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TECHNICAL REPORT 2

Workshop on Factors Affecting Production of Juvenile Salmon

Technical Editors: Richard Beamish, Yukimasa Ishida, Vladimir Karpenko,
Patricia Livingston, and Katherine Myers

Vancouver, Canada

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Workshop *on Factors Affecting Production of Juvenile Salmon: Comparative Studies on Juvenile Salmon Ecology between the East and West North Pacific Ocean*

Tokyo, Japan, October 29, 2000

**Technical Editors: Richard Beamish, Yukimasa Ishida, Vladimir Karpenko,
Patricia Livingston, and Katherine Myers**

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Foreword

The International Workshop on Factors Affecting Production of Juvenile Salmon: Comparative Studies on Juvenile Salmon Ecology between the East and West North Pacific Ocean was held in Tokyo, Japan, October 29, 2000. The Workshop was hosted by the North Pacific Anadromous Fish Commission (NPAFC), and co-organized by the NPAFC and the North Pacific Marine Science Organization (PICES). The Workshop Organizing Committee consisted of the NPAFC and PICES representatives, and was chaired by the Chairman of the NPAFC Committee on Scientific Research and Statistics. All necessary arrangements were made by the NPAFC Secretariat in cooperation with the Organizing Committee and local coordinators.

Over 80 scientists, industry representatives, and fisheries officials attended the Workshop. There were 5 review, 7 oral, and 14 poster presentations followed by a general discussion session. Extended abstracts of the oral and poster presentations are included in this Technical Report, which also contains opening remarks by the Chairman of the NPAFC Committee on Scientific Research and Statistics and the Chairperson of the PICES Science Board, and a short review of the Workshop by the Chairman of the Organizing Committee. The review papers presented at the Workshop will be published as the NPAFC Bulletin No. 3. The material presented in this Technical Report has not been peer reviewed and does not necessarily reflect the views of the NPAFC, PICES, or Parties. Some work may be preliminary. The material has been edited by the editors for clarity and publication purposes only.

Contents

Opening Remarks

Good morning. I would like to welcome and thank all of you for attending this workshop because today is Sunday. This is the first salmon workshop co-organized by NPAFC and PICES. The purpose of this workshop is to clarify the factors affecting production of juvenile salmon and to compare salmon ecology between the east and west North Pacific Ocean. At this workshop, I hope that we can clarify what kind of research we should do and what kind of cooperation should be promoted by NPAFC and PICES in the future. Lastly, I would like to express our sincere thanks to the Overseas Fishery Cooperation Foundation for providing these good meeting facilities and services. Now Patricia Livingston, the representative from PICES, will say a few words. Thank you.

Yukimasa Ishida
Chairman of the NPAFC Committee
on Scientific Research and Statistics,
Chairman of the Workshop Organizing Committee

* * *

I want to express my greatest thanks to the Overseas Fishery Cooperation Foundation for providing us with this wonderful room and equipment and for working so hard on a Sunday so that we could hold this meeting here in Tokyo just prior to the NPAFC Annual Meeting. Thanks also go to PICES Chairman Dr. Hyung-Tack Huh and NPAFC President Fran Ulmer for their ongoing commitment and work to bring these two organizations closer together. Although we already have connections between the two organizations, such as having the chairman of the NPAFC Science sub-committee as a member of the PICES Climate Change and Carrying Capacity Implementation Panel's Executive Committee and we have collaborated on the highly successful Beyond El Niño conference this past spring, we are very pleased to hold this first joint workshop. It provides solid evidence that our scientists are communicating and that the organizations are tackling important issues together. The large attendance here indicates that this is a topic of interest to both organizations. The agenda shows that many interesting talks are to come, and I look forward to hearing them. I sincerely hope that we will find from this workshop some fruitful areas of future scientific cooperation.

Patricia Livingston
Chairman PICES Science Board

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A Migration Model of Japanese Chum Salmon during Early Ocean Life

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Keywords: Chum salmon, juveniles, genetic stock identification, migration route

The early ocean migration route of Japanese chum salmon (*Oncorhynchus keta*) was estimated by genetic stock identification techniques using allozyme (22 loci) variation. The baseline was improved by adding 19 Japanese populations to Seeb et al. (1997).

Juvenile chum salmon (age 0.0) were abundant in the Okhotsk Sea from August through October, but rarely caught in Pacific waters along Hokkaido and the Kuril Islands in autumn. In the southern Okhotsk Sea, juvenile chum salmon catches were composed of 79% Japanese fish in October (Fig. 1), but this stock component decreased to 56% in November (Fig. 2).

Due to decreasing seawater temperatures in the Okhotsk Sea, chum salmon moved into Pacific waters east of the Kuril Islands in late November (Fig. 2) and remained in the western subarctic gyre at high density during winter. These overwintering young salmon (age 0.1) comprised 34% Japanese and 59% Russian stocks in January, and 47% Japanese and 44% Russian stocks in February (Fig. 3).

In the following summer, the abundance of young chum salmon (age 0.1) was low in the North Pacific Ocean, but the abundance was high in the Bering Sea. Young chum salmon caught in the western and central North Pacific Ocean were predominately of Russian origin (52–77%), but those caught in the central Bering Sea were a mixture of Japanese (65%), Russian (25%), and Alaskan (10%) stocks (Fig. 4).

These results indicate Japanese chum salmon juveniles stay in the Okhotsk Sea from summer until late autumn, overwinter in the western North Pacific Ocean, and then migrate into the Bering Sea by the following summer (Fig. 5).

Fig. 1. CPUE distribution of juvenile chum salmon in the southern Okhotsk Sea during October 1993 (A), and estimated contributions of Asian stocks to the mixtures (B). Bars indicate SD CPUE = number of fish caught per 1 h trawl.

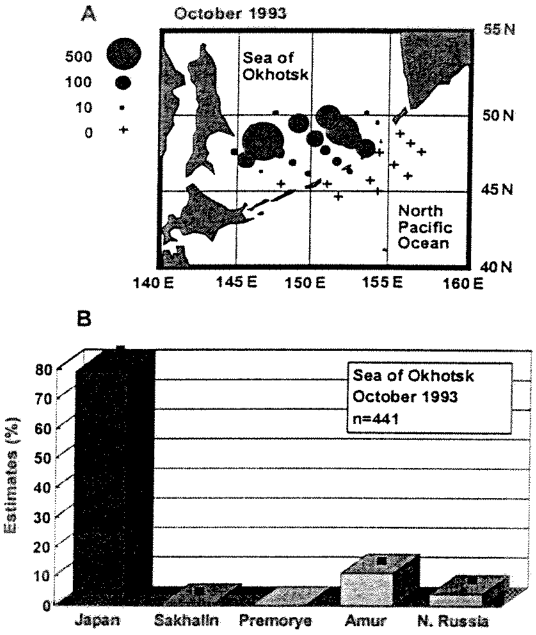


Fig. 2. CPUE distribution of juvenile chum salmon in the southern Okhotsk Sea and western North Pacific Ocean during November 1993 (A), and estimated contributions of Asian stocks to these mixtures (B and C). Bars indicate SD CPUE = number of fish caught per 1 h trawl.

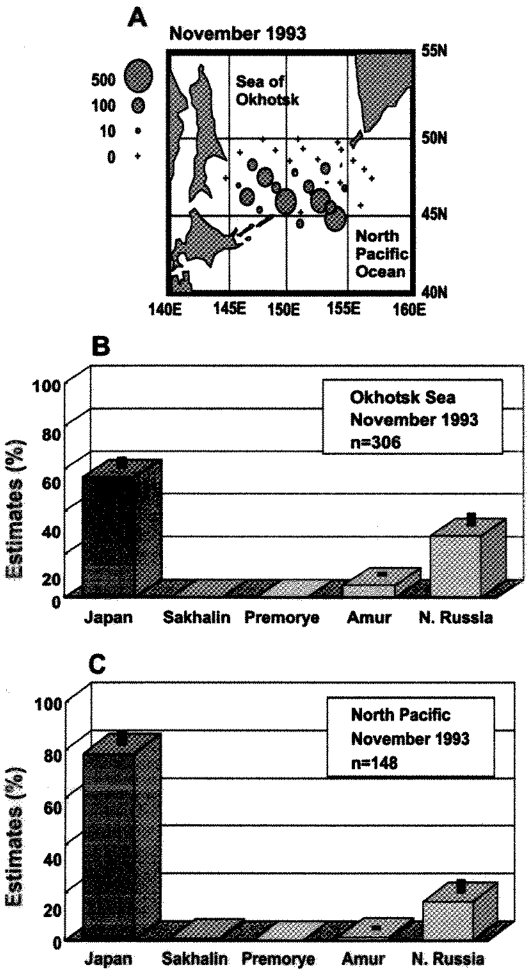


Fig. 4. Estimated average CPUE of age 0.1 chum salmon by stocks in the North Pacific Ocean and Bering Sea in the summers of 1996–99. CPUE = number of fish caught per a set of research gillnets (30 tans).

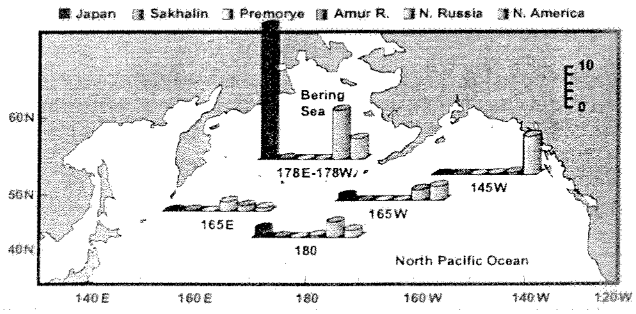


Fig. 3. CPUE distribution of age 0.1 chum salmon in the western North Pacific Ocean in January 1996 and February 1998 (A), and estimated contributions of Asian and North American stocks to these mixtures (B and C). Bars indicate SD CPUE = number of fish caught per 1 h trawl.

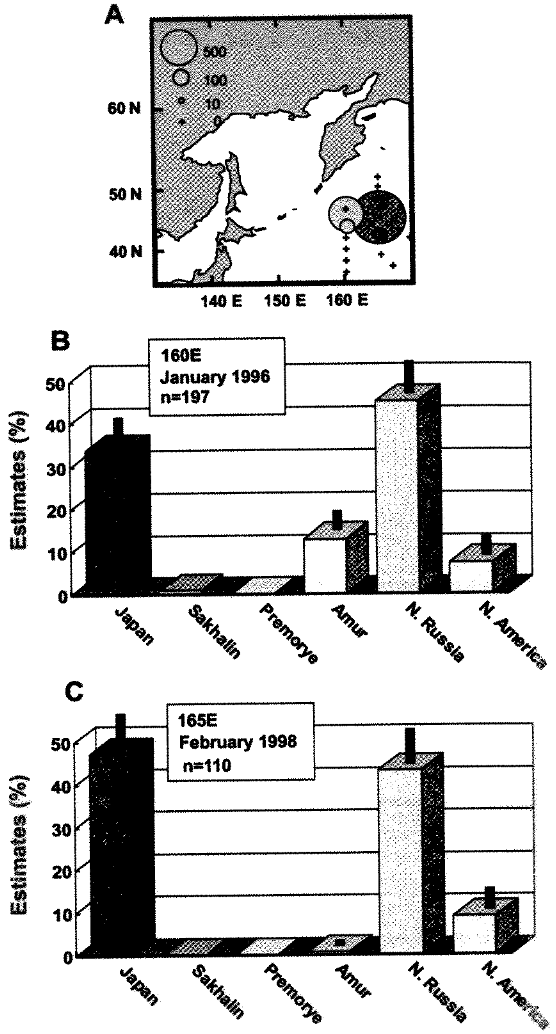
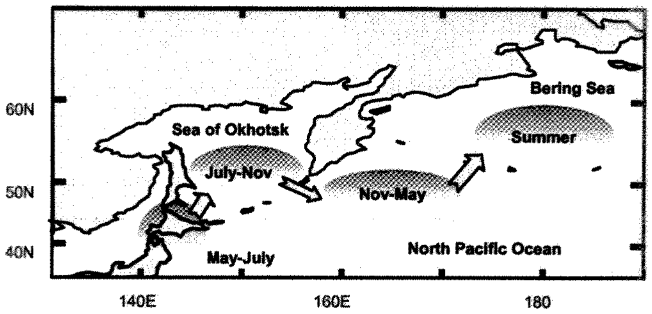


Fig. 5. A migration model of Japanese chum salmon during early ocean life.



