. Genetic approaches to the management of Pacific Salmon. Fisheries, Vol. 15, No. 5: 19-25.

White, B.W., and J.B. Shaklee. 1991. Need for replicated electrophoretic analyses in multiagency genetic stock identification (GSI) programs: examples from a pink salmon (*Oncorhynchus gorbuscha*) GSI fisheries study. Can. J. Fish Aquat. Sci. 48: 1396-1407.

Table 1. In-season uses of GSI data for management of Fraser River pink salmon.

In-Season Uses of GSI	Objectives of Panel Affected	Analyses Involving GSI
Allocating catches among user groups	* catch allocation	* GSI estimate x catch by user group for fishery
Determining migratory patterns and timing	* escapement goals * catch allocation * stock conservation	* pattern: e.g., determining patterns and timing diversion rate * timing: e.g., determining run timing through specific fisheries
Estimating run size	* escapement goals * catch allocation	* peak CPUE * scale growth characters * input for CND model

Table 2. Allocation of Fraser River pink salmon among user groups and the GSI estimates that are required.

	International Allocation	Domestic Allocation United States	Canada
Allocation by Country and User Group	U.S. fishermen Canadian fishermen	Treaty Indian Non-Indian	Inside Troll Outside Troll Purse Seine Gillnet
GSI Estimates Required	% Fraser River	% Fraser River	% Southerly Migrating (Fraser River, Puget Sound, Canada South Coast)

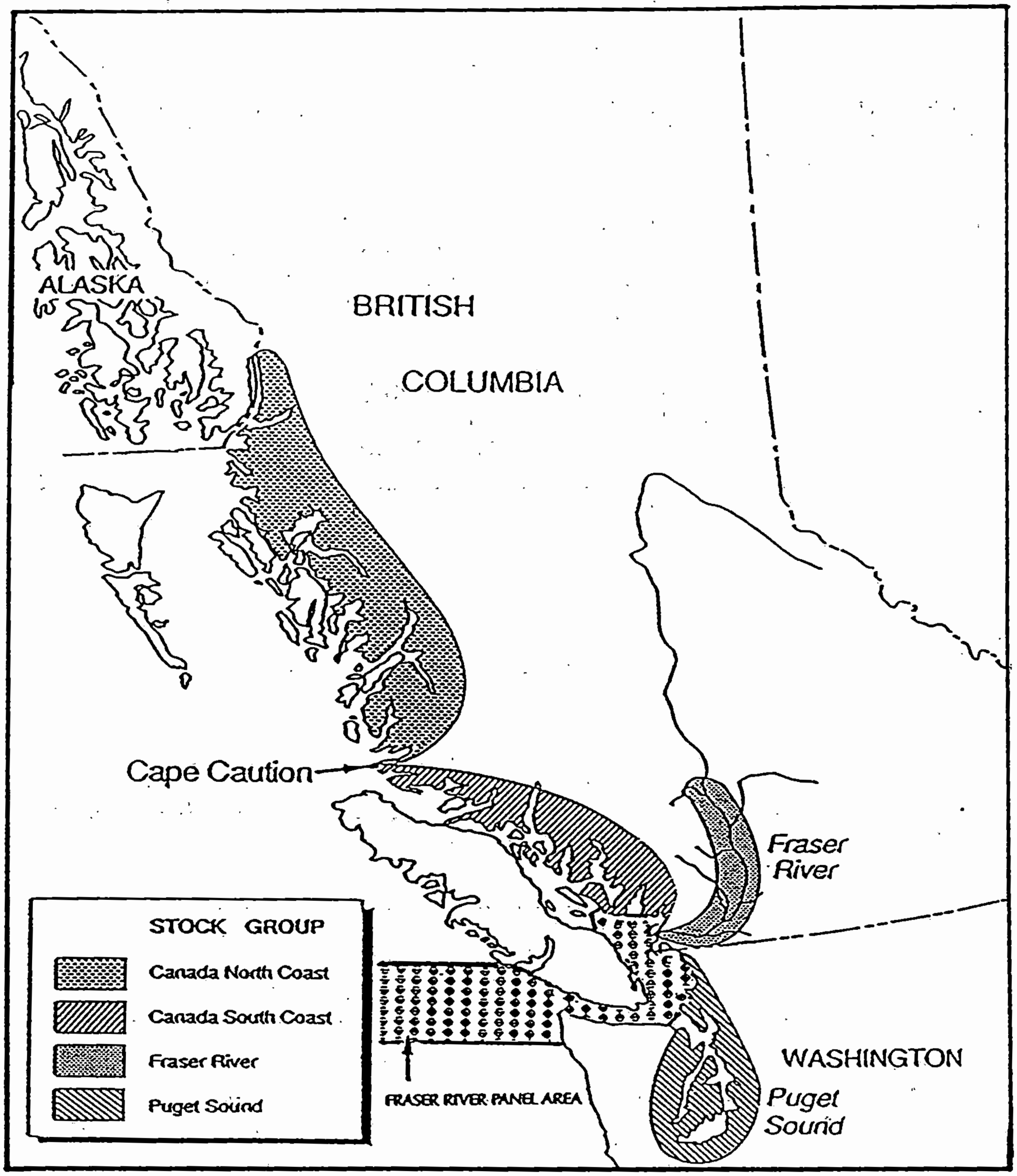


Figure 1. Map showing stock groups in pink salmon baseline and the Fraser River Panel Area of jurisdiction.

Enhancing Fisheries Resources Through Active Management of Riparian Areas

Robert E. Bilby and Peter A. Bisson

Weyerhaeuser Company
Technology Center
Tacoma, WA 98477

Many streams in the Pacific Northwest have experienced a loss of habitat complexity resulting, in part, from the conversion of structurally and biologically diverse riparian vegetation to uniform age stands of red alder following timber harvest. Reduced inputs of large conifer debris from riparian zones in second-growth forests has led to streams with fewer pools, lower sediment and organic matter retention capacities, and increased fine sediment transport potential. Although salmonids with extended freshwater residence have been affected most by these habitat changes, pink and chum salmon spawning success may be influenced by delivery of fine sediment from watersheds with reduced instream sediment storage. By utilizing forestry management techniques, riparian areas can be treated to restore vegetative diversity and provide the types and sizes of woody debris needed to preserve productive stream habitat and provide natural storage and routing characteristics. These techniques include conifer planting, patch cutting, thinning, and other methods of vegetation management. We suggest that timber harvest around streams in second-growth forests based on alternately managed and undisturbed patches of riparian vegetation can potentially accelerate the restoration of diverse and productive stream habitat.

Forest practice regulations governing treatment of riparian areas during timber harvest in the Pacific Northwest have changed rapidly during the last decade (Oregon Department of Forestry 1987; British Columbia Ministry of Forests 1988; Bilby and Wasserman 1989). Perhaps the most controversial aspect of these changes has been an increasing emphasis on the retention of standing, merchantable timber along streams. One of the primary purposes of leaving these trees is to provide a future source of large woody debris (LWD) for the channel.

Research over the last 20 years has shown that LWD plays a major role in determining the structural and functional attributes of lotic systems (Harmon et al. 1986). Large woody debris strongly influences channel form in many small to medium size streams, causing streambed scour that creates pools (Sullivan et al. 1987; Andrus et al. 1988) and stabilizing channel features such as gravel bars and sediment deposits (Lisle 1986; Bilby and Ward 1989). Tree boles, branches and rootwads also function in the retention of finer organic materials such as needles and leaves (Bilby 1981). In small streams, the vast majority of this type of material is associated with LWD (Naiman and Sedell 1979; Bilby and Likens 1980). In addition, LWD directly affects stream biota by providing a substrate and energy source for some invertebrates (Anderson et al. 1978; Benke et al. 1985) and by providing habitat and creating cover for fishes (Bisson et al. 1987; Shirvell 1990).

Protection of aquatic and riparian resources has clearly improved as a result of the recent changes in riparian management. However, we believe that current riparian management guidelines are failing to achieve desired goals in certain situations. The following discussion will briefly outline some inadequacies of riparian management on forested lands and suggest alternatives to address some of these problems.

CURRENT STATUS OF RIPARIAN SYSTEMS ON FORESTED LANDS

Historically, accumulations of LWD were common in flowing waters in the Pacific Northwest, including many of the major river systems of the region (Sedell and Luchessa 1982). Most of the wood was removed from larger rivers early in this century, as an aid to navigation. Transportation of logs along water courses by splash damming or the use of channels as skid trails also contributed to the loss of wood and destruction of habitat in some streams (Wendler and Deschamps 1955). Deliberate removal of LWD from some channels was done to improve water quality and provide upstream passage for anadromous fishes (Bryant 1983; Bilby 1984). In addition, removal of riparian vegetation, and thus the source of future LWD, during timber harvest or conversion of forest land to other uses has had a widespread influence on LWD in streams (Swanson and Lienkaemper 1978).

As a result of these practices, many streams in the Pacific Northwest contain far less LWD than they did originally (Grette 1985; Bisson et al. 1987; Bilby and Ward *in press*). Features of the channel associated with wood, including pools, sediment and organic matter depositional sites, and waterfalls, have decreased dramatically in these systems (Bilby and Ward *in press*). It is likely that declines in fish populations in these streams are in part attributable to the habitat changes caused by loss of LWD (Murphy et al. 1985; Hicks et al. *in press*; Sedell and Beschta *in press*). Reestablishment of productive habitat in these channels hinges on restoration of LWD.

HABITAT QUALITY IN STREAMS IN OLD-GROWTH AND SECOND-GROWTH FORESTS

Riparian vegetation in areas that have been logged is dominated by smaller trees (Figure 1), often red alder (*Alnus rubra*). The capacity for this vegetation to supply the size and amounts of LWD necessary for the full range of woody debris functions in streams depends upon a variety of factors, including the size of the channel. Debris produced by second-growth riparian vegetation may be too small to maintain a stable position in larger channels (Bilby and Wasserman 1989; Bilby and Ward 1989). In addition, LWD produced by red alder is much shorter-lived in streams than conifer debris (Harmon et al. 1986).

Stream habitat reflects changes in LWD amount and characteristics associated with altered riparian vegetation in managed areas. Comparison of channel features in streams flowing through unlogged forests with those in second-growth forests illustrates the relative influence of these stand conditions on aquatic systems. Data were from a study of woody debris characteristics and function in streams bordered by different types of riparian vegetation (Bilby and Ward 1989; Bilby and Ward *in press*). Surveys of LWD structure and function in western Washington streams were conducted on 22 sites in undisturbed, conifer-dominated stands and 29 sites in 40 to 60 year old second-growth stands, the typical age of harvest in commercial forests. Variables measured during these stream surveys included species, amount and size of LWD, as well as the frequency, surface area, and type of pool (Bisson et al. 1982) associated with the wood. Also measured were the frequency and surface areas of sediment accumulations associated with LWD, and the frequency and height of LWD-associated waterfalls. A detailed description of methods used in the surveys may be found in Bilby and Ward (1989).

Amount of LWD decreased with increasing stream size in both old-growth and second-growth forests; however, more LWD was found in streams at unlogged sites than at second-growth sites for all stream sizes (Figure 2; $P<0.05$, t-test). Pool frequency also decreased with increasing stream size for both stand types (Figure 3). LWD-associated pools were more common at old-growth sites than at second-growth sites, with the greatest differences observed in larger streams ($P<0.05$). Pool types were much more diverse at the unlogged sites (Figure 4). Over 90% of the pools in second-growth sites were scour pools. Scour pools were also the most prevalent type at the unlogged sites, accounting for approximately 45% of the pools, but plunge, backwater and dammed pools were all more common in old-growth than in second-growth sites.

Sediment routing in streams is influenced by LWD through the formation of depositional areas and the creation of waterfalls. Waterfalls reduce stream power with little erosion of bed or banks, and thus represent an inefficient energy expenditure from the standpoint of material movement (Heede 1972). Depositional areas were much more common at the unlogged sites than at second-growth sites (Figure 5). This difference was in large part due to the greater abundance of LWD in streams at unlogged sites. The old-growth forested streams also contained more waterfalls than the second-growth sites (Figure 6). Sediment routing through channels in the unlogged conifer-dominated riparian zones was likely slowed as a result of the greater numbers of depositional areas and waterfalls.

Since pink and chum salmon utilize streams almost exclusively for spawning, the rate and timing of delivery of fine sediment to stream reaches used for spawning is of critical importance. The greater efficiency of sediment transport in LWD-impoverished headwater channels suggests that delivery of fine sediment to downstream areas used by pink and chum salmon could occur at relatively low discharges. Intrusion of sediment into streambed gravel is more apt to occur at reduced streamflow than during periods of high discharge, when fine sediment tends to be flushed from the substrate (Beschta and Jackson 1979). Thus, lack of LWD may impact downstream spawning gravel by enabling transport of fine sediment at times when intrusion and deposition is most likely to occur.

MANAGEMENT OPTIONS TO ENCOURAGE RIPARIAN RECOVERY

Current conditions in many Pacific Northwest riparian zones are insufficient to meet a key objective of fish habitat managers: creating and maintaining structurally complex stream channels (Bisson et al. *in press*). Because channel complexity is strongly influenced by interactions between the stream and riparian zone, streamside management should focus on preservation of structurally and vegetatively complex riparian areas. Unfortunately, some prescriptions currently being applied to streamside management areas may impede the establishment of desired riparian conditions. Since timber harvest throughout the region will focus increasingly on second-growth forests, methods especially suited to managing riparian areas in these forests need to be developed.

Even in those cases where riparian zones presently exhibit the characteristics needed to ensure maintenance of productive stream habitat, long-term successional consequences of retaining a relatively narrow strip of trees along the stream should be considered. One possible outcome of this management approach is creation of riparian zones dominated by shrubs resulting from increased light reaching the forest floor following harvest of upland forests (Hibbs 1987). A dense shrub layer could hinder or preclude reforestation, ultimately yielding a riparian zone that contains very few trees. In most cases, such riparian conditions would not favor the restoration of productive stream habitat.

These problems suggest that an active approach to managing riparian vegetation in second-growth forests might be better suited to meeting fish habitat objectives than the current approach of leaving unmanaged buffer strips, often composed chiefly of red alder. The first and most important step in the development of an active riparian management program is determination of aquatic habitat objectives for the site. These objectives may vary due to key stream features including fish species present, size of the stream, morphology and substrate of the channel, previous history of disturbance, and downstream conditions. Some goals might include the development and long-term maintenance of complex channel structure, increased amounts of LWD, creation of pool habitat, deposition of gravel, or retention of sediment.

Once a set of aquatic objectives has been established, riparian conditions necessary to meet these objectives can be determined. Riparian objectives appropriate for meeting some of the aquatic habitat goals listed above might include production of large trees to provide stable LWD, increased diversity of riparian plant species, and creation of a more varied distribution of tree age classes. These objectives would also be influenced by the type of vegetation present at the site at time of timber harvest.

The condition of riparian vegetation at time of harvest also would influence the silvicultural approaches most appropriate to achieving riparian objectives. For example, a primary objective for sites dominated by even-aged stands of red alder could be the establishment of conifer species. Silvicultural options appropriate for this goal include thinning and underplanting or cutting patches and planting (Emmingham et al. 1989). Objectives and silvicultural treatments would be different for sites dominated by second-growth conifers. In these locations, encouraging the development of large trees, diversifying the age-class distribution, and increasing species diversity would be appropriate riparian objectives. Goals could be achieved through selective thinning (Berg 1990), cutting small patches in the riparian zone and planting desired species, or creating conditions conducive to hardwood establishment.

Application of this approach permits land managers to design riparian zones composed of alternating patches of actively managed and undisturbed forest. Undisturbed patches would be located in areas most apt to be sensitive to disturbance, for example, near tributary junctions, and in areas of unstable streambanks or around riparian wetlands. Since some amount of timber removal will occur from the managed patches, the undisturbed patches could be considerably wider than required by current regulations without any consequent loss in total amount of timber harvested.

There are a number of potential advantages of active management of riparian areas over current streamside prescriptions. Accelerating the growth of trees in riparian zones by thinning (Berg 1990) may greatly speed the production of larger pieces of LWD. Larger pieces of wood are needed to maintain position in wider stream channels, and they have a greater influence on channel form and function than small pieces (Bilby and Ward 1989). Windthrow risk, often increased by current riparian management regulations, may be reduced by leaving undisturbed or thinned patches in windfirm areas, or by cutting patches in locations prone to windthrow (Steinblums et al. 1984). Elevated light levels reaching the stream from patch cutting or thinning may increase algal production, producing greater amounts of food for fish (Hawkins et al. 1983; Bilby and Bisson *in press*). In some situations, trees cut from patches or during thinning could be deliberately added to the channel to provide an immediate source of LWD.

Water quality problems associated with active management of riparian vegetation can be minimized by applying this strategy only along suitable stream reaches and carefully locating the patches to be managed. For example, active management may be inappropriate along streams where aquatic resources are considered to be highly temperature sensitive. In less thermally sensitive systems, the proportion of managed and undisturbed areas can be adjusted to reflect the relative sensitivity of the system. Cut or thinned patches can be located where there is natural topographic shading, on the north side of the stream and along narrow riffles to reduce exposure to direct sunlight. Streambank erosion and sedimentation can be ameliorated by locating undisturbed patches along stream sections with actively eroding banks, by retaining trees with root systems that stabilize streambanks, and by preventing soil compaction caused by use of heavy equipment in riparian zones.

There are also potential advantages of active riparian management from a forestry perspective. This system does enable recovery of some of the currently unavailable timber from the riparian zone. However, this advantage would be partially or wholly offset by increasing the size of undisturbed patches. Yarding corridors through riparian zones could be established, provided sufficient deflection is available to lift logs completely as they cross the channel to avoid damage to the banks. This approach would permit the return to reforestation and harvesting of a portion of the area within riparian zones.

Many of the fisheries benefits associated with the riparian management approach outlined above will take decades to be realized. Nonetheless, establishment and maintenance of productive fish habitat will ultimately depend upon structurally complex and vegetatively diverse riparian communities. Application of well established silvicultural methods may significantly reduce the time required to achieve these conditions.

REFERENCES

Anderson, N.H., J.R. Sedell, L.M. Roberts, and F.J. Triska. 1978. The role of aquatic invertebrates in processing wood debris from coniferous forest streams. Am. Midl. Nat. 100:64-82.