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A Synthesis of Research on Early Marine Ecology of Juvenile Pacific Salmon in Southeast Alaska

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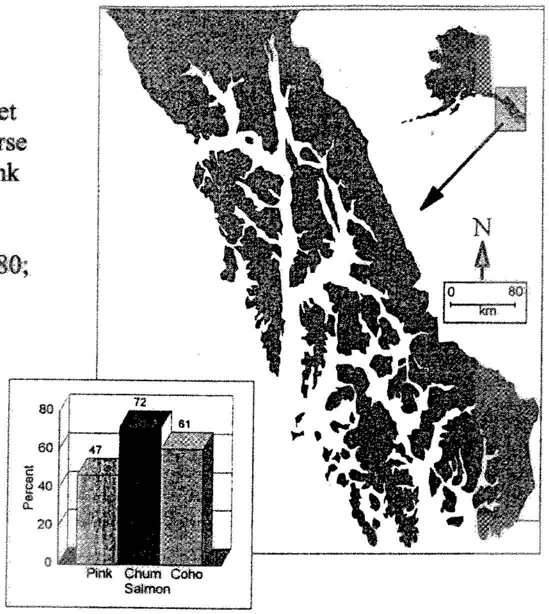
Keywords: Sampling, migration, seasonal occurrence, diets, predation, survival

Southeast Alaska, with over 2000 productive salmon rivers, is one of the State's most productive areas for Pacific salmon, accounting for 47%, 61%, and 72% respectively of Alaska's pink, coho, and chum salmon catch (Fig. 1) along with significant numbers of sockeye and chinook salmon in recent years. This productivity is due, in part, to pristine habitats, favorable environments, abundant foods during early sea life, and good management. Significant research has focused on early marine ecology of salmon to better understand behavior, survival, and carrying capacity of this region.

Most juvenile salmon originate from inner islands and mainland streams and migrate through complex, interconnecting waterways and diverse marine habitats to reach the Gulf of Alaska (GOA). Upon marine entry (March to early June) pink and chum salmon occupy nearshore, littoral habitats, and were captured using dip nets, beach seines, and small traps (Bailey et al. 1975; Orsi and Landingham 1985; Mortensen and Wertheimer 1988; Celewycz et al. 1994; Mortensen et al. 2000). Complex shorelines offer diverse littoral habitats that are utilized differently by young salmon. Pink and chum salmon juveniles actively migrate along long straight, smooth, "transition" beaches whereas they mill about and feed along more protected "nursery" beaches (Bailey and Mattson 1980; Jaenicke et al. 1985), while larger smolt species (sockeye, coho, and chinook salmon) move more readily from littoral areas into open water.

From late May to July juveniles move away from nearshore areas, and all five species occupy open-water habitats sympatrically where they were captured with round haul seines (Martin 1964), two-boat trawls (Mortensen et al. 2000), table and drum purse seines (Jaenicke and Celewycz 1994), small hooks and lures (Orsi 1987; Orsi et al. 1987), and epi-pelagic Nordic trawls that are now used in the Southeast Alaska Coastal Monitoring (SECM) Study (Orsi et al. 1997; Murphy et al. 1999).

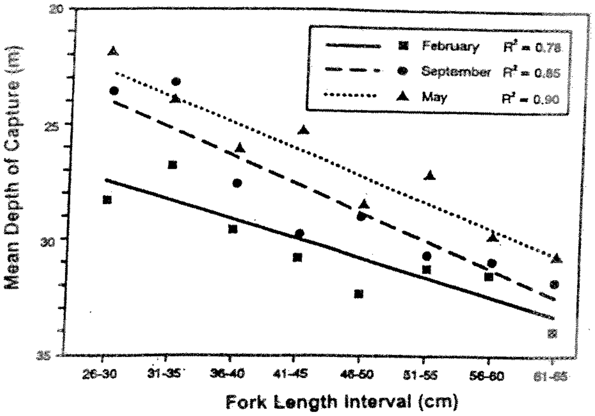
Fig.1. Percentage of statewide commercial harvest of pink, chum, and coho salmon caught in southeast Alaska, 1995–1999.



Occurrence and distribution studies of age-.0 juveniles from regional stocks generally find pink, chum, sockeye, and coho salmon spending an average of 3–4 mo in Southeast Alaska waters before reaching GOA, although some stay as long as 6 mo. Along the outer coast juveniles from southeast intermingle with more southerly stocks migrating northward, generally following the continental shelf. Juvenile chinook salmon from Southeast Alaska and to some extent more southerly stocks are present for 8 mo (June–December) as age-.0 fish in inside and outside waters. Some reside year round as prerecruits (age-.1 and -.2 fish), exhibiting seasonal size and depth preference patterns (Fig. 2) before reaching legal size in regional fisheries (Orsi and Jaenicke 1996).

Trophic relationships among juvenile salmon vary among species, other cohorts, and life history stages. Pink and chum salmon in littoral areas feed mostly on planktonic zooplankton and epibenthic harpacticoids depending on seasonal timing and habitats (Bailey et al. 1975; Celewycz and Cordell 1988; Landingham and Mothershead 1988). In open waters, along with sockeye salmon they feed on a larger variety of prey including many neustonic and planktonic taxa (Landingham et al.1998). Juvenile coho and chinook salmon eat some invertebrate prey but feed mostly on fishes. As visual predators with highly plastic diets juveniles eat a limited subset of prey based on size and visibility and not necessarily on local abundance (Landingham et al. 1998). Therefore, quantifying and understanding intra- or inter-specific interactions for food or space between juvenile salmon or sympatric cohorts is

Fig.2. Seasonal depth occurrence and size related behavior patterns in juvenile chinook salmon in southeast Alaska (from Orsi and Wertheimer 1995).

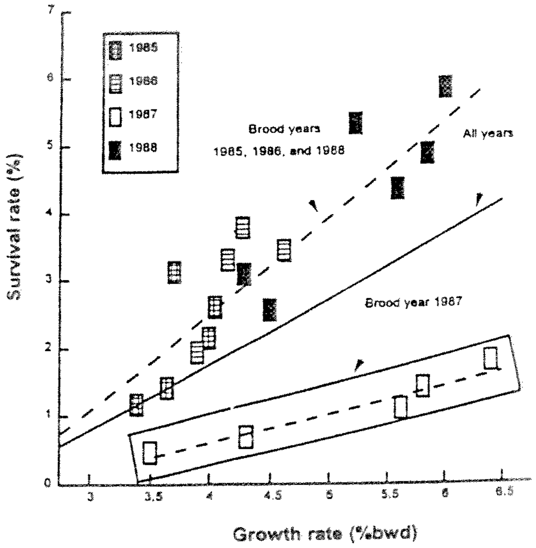


a difficult task. However, with concerns over hatchery-wild stock interactions (Heard 1998), carrying capacity, and perturbations in marine environments, fishery science has no choice but to carefully examine these complex issues.

Predation on juveniles during early sea life may cause significant mortality and influence year class survival. Predators in inshore waters of southeast Alaska can include Dolly Varden (*Salvelinus malma*), flatfishes, sculpins, herring, smelts, greenlings, and other salmon (Celewycz et al.1994; Mortensen et al. 2000). One study of 188 Dolly Varden stomachs from an estuary near a salmon stream found juvenile salmon remains in only four stomachs (Lagler and Wright 1962). SECM examined 661 stomachs from 19 potential predator species and found juvenile salmon in only four species; age 1+ sablefish (*Anoplopoma fimbria*), adult coho salmon, adult Pacific sandfish (*Trichodon trichodon*), and adult spiny dogfish (*Squalus acanthias*). Although walleye pollock (*Theragra chalcogrammus*) are also considered potential predators, SECM examined 138 pollock over three years and found no salmon in their stomachs (Orsi et al. 2000).

Rapid growth of juvenile salmon is important in reducing size-selective mortality from predators. Growth, in turn, depends on timing of juveniles leaving streams, temperatures, seasonal plankton blooms, and presence or absence of sympatric cohorts. Survival can vary in juveniles from early and late spawners in the same stream (Taylor 1980). Mortensen et al. (2000) studied timing of pink fry leaving a stream, early marine growth in the estuary, and survival to adults with four broods differentially tagged at weekly intervals. Significant correlations between early growth and survival, in all years, showed higher growth resulted in higher survival (Fig. 3). This study demonstrated that high initial growth reduces mortality from predation although intensity of predation varies across years. While annual survival may often be similar for regional groups of stocks, it can also vary significantly between stocks in close geographic proximity (Heard 1979; Sturdevant and Landingham 1993).

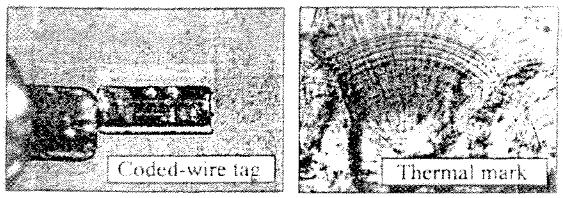
Fig.3. Interannual survival to mature adult life stage in four broods of Auke Creek pink salmon fry marked differentially at weekly intervals plotted against instantaneous growth rates as juveniles (from Mortensen et al. 2000).



Through the use of code-wire tags and thermally-induced otolith marks (Fig. 4), researchers are beginning to understand some of the seaward migration patterns and other stock-specific life history characteristics of juvenile salmon (Orsi and Jaenicke 1996; Murphy et al.1999; Courtney et al. 2000; Orsi et al. 2000). Why does a certain stock have a particular migration and timing pattern to reach the open sea? Is the chosen route related to available foods, to temperature, to salinity patterns, or predation pressures? Is the migration route genetically controlled? Do the same stocks always use the same migration pathway, and do adults retrace in reverse order the route they took as juveniles? Do adjacent hatchery and wild stocks co-occur, interact, and migrate together?

These and similar complex issues can only be answered through long-term research commitments. Since the 1960s studies in this region have produced over 60 reports on the early sea-life ecology of salmon. While many specific details have been learned, some research has been sporadic and not comprehensive due to funding limitations. A comprehensive focus on early marine-life behavior, survival and variability in year-class strength, carrying capacity, and some understanding of hatchery-wild stock interactions at sea will require a committed deployment of long-term programs to study fish populations, food resources, environmental, and oceanographic parameters.

Fig.4. Recaptures of marked juvenile salmon provide critical information for determining stock-specific migration and behavior patterns.



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Early Sea Mortality of Chum Salmon Juveniles in the Open Coastal Waters of the Japan Sea

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Keywords: Survival rate, mark-recapture experiment, coastal survey, hatchery-reared chum salmon

The early sea life is regarded as a critical period determining year-class strength in Pacific salmon. However, there are few estimates of early sea mortality available. For hatchery-reared chum salmon, Bax (1983) estimated early sea mortality ranged from 31 to 46% in the 2–4 day period after release from a hatchery. This high mortality may apply to that portion of the population remaining close to the release site in the first 4 days after release. In the Japan Sea, chum salmon juveniles ranging from 50 to 75 mm in fork length are distributed in river plumes (Fukuwaka and Suzuki 1998). There is concern about the mortality associated with this practice. Thus, the objectives of the study are to estimate juvenile mortality in early coastal life after release, and to compare the coastal mortality with successive offshore mortality of immature or maturing fish.

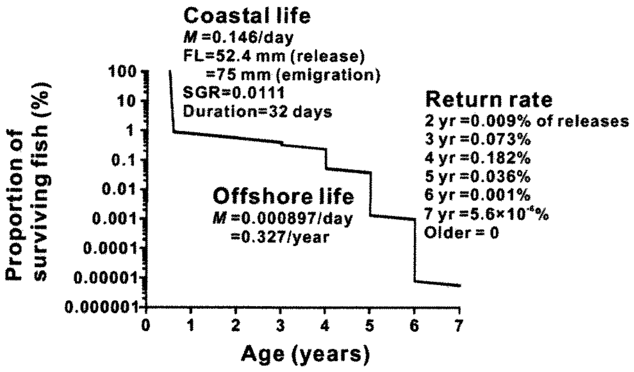
To estimate daily mortality in early coastal life, we analyzed the data record of 9 mark-recapture experiments. In these experiments, 2,572,323 juveniles had the adipose fin or both of the ventral fins clipped. These marked fish were released from hatcheries in 1992–1997 into the Miomote River, Sho River, and Hime River, which flow into the Japan Sea coast of Honshu, Japan. In the 14–43 day period after release, 1,538 marked juveniles were recaptured in coastal waters by the prefectural fisheries experimental stations or commercial fishermen using pelagic trawls, setnet, and beach seines. To calculate mortality, we used a mark-recapture model and the maximum likelihood method for parameter estimation (Kitada et al. 1992). To compare coastal mortality and offshore mortality, we used the mean age-specific return rate in Japan Sea coasts of Honshu over the past 20 years as a survival rate during the whole ocean life. We estimated mortality during the coastal life by assuming the duration of coastal life to be 32 days. We determined the offshore mortality by subtracting the coastal mortality from the age-specific mortality rate.