Andrus, C.W., B.A. Long, and H.A. Froelich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. Can. J. Fish. Aquat. Sci. 45:2080-2086.

Benke, A.C., R.L. Henry III, D.M. Gillespie, and R.J. Hunter. 1985. Importance of snag habitat for animal production in southeastern streams. Fisheries 10:8-13.

Berg, D.R. 1990. Active management of streamside forests. Master's thesis. University of Washington, Seattle, WA. 100p.

Beschta, R.L., and W.L. Jackson. 1979. The intrusion of fine sediments into a stable gravel bed. J. Fish. Res. Board Can. 36: 204-210.

Bilby, R.E. 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. Ecology 62:1234-1243.

Bilby, R.E. 1984. Post-logging removal of woody debris affects stream channel stability. J. Forestry 82:609-613.

Bilby, R.E., and G.E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology 61: 1107-1113.

Bilby, R.E. and L.J. Wasserman. 1989. Forest practices and riparian management in Washington state: data based regulation development. p. 87-94 *In* R.E. Gresswell, B.A. Barton, and J.L. Kershner (ed.) Practical approaches to riparian resource management. U.S. Dept. of the Interior, Bureau of Land Management, Billings, MT.

Bilby, R.E., and J.W. Ward. 1989. Changes in the characteristics and function of woody debris with increasing size of streams in western Washington. Trans. Am. Fish. Soc. 118:368-378.

Bilby, R.E., and P.A. Bisson. *In press*. Relative contribution of allochthonous and autochthonous organic matter to the trophic support of fish populations in clear-cut and old-growth forested headwater streams. Can. J. Fish. Aquat. Sci.

Bilby, R.E., and J.W. Ward. *In press*. Large woody debris characteristics and function in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. Can. J. Fish. Aquat. Sci.

Bisson, P.A., J.L. Nielsen, R.A. Palmasson, and L.E. Grove. 1982. A system of naming habitat types in small streams with examples of habitat utilization by salmonids during low streamflow. p. 62-73 *In* N. B. Armantrout (ed.). Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Bethesda, Maryland.

Bisson, P.A. and eight coauthors. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present and future. p. 143-190 *In* E. O. Salo and T. Cundy (ed.) Proceedings of an interdisciplinary symposium on streamside management: Forestry and fisheries interactions. University of Washington Press, Seattle, WA.

Bisson, P.A., T.P. Quinn, S.V. Gregory, and G. H. Reeves. *In press*. Best management practices, cumulative effects, and long-term trends in fish abundance in Pacific Northwest river systems. *In* R.H. Naiman and J.R. sedell (ed.) Watershed management for the 21st century: Balancing sustainability with cumulative environmental change. Springer-Verlag, New York.

British Columbia Ministry of Forests. 1988. Coastal forestry fisheries guidelines, Second edition. B.C. Ministry of Forests, B.C. Ministry of Environment, Dept. of Fisheries and Oceans, Council of Forest Industries. 113 p.

Bryant, M.D. 1983. The role and management of woody debris in west coast salmonid nursery streams. North. Am. J. Fish. Mgmt. 3:322-330.

Emmingham, W.H., M. Bondi, and D.E. Hibbs. 1989. Underplanting western hemlock in an alder thinning: early survival, growth, and damage. New Forests 3:31-43.

Grette, G.B. 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. Master's thesis. University of Washington, Seattle, WA. 105p.

Harmon, M.E. and twelve coauthors. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecol. Res. 15:133-302.

Hawkins, C.P., M.L. Murphy, N.H. Anderson, and M.A. Wilzbach. 1983. Density of fish and salamanders in relation to riparian canopy and physical habitat in streams of the northwestern United States. Can. J. Fish. Aquat. Sci. 40:1173-1185.

Heede, B.H. 1972. Influences of a forest on the hydraulic geometry of two mountain streams. Wat. Resour. Bull. 8:523-530.

Hicks, B.J., J.D. Hall, P.A. Bisson, and J.R. Sedell. *In press.* Response of salmonid populations to habitat changes caused by timber management. *In* W. R. Meehan. (ed.) The influence of forest and rangeland management on salmonids and their habitat. Special Publication of the American Fisheries Society, Bethesda, MD.

Lisle, T.E. 1986. Stabilization of a gravel channel by large streamside obstructions and bedrock bends, Jacoby Creek, northwestern California. Geol. Soc. of Amer. Bull. 8:999-1011.

Murphy , M.L. and five coauthors. 1985. Role of large organic debris as winter habitat for juvenile salmonids in Alaska streams. Proceedings, Western Assoc. of Fish and Wildf. Agencies 1984:251-264.

Naiman, R.J., and J.R. Sedell. 1979. Relationships between metabolic parameters and stream order in Oregon. Can. J. Fish. Aquat. Sci. 37:834-847.

Oregon Department of Forestry. 1987. Riparian protection. Forest Practices Notes. No. 6, 4 p.

Sedell, J.R. and K.J. Luchessa. 1982. Using the historical record as an aid to salmonid habitat enhancement. p.210-223 *In* N.B. Armantrout (ed.) Acquisition and utilization of aquatic habitat inventory information. Amer. Fish. Soc., Bethesda, MD.

Sedell, J.R., and R.L. Beschta. *In press.* Bringing back the "bio" in bioengineering. *In* Special Publication of the Bioengineering Section of the American Fisheries Society, Bethesda, MD.

Shirvell, C.S. 1990. Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows. Can. J. Fish. Aquat. Sci. 47:852-861.

Steinblums, I.J., H.A. Froelich, and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. J. Forestry 82:49-52.

Sullivan, K., T.E. Lisle, C.A. Doloff, G.E. Grant, and L.M. Reid. 1987. Stream channels: The link between forests and fishes. p. 39-97 *In* E.O. Salo and T.E. Cundy (ed.) Proceedings of an interdisciplinary symposium on streamside management: Forestry and fisheries interactions. University of Washington Press, Seattle, WA.

Swanson, F.J. and G.W. Lienkaemper. 1978. Physical consequences of large organic debris in Pacific Northwest streams. U. S. For. Ser., Gen. Tech. Rep. PNW-69.

Wendler, H.O. and G. Deschamps. 1955. Logging dams on coastal Washington streams. Fisheries Research Papers of the Washington Dept. of Fish. 1:1-12.

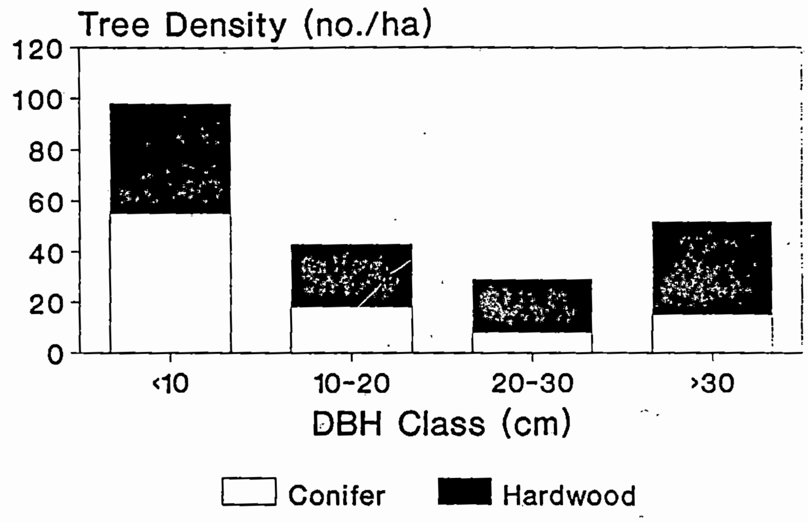


Figure 1. Proportion of hardwood and conifer trees in four diameter classes remaining in riparian areas in western Washington after timber harvest (Washington Department of Wildlife, unpublished data).

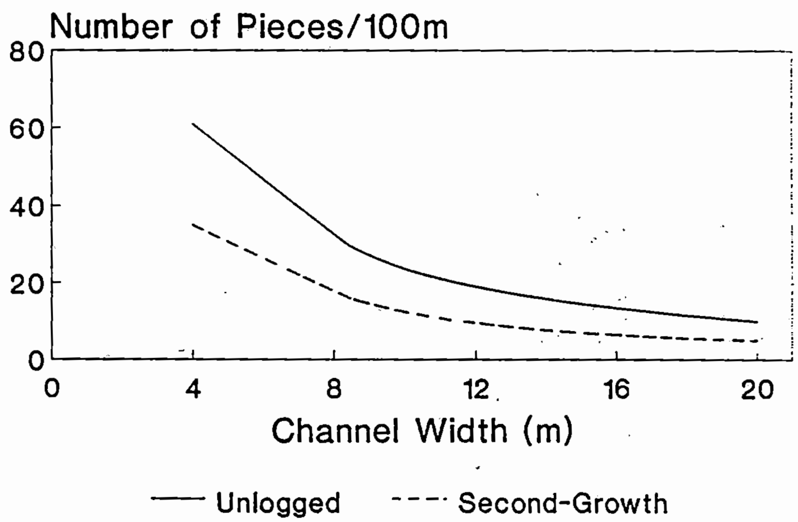


Figure 2. Abundance of pieces of large woody debris as a function of channel width at unlogged and second-growth sites. Regression equations for the relationships are:

Unlogged; $\log_{10}$LWD frequency=-1.12$\log_{10}$channel width+0.46, r^2=0.69

Second-Growth; $\log_{10}$LWD frequency=-1.23$\log_{10}$channel width+0.28, r^2=0.75.

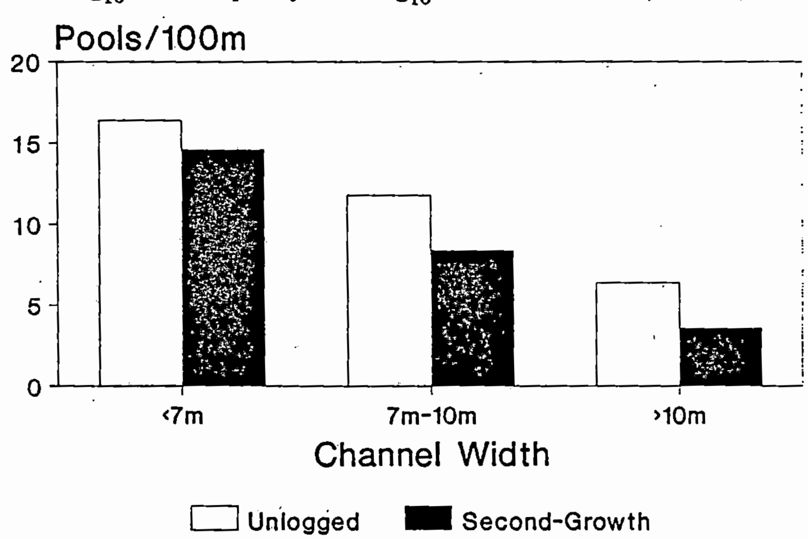


Figure 3. Frequency of LWD-formed pools at unlogged and second-growth sites.

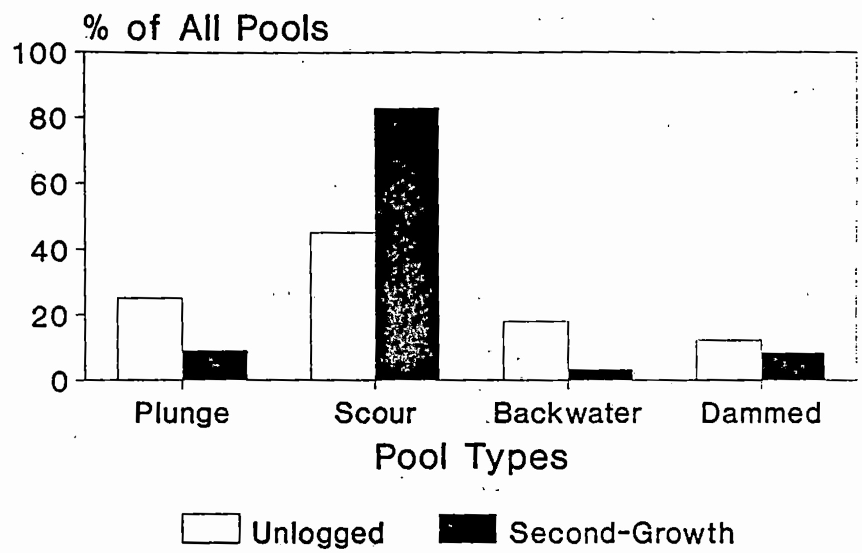


Figure 4. Types of pools associated with LWD in streams at unlogged and second-growth sites. Pool types were classified according to the method of Bisson et al. (1982).

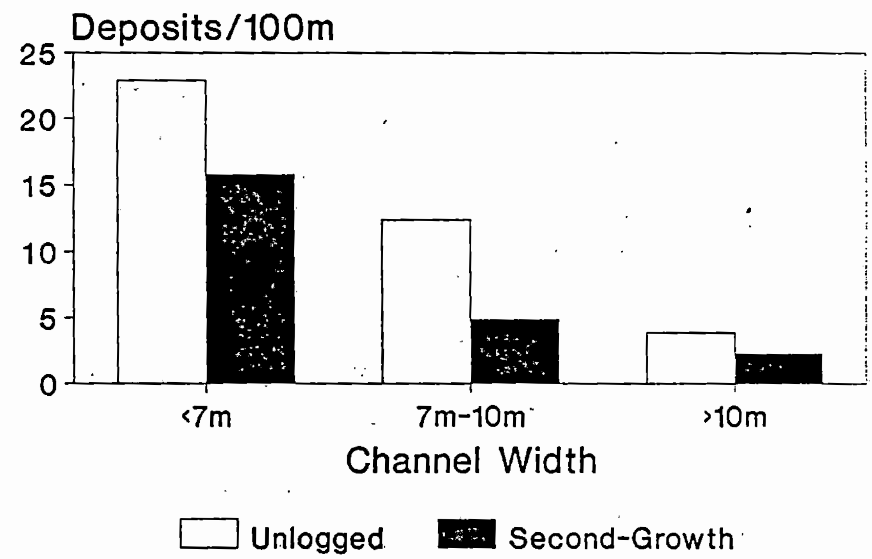


Figure 5. Abundance of depositional sites formed by LWD at unlogged and second-growth sites.

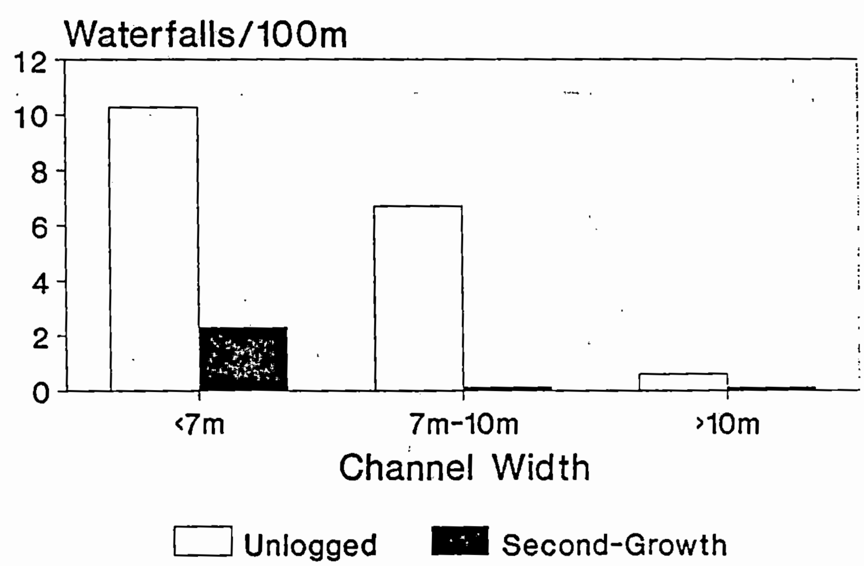


Figure 6. Abundance of LWD-formed waterfalls at unlogged and second-growth sites.

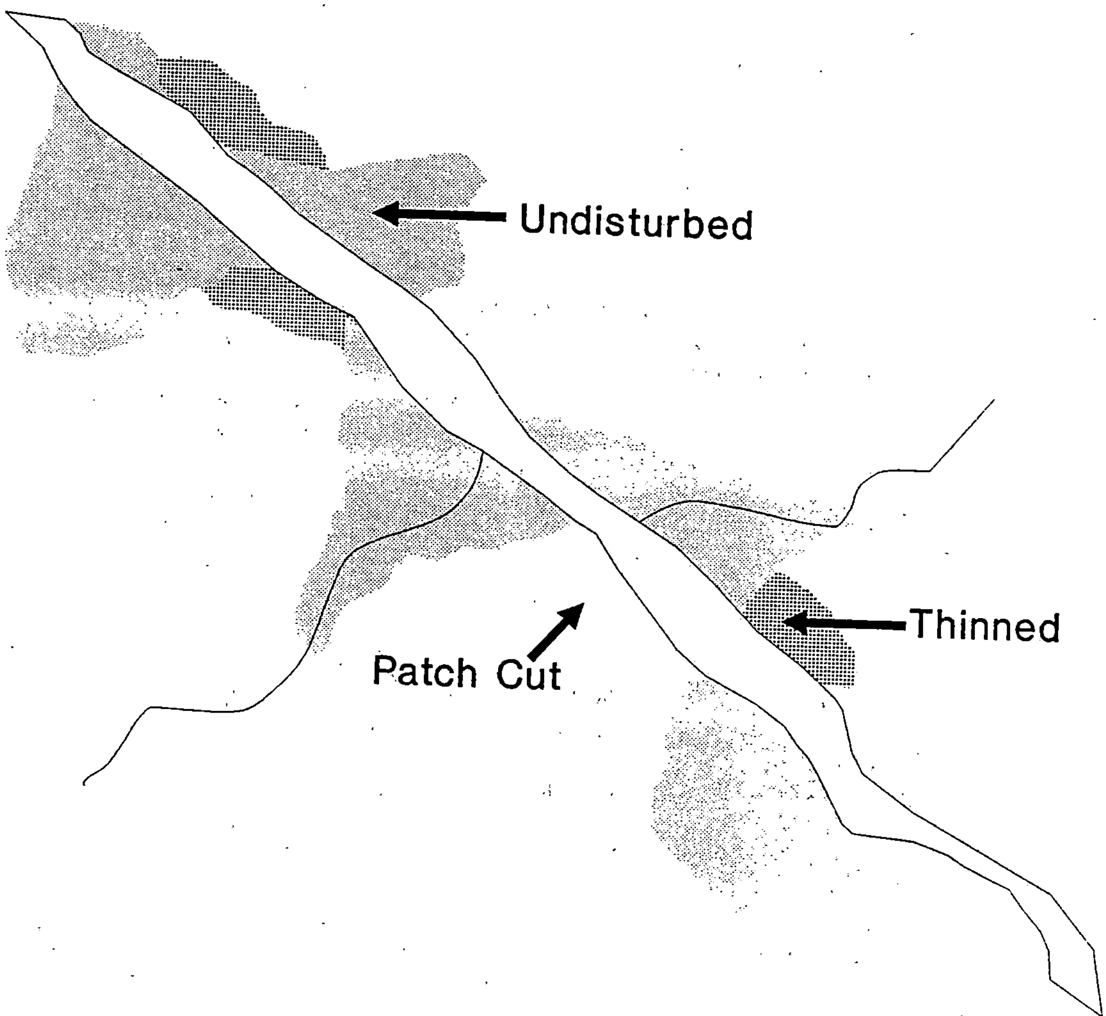


Figure 7. Illustration of a hypothetical riparian treatment utilizing some of the options outlined in this paper.