Table 1. Estimated mortality rate (mean ± standard deviation) of mark-released chum salmon juveniles during early sea life in Japan Sea coastal waters.

Year	Release site	Duration of surveys (days after release)	Instantaneous mortality rate (day^{-1})	Daily survival rate (%)
1992	Miomote R.	6–15	0.192 ± 0.055	82.5
1993	Sho R.	4–30	0.245 ± 0.064	78.3
1994	Miomote R.	0–43	0.105 ± 0.011	90.0
1994	Sho R.	2–14	0.268 ± 0.051	76.5
1995	Sho R.	1–26	0.193 ± 0.025	82.5
1996	Miomote R.	2–33	0.033 ± 0.020	96.7
1996	Sho R.	1–30	0.180 ± 0.024	83.5
1997	Hime R.	10–41	0.059 ± 0.015	94.3
1997	Sho R.	1–35	0.039 ± 0.034	96.2

Estimated instantaneous mortality rate ranged from 0.033 to 0.268 day^{-1} in the 14–43 day period after release (Table 1). It is equivalent to a daily survival rate from 76.5 to 96.7%. This is higher than 54–69% in the 2–4 day period estimated by Bax (1983). This may be due to the difference in length of study period and size of study area. Bax's estimates may apply to that portion of the population remaining close to the release site in the first 4 days after release. Survival rate of chum juveniles may be the lowest in the near shore area and may increase with growth in coastal waters.

Fig. 1. A hypothetical survivorship curve of hatchery-released chum salmon.



The instantaneous mortality rate during offshore life (0.000897 day^{-1}) was much lower than that during coastal life (Fig. 1). Mortality rate summed during coastal life was 99.1% of released juveniles, while during the offshore life it was 0.6%. This indicated that early coastal mortality was 99.3% of overall ocean mortality.

While we cannot show direct evidence for mortality agents during early sea life in this study, some possible mortality agents are suggested from our studies on chum salmon populations in the Japan Sea. Spring coastal sea surface temperatures in the release year were negatively correlated with year-class strength of returning adults (Fukuwaka and Suzuki 2000). Juveniles may be easily transported out of the narrow nursery area in open coastal waters of the Japan Sea. Starvation might be a mortality agent, because chum juveniles competed with each other for food in coastal waters (Fukuwaka and Suzuki 2000). Predation on chum salmon juveniles by masu salmon smolts was observed in the study area (unpublished data).

In summary, we could estimate early sea mortality during coastal life using large-scale marking experiments and intensive coastal surveys. Estimated early mortality during coastal life was much higher than the successive mortality during offshore life. Results indicated that large-scale mark-recapture experiments are useful for monitoring the coastal environment, where salmon juveniles may experience a critical survival period. Censuses of juvenile salmon abundance after their early sea life may be needed for assessment of the abundance of salmon entering the Pacific basin area.

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Seabird Predation on Juvenile Chum Salmon

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Keywords: Chum salmon; coastal life; predation; consumption; seabird

Production of Pacific salmon (*Oncorhynchus* spp.) is affected by environmental and biological factors. High mortality of juvenile salmon has been considered to occur between the seaward migration and early coastal life (Parker 1968; Healey 1982; Bax 1982). However, little is known about the predation by fish and birds on juvenile chum salmon, *O. keta* (Nagasawa 1998). The river mouth is the habitat where juveniles adapt to a new frontier, and provides predators with a foraging ground. In this study, we examined the predation by fish and seabirds on juvenile chum salmon around a river mouth.

Our study area was the Syokanbetsu River mouth in the Mashike coast of the Sea of Japan off northern Hokkaido. Juvenile chum salmon have been released in the Syokanbetsu River since 1957, and about 13 million juveniles were released from the Mashike hatchery from early April to mid-April, 1995–1999.

Potential fish predators were captured with gillnet, set net, and Sayori townet (a small surface trawl net) in the coastal waters off Mashike from pre-release to post-released, 1995–1999, and stomach contents were analyzed. We took a census of seabirds, and observed their feeding behavior using binoculars.

We estimated the consumption of juvenile salmon by gulls within the river mouth area, 250-m long and 30-m wide, from late April to mid May in 1999. We used the following the equation for estimating consumption:

$$C=N\cdot T\cdot Af\cdot As$$

where, C is consumption (fish.bird^{-1}.day^{-1}), N is the number of seabirds feeding on juveniles in the census area, T is the amount of time spent feeding on juveniles in one day, Af is the frequency of occurrence of a bird's attacking behavior (per min), and As is the success of catching juveniles / occurrence of attacking behavior.

We examined the stomachs contents of 13 species of fish. Some juvenile chum salmon were found in the stomachs of adult arabesque greenling (*Pleurogrammus azonus*), masu salmon (*O. masou*), and white-spotted charr (*Salvelinus leucomaenis*) juveniles. However, arabesque greenling appeared to feed on juveniles only when they were in the set net, because the juvenile chum salmon were not digested compared with other stomach contents. We did not consider masu salmon and charr to be important predators because the sea entry of masu salmon was a month later than that of juvenile chum salmon and the abundance of charr was low.

We found seven birds (slaty-backed gull, *Larus schistisagus*; black-tailed gull, *L. crassiostris*; glaucous gull, *L. hyperboreus*; harlequin duck, *Historionicus histrionicus*; red-breasted merganser, *Mergus serrator*; Japanese cormorant, *Phalacrocorax capillatus*; heron, *Egretta garzetta*) around the river mouth and rhinoceros auklet (*Cerorhinca monocerata*) in offshore waters. Of the eight birds, gulls, mergansers and cormorants were observed feeding on juvenile chum salmon. Rhinoceros auklets were not observed feeding on juvenile salmon because of their diving behavior offshore waters. Because rhinoceros auklets establish a large colony (600 thousand birds) on Teuri Island near the Mashike coast, they are likely to be a potential predator. Abundance of gulls and mergansers reached a peak in April. The timing of the peaks coincided with the sea entry of juvenile chum salmon.

Gulls showed four different types of feeding behavior, which were ambushing, dipping, and surface seizing (stationary and mobile). Although dipping and mobile surface seizing showed a higher frequency of attacking behavior than other behavior types, surface seizing type showed a trend to decrease after releasing. Dipping behavior was observed during the seaward migration of salmon.

The relation between the occurrence of attacking behavior and days after salmon release was: $Y = 8.12–0.739X$ ($r2 = 0.895$), where Y is occurrence of attacking behavior (per min) and X is days after release. The average success rate was 0.63, which is similar to that of the ring-billed gull, *L. delawarensis* (Ruggerone 1986). The days examined ranged from the first day to the ninth day after release. The mean number of gulls feeding on juveniles in the census area was 80 birds. Feeding behavior was observed from 6 a.m. to 6 p.m. (720 min). The occurrence of attacking behavior per day was calculated with the equation. We estimated the loss of chum salmon juveniles by gulls at 1,443,500 fish. This was 11.1% of the total fish released (Table 1). Consumption may have been underestimated because of the restricted area and the limited number of predator species examined. Wood (1987) reported that maximum mortality rate by common mergansers (*M. merganser*) did not exceed 10% over the entire salmon seaward migration, thus our estimate may not be low.

Table 1. Total numbers of juvenile chum salmon consumed by gulls.

Days	1	2	3	4	5	6	7	8	9	Total
N	80	80	80	80	80	80	80	80	80	
T	720	720	720	720	720	720	720	720	720	
Af	7.38	6.64	5.9	5.16	4.42	3.68	2.94	2.2	1.46	
As	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	
C	267800	241000	214100	187200	160400	133500	106700	79800	53000	1443500

We concluded that predation by seabirds (gulls, cormorants, and mergansers, and possibly rhinoceros auklets) has more impact than predation by fish on survival of juvenile chum salmon during seaward migration and early coastal life. We need to examine more predators in the future and determine the mortality of juveniles quantitatively. We also want to examine the relationship between the magnitude of predation and salmon production.

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Predation-based Mortality on Juvenile Salmon in the Strait of Georgia

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* * *

Keywords: Pacific salmon, predation, early marine mortality, spiny dogfish, river lamprey

Predation is considered to be the mechanism that causes the mortality regulating the abundance of salmon, and was the biological mechanism that Ricker (1954) proposed was responsible for the shape of his recruitment curve. However, Ricker proposed that the density-related impact of predation occurred in fresh water. In the ocean, it is known that the mortality is large and is believed to occur very early after salmon enter the ocean. There are a small number of studies that support this belief, but careful review of these studies also shows that substantial marine mortality occurs after this initial period and that total mortality is variable (Parker 1968).

In this study we attempted to identify the key predators of three species of Pacific salmon in the Strait of Georgia. We identify spiny dogfish (*Squalus acanthias*) and river lamprey (*Lampetra ayresi*) as the major predators of ocean age-0 salmon. We use an ECOPATH mass-balance food web model (Christensen and Pauly 1992) to study the relative important of juvenile salmon in the diets of other potential predators.

Surveys using sunken gill nets were conducted during the spring through winter months of 1998 to 1991 to study spiny dogfish predation. The total number of identifiable juvenile salmon in their guts from all years of the study was 115 chinook, 78 coho, and 7 pink and/or chum. The percentage of dogfish feeding on salmon ranged from 0.8% to 11.9% among years. The abundance of spiny dogfish in the study area ranged from 298,000 in 1990 to 1.4 million in 1988. In 1988, an estimated 7.7 million (or 100% of the release) of chinook and coho salmon were killed by spiny dogfish within 4 weeks. In 1989, 1990, and 1991 the estimated mortality was 0.2 million, 0.1 million and 0.2 million, respectively. The abundance of dogfish and the percent incidence of salmon in dogfish stomachs declined in July.

Surveys for river lamprey were conducted in the Fraser River plume and adjacent waters using a surface trawl (Beamish and Neville 1995). The abundance of river lamprey in the Fraser River plume in 1990 and 1991 was 3.0 and 3.9 million, respectively. In 1990, lamprey fed on herring (19%), chinook (13%), and coho (16%). Using an average of 20% salmon in the diet (Beamish and Neville 1995) and an average of 65 prey killed (Beamish and Williams 1976), we estimated that 20 million chinook, 15 million chum, and 2 million coho were killed in 1990. In 1991, 18 million chinook and 10 million each of chum and coho salmon were killed by river lamprey. This predation amounted to 13% of all coho hatchery production from Strait of Georgia hatcheries in 1990 and 65% of all coho production in 1991.

Trawl sets (616) were conducted throughout the Strait of Georgia in 1998 and 1999 (Table 1). Only two of the potential predators of salmon were found to contain juvenile salmon remains. We also examined the impact of

Table 1. Numbers of potential predators by species and depth caught in mid-water trawl nets during surveys in 1998 and 1999.

	Depth (m)	Pacific hake	Spiny dogfish	Chinook salmon [a]	Coho salmon [a]	Lingcod	Walleye pollock	Wolfeel	Rockfish
1998	0–14	3	251	158	26	3	2	9	0
(372 sets)	15–29	2	108	54	2	0	4	5	0
	30–44	39	759	39	1	0	68	2	0
	45–59	0	141	10	0	0	13	1	0
	60+	10,824	1125	20	2	0	445	0	0
1999	0–14	257	413	54	9	1	207	5	0
(244 sets)	15–29	43	41	25	1	0	15	0	0
	30–44	1504	47	7	0	0	246	0	0
	45–59	39	394	8	0	0	25	0	0
	60+	13,768	42,768	6	0	0	326	0	0

[a] Numbers of coho and chinook are for ocean age-1+ fish only.

potential predators using an ECOPATH mass-balance food web model of the Strait of Georgia. This model indicated that the functional groups were at the expected trophic levels (Fig. 1). In the model, juvenile salmon accounted for 20% of the diet of river lamprey and 11% of the diet of dogfish. The percentage of salmon in the diet of other predators was lower (Table 2). We examined the impact of increasing juvenile salmon consumption percentages in the small pelagics (27 species) and miscellaneous demersal (103 species) groups to 5%. For the small pelagics, the change would require a production of 104,000 t of juvenile salmon or approximately 10.4 billion individuals. For the miscellaneous demersal fish category the increase would require a production of juvenile salmon of 116,000 t or 11.6 billion individuals. Our estimates of coho, chinook and chum production from the Fraser River and other rivers entering the Strait of Georgia in 1990 and 1991 was189 million and 296 million juveniles, respectively (Beamish and Neville 1995). Therefore, the production of 10.4–11.6 billion juveniles required to support an increase of salmon in the diet of small pelagics or miscellaneous demersal fish is impossible because only a fraction of this amount of smolts was actually produced.

Fig. 1. Trophic relationships from the ECOPATH mass-balance food web model of the Strait of Georgia. Solid lines indicate that a prey composes 25% or more of function group's diet. Dotted lines indicate that a prey composes 20-25% of functional group's diet.

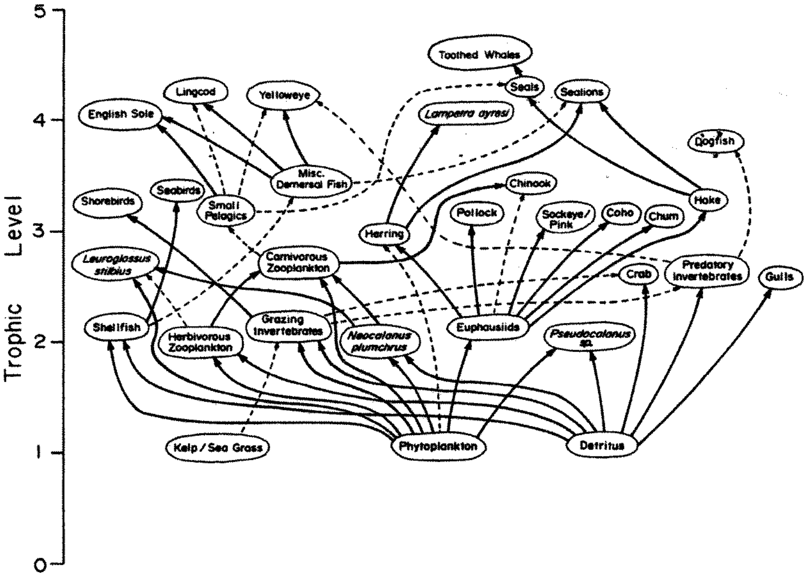

Table 2. Estimated tonnes consumed and percent incidence of salmon in the diet of predators in the Strait of Georgia ECOPATH mass-balance food web model. Percent incidence less than 0.1% is highlighted with an asterisk. In these cases there may be predation below 0.1%. However, this cannot be tested in our current model and using a predation rate of 0.1% resulted in more salmon being consumed than could be supported.

Predators	Chum (t)	%Chum	Coho (t)	%Coho	Chinook (t)	%Chinook	Sockeye/ Pink (t)	%Sockeye/ Pink
Shorebirds	62	2.0					62	2.0
Small pelagics		< 0.1*		< 0.1*		< 0.1*		< 0.1*
River lamprey	59	5.3	56	5.1	56	5.1	50	4.5
Seabirds	11	0.1	34	0.3	34	0.3	11	0.1
Gulls	26	1.0	3	0.1	3	0.1	3	0.1
Misc. demersal		< 0.1*		< 0.1*		< 0.1*		< 0.1*
Pink/sockeye								
Coho	552	1.0	110	0.2	55	0.1	55	0.1
Chinook	690	1.0	138	0.2	138	0.2	345	0.5
Toothed whales [a]								
Hake	265	0.1		< 0.1*	265	0.1	0	0.0
Dogfish	145	0.5	1449	5.0	1449	5.0	145	0.5
Lingcod	97	2.0	97	2.0	5	0.1	5	0.1
Sealions[a]								
Seals[a]								
Total consumed	1,907		1,887		2,005		676	

[a] These predators feed primarily on adult salmon.

These studies identified river lamprey and spiny dogfish as the major fish predators of juvenile salmon in the early marine period. However, both these predators reduce their feeding on salmon by late summer. Our surveys show that there are relatively few other potential predators. The variability in predation mortality, the incidental nature of salmon as prey, the decline in salmon in diets by mid-summer, the low amount of salmon in the total annual consumption of potential predators, and the scarcity of potential predators in our catch indicates that early marine mortality is probably not the only mechanism that regulates the numbers that return. This conclusion is consistent with some of the first studies of marine mortality that showed that 2–4% mortality occurred daily in the first 40 days, but 0.4–0.8% occurred daily after this period (approximately 410 days) (Parker 1968). We interpret the results of our study to indicate that the predation-based concept for the natural regulation of adult salmon abundance is more complex than previously thought. Therefore, we propose that there are two distinct mortalities. We call these mortalities an early marine mortality and a carrying capacity mortality. These mortalities combine to produce the total natural mortality; Early marine mortality (EM_m) + Carrying capacity mortality (CC_m) = Total mortality (T_m).

Both EM_m and CC_m could operate at the same time but the impact of one could diminish as the other predominates. Predation-based mortality may be the dominant early marine mortality while growth may be more associated with carrying capacity mortality. The carrying capacity mortality is the linkage to climate change. Partitioning the impact of mortalities facilitates the understanding of the natural regulatory process and provides a theory to assess the impact of climate. Holling (1965) improved our understanding of the predation process by separating the numerical responses (more predators arrive to feed) from the functional response (one predator eats more prey). The hypothesis of two distinct mortalities is an idea that needs to be tested, but it is an idea that we think is a timely contribution to the developing concern of managing salmon in a changing climate.

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Ecological Processes Influencing Mortality of Juvenile Pink Salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska

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Keywords: Pink salmon, juvenile, ecology, predation, bioenergetics, modelling

This component of the Sound Ecosystem Assessment (SEA) program focused on improving our understanding of the mechanisms regulating survival of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound (PWS), Alaska. Our approach involved field studies and development of a mechanistic numerical foraging-physiology model of the predator-prey interactions regulating juvenile salmon mortality. The model was used as a tool to integrate our knowledge of system function and examine processes that could not be directly observed. Field studies were directed at (1) identifying the predator taxonomic groups that accounted for the greatest predation losses of salmon, (2) validating our foraging-physiology model, and (3) testing our hypotheses related to mortality processes. Field sampling was conducted from May through June at 16–25 sites each year, 1994–1997. The following parameters were estimated at each site: (1) juvenile salmon relative abundance, (2) juvenile salmon diet composition, (3) juvenile salmon growth rate, (4) predator relative abundance, (5) predator species and size composition, (6) predator diet composition, (7) surface-layer macrozooplankton density and composition, (8) surface-layer ocean temperature, and (9) ambient light intensity. Multiple coded-wire tagged (CWT) groups of juvenile salmon released from four hatcheries bordering PWS proved to be an invaluable tool for examining mortality processes both in the field and through numerical modelling.

Approximately 726 million juvenile pink salmon entered PWS from bordering streams and hatcheries each year. Predation during the spring plankton bloom accounted for the mortality of approximately 413 million juveniles (57%) and therefore appeared to be the primary mechanism causing mortality during this life stage. Two facultative planktivores, herring (*Clupea pallasi*) and walleye pollock (*Theragra chalcogramma*) consumed the greatest numbers of juvenile salmon. Several piscivorous fish (*Gadus macrocephalus, Microgadus proximus*, and *Salvelinus malma*) consumed the second greatest numbers and an assemblage of nearshore demersal fishes (Cottidae, Hexagrammidae, and *Sebastes spp.),* and seabirds (*Rissa tridactyla, Larus spp.*) consumed the smallest numbers of salmon. Numerical modelling demonstrated that a relatively small subset of trophic elements of the system were needed to predict patterns of survival of CWT groups by release date. In our study, these elements were the densities and sizes of juvenile salmon and their predators, and six key zooplankton taxonomic groups. The predictive capability of the model was dependent on model time scales on the order of one day, tracking growth and mortality of multiple CWT groups, and modelling the dispersion and spatial overlap of multiple CWT groups. Interactions within the simulated predator and prey complex determined predation losses of salmon and no single variable could consistently predict survival. Our field results indicated that the copepod *Neocalanus* played a unique role in modifying predation losses of juvenile pink salmon in PWS. Reduced large copepod densities caused (1) reduced growth when juvenile salmon densities were high, (2) greater predation losses to facultative planktivorous fish as these predators switched to alternative prey including salmon, and (3) dispersion of foraging juvenile salmon offshore where they suffered greater predation losses to piscivorous and demersal fishes. Thus, bottom-up processes affecting the spring *Neocalanus* bloom influenced juvenile salmon growth rates and foraging behavior, but also modified top-down processes through size-selective predation on juvenile salmon and by altering the timing of a shift from planktivory toward piscivory among major predators on juvenile salmon.

Future research in this area should focus on further developing and validating numerical models of predator-prey interactions. Field sampling programs should measure parameters needed as model inputs and for model validation. Tagging of multiple groups of salmon entering the system at various times during the spring bloom will be an essential tool needed to understand system function.

Monitoring of Salmon Smolt Numbers in the Khabarovsk Region

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Keywords: Chum salmon, pink salmon, smolt, monitoring, Amur River

The Khabarovsk region is divided into seven fishery districts: the Okhotsky district, the Ayano-Maysky district, the Tuguro-Chumikansky district, the Sakhalinsky Bay, the Amur River drainage, the Amur River estuary, and the Northern Primorye (Sea of Japan coast). In five of these districts we count the number of salmon smolts in reference streams. We use a standard method of selective catches with cone-shaped fyke nets, invented in 1939 by a Russian scientist, A.Ya.Taranetz. Our reference streams are the Okhota River in the Okhotsky district, the Iski River in Sakhalinsky Bay, the My River in the Amur River estuary, and the Ulika River, a tributary to the Tumnin River, in Northern Primorye (Fig. 1). In the Amur River drainage the monitoring of smolts is carried out on several of the main spawning tributaries (Fig. 2). In the Amur River, which is the most important salmon drainage of the Khabarovsk region, we count pink salmon and both summer and fall forms of chum salmon.

Fig. 1. The reference rivers for monitoring salmon fry numbers in the Khabarovsk District, Russia.

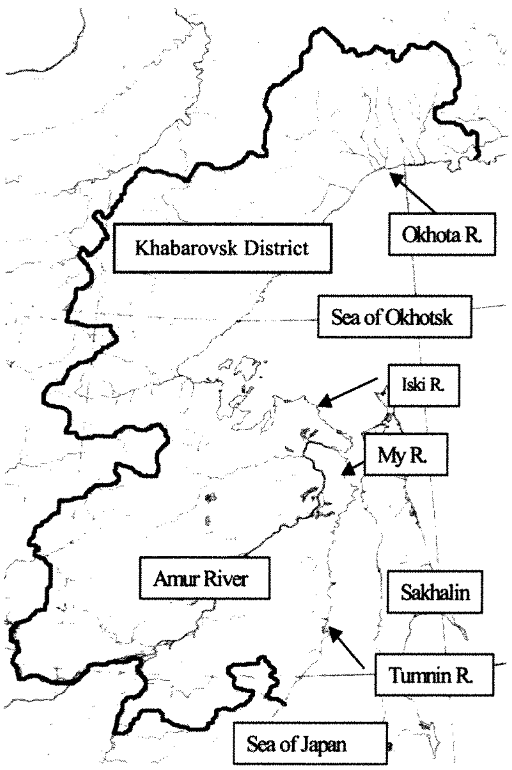
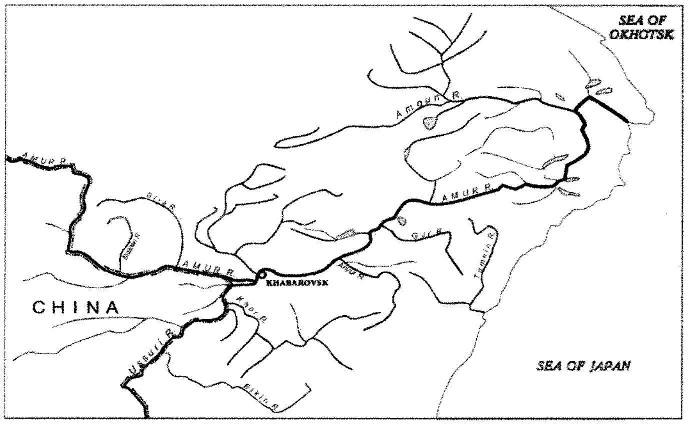


Fig. 2. The lower Amur River and main tributaries.