An Update and Application of the Production Model for Carnation Creek Chum Salmon[1]

J.C. Scrivener

Biological Sciences Branch,
Fisheries and Oceans Canada,
Pacific Biological Station,
Nanaimo, B.C. V9R 5K6

Logging impacts on the physical environment and on the variability of chum salmon have been studied at Carnation Creek since 1970. A production model was developed that explained 77% of the annual variability among returning spawners. They declined 52% during the first postlogging decade. Two thirds of this decline was attributed to climate change, while one third was attributed to logging. Logging impacts appeared to cause a 26% decline during recent years. The production model explained 58% of the annual variability of chum salmon returning to Area 23, Barkley Sound. Poor ocean productivity during early marine life, periods of overfishing, and logging of their natal watersheds have probably caused a decline among West coast of Vancouver Island chum salmon during the last 40 years.

A 10-fold variability in abundance is common among West Coast of Vancouver Island (WCVI) stocks of chum salmon (*Oncorhynchus keta*) (Lightly et al. 1985). An understanding of the causes of this inter-annual variability is only now being obtained (Koski 1975; Blackbourn 1987; Scrivener 1988; Helle 1989; Hartman and Scrivener 1990). Intensive and long-term data bases were the essential ingredient. Studies of spawning density (Hunter 1959), spawning gravel quality (Scrivener and Brownlee 1989), fry size (Hargreaves and LeBrasseur 1986; Helle 1989), and emigration timing (Beacham and Murray 1986; Holtby et al. 1989) have described some freshwater causes of the variability. Studies of predation (Healey 1982), near-shore productivity (Fulton and LeBrasseur 1985; Walters et al. 1978), and age-at-maturity (Blackbourn 1987) have described some marine causes of the variability. These findings can now be integrated in computer simulation models.

The population dynamics of chum salmon have been studied at Carnation Creek since early 1970 as part of a multi-disciplinary study of the effects of clearcut logging on a small salmon stream in a coastal rain forest (Hartman and Scrivener 1990). Computer models were used to separate logging and "natural" (i.e., climatic) effects on salmon variability so that the logging impacts could be quantified (Holtby and Scrivener 1989). The model's value as a preharvest forecaster can now be explored.

METHODS AND DATA-BASE DESCRIPTION

Carnation Creek is a 7.8 km stream that flows into the south side of Barkley Sound on the west coast of Vancouver Island. Approximately 41% of its watershed was logged during 1976 to 1981 and another 27% was logged during 1987 to 1991. The lower 3.1 km of stream available to anadromous fish was included in the logged area. Logging caused marked changes to the thermal regime (Holtby 1988), to the banks and morphology (Powell 1988), and to the substrate (Scrivener and Brownlee 1989) of the stream.

Several population parameters have been routinely collected from Carnation Creek chum salmon. During each autumn, the number of spawners were obtained from visual counts obtained every few days in the 300m of stream in the estuary and from counts of chum salmon passing a permanent fish fence at the stream/estuary interface. From 3% to 30% of the population spawned above the counting fence (Holtby and Scrivener 1989). The sex and fork length (FL) were determined for all spawners passing through the fence. Sex ratios, hypural length, and age composition (otolith reading) of spawners were obtained from ~200 carcasses each year. A size-fecundity relationship for chum spawners was determined from 35 females that were sacrificed in 1980, 1981, 1983, or 1985 (Hartman 1981; Holtby and Scrivener 1989).

[1] Contribution No. 165 of the Carnation Creek Experimental Watershed Project.

Total egg depositions above and below the fence were calculated using this relationship and the size-frequency distributions of the females. During each spring, fry numbers, fry size (FL), and the date of median fry emigration were obtained from the counting fence and 30 emergence traps that were placed in the estuary. Egg-to-fry survival was calculated as number of fry passing the fence divided by total egg deposition above the fence.

Physical measurements included continuous recordings of stream temperature, air temperature, and stream stage height. Since 1970, they have been recorded at or near a hydrological weir located 400m upstream of the fish counting fence. Stream stage height was converted to instantaneous discharge using rating curves that were frequently calibrated by Inland Waters Directorate of Environment Canada. Mean stream temperature and peak discharge during egg incubation were used for the model. Data prior to 1970 were estimated from rated staff gauges at Sarita River (Anon 1989) and from correlations between Carnation Creek air and water temperatures and air temperatures at Estevan Point (Holtby and Scrivener 1989). Spawning gravel quality was determined each year from ~200 freeze cores of the streambed. The cores were split into layers and particle size distributions were obtained by dry sieving each layer (Scrivener and Brownlee 1982). Geometric mean particle size (Dg) was calculated from each distribution and the annual mean Dg of the top layer (0-15cm) was used for the chum model.

Salinity at Amphitrite Point provided an annual indicator of near-shore conditions when chum salmon fry entered the ocean from February to May. Annual anomalies were calculated for February to May as the mean of daily salinities of each month minus the 50-year mean for that month (1934-84; Dodimead 1984) and then averaged for the four months. Positive anomalies could indicate the presence of nutrient upwelling, high ocean productivity, or large high nutrition prey (Fulton and LeBrasseur 1985). Negative anomalies could indicate high runoff from the land, poor productivity in the ocean (Blackbourn 1989), or a northward shift of the "subarctic boundary" (Fulton and LeBrasseur 1985) bringing predators such as hake and mackerel into the near-shore zone.

Surface temperature within an area 50-55°N latitude by 165-170°W longitude could indicate ocean conditions during maturity (Blackbourn 1987; NODC 1989). WCVI chum salmon are probably just south of the Aleutian Islands during August and September and mean ocean temperatures for this time and place have been used to predict age-at-maturity for other stocks of chum salmon (Blackbourn 1987).

CHUM SALMON MODEL

The model predicting the number of returning adults utilizes a series of eight regression sub-models (Table 1). Sub-models 1, 3, 4, and 6 were reported earlier (Holtby and Scrivener 1989), and they have been updated with data from more recent brood years (1983-85). Sub-model 2 predicts egg-to-fry survival from a measure of streambed composition (Dg) and peak stream discharge during egg incubation. Egg survival is known to be a function of the amount of fine particles in the streambed (Everest et al. 1987), and of scour during floods (McNeil 1966). A survival correction for the estuary is calculated with sub-model 3 using egg density and total spawning area (1800 m^2; Table 1). It is standardized with the mean survival 24.2% (Hunter 1959). Sub-model 5 predicts fry size from maternal size (FL), streambed composition (Dg), and peak discharge until fry emergence. Egg size and thus fry size are known to be dependent on maternal size (Koski 1975; Beacham et al. 1985). Fine particles in the streambed are known to reduce interstitial spacing and thus to selectively trap larger fry within redds (Koski 1975; Dill and Northcote 1970; Sowden and Power 1985). Large fry might also survive large freshets better than small fry (Hartman and Scrivener 1990). Sub-model 7 is updated and corrected because an erroneous salinity anomaly slope, fry size slope, and intercept appeared in the earlier report (Holtby and Scrivener 1989). Sub-model 8 partitions returning spawners from a brood year into three age classes (3, 4 and 5-year-olds). The percentage of 3-year-old spawners resulting from a brood is predicted from mean ocean temperatures during August and September of the previous year (brood year +2). Similar correlations have been observed for other stocks of chum salmon (Blackbourn 1987). The percentage of 4-year-old spawners is predicted by regressing it against the percentage of 3-year-olds (Table 1). Any residual of a brood year is assigned to 5-year-olds. The production model calculates these regressions in chronological order using as inputs the physical variables and the outputs from regressions used earlier in the model.

A correlation between observed and predicted indicated that the model explained 77% of the variability in annual returns of chum salmon to Carnation Creek (r=0.88, n=19, P<0.001). Observed number of spawners, their sex ratio and size distribution, and the time series of physical variables were used as model inputs. Most years with peak or minimum returns were replicated by the model, but the predicted variability was not as extreme as the observed variability during postlogging years (Figure 1). Average observed and simulated returns were similar for both prelogging and postlogging periods (Table 2).

Fishing mortality has had little impact on Carnation Creek chum salmon so a factor for it was not included in the model. Since 1962, Barkley Sound has had no commercial chum fishery during 19 years, and a significant fishery during only 3 years (Figure 2). Any commercial fishery was concentrated on the north side of Barkley Sound after the collapse of the Sarita River stock during 1962 (Lightly et al. 1985). A small native food fishery (~3% of Carnation Creek escapement) off the mouths of Sarita River and Carnation Creek occurred each year. Any variability in this catch might explain the model's reduced accuracy of prediction during recent years (Figure 1). This impact could increase as the stock declined.

The model predicted returns of 302 and 568 spawners to Carnation Creek during 1991 and 1992, respectively. An ocean temperature of 10.2 °C (decade mean) was used to predict the return of 3-year-olds in 1992. Returns of 557 and 594 for 1992 were obtained using the decade minimum and maximum temperatures, respectively. This stock has probably been reduced to a single dominant year class every four years (1988, 1992; Figure 1), with a mean (1986-92 = 464) that would be 18% of the prelogging mean (2535; Table 2).

LOGGING IMPACTS

Both logging and climate affected chum salmon variability, but climate impacts were more numerous in the model (9 versus 7; Table 1). A comparison of simulations during the prelogging and postlogging period indicated that climate change was responsible for two thirds (-34% versus -18%) of the 52% decline of Carnation Creek chum salmon (Table 2). Logging impacts were also quantified for the postlogging period by comparing simulations using the observed variables and variables adjusted for No Logging. Variables that were affected by logging (Table 1) were adjusted by their average difference between prelogging and postlogging years. Logging impacts caused a 26% decline of recent returns, two third (-17%) of which was caused by increased fines in the streambed gravel (Table 2). Declining mean particle size of the streambed decreased both incubation survival and fry size in this model (Table 1). Stream temperature increases had appeared to be a more important impact in previous versions of the model (Holtby and Scrivener 1989).

Interaction between variables and between climate and logging impacts were either limited in the model, or quantified in earlier reports. Composition of the top 15cm of the streambed (Dg) was not correlated with peak stream discharge (r=-0.13, n=19, P=0.59). Compositions of the deeper streambed layers were correlated with stream discharge as expected (Scrivener and Brownlee 1989), but they were not used in this model. Thus all three variables in sub-models 2 and 5 (Table 1) appeared to be independent. Logging impacts on stream discharge were limited to a small increase in water yield during the summer and to increases of peak flow during early autumn storms which occurred before chum salmon spawned (Hetherington 1982; Hartman and Scrivener 1990). Other models have shown that climate and logging impacts on stream temperature were equally important during the period of egg incubation (Holtby 1988). Thus postlogging stream temperatures were adjusted by only 50% when the "No Logging" condition was being simulated.

VARIABILITY OF WCVI STOCK AGGREGATES

The model explained 58% of the variability in annual returns of chum salmon to Area 23, Barkley Sound, as indicated by the correlation between observed (escapement and catch) and predicted (r=0.76, n=40, P<0.001). Observed number of spawners (Lightly et al. 1985), their size distributions, and the time series of physical data (1948-89) were used as model inputs. The proportion of females was either the observed value or 0.50. The proportion spawning within tidal influence was set at 0.75 with a spawning area of 180,000 m^2 (Carnation Creek is about 1% of Area 23 stream and stock size; Figures 1 and 3).

Spawning gravel composition was set to Carnation Creek prelogging values during 1948-54 (Dg = 15.9-17.2mm), to two thirds of the sequential postlogging decline observed at Carnation Creek (1976-90) during 1955-69 (15.8-12.9mm), and to seven eights of it during 1970-84 (14.4-11.4mm), because these fractions of the Area 23 stock aggregate could have been affected by logging during these time periods (Brown et al. 1987). Most years with peak or minimum returns were replicated by the model, but returns tended to be underestimated (30 of 40 years; Figure 3). The largest deviations between observed and predicted occurred during 1953-57 and 1969-73 (Figure 3) when the largest commercial catches were recorded (Figure 2). The model could underestimate returns during these periods because catch was never a factor in its design.

A chum salmon fishery is unlikely to occur in Area 23 during the next few years. The model predicts returns of 29,904 and 63,257 during 1991 and 1992, respectively, which are below escapements reported for most years (Figure 2). A few generations with high ocean productivity are probably required before returns can again support a chum salmon fishery.

Cumulative impacts from climate change, fishing pressure, and clearcut logging have caused the decline among Area 23 stocks of chum salmon. Returns to Area 23, which include those to Carnation Creek, declined during 1961-65 and they still have not recovered (Figure 2). This decline was probably precipitated by the 1958-59 El Nino event (Dodimead 1984), resulting in reduced ocean productivity (Fulton and LeBrasseur 1985) and more predators (Healey 1982) in the coastal zone. Contributing factors were overfishing between 1953 and 1961 (Figure 2) and commencement of logging in watersheds with chum salmon habitat. Intensive logging was begun along Sarita River in 1951, Nahmint River in 1940, Effingham River in 1957, Henderson River in 1953, and Sugsaw Creek in 1955 (Brown et al. 1987). These streams are used for egg incubation habitat by >65% of the chum salmon in Area 23 (Lightly et al. 1985). Impacts on chum salmon were not fully apparent for a decade after logging commenced in Carnation Creek (Hartman and Scrivener 1990) and the development of logging impacts was probably similar for each stream in Area 23. Natal watersheds for the remainder of the stock aggregate including Carnation Creek were affected by logging between 1968 and 1987 (Brown et al. 1987). Reduced coastal productivity during spring from 1980 to 1986 probably produced poor early marine survival during recent years, especially during the 1982 and 1983 El Nino event (Fulton and LeBrasseur 1985). If this hypothesis is correct, returns of chum salmon to Area 23 are unlikely to improve without a period of increased ocean productivity and a recovery of stream habitats from logging impacts.

Annual returns of chum salmon in Area 25, Nootka Sound, supported the above hypothesis. Returns declined during 1962-68 after the period of reduced coastal productivity and of intense fisheries (35-65%; Figure 4). Unlike Area 23 stocks, Area 25 stocks recovered during 1970-75. Unlike Area 23, Area 25 stocks are more dispersed with no stream having >13% of the area chum salmon (Lighty et al. 1985) and logging has still not begun in natal watersheds of 20% of Area 25 chum salmon (see Forest Cover Maps; J. Lamb, DFO, Nanaimo). Logging was begun later and progressed more slowly around Nootka Sound. Thus only 21% of returns of Area 25 chum salmon could have been affected by logging before 1975 (J. Lamb pers. comm.). Therefore, stocks rapidly increased when climatic impacts were favourable. The stocks collapsed again (1987-90; Figure 4) four years after the second El Nino event, after another period of intense fisheries (1980-86), and after 59% of the stock aggregate (Lightly et al. 1985) could have been affected by logging.

ACKNOWLEDGEMENTS

This long-term project was made possible by the dedicated participation of many individuals such as B.C. Andersen, T.G. Brown, G.F. Hartman, L.B. Holtby and R.M. Leahy. Support from B.C. Ministry of Forests, Environment Canada and MacMillan Bloedel Limited is gratefully acknowledged. The manuscript was reviewed by D.J. Blackbourn, L.B. Holtby, C.D. Levings, and J.S. Macdonald.

REFERENCES

ANON. 1989. Historical streamflow summary, British Columbia. Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa, Ontario.

Beacham, T.D., F.C. Withler, and R.B. Morley. 1985. Effects of egg size on incubation time and alevin and fry size in chum salmon (*Oncorhynchus keta*). Can. J. Zool. 63: 847-850.

Beacham, T.D., and C.B. Murray. 1986. Comparative development biology of chum salmon (*Oncorhynchus keta*) from the Fraser River, British Columbia. Can. J. Fish. Aquat. Sci. 43: 252-262.

Blackbourn, D.J. 1987. Sea surface temperature and the prediction of age-at-return in stocks of chum salmon from the Fraser River, British Columbia, and other areas, p.94-110. In: P. Rigby [ed.]. Proceedings of the 1987 Northeast Pacific Pink and Chum Salmon Workshop. Alaska Dept. Fish Game, P.O. Box 3-2000, Juneau, AK. 1989. Comparison of release size and environmental data with the marine survival rates of some wild and enhanced stocks of pink and chum salmon in British Columbia and Washington State, p.82-87. In: P.A. Knudsen [ed.]. 14th Northeast Pacific Pink and Chum Salmon Workshop. Washington State Dept. Fish., 115 Administration Building, Olympia, WA.

Brown, T.G., I.V. Williams, and A. Langston. 1987. Watershed data base: Barkley Sound, Vancouver Island. Can. Data Rep. Fish. Aquat. Sci. 667: 143p.

Dill, L.M., and T.G. Northcote. 1970. Effects of gravel size, egg depth, and egg density on intergravel movement and emergence of coho alevins. J. Fish. Res. Bd. Canada 27: 1191-1199.

Dodimead, A.J. 1984. A review of some aspects of the physical oceanography of the continental shelf and slope waters of the west coast of Vancouver Island, British Columbia. Can. MS Rep. Fish. Aquat. Sci. 1773: 309p.

Everest, F.H., R.L. Beschta, J.C. Scrivener, K V. Koski, J.R. Sedell, and C.J. Cederholm. 1987. Fine sediment and salmon production: a paradox, p.98-143. In: E.O. Salo and T.W. Cundy [eds.]. Streamside Management: Forestry and fisheries interactions. College of Forest Resources, AR-10, University of Washington, Seattle, WA.

Fulton, J.D., and R.J. LeBrasseur. 1985. Interannual shifting of the subarctic boundary and some of the biotic effects on juvenile salmonids, p.237-252. In: W.S. Wooster and D.L. Fluharty [eds.]. El Nino North: El Nino effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program, University of Washington, Seattle, WA.

Hargreaves, N.B., and R.J. LeBrasseur. 1986. Size selectivity of coho (*Oncorhynchus kisutch*) preying on juvenile chum salmon (*O. keta*). Can. J. Fish. Aquat. Sci. 43: 581-586.

Hartman, G.F. [ed.]. 1981. The Carnation Creek experimental watershed project report for 1979 and 1980. Pacific Biological Station, Nanaimo, B.C. 21p.

Hartman, G.F., and J.C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Can. Bull. Fish. Aquat. Sci. 223: 148p.

Healey, M.C. 1982. Timing and relative intensity of size selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. Can. J. Fish. Aquat. Sci. 39: 952-957.

Helle, J.H. 1989. Relation between size-at-maturity and survival of progeny in chum salmon, *Oncorhynchus keta* (Walbaum). J. Fish Biol. 35(Suppl.A): 99-107.

Hetherington, E.D. 1982. A first look at logging effects on the hydrologic regime of Carnation Creek experimental watershed, p.45-63. In: G.F. Hartman [ed.]. Proceedings of the Carnation Creek Workshop: A 10 year review. Pacific Biological Station, Nanaimo, B.C.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and resultant impacts on the coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 45: 502-515.

Holtby, L.B., and J.C. Scrivener. 1989. Observed and simulated effects of climatic variability, clear-cut logging, and fishing on the numbers of chum salmon (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) returning to Carnation Creek, British Columbia, p.62-81. In: C.D. Levings, L.B. Holtby, and M.A. Henderson [eds.]. Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Can. Spec. Publ. Fish. Aquat. Sci. 105.

Holtby, L.B., T.E. McMahon, and J.C. Scrivener. 1989. Stream temperatures and the inter-annual variability in the emigration timing of coho salmon (*Oncorhynchus kisutch*) smolts and fry and chum salmon (*O. keta*) fry from Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 46: 1396-1405.

Hunter, J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Bd. Canada 16: 835-886.

Koski, K V. 1975. The survival and fitness of two stocks of chum salmon (*Oncorhynchus keta*) from egg deposition to emergence in a controlled stream environment at Big Beef Creek. Ph.D. thesis, University of Washington, Seattle, WA. 212p.

Lightly, D.T., M.J. Wood and S.R. Heizer. 1985. The status of chum salmon stocks of the west coast of Vancouver Island, 1951-1982, statistical areas 22-27. Can. Tech. Rep. Fish. Aquat. Sci. 1366: 150p.

McNeil, W.J. 1966. Effect of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish. Wildl. Ser. Fish. Bull. 65: 495-523.

NODC (National Oceanographic Data Center). 1989. Experimental compact disc, NODC-01, Pacific Ocean temperature-salinity profiles (1900-1988). NODC, Washington, D.C.

Powell, L.H. 1988. Stream channel morphology changes since logging, p.16-25. In: T.W. Chamberlin [ed.]. Proceedings of the Workshop: Applying 15 years of Carnation Creek results. Pacific Biological Station, Nanaimo, B.C.

Scrivener, J.C. 1988. A summary of population responses of chum salmon to logging in Carnation Creek, British Columbia between 1970 and 1986, p.150-158. In: T.W. Chamberlin [ed.]. Proceedings of the Workshop: Applying 15 years of Carnation Creek results. Pacific Biological Station, Nanaimo, B.C.

Scrivener, J.C., and M.J. Brownlee. 1982. An analysis of the Carnation Creek gravel quality data 1973-1981, p.154-173. In: G.F. Hartman [ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, B.C. 1989. Effects of forest harvesting on spawning gravel and incubation survival of chum (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) in Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 46: 681-696.

Sowden, T.D., and G. Power. 1985. Prediction of rainbow trout survival in relation to groundwater seepage and particle size of spawning substrates. Trans. Am. Fish. Soc. 114: 804-812.

Walters, C.J., R. Hilborn, R.M. Peterman, and M.J. Staley. 1978. Model for examining early ocean limitation of Pacific salmon production. J. Fish. Res. Bd. Canada 35: 1303-1315.

Table 1. A production model for calculating the number of chum salmon spawners returning to Carnation Creek each year. Input variables include the number of spawners, proportion of females, size distribution of females, proportion spawning above the estuary, Dg of spawning gravel, mean stream temperature during egg incubation, peak discharge during egg incubation, salinity anomaly during fry occupation of the near-shore zone, and mean sea-surface temperature during maturation.

SUB-MODEL	OUTPUT = fn(INPUTS)	OUTPUT EFFECTED BY Density	 Climate	 Logging
1. Egg Deposition Below / Above Fence	Log_{10} Fecundity = 2.0506 x Log_{10} FL_{Fem}(cm) -0.3873 (r=0.74, n=35, P<0.001) $\#Egg_{Above}$ = fn(#Fem,Size,Fec.)		 ○	
2. % Egg Survival	$\%S_{Egg}$ = -18.747 + Dg(mm)x2.8699 - P_{Flow} (L/sec/Ha)x0.2103 (R=0.77, n=17, P<0.01)		 ○	■
3. Estuary Survival fn (Egg Density)	$Log_{10}(\%S_{Below})$ = -0.0002203 x ($\#Egg_B$/1800. m^2) +1.4282 (r=0.84, n=11, P<0.002) S_{Prop} = $\%S_{Below}$ /24.2%	 ▲		 ■
4. # Fry	#Below = 0.01 x $\#Egg_B$ x$\%S_{Egg}$ xS_{Prop} #Above = 0.01 x $\#Egg_A$ x $\%S_{Egg}$	▲		
5. Fry Size	FL_{Fry}(mm) = 22.742 + 0.2442xFL_{Fem}(cm) + 0.0976xDg(mm) + 0.0236x P_{Flow} (L/sec/Ha) (R=0.78, n=17, P<0.001)		○ ○	■ ■
6. $Day_{50\%}$ Fry Emigration	$D_{50\%}$ = 184.173 - 14.13xWT_{Stream} (°C) (r=0.89, n=19, P<0.001)		○	■
7. # of Recruits	Log_{10}(#R) = 0.6763xLog_{10} (#Fry) + 0.2360xSal_{Anom} + 0.1265xFL_{Fry} + 0.008x$D_{50\%}$ - 5.9327 (R=0.91, n=17, P<0.001)		 ○ ○	 ■ ■
8. Age-at-Maturity	$\%3_{YR}$ = 15.668 xWT_{Ocean} - 137.061 (r=0.63, n=18, P<0.01) $\%4_{YR}$ = 94.836 - 0.9691x $\%3_{YR}$ (r=-0.98, n=18, P<0.001)		○ ○	

Table 2. Calculation of the average effects of logging and climate on chum salmon recruitment to Carnation Creek. Prelogging years were 1970 to 1978, while postlogging years were 1979 to 1990 or 1991. Recruitment was also predicted where the physical variables affected by logging were set to prelogging levels, i.e., mean particle size (Dg) of spawning gravel and stream temperature.

	Years	Mean # of Spawners	Difference	Effect
Observed				
PreLog.	1970-78	2535		
PostLog.	1979-90	1215	-52%	
Simulated				
PreLog.	1972-78	2531		
PostLog.	1979-91	1231	-51%	
PreLog.	1972-78	2531		
NoLogging	1979-91	1657	-34%	-18%
PreLog. Dg	1979-91	1510	-40%	-12%
NoLogging	1979-91	1657		
PostLog.	1979-91	1231	-26%	
PreLog. Dg	1979-91	1510	-9%	17%
PreLog. W/T	1979-91	1285	-22%	-4%
FL_{Fem}+Density	1979-91	1302	-21%	-5%

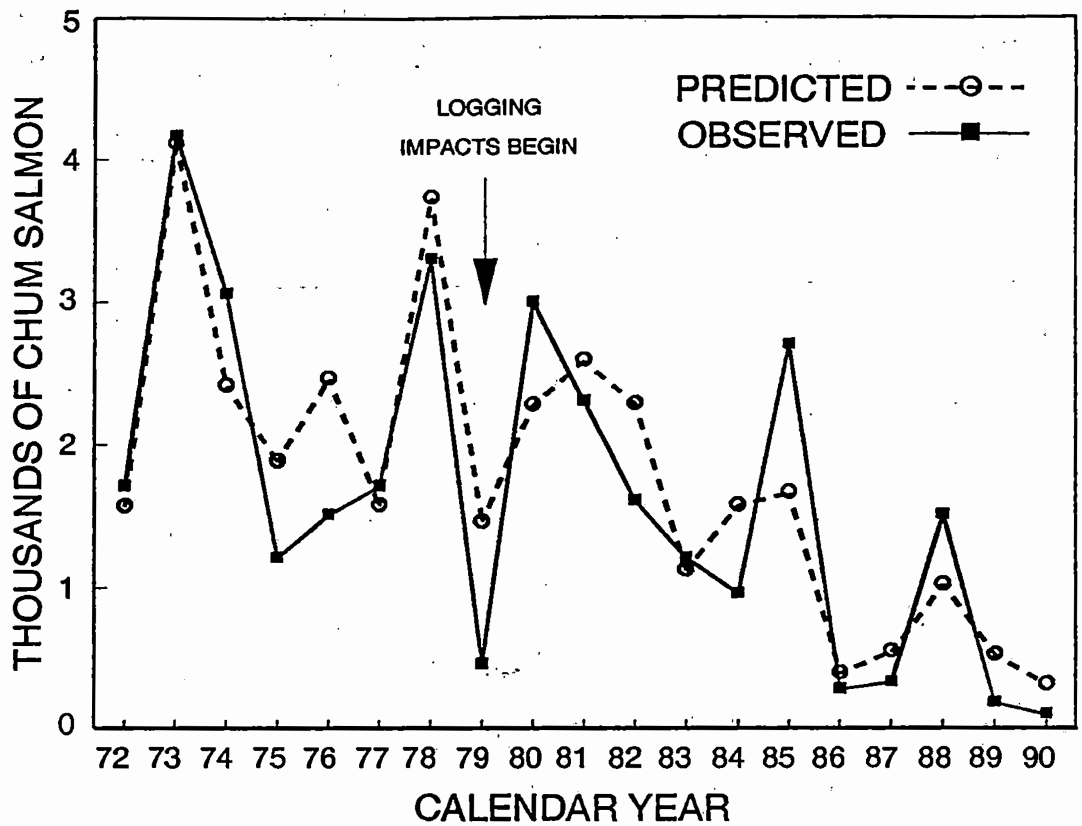


Figure 1. Observed and predicted annual escapement of chum salmon adults to Carnation Creek.

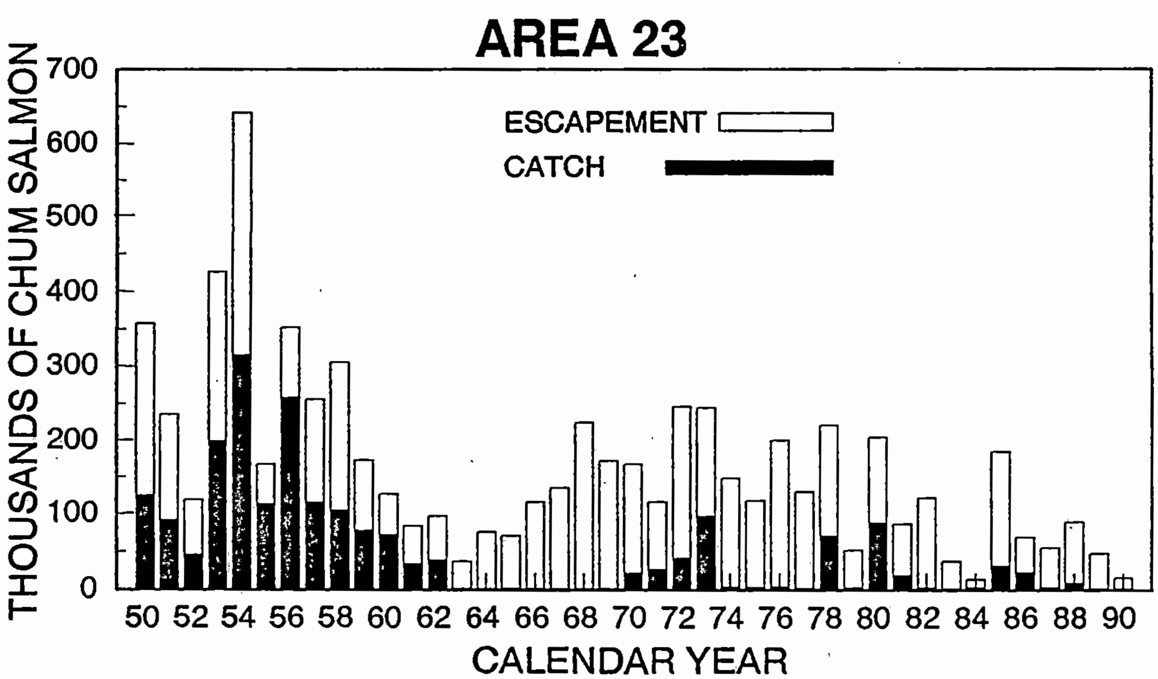


Figure 2. Fishing catch, escapement, and total annual returns of chum salmon to Area 23, Barkley Sound, WCVI.

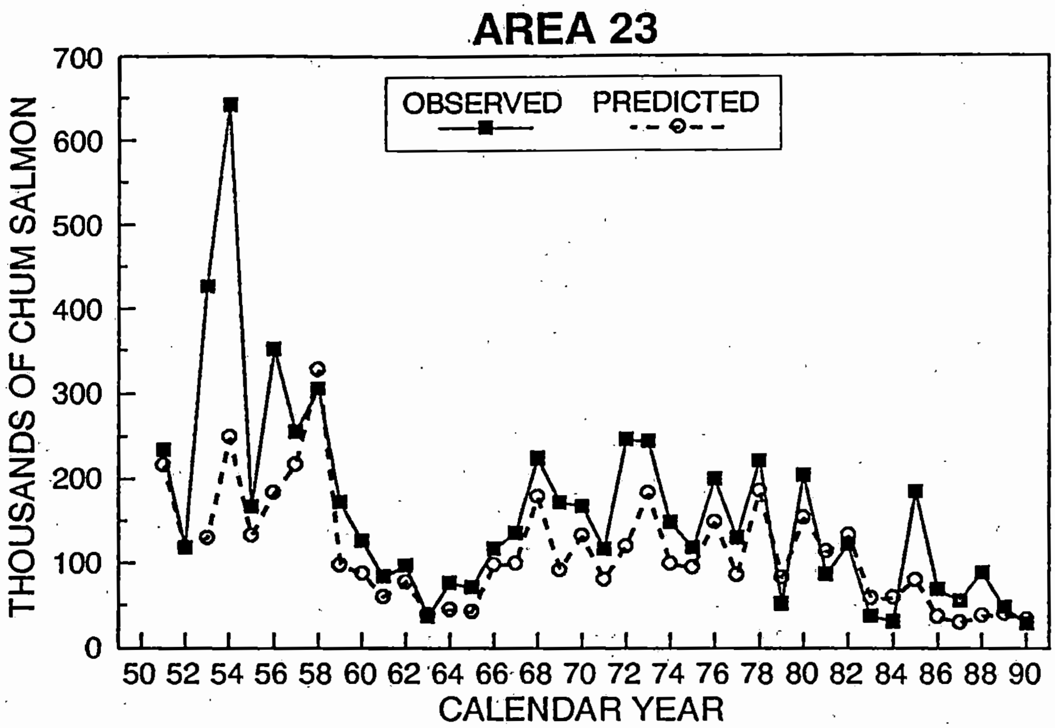


Figure 3. Observed (catch and escapement) and predicted annual returns of adult chum salmon to Area 23, Barkley Sound, WCVI.

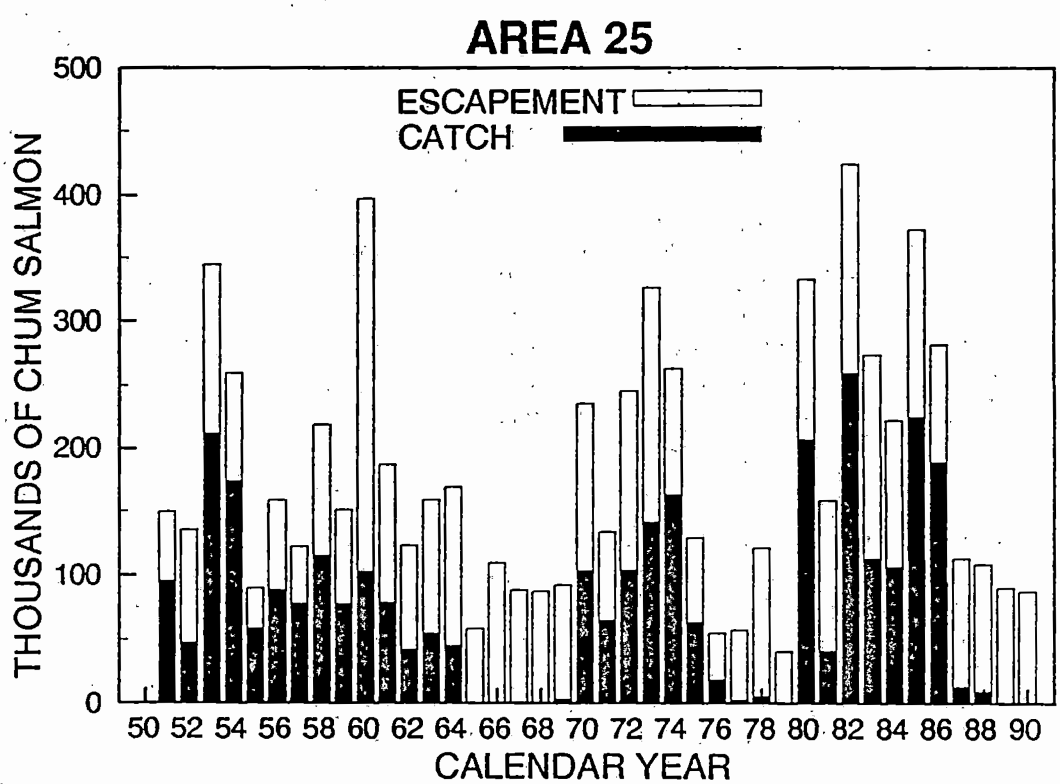


Figure 4. Fishing catch, escapement, and total annual returns of chum salmon to Area 25, Nootka Sound, WCVI.