Some of the fall chum salmon smolts in the Amur drainage are of hatchery origin. There used to be four hatcheries, and a fifth hatchery on the Anui River started operating in 1999. The total number of fish released by these hatcheries over a period of 11 years is insignificant—409 million smolts, which confirms that the hatchery program in the Amur River drainage is not yet effective. We also think that the hatcheries have not affected the population structure and natural dynamics of the numbers of wild salmon smolts in the Amur River (Fig. 3).

Our salmon fry monitoring has highlighted some negative changes in the potential of different Amur River tributaries for natural reproduction of fall chum salmon. Since 1968, the share of natural reproduction of fall chum salmon in the upper tributaries, Bidshan, Bira and Ussury, has seriously decreased. The decrease is caused by very active driftnet fishing by Chinese fishermen in the headwaters of the Amur River drainage. Most of the spawners in these upper tributaries cannot reach their spawning grounds. The problem is serious for fall chum salmon because the Ussury River spawning grounds used to account for 40% of the natural reproduction, and those of the Bidshan, Bira, and some other tributaries of the middle Amur (combined) were 10% of the natural reproduction for the entire Amur drainage (Fig. 2).

The fall chum salmon spawning grounds in Russia, situated downstream from the border-zone with China, are always filled with spawners. The quality of the spawning grounds is high because the territory is not populated, and industries have not developed on spawning tributaries. Therefore, the annual harvest of wild fall chum salmon smolts in the Anui River (393 km long) is between 10 and 35 million fish (Fig. 4).

The spawning streams of the right tributaries to the Ussury River, situated in Russian territory, also are of very good quality for salmon reproduction, but the spawners cannot reach them. The counting of fall salmon chum smolts has shown that the Khor River (453 km long), for example, has an annual harvest of about 0.1 million fish only. The Anui and Khor are neighboring rivers, but their mouths are separated by Russia-China frontier waters.

At present, the most important spawning stream is the Amgun River—the left tributary of the Lower Amur. This river hosts up to 60% of all summer chum fry and up to 60% of all pink salmon fry in the Amur River.

Fig. 3. The numbers of wild smolts of summer and fall chum (A) and of hatchery fall chum smolts (total from all hatcheries) (B) in the Amur River (in millions of fish).

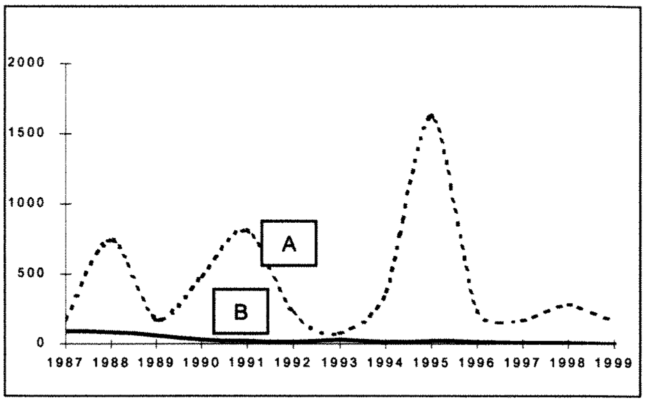
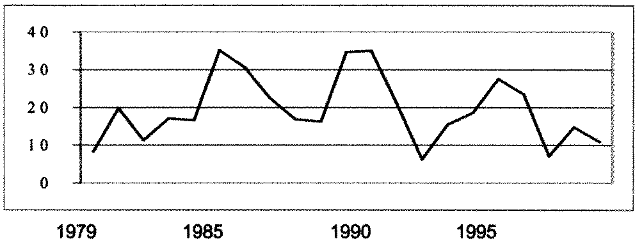
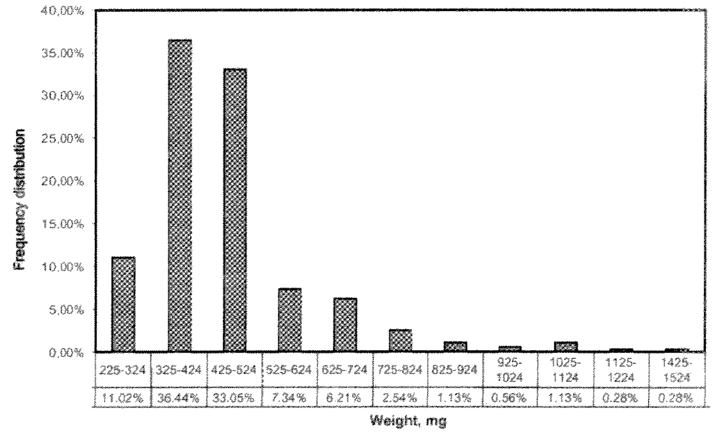


Fig. 4. The numbers of wild fall chum salmon smolts in the Anui River drainage (millions of fish) between 1979 and 1999.



In 2000, we counted pink and chum salmon smolts in the narrowest stretch of the main channel of the Amur River near Susanino, 110 km from the river mouth. The fyke-net was fixed to an anchored boat. The maximum speed of current was 100–120 cm/sec. The water temperature at the beginning of observations (May 24) was 11.2°C; on June 8—13.7°C; and at the end of the survey (June 17)—17.6°C. Chum salmon smolts were represented mostly by specimens from 35 to 44 mm long (81.4%), and the prevalent weight group was 325–524 mg (69.5%). The average sizes of chum salmon smolts were 38.3 mm FL and 463 mg. The average sizes of pink salmon smolts were 33.2 mm FL and 245 mg. In 1973 the average sizes of chum salmon smolts were 37.1 mm FL and 477 mg, and pink salmon averaged 32 mm FL and 261 mg (Yu. S. Rosly, Khabarovsk Division of TINRO, unpublished data). Therefore, the average length and weight of salmon smolts has actually not changed in last 27 years. The distribution of weight frequencies of chum smolts is normal (Fig. 5).

Fig. 5. Frequency distribution of the weight of the chum salmon smolts in the lower Amur River, May 24–June 17, 2000.



The peak of the downstream migration of chum fry started on May 26 and finished on June 7 with a maximum on June 7. The period of downstream migration of pink salmon smolts was even shorter than that of chum salmon—from May 28 till June 9 only. The maximums of the runs of both species have coincided. The interpolation of smolt catches over the entire migration period gives us an estimate of the total number of Amur River downstream salmon migrants (excluding the Amgun River) of 289,646 million chum salmon and 31,726 million pink salmon.

Effects of Ocean Currents on Juvenile Chum Salmon Migration

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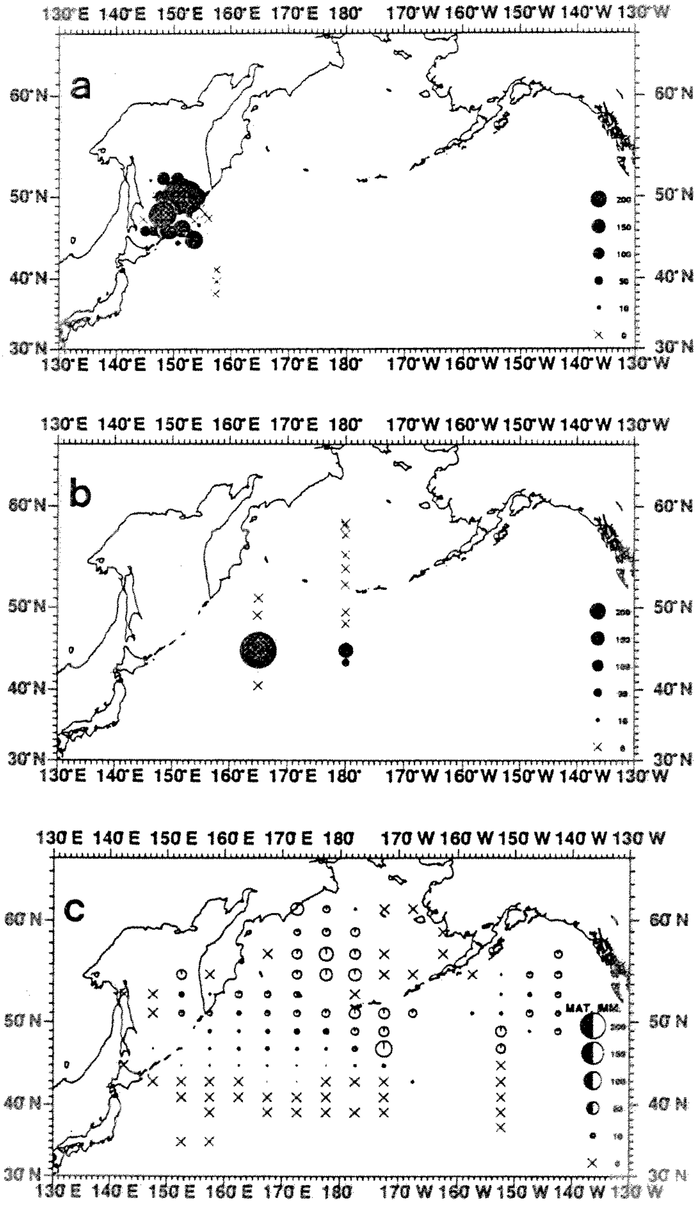
Keywords: Juvenile chum salmon, ocean current, migration model

Fig. 1. Observed distributions of juvenile and immature chum salmon. (a) November. (b) February. (c) July.



Recent juvenile salmon research indicates that juvenile chum salmon at age .0 migrate from the central part to the southern part of the Sea of Okhotsk in mid autumn (Ueno and Sakai 1998) (Fig. 1 (a)). Juvenile chum salmon at age .0 were not found in the north part of the central North Pacific Ocean in the early winter, but they were distributed in the western North Pacific in mid and late winter. But juvenile chum salmon at age .1 were not found in the Bering Sea in mid winter (Fig. 1 (b)). In June, immature chum salmon at age .1 were distributed from 40°N to 50°N. In July, they were widely distributed from 45°N to 60°N (Fig. 1 (c)). Immature chum salmon at age .1 were most abundant in the Bering Sea in July and August, compared to the number in the central North Pacific Ocean. Urawa (personal communication) reported that Japanese and Russian chum salmon were distributed in the central North Pacific Ocean and the Bering Sea in the summer. Thus, juvenile chum salmon might migrate eastward from the western North Pacific Ocean to the central North Pacific Ocean during winter and spring, and enter the Bering Sea in summer of their second marine year. Ueno et al. (1999) hypothesized that salmon juveniles were carried eastward by the strong eastward ocean currents from the western to the eastern North Pacific Ocean. However, it is still unclear how the ocean currents contribute to the migration of chum salmon and why juvenile Japanese chum salmon enter the Bering Sea in summer of their second marine year. We examined this problem by studying the temporal effect of ocean currents and salmon distribution using a salmon migration model.

The data were collected from Japanese salmon research vessels in offshore waters of the North Pacific Ocean from 1972 to 1999. Sea surface temperatures (SST) were monthly mean sea surface temperature from 1991 to 1997 provided by Japan Meteorological Agency. Wind driven currents were calculated from climatological wind stress data by Hellerman and Rosenstein (1983). Geostrophic currents were computed from satellite altimetry data of TOPEX/Poseidon in 1991 to 1997 with 5-day and 1 degree of latitude and longitude resolution provided by the Japan Meteorological Agency.