Reform of Logging Practices in Alaska

Michael L. Murphy and K V. Koski

Auke Bay Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
11305 Glacier Highway
Juneau, Alaska 99801-8626

Recent federal and state laws have changed the regulations governing logging along streams in Alaska. This paper describes those laws and the events leading to their enactment.

In the 1970s and early 1980s, clear-cutting to the stream bank and salvaging any trees that blew down were the most common management practices used along streams. Buffer zones of uncut trees were seldom left along streams because of the high value of streamside trees and because narrow strips of trees left as buffers often blew down. Blowdown was thought to damage fish habitat.

Concern about impacts of logging on fish and wildlife led to the formation of the Alaska Working Group on Cooperative Forestry/Fisheries Research, composed of representatives from state and federal agencies, timber and fishing industries, and environmental groups. The Working Group prioritized and facilitated research on logging issues. Subsequent research showed that 30-m-wide buffer strips of uncut trees along both stream banks were needed to protect fish habitat, particularly to provide long-term sources of large woody debris. Blowdown in usual situations was found to enhance rearing habitat by providing large woody debris. Based on this research, the National Marine Fisheries Service, Alaska Region, issued a policy statement in 1988 calling for minimum 30-m buffer zones of uncut trees along each side of all anadromous fish streams and their tributaries to protect fish habitat. This policy became the focal point for debate as the U.S. Congress and the Alaska State Legislature considered reforming forest practices on federal, state, and private lands.

The U.S. Congress passed the Tongass Timber Reform Act (Public Law 101-626) in November 1990, reforming logging practices on federal lands in the Tongass National Forest. The Act amended the Alaska National Interest Lands Conservation Act "to protect certain lands in the Tongass National Forest in perpetuity, to modify certain long-term timber contracts, to provide for protection of riparian habitat, and for other purposes." The Tongass Timber Reform Act requires buffer zones at least 100 feet (30 m) wide on each side of all Class I streams (i.e., those with anadromous fish) and on those Class II streams (i.e., those with resident fish only) that flow directly into a Class I stream. Timber harvest is prohibited within these buffer zones. No buffer zones are required along Class III streams (i.e., those with no fish), but Best Management Practices (BMPs' regulations controlling the manner of harvest) must be followed to protect water quality and prevent downstream effects of sedimentation and excessive increases in temperature.

The Alaska State Legislature amended the Alaska Forest Resources and Practices Act (AS 41.17) in May 1990 to reform forest practices on state and private lands. The new standards for riparian management differ between state-owned and private lands. On state-owned lands, timber harvest is prohibited within 100 feet of anadromous fish streams; timber may be harvested between 100 and 300 feet (30-90 m) from the stream, but harvest must be consistent with maintaining fish and wildlife habitat. On private lands, standards differ according to stream type: (1) along a "Type A" stream (i.e., anadromous fish stream not incised in bedrock), no timber may be harvested within 66 feet (22 m) of the stream bank; (2) along a "Type B" stream (i.e., anadromous fish stream incised in bedrock), timber harvest within 100 feet of the stream or to the slope break (i.e., small tributary BMPs; and (3) along a "Type C" stream (i.e., small tributary without anadromous fish), timber harvest within 50 feet (15 m) of the stream or to the slope break must comply with BMPs.

The Alaska Forest Resources and Practices Act allows variations from requirements in some cases involving small streams on private land. The Commissioner of the Department of Natural Resources (DNR) must adopt regulations that specify standards for granting such variations. A landowner may propose a variation to the state forester. If refused, the landowner may appeal to the DNR Commissioner. In considering variation requests, DNR gives due deference to the Department of Environmental Conservation (DEC) concerning water quality and to the Department of Fish and Game (DFG) concerning fish and wildlife habitat. DFG has due deference within riparian areas in decisions concerning timber harvest, variations to riparian standards, and road locations. Where DNR disagrees with DEC or DFG, DNR must prepare a written statement of reasons for disagreement. An officer of DEC or DFG may require reevaluation of the disagreement at a higher level, by the Governor if necessary, before a decision is made. The Alaska Forest Resources and Practices Act was adopted on an interim basis and will be reviewed by the Alaska State Legislature and amended as necessary after the 1992 field season.

These new laws enacted in 1990 substantially improve the protection of salmonid habitat in Alaska. Further research is needed, however, to assess effectiveness of BMPs in preventing downstream cumulative effects of logging along small tributaries and in preventing sedimentation from construction and use of logging roads.

Stream Channel Response to Landslides in the Queen Charlotte Islands, B.C.: Changes Affecting Pink and Chum Salmon Habitat

D. L. Hogan

Forest Sciences Section
Vancouver Forest Region
B. C. Ministry of Forests
4595 Canada Way
Burnaby, B.C., V5G 4L9

J. W. Schwab

Forest Sciences Section
Prince Rupert Forest Region
B. C. Ministry of Forests
Bag 5000
Smithers, B.C., V0J 2N0

Landslides entering stream channels can create serious, long term problems for certain physical components of pink and chum salmon habitat. These impacts are evaluated in two moderately small watersheds on the Queen Charlotte Islands. Three main conclusions are reached. First, although landslides have delivered significant volumes of sediment and debris directly to the streams, the frequency of delivery is highly episodic. Over 85% of all landslide derived material was produced during major storms in 1891, 1917, 1935, and 1978; all but the latter pre-date local logging. Second, there is a direct link between landslides and channel morphology. A fundamental consequence of landslide inputs to stream channels is the formation of sediment wedges associated with debris jams. Specific changes occur upstream and downstream of the jams and these have particular importance to fish spawning and incubation environments. The influence of the jam on the stream channel changes over time as the log jam deteriorates so the episodic nature of landslide activity is important for long periods of time between events. Severe morphological alterations persist during the first decade following landslide debris input. The morphological nature of the stream channels 30 years after disturbance begins to resemble undisturbed channels. Third, because logging steep hillslopes tends to accelerate landslide frequency, there is a corresponding increase in the number of recently formed log jams. Stream channels associated with these young jams are characterized by more variable sediment textures, less stable sediment storage zones, deep scour and fill and increased frequency, extent and duration of de-watered channel. Management of steep, unstable hillslopes must ensure that the shift in the landslide/log jam age distributions are minimized to ensure pink and chum habitat integrity.

The influence of landslides on stream environments has been a concern in the Queen Charlotte Islands for many years. Past studies have shown that increased sediment loads derived from hillslope processes lead to many morphological and fish habitat changes along the stream system. Morphological alterations include a general reduction in channel complexity with reduced depth, width and sediment texture variability, less stable channel bed and banks, diminished pool area and more pronounced riffles (Hogan 1987). Fish rearing, incubation and spawning habitats are also impaired (Tripp and Poulin 1986 a, b and c).

An important consideration not adequately resolved previously is the importance of time as an independent variable influencing channel conditions, both in terms of morphology and fish habitat. Studies in other geographic areas have tried to evaluate the channel response to landslide deposits entering the stream and to relate these to fish habitats. Sullivan et al. (1987) summarize many of the studies conducted in Northern California, Central Idaho and the Western Oregon Cascades (all rivers are relatively large compared to the Queen Charlotte Islands study streams). They show that in most cases the channel bed aggrades, bank stability is reduced as the channel widens and pools are in-filled. In extreme cases, large sedimentation zones with extensive braiding occur, as documented in the Queen Charlotte Islands by Roberts and Church (1986). Associated habitat changes include increased proportions of fine grained sediment in spawning areas, reduced rearing habitat, increased de-watering during low flow periods, reduced food sources with loss of tree canopies and changed water temperature regimes.

Sullivan et al. (1987) also reviewed channel recovery rates and processes in four research areas of the United States. They show that the time required for the stream to recover to pre-disturbance conditions varied from 5 to over 60 years. The recovery time depends upon input sediment characteristics (location along the stream system, amount and particle size distribution) and the form and structure of the riparian zone. Therefore, streams respond in specific ways to both natural and logging related sediment inputs and the response time of the stream system can be relatively rapid or prolonged for decades.

The temporal response of stream channels to landslides has important implications for fisheries management. Stream channels in the Queen Charlotte Islands exhibit a wide range of morphological characteristics. The natural variability of these must be known when evaluating potential or actual impacts. Further, if landslides deliver large volumes of sediment to the stream, specific habitat changes will occur at the site. The sediment may then be moved downstream in a wave, or pulse, and this can progressively impair habitat for various lengths of time. The duration, and relative severity, that habitat is degraded is unknown. Finally, it is very difficult to attempt habitat rehabilitation when little is known about how the channel adjusts over time. Channel stabilization and rehabilitation structures should be designed to perform well over the long term, but designs are usually based on the channel condition at one point in time. A better understanding of the spatial and temporal nature of a stream channel's response to altered sediment supply characteristics is required for this application.

This paper presents preliminary results from the second phase of the Fish/Forestry Interaction Program (FFIP II). The material reported here deals with temporal and spatial changes in stream channels and subsequent implications to pink and chum salmon are considered.

STUDY DESIGN AND ENVIRONMENTAL SETTING

The FFIP II study design incorporates a paired watershed approach. This involves comparison of drainage basins with similar biophysical characteristics (e.g., climate, geology, soils, vegetation and morphometry, etc.) but different slope failure and logging histories. The approach is detailed in Hogan (1989) and enables the comparison of channels with disturbances ranging from the very recent to the very old (e.g., 150 years ago) in addition to those that have never been disturbed by mass wasting or logging activities.

Four general areas will be studied over the course of FFIP II (Figure 1). The importance of channel disturbances to pink and chum habitat will be illustrated here by considering two watersheds in Rennell Sound, located on the west coast of the Queen Charlotte Islands.

The general watershed characteristics of Riley and Gregory creeks are given in Table 1. The watersheds are within the Skidegate Plateau physiographic region and are comprised mainly of weathered volcanic rocks (Sutherland Brown 1968). The watersheds receive in excess of 3600 mm of precipitation each year and the main tree cover is western hemlock and Sitka spruce. Minimal logging has occurred in Gregory Creek but a total of 4 km^2 (14%) of the Riley Creek watershed was logged during the late 1970s. The Riley Creek basin has the highest landslide frequency, at 5.97 events per km^2, in the Rennell Sound study area (Rood 1984). The second highest frequency in the area is 3.38 events per km^2. Pink salmon are abundant; the 1988 escapement records show in excess of 20,000 adult Pinks returning to each stream. Chum returns are negligible.

METHODS

Both hillslope and stream channel surveys have been conducted in this project. The landslide inventory of both watersheds was based on a chronological sequence of air photographs (1937-1982). All landslides identified on the photographs were then visited in the field. An increment bore was used to obtain cores from trees growing on the landslide deposit. The time since the landslide occurred was determined from the tree ages.

Detailed longitudinal profiles were surveyed over extensive stream channel lengths to document morphological conditions in channels with different ages of disturbance. The methods are detailed in Hogan (1989). Besides morphological information, particular attention was paid to large organic debris (LOD). Both individual pieces and accumulations of debris were surveyed. Debris accumulations, or log jams, are particularly important and were described in additional detail. A jam is defined as a major accumulation of debris (either currently or over the last decades--that is, remnants are still evident) that alters(ed) sediment transport downstream. The classification (presented in full in Hogan 1989) is intended to describe the current function of the jam in terms of how it influences sediment transport and channel stability. Log jam age is estimated by coring nurse trees growing the debris or trees growing on associated channel bars.

Table 1. General watershed characteristics of the Riley and Gregory Creeks.

	Riley Creek	Gregory Creek
Drainage basin area (km^2)	28.3	35.5
Valley flat extent (km^2)	6.6	4.1
Steepland extent (km^2)	11.0	14.5
Relief (m)	840	840
Precipitation (mm/yr)[a]	>3600	>3600
Logging extent (% basin area)	14	2
Landslide frequency (no./km2)[b]	5.97	3.04

Notes:

[a] From Hogan and Schwab (1990)

[b] From Rood (1984)

RESULTS AND DISCUSSION

The time since occurrence, or age, of 162 landslides was determined in the two watersheds. The ages tend to be grouped with many landslides having the same year of occurrence. This indicates that the frequency of landslide activity is highly episodic. Over the last century, more than 85% of all landslide derived sediment and debris entering stream systems occurred during just 4 major storms (Figure 2). These large storms occurred during 1891, 1917, 1935 and 1978; all but the most recent pre-date local logging.

A fundamental consequence of landslide inputs to stream channels is the formation of sediment wedges associated with debris jams. Specific stream channel changes occur upstream and downstream of the jams and these have particular importance to fish spawning and incubation environments. The importance of this link between hillslope (mass wasting) and stream channel processes is central to the following discussion of fish habitat changes over time.

Log jams that formed as a result of landslides a century ago appear very different today than those formed recently. Newly formed log jams are clearly evident in the field and on low level air photographs. Old jams are usually much more difficult to detect; often only remnants remain embedded in the channel bed and banks.

The age distribution of the log jams surveyed in the two watersheds reflects the pattern of historical landslide events (Figure 3). The over 50 year log jam category coincides with the 1891 and 1917 events and the 30-50 year log jam category is associated with the 1935 event. The 2-10 year category corresponds to the 1978 storm.

The age of the jam is the primary factor controlling channel morphology. Log jams play a key role in determining channel character because they interrupt the downstream transfer of sediment; the morphology of an alluvial stream is determined by the movement and storage of sediment along the channel. However, because the debris breaks down over time (the debris pieces rot, are broken into smaller sizes and are moved by floods), the structure's functional role is altered as the jam ages. That is, as the log jam becomes older, the debris gradually deteriorates, its structural integrity is diminished and it does not trap sediment as effectively as a young jam.

The importance of log jam age on morphology has been discussed previously (Hogan 1989) and is summarized in Figure 4. Generally, it was shown that severe morphological alterations persist during the first decade following landslide damage. These changes include diminished pool extent, increased channel widths, and prevalence of braided channels. The channel begins to develop more normal characteristics during the second and third decades. The morphological nature of the stream channels 30 years after disturbance begins to resemble undisturbed channels. These have a complex morphology, typical pool-riffle-bar complexes and abundant individual LOD pieces. The evolution of channel features is detailed in Figure 4 and only those characteristics important to Pink and Chum salmon habitat will be considered in the following.

The most obvious influence of log jams is on stream channel gradient. The longitudinal profile for a continuous section of channel in Riley Creek (Figure 5) shows a series of extensive sediment accumulations upstream of young jams (zones lying above the smooth line). The recently formed jams are effective sediment traps causing channel aggradation. The sediment accumulations are much less extensive upstream of older jams because as the jam breaks down the channel undergoes downcutting and the sediment is re-mobilized and moved downstream.

The spatial extent of log jams is also evident in Figure 5b. They occur frequently and often several smaller jams in close proximity to one another have the same overall result as large jams and major sediment wedges. Another aspect of the longitudinal profiles are the smaller channel bed undulations. Previous studies in the Queen Charlotte Islands, and many others, show that these smaller scale pools and riffles are frequently associated with large organic debris. Hogan (1987) discussed LOD characteristics in these small coastal streams and concluded that LOD is a critical factor controlling channel morphology. LOD exerts considerable influence over the bed elevations shown in Figure 5b.

There are two main reasons why these changes to the longitudinal profile are important to pink and chum salmon. First, the large sediment accumulations de-water frequently during low flow conditions. The wedges tend to increase the extent, frequency and duration of dry stream bed compared to channels without log jams. Second, channel stability is reduced because disruption of the large wedges during floods results in deep channel scour and major redistribution of sediment. Large storms usually occur during the winter months when egg incubation can be impaired due to scour and fill.

The age of the log jam also influences sediment textural characteristics. In most cases where the channel walls are not confined by bedrock there is an increase in channel width associated with the newer jams. Coinciding with the new jam and wider channel is a reduction in both channel bed gradients and surface sediment sizes. In most instances the sediment is finer immediately upstream of the young jam and considerably coarser downstream. This sorting pattern is evident in Figure 6 between 3300 and 3400 m. The width and sediment sorting characteristics are not as evident in the older jams. For example, there is relatively little difference in sediment size around the moderately aged log jam located between 3150 and 3200 m (Figure 6).

A more thorough examination of sediment texture was undertaken in the two watersheds by Rice (1990). Surface sediment textures are compared in Figure 7. The rigorous sampling confirmed the trends shown in Figure 6. The surface sediment texture is significantly finer upstream of the young jam and coarser downstream (Figure 6a). There is no upstream/downstream difference between sediment sizes at the older log jams. There is some indication that the pattern is reversed near older jams with coarser sediment upstream (Figure 7b).

Although log jam age influences surface sediment texture, there appears not to be a similar pattern in subsurface sediment (Figure 8). There is no significant difference between subsurface textures upstream and downstream of young jams.

Channel bed scour and fill in the vicinity of different aged log jams was also examined by Rice (1990). Using tracer stones and scour chains, Rice recorded burial depths of 0.6 m upstream of new jams and 0.2 m on the downstream side. In the older jams the tracers were moved downstream and scour and fill depths were much less than those experienced near the young jams. Log jams do, therefore, influence scour and fill, but again jam age is the important factor.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Landslides entering stream channels can seriously damage the physical habitat of pink and chum salmon. These impacts are spatially important and can persist for more than three decades.

Many of the hillslopes in the Queen Charlotte Islands are naturally unstable and extremely large, wide spread landslide episodes have occurred on at least four occasions during the last century. Many channel features are linked directly to these landslides.

Other FFIP studies have documented that logging steep and unstable hillslopes can accelerate landslide frequency. For instance, Rood (1984) documented a 90-fold increase in landslide material entering Riley Creek from logged areas compared to forested land. The corresponding increase in the number of log jams associated with the 1978 storm is evident in Figure 3. As a result Riley Creek has many more young, or recently formed, log jams compared to Gregory Creek. Stream channels associated with these young jams are characterized by more variable sediment textures, less stable sediment storage zones, deep scour and fill and increased frequency, extent and duration of de-watered channel. These characteristics will persist for at least one decade, but the negative impacts will be reduced over the following 10 to 20 years This assumes that landslides do not re-enter the stream before the channel has recovered fully.

Management of steep, unstable terrain must consider the links between hillslopes, stream channels and fish habitat. Effort must be made to ensure that the shift in the landslide/log jam age distributions is minimized. In recognition of this, the B. C. Forest Service has introduced a number of policy and management practises aimed at mitigating the impacts of logging on sediment yield (see Chatwin 1990, for a review these mitigative measures). The majority of these changes have been directed at trying to reduce the incidence of hillslope mass-wasting.

REFERENCES

Chatwin, S. 1990. Hillslope sediments in forested and logged coastal watersheds. In Proceedings of B. C. - Yukon Sediment Issues Workshop, April 24-26, 1990, Vancouver , British Columbia, 67-71.

Hogan, D. L. 1986. Channel morphology of unlogged, logged and torrented streams in the Queen Charlotte Islands. B. C. Ministry of Forests, Land Management Report No. 49, 94p.

Hogan, D. L. 1987. The influence of large organic debris on channel recovery in the Queen Charlotte Islands, British Columbia, Canada. In Erosion and Sedimentation in the Pacific Rim, Proceedings of the Corvallis Symposium, August 3-7, 1987, IAHS Publ. No. 165, 343-353.

Rice, S. P. 1990. The spatial variation of bed material texture in coupled basins on the Queen Charlotte Islands. Unpublished M. Sc. thesis, University of British Columbia, Vancouver, B.C. 127p.

Roberts, R. G, and M. Church. 1986. The sediment budget in severely disturbed watersheds, Queen Charlotte Ranges, British Columbia. Can. Jour. Forest Research, 16: 1092-1106.

Rood, K. 1984. An aerial photography inventory of the frequency and yield of mass wasting in the Queen Charlotte Islands. B. C. Ministry of Forests, Land Management Report No. 34, 55p.

Sullivan, K., Lisle, T. E., Dolloff, C. A., Grant, G.E. and L. M. Ried. 1987. Stream channels: the link between forests and fishes. In Streamside Management: Forestry and Fishery Interactions, E. O. Salo and T. W. Cundy (Eds.). College of Forest Resources, Univ. Washington, Seattle, Washington, Contribution No. 57, 39-97.

Sutherland Brown, A. 1968. Geology of the Queen Charlotte Islands, British Columbia. Province of British Columbia, Department of Mines and Petroleum Resources Bulletin No. 54, Victoria, B. C. 226p.

Tripp, D. and V. A. Poulin. 1986a. The effects of mass wasting on juvenile fish habitats in Queen Charlotte Islands streams. B. C. Ministry of Forests, Land Management Report, No. 45, 48p.

Tripp, D. and V. A. Poulin. 1986b. The effects of logging and mass wasting on juvenile salmonid populations in Queen Charlotte Islands streams. B. C. Ministry of Forests, Land Management Report.

Tripp, D. and V. A. Poulin. 1986c. The effects of mass wasting on salmonid spawning habitats in Queen Charlotte Islands streams. B. C. Ministry of Forests, Land Management Report, No. 50. 29p.

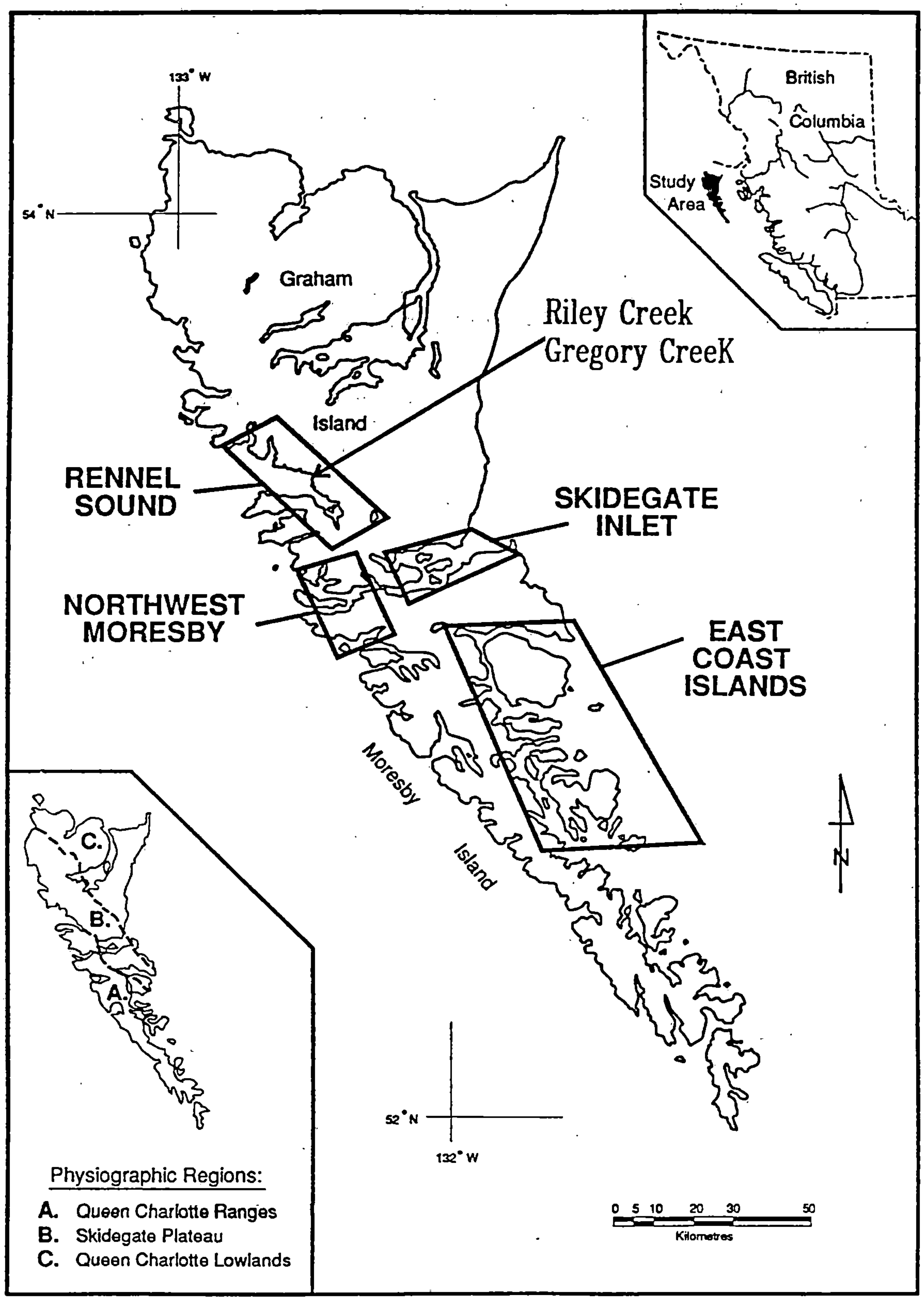


Figure 1. Location map showing the Riley and Gregory creek watersheds in Rennell Sound.

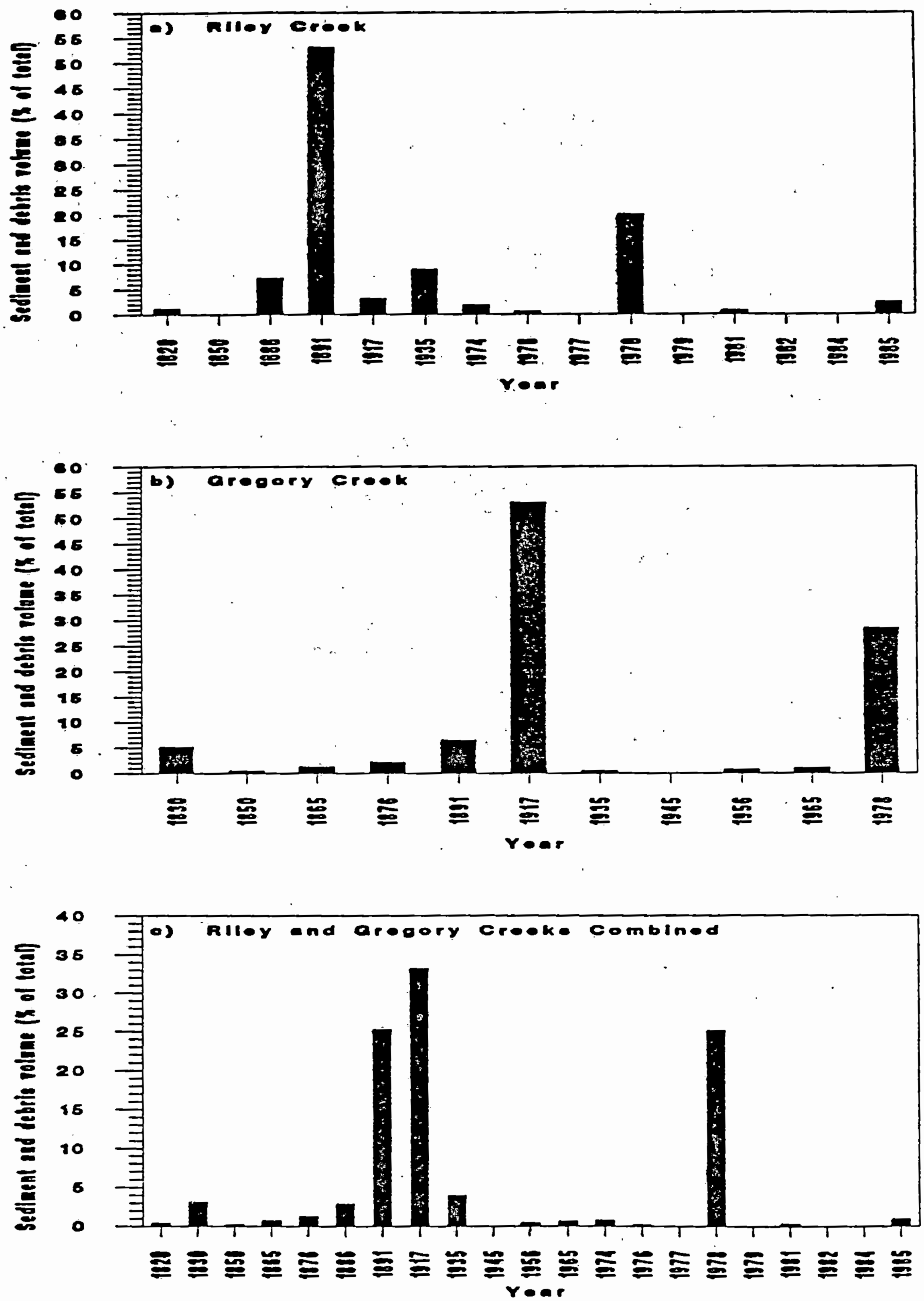


Figure 2. Frequency of landslides in Riley and Gregory creeks: 1820-1985.

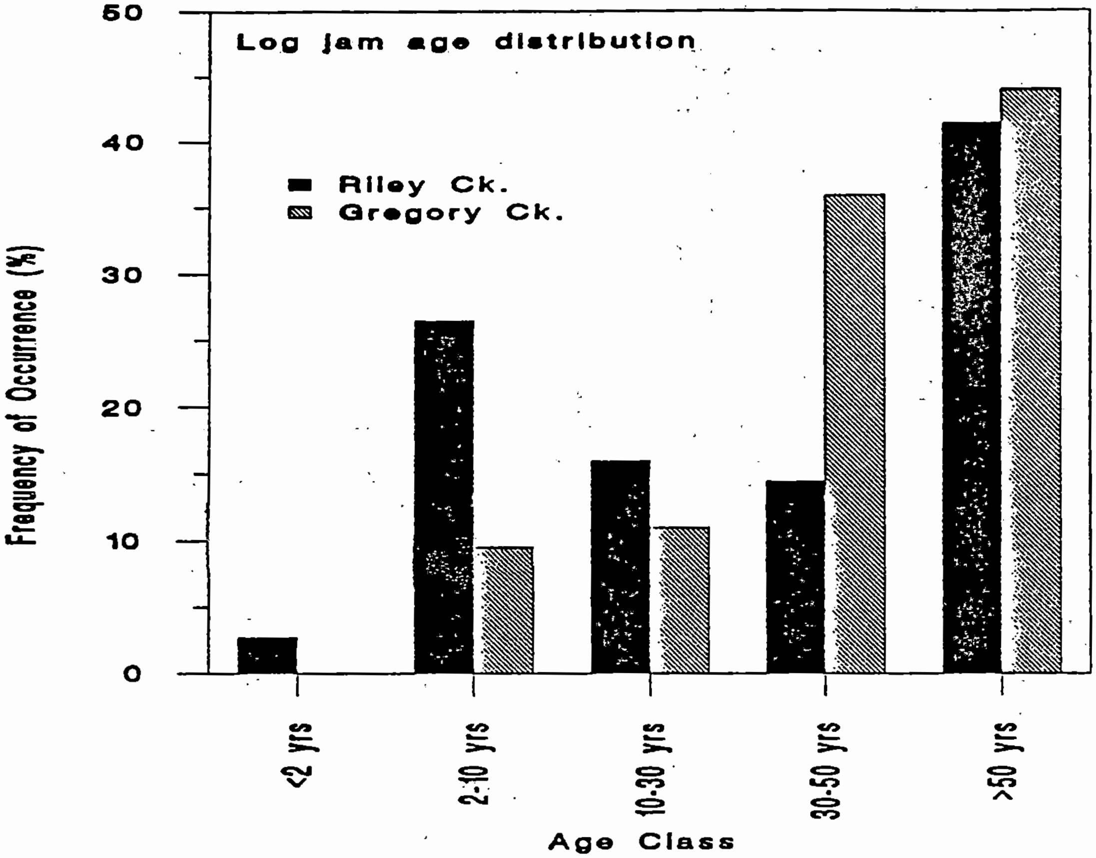


Figure 3. Frequency distribution of log jams by age.

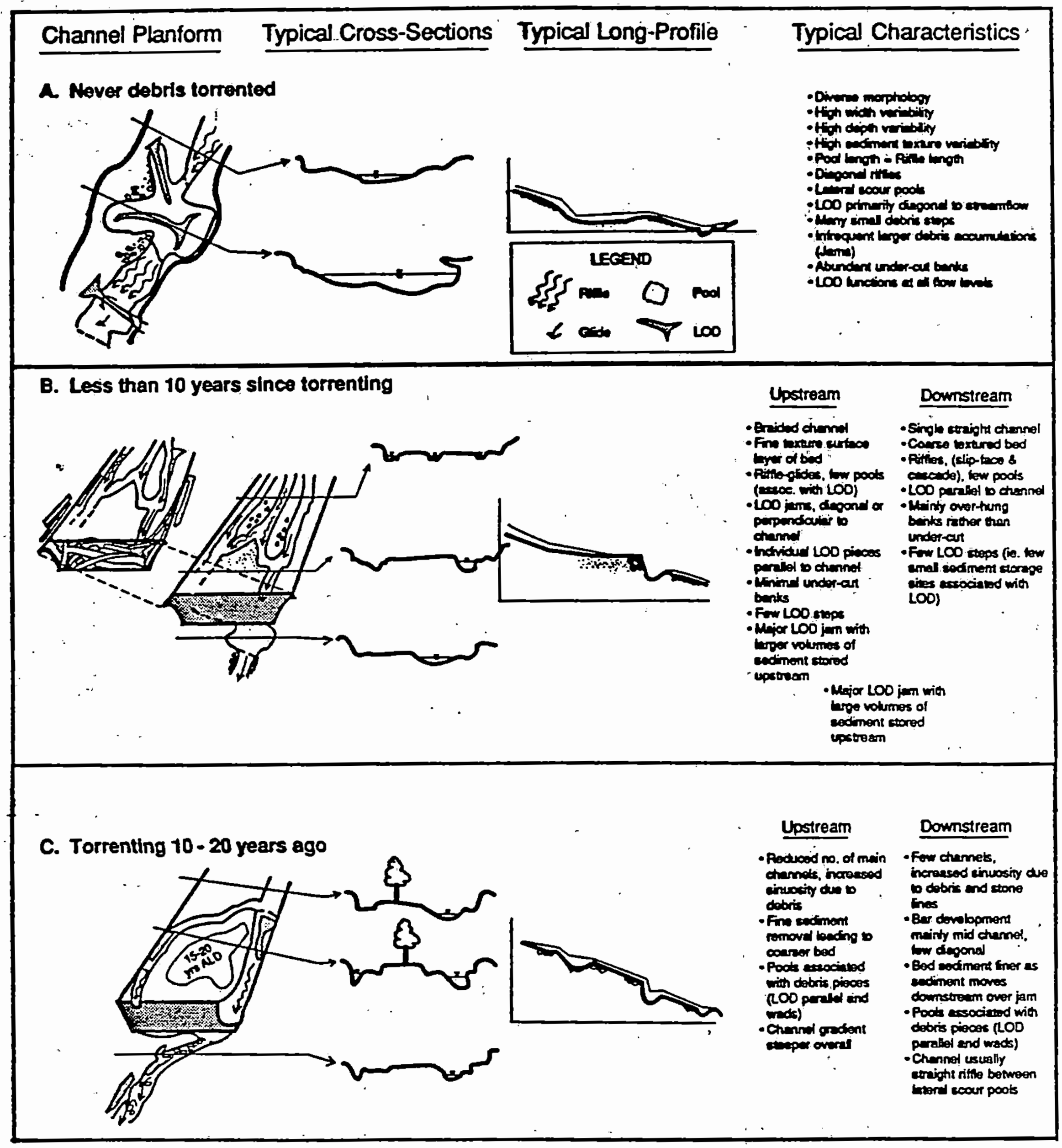


Figure 4. Stream channel recovery models (from Hogan, 1989).