The salmon migration model was essentially a particle-tracking model coupling the passive particle-tracking component and the active salmon swimming component. The passive particle-tracking component was driven by the surface currents, geostrophic currents, and wind driven currents. The active swimming speed of chum salmon was assumed to be 1 body length/second as suggested by Ware (1978). Direction of the salmon swimming depended on the salmon's preferred SST. This water temperature in which salmon were distributed was estimated by weighted average with CPUE of salmon. Ocean migration was simulated for the period of 17 months from 15 September of the first simulation year to 28 February of its third year. The starting date of the simulation coincided with the date when juveniles at age .0 were found in the Sea of Okhotsk (Ueno and Sakai 1998). The starting positions of migration for Japanese, Russian, and Alaskan chum salmon were located in the Sea of Okhotsk, along the east coast of the Kamchatka, and the Alaska coast, respectively.

Calculated Japanese and Russian chum salmon at age .0 started from the Sea of Okhotsk in September and gradually moved into the western North Pacific Ocean by 30 November (after 75 days) (Fig. 2 (a)). In February (after 165 days), calculated distributions of Japanese and Russian chum salmon at age .1 were from 40°N to 50°N (Fig. 2 (b)). In 30 July (after 315 days), calculated Japanese and Russian chum salmon at age .1 were shown to enter the Bering Sea as they were observed (Fig. 2 (c)). The salmon migration model therefore reproduced the observed migration patterns of chum salmon.

We examined the following three velocity components affecting the migration of Japanese chum salmon: geostrophic currents, wind driven currents, and swimming speed of chum salmon (Fig. 3). Wind driven currents affected the migration as well as the active swimming speed of chum salmon in winter. While in summer, mainly the active swimming speed of the salmon affected the migration. These results suggested that Japanese chum salmon were transported eastward by the ocean currents, and they migrated northward from the North Pacific Ocean to the Bering Sea mainly by their own swimming activity in summer.

Fig. 2. Simulated distributions of juvenile and immature chum salmon. Solid circles represent Japanese and Russian chum salmon. Crosses represent Russian chum salmon. Open circles represent Alaskan chum salmon. (a) November. (b) February. (c) July.

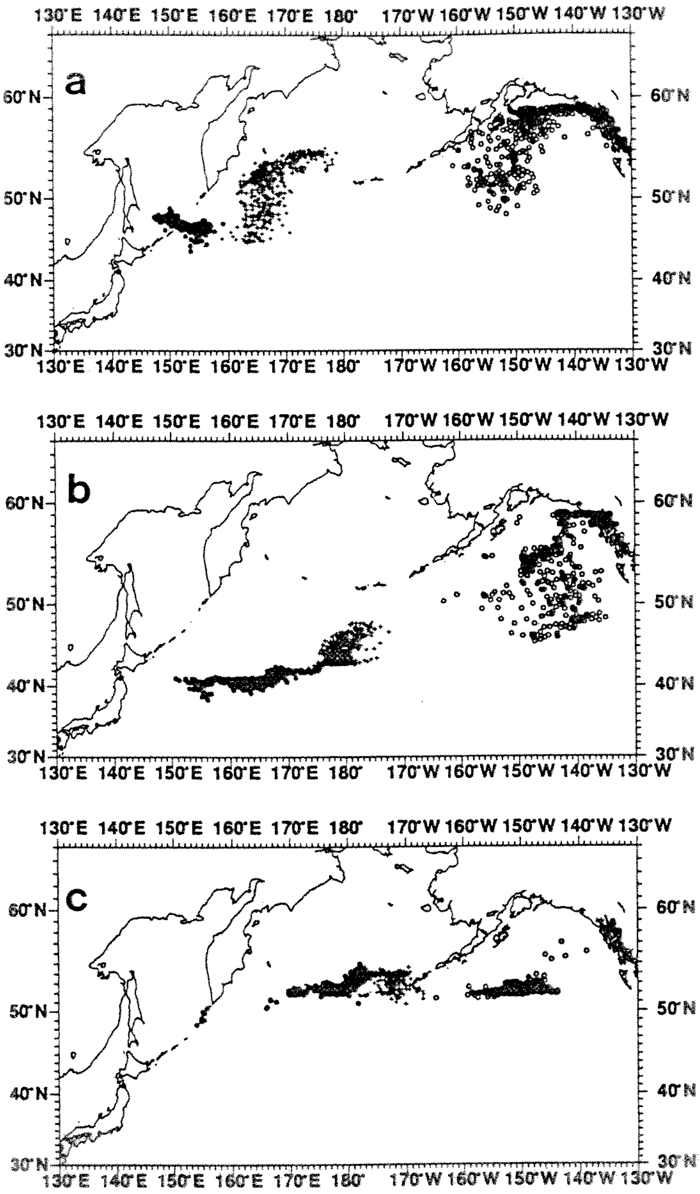
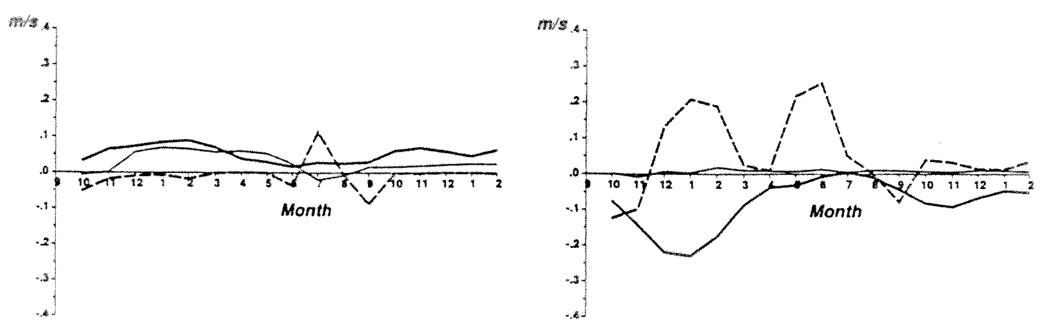


Fig. 3. Seasonal change of longitudinal component of velocity (left panel) and latitudinal component of velocity (right panel). Thick solid lines are velocity of wind driven current. Thin solid lines are velocity of geostrophic current. Broken lines are velocity of salmon actively swimming.



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Effects of Water Temperature and Day Length on Seawater Tolerance of Yearling Sockeye Salmon (*Oncorhynchus nerka*)

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Keywords: Sockeye salmon, seawater tolerance, water temperature, day length

The early life history of sockeye salmon (*Oncorhynchus nerka*) is characterized by an increase in seawater tolerance preceding seaward migration. This phenomenon usually occurs in spring in response to environmental factors such as day length or water temperature or both. It is possible to change the timing of this phenomenon. For example, underyearling masu salmon exposed to longer day lengths than their natural photoperiod develop their seawater tolerance in autumn (Ikuta et al. 1987). Juvenile chinook salmon reared at 17°C reached maximum seawater tolerance two months earlier than those reared at 9°C (Clarke and Shelbourn 1985). However, less is known about these relationships in sockeye salmon. In this study, the effects of water temperature and day length on seawater tolerance of yearling sockeye salmon were investigated.

In mid-January, 600 yearling sockeye salmon were separated equally into six groups (A to F groups) and moved to 100L tanks. They were reared under a uniform feeding rate at 3% body weight per day until early April. Throughout the experiment, groups A, B and C were supplied with river water (3–5°C), and groups D, E and F were supplied with well water (7–8°C). All tanks were shielded with vinyl cloth, and day lengths were controlled by using artificial lighting (Table 1). The day lengths of groups A and D were gradually increased from 9.5 hrs in mid-January to 12.5 hrs in early April, which simulated the natural photoperiod. The day length of groups B and E were fixed at 11 hrs and 13 hrs respectively from mid-January to mid-February, and groups C and F at 13 hrs and 15 hrs respectively from mid-February to early April. Natural day length at the beginning of the experiment was 9.5 hrs in mid-January. During the experimental period, all groups were used in four monthly seawater challenge tests. For each seawater challenge test, 10 individuals were collected from each tank and transferred directly into seawater for 24 hrs. Blood was continuously drawn from them in order to measure serum sodium concentrations. At the same time, blood samples for the analysis of serum thyroxine (T4) concentration, and gill and kidney samples for the assay of Na^+,K^+-ATPase activity were taken from another 10 individuals from each of the six fresh water groups. This was done after measuring fork lengths. Seawater tolerance was assessed by gill and kidney Na^+,K^+-ATPase activity, and serum sodium concentration 24 hrs after the transfer of the fish to seawater.

The mean fork length of groups A, B, C and groups D, E, F increased from 108 mm in mid-January to 112–117 mm and 125–131 mm respectively in early April. The serum sodium concentration of groups C and F fell from 195.7 mEq/L in mid-January to 160.0 mEq/L and 157.8 mEq/L in early April. The groups B, D, E and group A had a serum sodium concentration of 164.9–168.0 mEq/L and 180.9 mEq/L respectively. While all groups showed a reduction during the experimental period, the serum sodium concentration of the groups C and F were much lower than those of other groups. Conversely, the gill Na^+,K^+-ATPase activity in all groups increased continuously in every month. However, groups E and F showed a much higher increase in the enzyme activity from 3.4 µmols Pi/mg pro./h in mid-January to 14.9µmols Pi/mg pro./h and 20.9 µmols Pi/mg pro./h in early April. The enzyme activities of groups B, C, D and group A were 7.4–8.2µmols Pi/mg pro./h and 5.1µmols Pi/mg pro./h respectively in early April. Group F, which had the longest day length and warmer water than other groups, showed the highest seawater tolerance and gill Na^+,K^+-ATPase activity. The kidney Na^+,K^+-ATPase activity of all groups fluctuated between 12.5–18.3 µmols Pi/mg pro./h throughout the experiment, but there was no significant difference (using a *t*-test) among the six groups at each collection time. These results indicate that seawater tolerance of yearling sockeye salmon is stimulated by increases in day length, as a result of elevation in the gill Na^+,K^+-ATPase activity. Furthermore, longer day length and higher water temperature accelerate the development of these phenomena.

Table 1. Rearing condition of Groups A, B, C, D, E and F.

	Day length		
Water temperature	9.5 h–12.5 h	11 h–13 h	13 h–15 h
3–5 C, river water	Group A	Group B	Group C
7–8 C, well water	Group D	Group E	Group F

The serum T4 concentrations of the six groups were 77.6 ng/ml in mid-January, 123.7–129.5 ng/ml in mid-February, 99.2–113.1 ng/ml in mid-March, and 165.2–175.7 ng/ml in early April. Though the mean value fluctuated widely during the experimental period, there were no significant differences (*t*-test) among the six groups in each month. These results indicate that increased day length triggered a secretion of T4 in yearling sockeye salmon. However, there was no correlation between differences in day length and the profile of serum T4 concentration.

From the present study, it is clear that longer day length and higher water temperature stimulate the development of seawater tolerance in yearling sockeye salmon as a result of increases in the gill Na^+,K^+-ATPase activity. These phenomena may be correlated with the increase of serum T4, which is triggered by increased day length.

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Forecasting Coho Salmon Survival in the Oregon Production Index Region

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* * *

Keywords: Coho salmon, SST, OPI, survival, coastal ocean

Inter-annual fluctuations in the overall productivity of hatchery-reared coho salmon (*Oncorhynchus kisutch*) in the Oregon Production Index (OPI) region are thought to be mainly determined by marine conditions, given that hatcheries are usually near the mouth of rivers and that smolts spend little time in estuaries before migrating to sea. Previous studies have found good relationships between smolt to adult survival and various ocean indices (Nickelson 1986, Pearcy 1992, Lawson 1997, Koslow et al. in press). Cole (2000) found that coastal sea surface temperature (SST) anomalies along the Oregon and southern Washington coasts could account for over 90% of the variation in OPI coho salmon survival for the 1985 to 1995 ocean entry (OE) year classes. The purposes of this study are to (1) update and modify as necessary the Cole (2000) model for the 1985–1998 OE year classes, (2) to make forecasts for the survival of the 1999 OE year class, and (3) to evaluate the model's robustness by using two different sources of SST data.

Mean weekly SST anomalies within 40 km of the coast were calculated from Pathfinder SST data (http://podaac.jpl.nasa.gov/sst) using a 14.5 year climatology (January 1985–June 1999). Mean weekly SST anomalies were similarly derived from the Reynolds SST data (http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/) also using a 1985–1999 climatology. Estimates of public hatchery coho salmon marine survival came from the Oregon Department of Fisheries and Wildlife (J. Fisher, College of Oceanic & Atmospheric Sciences, Oregon State University, Corvallis, OR 97331 USA, and P. Lawson, Hatfield Marine Science Center NOAA-NMFS/NWFSC, Newport OR 97365 USA, personal communications).