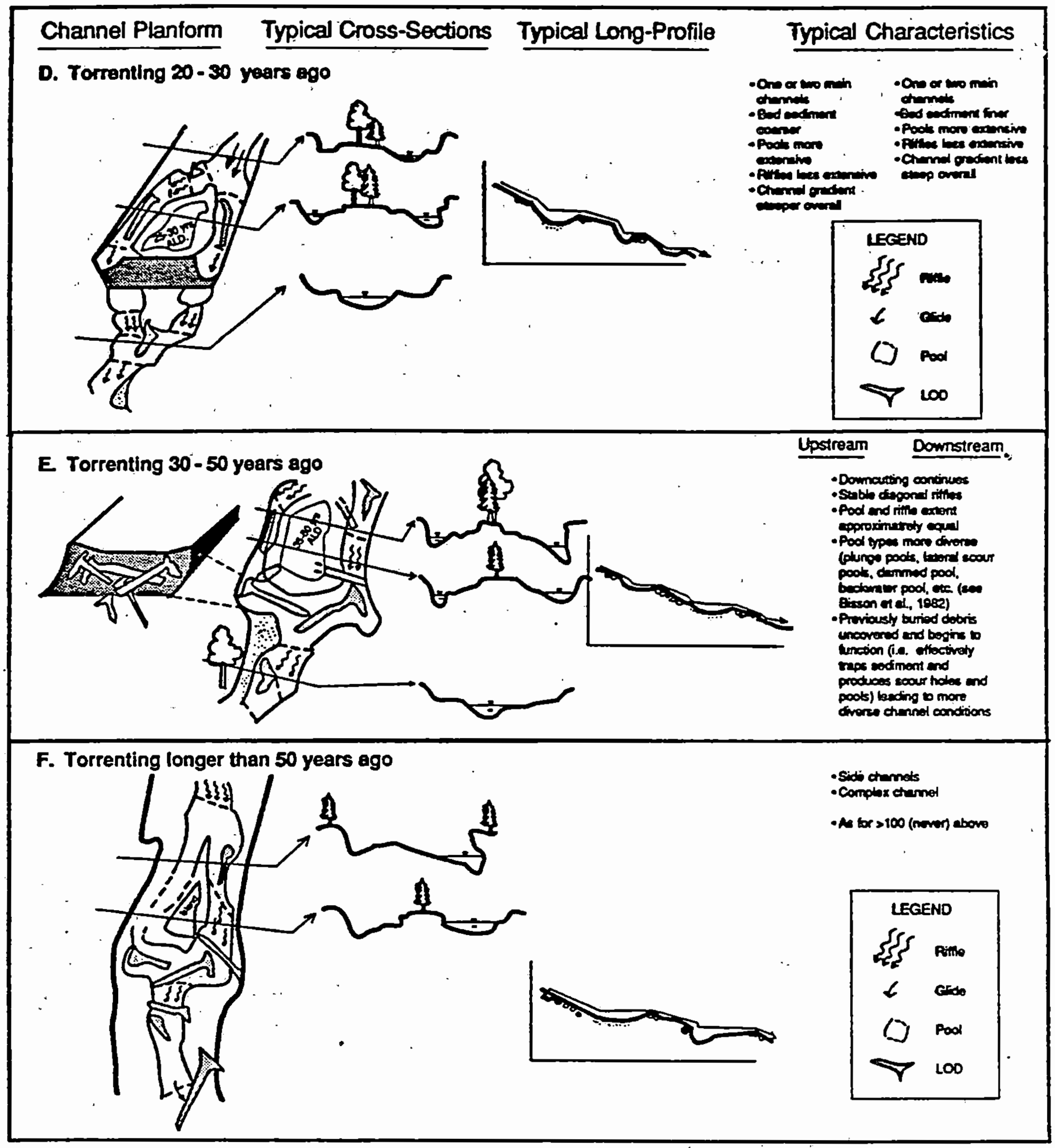


Figure 4. (Continued)

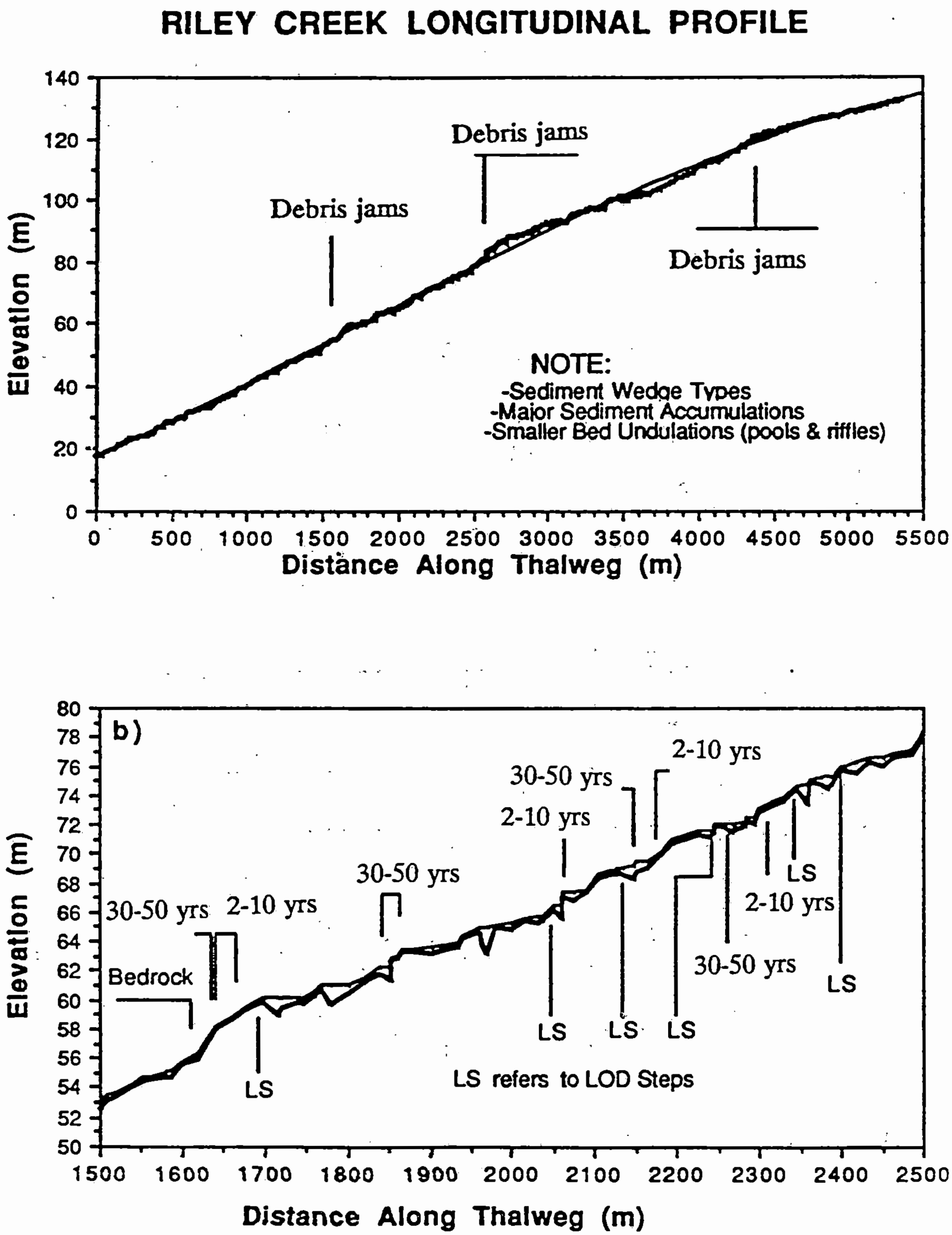


Figure 5. Longitudinal profiles of Riley Creek.

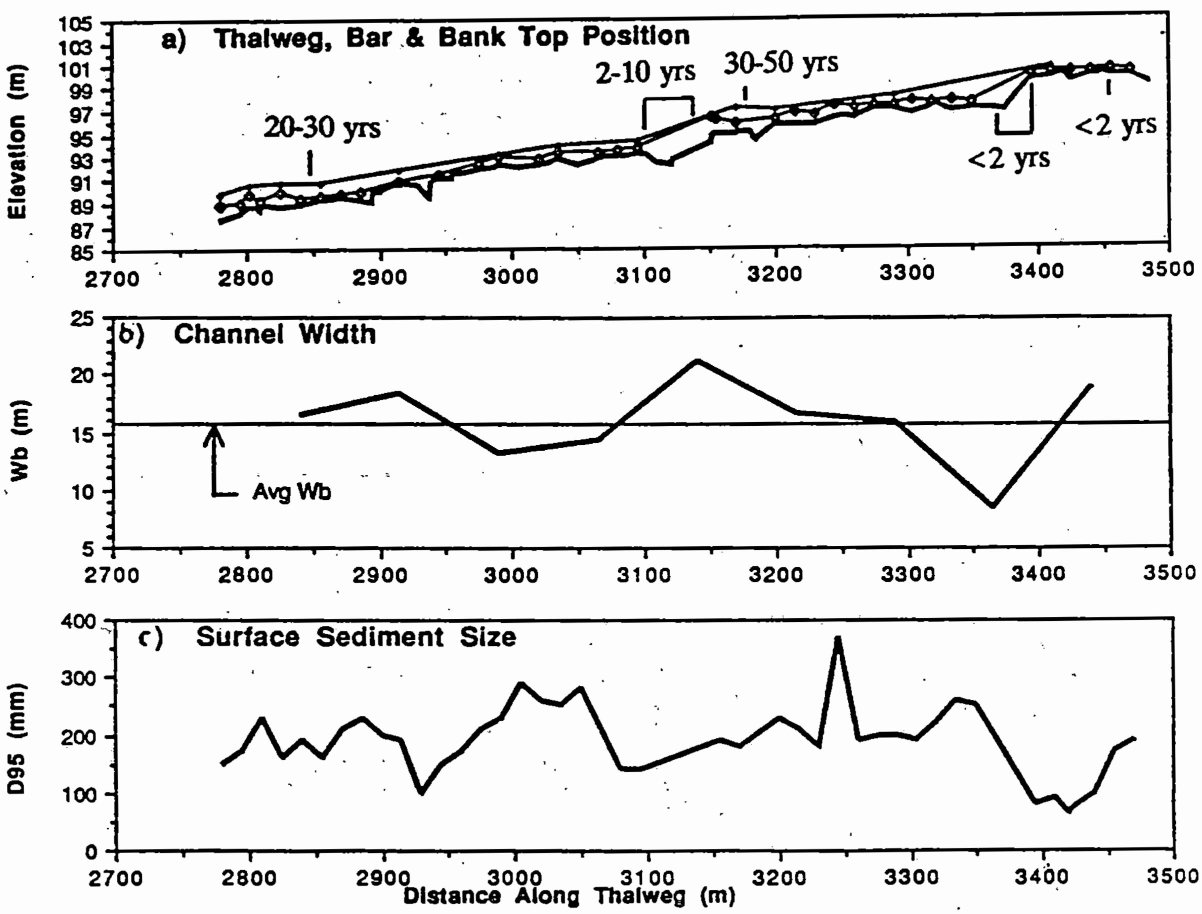


Figure 6. Channel and sediment changes associated with log jams.

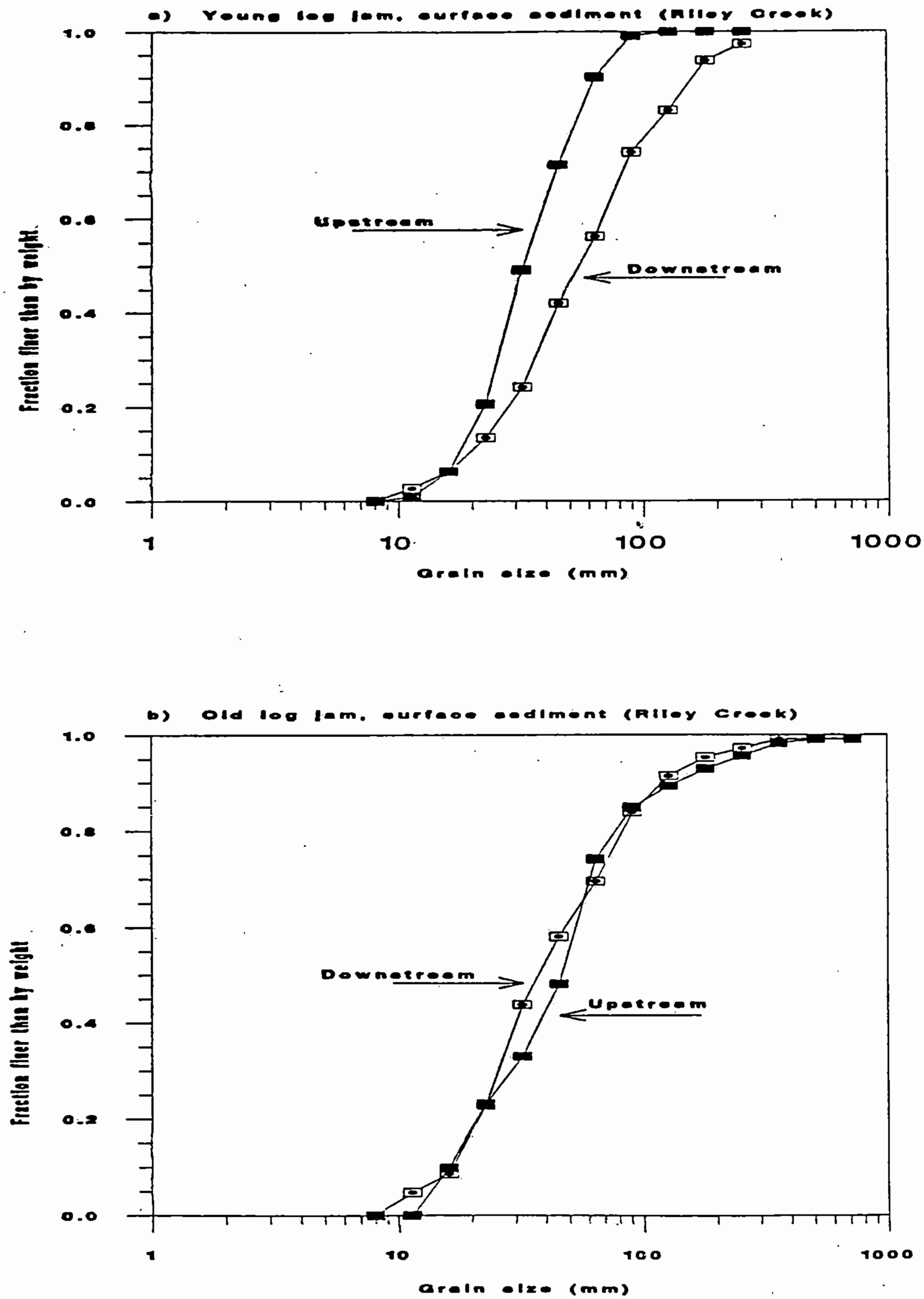


Figure 7. Sediment texture upstream and downstream of log jams (from Rice, 1990).

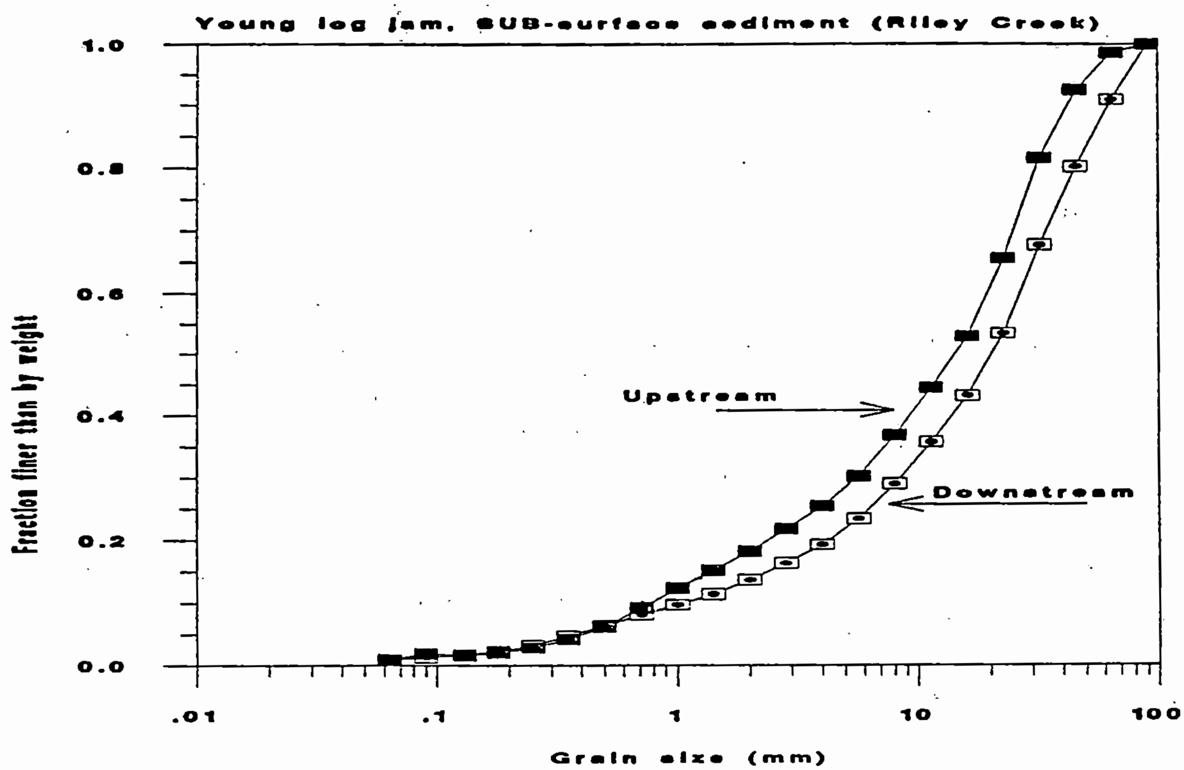


Figure 8. Subsurface sediment upstream and downstream of a young log jam (from Rice, 1990).