For each OE year class the sum of negative SST anomalies in the year of ocean entry was derived for an Early Marine Phase (EMP), and the sum of positive SST anomalies in the calendar year following the year of ocean entry was derived for a Late Marine Phase (LMP). The sum of positive anomalies for the LMP was linearly weighted by the sum of EMP negative anomalies. The lower the sum, i.e., the more negative the sum, the higher the weighting.

Survival models were constructed for both SST datasets from the output of non-linear multiple regressions (using the ACE algorithm, Breiman and Freidman 1985). Survival was the dependent variable, with the sum of EMP negative anomalies and the sum of LMP positive anomalies as the two independent variables (Cole 2000).

The 1999 OE year class survival was forecast from the 'Pathfinder' and 'Reynolds' models using the appropriate EMP and LMP anomaly sums. N.B., the 'Pathfinder' LMP values for the 1999 OE year class were estimated from the regressed relationship of existing Pathfinder versus Reynolds LMP values.

The two survival models account for over 90% of the variation in coho salmon survival from 1985 to 1998 (Figs. 1 and 2). Good survival is forecasted for the 1999 OE year class, 12.2% from the Pathfinder model and 7.5% from the Reynolds model. Cool conditions during EMP are associated with improved survival (Fig. 1). In contrast, if EMP conditions were cool, warm conditions during the LMP are associated with reduced survival. For example, conditions during the 1991 EMP were cool, and hence conducive to good juvenile survival. This good early survival, however, may have been over-ridden by the 1992 El Niño. Cole (2000) has a more detailed discussion of the relations between SST anomalies and ocean processes and factors affecting coho salmon survival.

Differences between the two models (e.g., shape of the contours and different 1999 forecasts) are due to some differences between SST values in the two datasets. For example, the Oregon SST upwelling signal, which is often found only close to the coast, may sometimes be lost or weakened in the Reynolds anomalies, given that they come from an area that extends further offshore than the Pathfinder anomalies.

In spite of high R^2 values for both models, caution is still needed. For example, a 1984 hindcast using the Reynolds model is very different than actual survival (Fig. 3). N.B., the Pathfinder data does not extend back beyond 1985. Reasons for the inaccurate hindcast are as follows: (1) SST may sometimes be an inadequate proxy of environmental conditions, e.g., 1984 had a very late transition from winter downwelling to summer upwelling conditions (Bilbao 1999; A. Hobday, CSIRO Marine Research, GPO Box 1538, Hobart Tasmania 7001 Australia, personal communication) that was not reflected by coastal SSTs; (2) sometimes the Reynolds anomalies may not adequately reflect conditions very close to the coast (i.e., within ~40 km); and (3) perhaps some unknown biological or ecological factor was acting.

Fig. 1. Survival models and 1999 forecasts from the (a) Pathfinder and (b) Reynolds datasets. The contours (z) represents levels of annual smolt-adult survival. The position of each year-class in the time series is represented by the symbols.

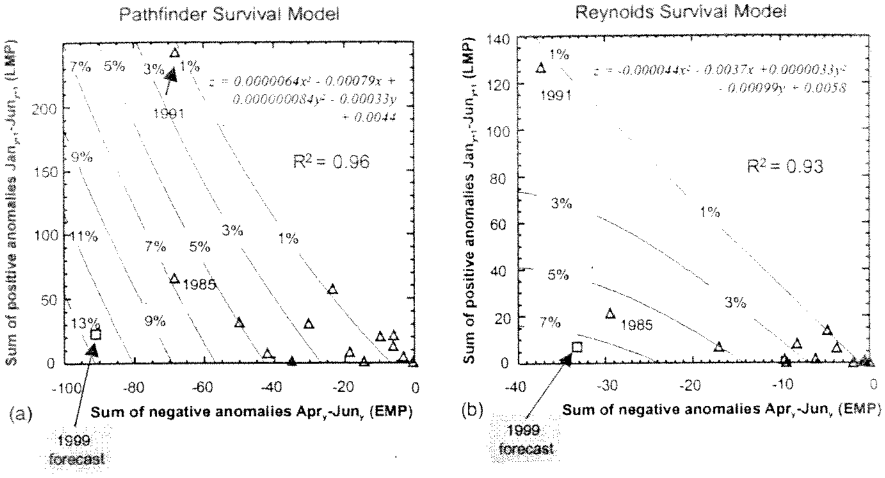


Fig. 2. Actual versus predicted survival from the (a) Pathfinder, and (b) Reynolds models, and 1999 Ocean entry year-class survival estimates.

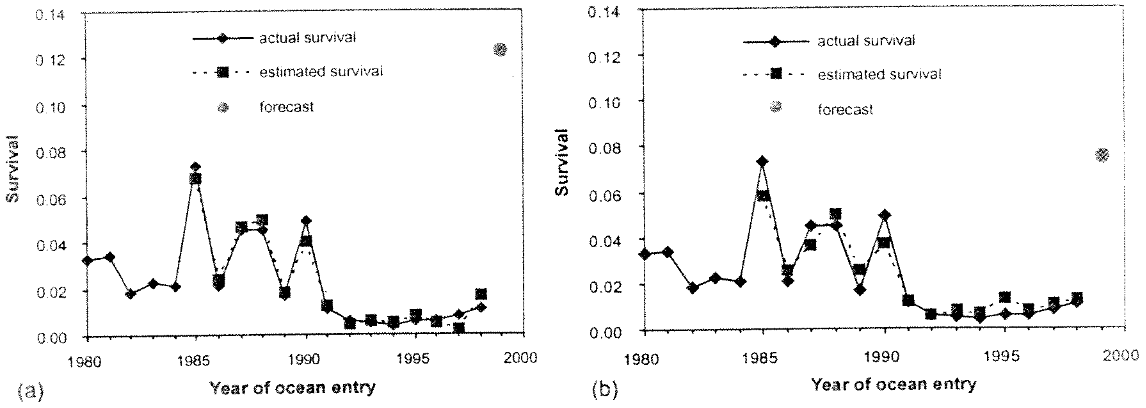
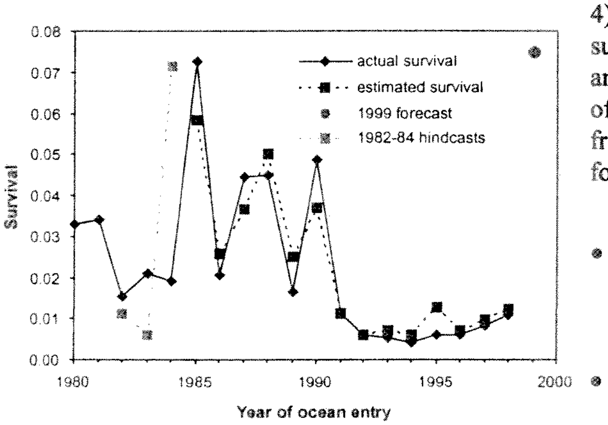


Fig. 3. Reynolds survival model with hindcasts for 1982–1984.



One final note of caution regarding the 1999 forecasts comes from the returns of precocious males ('jacks') (Fig. 4). From jack returns alone we would not expect overall survival to be anywhere near as high as predicted by the SST anomaly models (i.e., ~2.5% vs. 7.5% or 12.2%). Survival of the 1999 year class is likely to deviate strongly either from the jack-based forecast or from the anomaly-based forecasts.

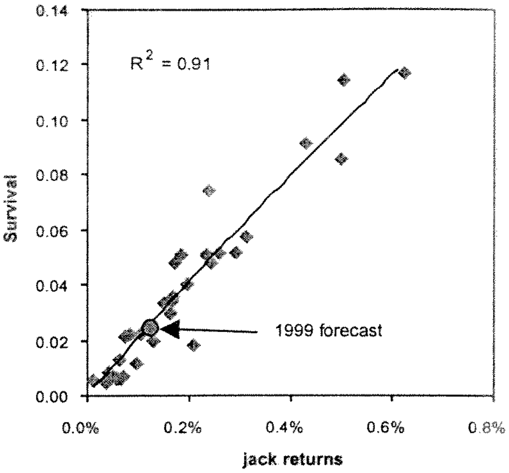
Our conclusions are summarized as follows:

- Cool conditions when coho salmon enter the ocean are associated with good survival. Exceptions appear to be associated with very warm (i.e., El Niño) conditions later in ocean residency.
- Coastal SST anomalies can account for > 90% of variation in survival in 1985–1998.

- Reynolds and Pathfinder survival models are broadly similar.
- The forecasted survival of the 1999 OE year class is very good, 12.2% from the Pathfinder model and 7.5% from the Reynolds model.
- The models have clear management applications, but caution is still needed. Environment-fisheries models often periodically break down, as illustrated by the 1984 hindcast in Fig. 3, and the 1999 forecasts are very different from what would be expected based on the number of jacks that returned.

The following are thanked for their assistance: Joe Fisher, Oregon State University, and Peter Lawson, Hatfield Marine Science Center (NOAA-NMFS, Newport, Oregon), for providing the OPI coho salmon data, and Jorge Vazquez from the Jet Propulsion Laboratory for his help with the Pathfinder dataset.

Fig. 4. Jack returns, as a percentage of smolts released, versus smolt: adult survival. A survival estimate for the 1999 ocean entry year class, based on jack returns during 1999, is as indicated.



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Factors Affecting Distribution, Migration, and Growth of Juvenile Sockeye Salmon in the Eastern Bering Sea (July and September 1999)

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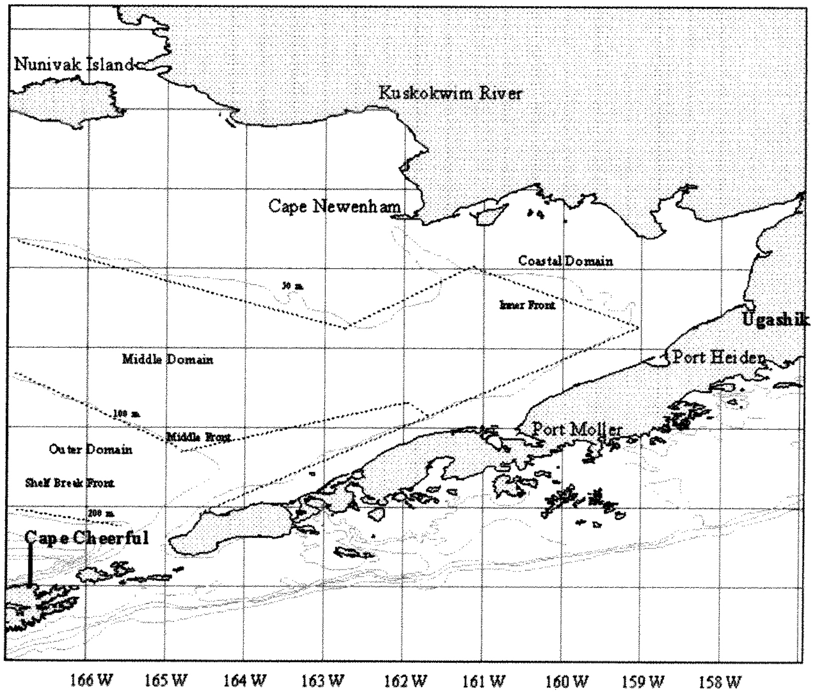
Keywords: Sockeye salmon, juvenile, Bristol Bay, Bering Sea

Eastern Bering Sea research cruises were conducted by the Auke Bay Laboratory, Ocean Carrying Capacity (OCC) program during July and September 1999 to study the early marine distribution, migration, and growth of juvenile Bristol Bay sockeye salmon (*Oncorhynchus nerka*). The survey area was bounded to the west by Cape Cheerful and to the east by the Ugashik River, crossing the coastal, middle, and outer domains of the eastern Bering Sea (Fig. 1). The 1999 surveys were the first in a series of annual assessments to document variations in the biological characteristics (growth, migration, and distribution) of juvenile sockeye salmon leaving Bristol Bay (Farley et al. 1999). The primary goal of the annual assessments is to establish and verify the linkages between adult sockeye salmon survival and annual variations in biological characteristics of juvenile sockeye salmon.