LIST OF CONTRIBUTORS TO POSTER SESSION

Thermal Marking of Pink Salmon Fry

W. Smoker
University of Alaska
Department of Fisheries
11120 Glacier Highway
Juneau, Alaska 99801

Genetic Comparisons Among Distinct Stocks of Alaska Chum Salmon

R. Baccus and R.J. Everett
U.S. Fish and Wildlife Service
Alaska Regional Office
1011 E. Tudor Rd.
Anchorage, Alaska 99503

Easy to Read Tag for Pink and Chum Salmon Streamlife Studies

H. Yuen and B. Bechtol

H. Yuen
Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, Alaska 99518-1599

B. Bechtol
Alaska Department of Fish and Game
3298 Douglas Street
Homer, Alaska 99603-7942

Something Different in Fish Production: Moist Incubation, Cassette Incubation, Floating Hatcheries, Channel Incubation, Groundwater Side Channels and Gravel Planting

M. Foy
Department of Fisheries and Oceans
555 West Hastings Street
Vancouver, B.C., V6B 5G3

LIST OF ATTENDEES

Jim Ames
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Brian Anderson
Department of Fisheries & Oceans
555 West Hastings
Vancouver, B.C., V6B 5G3

Don Anderson
Department of Fisheries and Oceans
3225 Stephenson Point Road
Nanaimo, B.C., V9T 1K3

Carol Arffman
Pacific Salmon Commission
#600 - 1155 Robson Street
Vancouver, B.C., V6E 1B5

Bruce Bachen
Northern S.E. Regional Aquaculture Assn.
1308 Sawmill Creek Road
Sitka, Alaska, 99835

Don Bailey
Department of Fisheries and Oceans
555 West Hastings Street
Vancouver, B.C., V6B 5G3

Terry Beacham
Department of Fisheries & Oceans
Pacific Biological Station
Nanaimo, B.C., V9R 5K6

Cliff Bengston
The Tulalip Tribes
10610 Waterworks Road
Tulalip, Washington, 98270

Brian Bigler
Wards Cove Packing Company
P.O. Box C-5030
Seattle, Washington, 98105-0030

Robert Bilby
Weyerhaeuser Company
Technology Center, 2H4
Tacoma, Washington, 98477

David Blackbourn
Pacific Biological Station
Hammond Bay Road
Nanaimo, B.C., V9R 5K6

Jim Blick
Alaska Department of Fish & Game
P.O. Box 240020
Douglas, AK, 99824

Greg Bonnell
Department of Fisheries & Oceans
555 West Hastings Street
Vancouver, B.C., V6B 5G3

Ralph S. Boomer
U.S. Fish & Wildlife Service
2625 Parkmont Ln, Bld A.
Olympia, WA, 98502

Kevin Brennan
Alaska Dept. of Fish and Game
211 Mission Road
Kodiak, Alaska, 99615

Brian Bue
Alaska Department of Fish & Game
333 Raspberry Road
Anchorage, AK, 99518

Jackson Buxton
Department of Fisheries and Oceans
S.E.P.
Chilliwack River Hatchery
Sardis, B.C., V2R 2P1

David Cantillon
National Marine Fisheries Service
P.O. Box 020226
Juneau, Alaska, 99802

Al Cass
Department of Fisheries & Oceans
Pacific Biological Station
Nanaimo, B.C., V9R 1A5

David Celli
Department of Fisheries & Oceans
Box 477
Brackendale, B.C., V0N 1H0

Alan B. Chapman
Lummi Fisheries Department
2616 Kwina Road
Bellingham, Washington, 98226

Peter Cheng
Pacific Salmon Commission
#600 - 1155 Robson Street
Vancouver, B.C., V6E 1B5

Bruce Clark
Department of Fisheries and Oceans
610 Derwent Way, Annacis Island
New Westminster, B.C., V5R 4W5

Tracy Cone
Department of Fisheries and Oceans
3225 Stephenson Point Road
Nanaimo, B.C., V9T 1K3

Robert Conrad
Northwest Indian Fisheries Commission
6730 Martin Way E.
Olympia, WA, 98506

Robert Cooney
University of Alaska/Fairbanks
Institute of Marine Science
Fairbanks, Alaska, 99775-1080

Valerie Craig
Pacific Salmon Commission
#600 - 1155 Robson Street
Vancouver, B.C., V6E 1B5

Ross Davies
Pacific Salmon Commission
600 - 1155 Robson St.
Vancouver, B.C., B6E 1B5

Colleen Davis
714 Newport Ave.
Victoria, B.C., V8S 5C9

John Davis
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C., V8L 4B2

Sherman Davis
Department of Fisheries
Minter Creek Salmon Hatchery
12710 124th Avenue Ct. KPN
Gig Harbor, Washington, 98329

Kent Dimmitt
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Glen Dixon
Department of Fisheries and Oceans
Inch Creek Hatchery
P.O. Box 61
Dewdney, B.C., V0M 1H0

Douglas Dobyns
Nooksack Tribe
P.O. Box 157
Dening, WA, 98244

Paul Dorn
Suquamish Tribe
P.O. Box 498
Suquamish, Washington, 98392

Gregg S. Dunphy
Lummi Fisheries Department
2616 Kwina Road
Bellingham, Washington, 98226

Syma Ebbin
Squaxin Island Tribe
W. 81 Highway 108
Shelton, Washington, 98584

Ron Egan
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Duncan Fields
KRAA
Box 25
Kodiak, AK, 99615

David Flegel
Department of Fisheries & Oceans
Box 130
Bella Coola, B.C., V0T 1C0

Mike Flynn
Department of Fisheries & Oceans
555 West Hastings St.
Vancouver, B.C., V3C 4G2

Keith Forrest
Pacific Salmon Commission
#600 - 1155 Robson Street
Vancouver, B.C., V6E 1B5

Matthew Foy
Department of Fisheries & Oceans
555 West Hastings St.
Vancouver, B.C., V6B 5G3

Shane Frederick
Simon Fraser University
3201 Mctaggart-Cowan
Burnaby, B.C., V5A 1S6

Howard Fuss
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Jim Gable
Pacific Salmon Commission
#600 - 1155 Robson Street
Vancouver, B.C., V6E 1B5

Sam Gidora
Department of Fisheries and Oceans
610 Derwent Way, Annacis Is.
New Westminster, B.C., V3M 5P8

Daniel C. Girard
Lieff, Cabraser & Heimann
275 Battery Street - Suite 3000
San Francisco, CA, 94010

LIST OF ATTENDEES CONT'D.

Camille Gosselin
Department of Fisheries & Oceans
c/o 3841 West 23rd Avenue
Vancouver, B.C., V6S 1K8

Gary Graves
Northwest Indian Fisheries Commission
6730 Martin Way E.
Olympia, Washington, 98506

Mike Grayum
Northwest Indian Fisheries Commission
6730 Martin Way E.
Olympia, Washington, 98506

Dennis Haanpaa
Alaska Deptartment of Fish and Game
333 Raspberry Road
Anchorage, Alaska, 99518

Bill Halbran
Southern Southeast Regional Aquaculture Assoc.
1621 Tongass, No. 103
Ketchikan, Alaska, 99901

David R. Harding
Department of Fisheries & Oceans
323 - 555 West Hastings
Vancouver, B.C., V6B 5G3

Randy Hatch
Suquamish Tribe
P.O. Box 498
Suquamish, Washington, 98392

Jeff Haymes
Quileute Fisheries
P.O. Box 187
La Push, Washington, 98350

Michael Healey
Westwater Research Center
University of British Columbia
Vancouver, B.C., V6T 1Z2

Darren Hebert
Seton Creek Spawning Channel
DFO/Triton Environ.
Box 1676
Lillooet, B.C., V0K 1V0

Don Hendrick
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Mark Henry
Department of Fisheries
Washington State Salmon Culture
P.O. Box 606
Hoodsport, Washington, 98548

Dwight Hickey
Department of Fisheries and Oceans
610 Derwent Way, Annacis Island
New Westminster, B.C., V3M 5B3

Russ T. Hilland
Snootli Creek Hatchery
P.O. Box 95
Bella Coola, B.C., V0T 1C0

Karl Hofmeister
Alaska Department of Fish & Game
11275 Goathill Road
Juneau, AK, 99801

Dan Hogan
B.C. Ministry of Forests
4595 Canada Way
Burnaby, B.C., V5G 4L9

Peter Holmes
Sea Life Specialties
Route 1, Box 2011
Lopez Island, Washington, 98261

Leroy Hop Wo
Department of Fisheries and Oceans
3225 Stephenson Point Road
Nanaimo, B.C., V9T 1K3

Dail Hurdlow
Northern S.E. Regional Aquaculture Assn.
1308 Sawmill Creek Road
Sitka, Alaska, 99835

Robert Hurst
Department of Fisheries and Oceans
3225 Stephenson Point Road
Nanaimo, B.C., V9T 1K3

Mike Jaenicke
University of Alaska Fairbanks
11120 Glacier Highway
Juneau, Alaska, 99801

Verne A. Johnson Jr.
Lummi Nation
2616 Kwina Rd.
Bellingham, WA, 98226

Marilyn Joyce
Department of Fisheries and Oceans
610 Derwent Way, Annacis Is.
New Westminster, B.C., V3M 5P8

Larry Kahl
Department of Fisheries & Oceans
RR 1 - 16250 Morris Valley Road
Agassiz, B.C., V2V 6B2

Eero Karanka
Department of Fisheries and Oceans
North Coast Habitat
716 Fraser Street
Prince Rupert, B.C., V8J 1P9

Wolfgang J. Konkel
Exxon Co. U.S.A.
P.O. Box 2180
Houston, TX, 77063

Tom Kron
Alaska Dept. of Fish & Game
FRED Division
333 Raspberry Road
Anchorage, Alaska, 99518

Russ Ladley
Puyallup Tribe
6824 Pioneer Way
Puyallup, Washington, 98371

Nick Lampsakis
Point No Point Treaty Council
7999 N.E. Salish Lane
Kingston, Washington, 98346

Joyce Landingham
National Marine Fisheries Service
Auke Bay Lab
P.O. Box 210155
Auke Bay, Alaska, 99821

George F. Lane Sr.
Lummi Tribe
2669 Salmon Road
Bellingham, WA, 98226

George Lane
Lummi Indian Business Council
2616 Kwina Road
Bellingham, WA, 98226

Peter Larkin
Professor Emeritus - UBC
4166 Crown Crescent
Vancouver, B.C.,

Dave Leonwardt
Jones & Stokes Assoc., Inc.
2600 V Street, Suite 100
Sacramento, California, 95818-1914

Michael Link
Natural Resources Management
Simon Fraser University
Burnaby Mountain
Burnaby, B.C., V5A 1S6

Tim Linley
Northern S.E. Regional Aquaculture Assn.
1308 Sawmill Creek Road
Sitka, Alaska, 99835

Wilf Luedke
Department of Fisheries and Oceans
3225 Stephenson Point Road
Nanaimo, B.C., V9T 1K3

Gary MacWilliams
Nooksack Tribe
P.O. Box 157
Denning, WA, 98247

Larry Malloy
K.R.A.A.
P.O. Box 2034
Kodiak, AK, 99615

Dave Marshall
Department of Fisheries & Oceans
555 West Hastings St.
Vancouver, B.C., V6B 2G3

Murdoch McAllister
School of Fisheries, University of Washington
WH-10, University of Washington
Seattle, Washington, 98195

Chuck Meacham
Alaska Deptartment of Fish and Game
333 Raspberry Road
Anchorage, Alaska, 99518

Joan Miniken
Nisqually Indian Tribe
4820 She Nah Num Drive S.E.
Olympia, Washington, 98503

Dennis Moore
Muckleshoot Tribe
25305 S.E. Mud Mountain Road
Enumclaw, Washington, 98022

Donald G. Mortensen
NMFS/Auke Bay Laboratory
P.O. 210155
Auke Bay, AK, 99821

Lawrence Moulton
MJM Research
5460 N.E. Tolo Road
Bainbridge Island, Washington, 98110

Mike Murphy
NMFS Auke Bay Lab
P.O. Box 210155
Auke Bay, AK, 99821

Brian Naito
Department of Fisheries & Oceans
3225 Stephenson Point Road
Nanaimo, B.C., V9T 4T9

LIST OF ATTENDEES CONT'D.

Rick Oestman
Jones & Stokes Assoc. Inc.
2600 V Street, Suite 100
Sacramento, California, 95818-1914

Jeff Olsen
Prince William Sound Aquaculture Corp.
P.O. Box 1110
Cordova, Alaska, 99574

Lynda Orman
Department of Fisheries & Oceans
202 - 417 2nd. Ave W.
Prince Rupert, B.C., V8J 1G8

Stevan Phelps
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Duane Phinney
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Cynthia Powell
Department of Fisheries and Oceans
555 West Hastings Street
Vancouver, B.C., V6B 5G3

Terrance Quinn II
Juneau Center for Fisheries & Ocean Sciences
11120 Glacier Highway
Juneau, Alaska, 99801-8677

Thomas Quinn
School of Fisheries, University of Washington
University of Washington
Seattle, Washington, 98195

David Rahn
Westcoast Fisherman Magazine
1496 W. 72 Ave.
Vancouver, B.C., V6P 3C8

Stanley Rice
NMFS - Auke Bay Fish Lab
P.O. Box 210155
Auke Bay, AK, 99821

Rob Russell
Department of Fisheries & Oceans
3225 Stephenson Point Road
Nanaimo, B.C., V9T 1K3

Carl Samuelson
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Greg Savard
Department of Fisheries and Oceans
117 - 417 2nd Avenue West
Prince Rupert, B.C., V8J 1G8

Thomas Schroeder
Cook Inlet Fisheries Consultants
P.O. Box 636
Homer, Alaska, 99603

J. C. Scrivener
Department of Fisheries & Oceans
Pacific Biological Station
Nanaimo, B.C., V9R 5K6

Robert Semple
U.S. Fish & Wildlife Service
Makah Nat. Fish Hatchery
P.O. Box 730
Neah Bay, Washington, 98357

Daniel Sharp
Alaska Department of Fish & Game
Box 2541
Cordova, AK, 99574

Blake Smith
Puyallup Tribe of Indians
6824 Pioneer Way
Puyallup, Washington, 98371

Glenn Smith
Department of Fisheries and Oceans
610 Derwent Way, Annacis Island
New Westminster, B.C., V3M 5B3

Bill Smoker
University of Alaska
Juneau Center Fisheries & Oceans Sci.
11120 Glacier Highway
Juneau, Alaska, 99801

Gary Sprague
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Molly Sturdevant
National Marine Fisheries Service
Auke Bay Lab
P.O. Box 210155
Auke Bay, Alaska, 99801

Gary Taccogna
Department of Fisheries & Oceans
610 Derwent Way
New Westminster, B.C., V3M 5P8

William Templin
Juneau Center for Fisheries & Oceans
4300 University Dr. C-2
Juneau, Alaska, 99801

Arlene Tompkins
University of British Columbia
Resource Ecology
2204 Main Mall
Vancouver, B.C., V6T 1W5

Bill Tweit
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

James Uehara
Washington Dept. of Fisheries
115 General Administration Building
Olympia, Washington, 98504

Yasuhiro Ueno
National Research Institute of Far Seas Fisheries
7-1, Orido 5 chome
Shimizu-shi, Shizuoka, 424

Chuck Walters
National Marine Fisheries Service
7600 Sand Point Way N.E., Bldg. 1
BIN C 15700
Seattle, Washington, 98115

Bill Warren
Puyallup Tribe Fisheries Division
6824 Pioneer Way
Puyallup, Washington, 98371

Alex Wertheimer
National Marine Fisheries Service
Auke Bay Lab
P.O. Box 210155
Auke Bay, Alaska, 99821

Bruce White
Pacific Salmon Commission
#600 - 1155 Robson Street
Vancouver, B.C., V6E 1B5

Kelly Wilcox
North Vancouver Island Salmon Enhancement Association
Box 1409
Port Hardy, B.C., V0N 2P0

Mark Willette
University of Alaska
2221 E. Northern Lights Blvd., #110
Anchorage, Alaska, 99508-4143

Norman Williams
Muckleshoot Tribe
34900 - 212th Avenue S.E.
Auburn, Washington, 98002

Gary Winans
National Marine Fisheries Service
Northwest and Alaska Fisheries Center
2725 Montlake Boulevard East
Seattle, Washington, 98112

Ronnie Wong
U.S. Fish & Wildlife Service
Quilcene Nat'l. Fish Hatchery
281 Fish Hatchery Road
Quilcene, Washington, 98376

Jim Woodey
Pacific Salmon Commission
#600 - 1155 Robson Street
Vancouver, B.C., V6E 1B5

Carol A. Woody
U.S. Forest Service
P.O. Box 755
Petersburg, AK, 99833

David Zajac
U.S. Fish & Wildlife Service
2625 Parkmont Lane
Olympia, Washington, 98502

Jay Zischke
Suquamish Tribe
P.O. Box 498
Suquamish, Washington, 98392

RESULTS OF 15TH NORTHEAST PACIFIC PINK AND CHUM SALMON WORKSHOP QUESTIONNAIRE

The following is a summary of the results of the questionnaires received from participants at the 1991 Pink & Chum Workshop. A total of 49 questionnaires were returned from the 142 registrants.

The participants felt that on a scale of 1 (too few/not enough) to 10 (too many/too much) the number of speakers (5.7), the amount of time per speaker (5.4), and the amount of time per session (5.3) was about right, however, the amount of time for discussion was inadequate (4.2). On a scale of 1 (poor) to 10 (excellent) the participants rated the accommodations (8.9), food (8.3), and the overall quality of the workshop (8.3) very highly. The overall personal gain for the participants was rated a very satisfactory 7.6.

Of those stating a preference, Alaska (80%) was the preferred location for the next workshop to be held 2 years (86%) from this one. The preferred workshop length was 2.5 (49%) to 3.0 (32%) days and preferred site was a destination resort (76%). Preferred timing is Feb-Mar (80%).

The participants felt that the number of speakers was adequate (79%), that there be no concurrent sessions (86%), but more time to be allotted for discussion (79%). This is probably reflected in the participants' wishes to extend the workshop to between 2.5-3.0 days compared to the 1991 length of 2.0 days. The participants felt that the numbers of people present was not too many (93%) and that attendance not be restricted (93%). The participants were also generally in favour of having single topic small workshop sessions (70%). The participants were somewhat split on making the proceedings a formal publication with 40% for and 60% against.

Topics of interest for the next workshop on a scale of 1 to 5 were fisheries management with the highest (4.2) followed by biology (3.8), enhancement (3.5), case histories (3.1), and economics (2.9). Habitat, migration and homing, and bio-technology were also mentioned as possible topics.