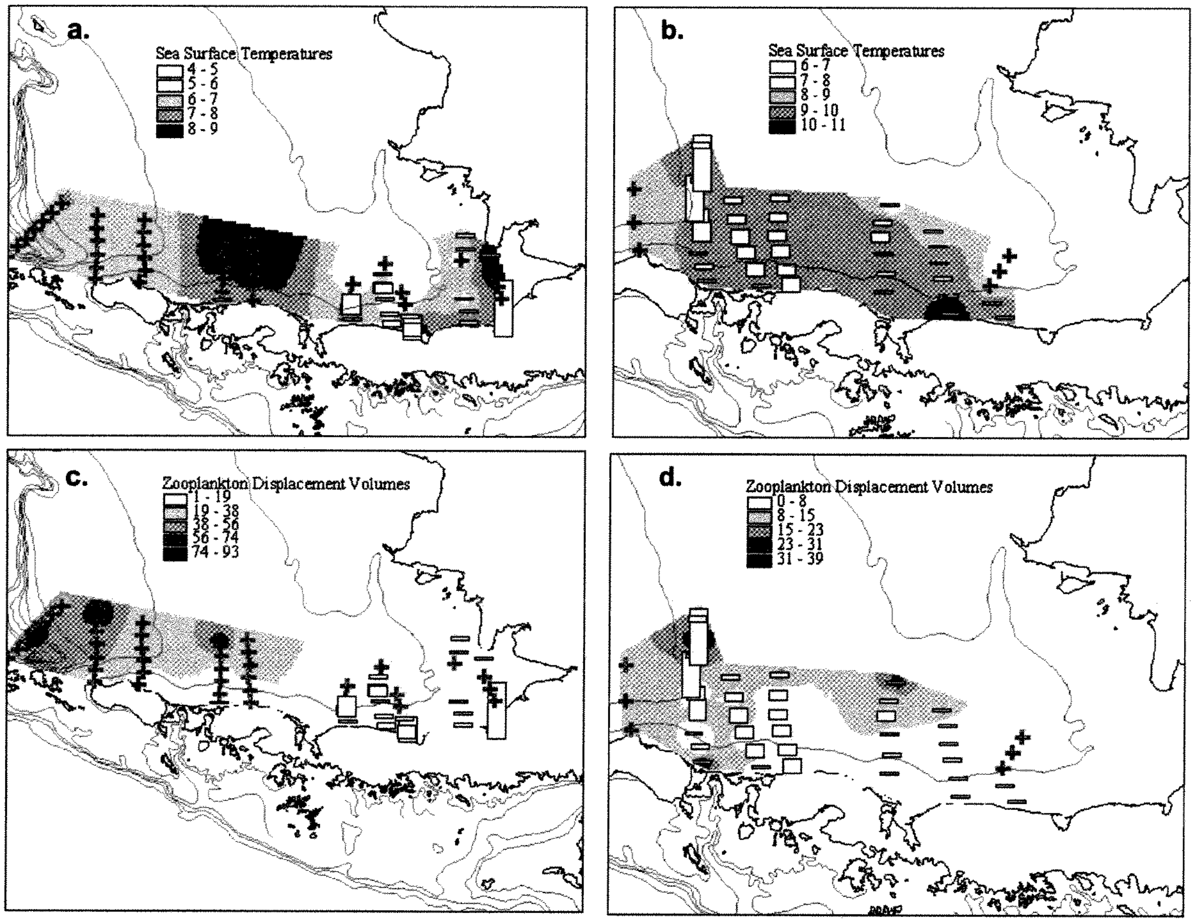
Fig. 1. Area surveyed by the *F/V Great Pacific* (coastal waters of the eastern Bering Sea from Cape Cheerful to Ugashik) during July and September 1999.



Past studies of Bristol Bay sockeye salmon have given us a good description of the habitat and migration characteristics of juvenile sockeye salmon as they leave Bristol Bay, moving along the north shore of the Alaska Peninsula (Straty 1974; Straty and Jaenicke 1980; Straty 1981). These studies have also shown how juvenile salmon respond to environmental conditions along their migration path, suggesting the following conceptual model of the affects of marine environment on distribution, migration, and growth of juvenile Bristol Bay sockeye salmon in the eastern Bering Sea: (1) the distribution of juvenile sockeye salmon in the coastal waters of Bristol Bay is influenced by environmental conditions such as temperature and salinity; (2) migration rates vary as a function of temperature, food density, juvenile salmon body size, and stock origin; and (3) growth rates are related to migration rates, coastal distribution patterns, and food production in Bristol Bay.

The 1999 surveys were designed to test for seasonal (summer and fall) differences in distribution, migration, and growth of juvenile sockeye salmon along the coastal waters of the eastern Bering Sea and also to substantiate the conceptual model. During July, most of the juvenile sockeye salmon were encountered northeastward of Port Moller, and were distributed from nearshore to 74 km offshore (Fig. 2a). The extent of offshore distribution of juvenile sockeye salmon during July may have been related to sea surface temperatures. Sea surface temperatures during this period indicated that a cold pool of surface water (< 6°C) was located offshore between Port Moller and Port Heiden (Fig. 2a). Juvenile sockeye salmon were encountered shoreward of the cold pool, apparently preferring the warmer surface waters along the coast. Most of the juvenile sockeye salmon encountered during September were southwestward of Port Moller, and were distributed from nearshore to 150 km offshore (Fig. 2b). The expanded offshore distribution of juvenile sockeye salmon encountered during September may have been the result of increased sea surface temperatures (> 8.5°C) within this area.

Fig. 2. Contours of sea surface temperatures (°C) (a and b) and zooplankton displacement volumes (ml·m^{-2}) (c; 333 μm mesh and d; 505 μm mesh) and associated juvenile sockeye salmon catch in the eastern Bering Sea during July (a and c) and September (b and d). Bars indicate areas where juvenile sockeye salmon were caught, larger bars indicate larger catch. Plus signs indicate areas sampled where no juvenile sockeye salmon were caught.



The 1999 OCC summer and fall surveys were unique in that they occurred after a cold spring in the eastern Bering Sea, which was characterized by a delay in the breakup of lake-ice in sockeye salmon nursery lakes and anomalously cold sea temperatures (Farley et al. 1999). The cold spring may have delayed the seaward migration of juvenile sockeye salmon. For example, during July we caught only one juvenile sockeye salmon west of Port Moller; whereas, past studies of juvenile salmon migration in the eastern Bering Sea that occurred after relatively warm springs, indicated that large catches of juvenile sockeye salmon could occur west of Port Moller during this time period (Straty and Jaenicke 1980; Hartt and Dell 1986; Isakson et al. 1986).

Our 1999 survey results suggest that the anamolously cold spring and surface water temperatures possibly delayed offshore migration of juvenile sockeye salmon into areas of greater forage densities, affecting their early marine growth. During July and September 1999, zooplankton densities (ml·m^{-2}) were greatest within the middle domain and within the coastal domain west of Port Moller (Fig. 2c,d). Differences in seasonal distribution of juvenile sockeye salmon (distributed within low zooplankton densities during July and high zooplankton densities during September) may explain the significantly higher growth and condition factor found for juvenile sockeye salmon captured during September than those captured during July (Table 1). Similar observations of early marine distribution, migration, and growth of juvenile sockeye salmon encountered within the coastal waters of the eastern Bering Sea during the summer of 1971 (which followed a anamolously cold spring) by Straty (1974) were followed

Table 1. Number of samples (*n*) and mean and standard deviation (SD) of length (mm), weight (g), and condition factor (k) by freshwater age of juvenile sockeye salmon collected during July and September 1999. Numbers that are bold indicate significant differences ($p < 0.01$).

	Length			Weight		Condition	
	n	mm	SD	g	SD	k	SD
Age 1.							
July	646	92.8	11.0	7.0	2.93	0.990	0.06
September	248	**145.7**	16.4	**32.4**	11.9	**1.008**	0.03
Age 2.							
July	282	124.9	15.3	19.0	7.1	0.998	0.09
September	108	**168.9**	22.3	**51.8**	20.8	**1.020**	0.06

by dramatically reduced adult sockeye salmon returns to Bristol Bay two (1973) and three (1974) years later. If this qualitative comparison holds true, then we may expect lower than average returns of 2-ocean sockeye salmon to Bristol Bay during summer 2001.

The authors thank the Alaska Boat Company, particularly Captain Charles J. (Jack) Bronson and Captain Mathew Zimny and the crew of the F/V *Great Pacific* for their fine efforts on behalf of our research goals. We also thank staff from Fisheries Oceanographic Coordinated Investigations (FOCI) especially Christine Baier for her support in zooplankton collections during the July survey. Funding for processing the July zooplankton collections was provided by FOCI. The National Marine Fisheries Service, Alaska Regional Office, provided funding support for the September 1999 cruise.

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Analysis of Glucose, Triglyceride and RNA/DNA Ratio to Evaluate Starvation in Hatchery-Reared and Wild Juvenile Masu Salmon, *Oncorhynchus Masou*

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Keywords: Masu salmon, starvation, liver, triglyceride, mortality

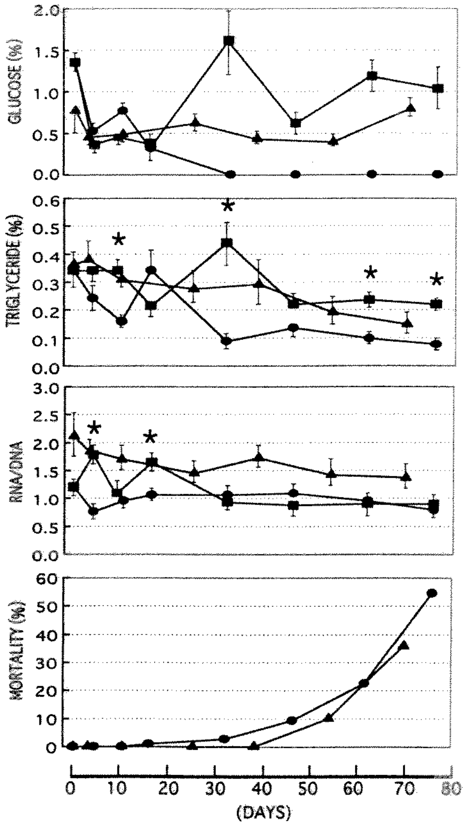
Masu salmon spend at least one year in the river after emergence. In general, survival rates in the river are not high (Nagata et al. 1984). Although the causes of their death remain unclear, starvation is considered one of major sources of mortality as has been observed in young jack mackerel, *Trachurus symmetricus* (Theilacker 1986).

Glucose and triglyceride are the main energy reserve in anchovy, *Engraulis mordax* (Håkanson 1989) and in Japanese flounder, *Paralichthys olivaceus* (Takaya 1997). RNA/DNA ratio analysis is useful for the estimation of growth rate in several species of marine fish larvae (Buckley 1984). There are few studies that clarify the relationship between mortality and body composition during starvation in salmonids. In the present study, glucose (GC) and triglyceride (TG) content and RNA/DNA ratio in the liver of hatchery-reared and wild juvenile masu salmon, reared without supply of food up to death, were analyzed to determine whether these body compositions were suitable as an indicator of starvation.

Hatchery-reared juveniles were raised in Erimo Research Branch for about four months after emergence using commercial pellets. A sample of fish were starved from 25 May 1999, and sampled for analysis on days 0, 4, 10, 16, 32, 46, 62, and 76. The rest were released into Utabetsu River near Erimo Research Branch on 25 May 1999. Fish were caught in the river for analysis on almost the same days as the starved juveniles (HS) were sampled. In addition, wild juveniles (WS) were caught in Atsuta River. They were transported to Erimo Research Branch and starved beginning 2 July 1999. Sampling for analysis occurred on days 0, 3, 10, 25, 38, 54, and 70. Mean fork lengths of HS and WS were 6.29 and 6.41 cm respectively on 0 day. The number of dead juveniles was counted every day during the experiment, and the mortality was calculated in each sampling period. More than five juveniles were used for each analysis of GC and TG content and RNA/DNA ratio.

Figure 1 shows changes in GC and TG content, RNA/DNA ratio, and mortality of hatchery-reared and wild juveniles during the experiment. In HS, GC content decreased rapidly from 0 day (1.35±0.15%), and was not detected on or after 32 days. In juveniles released into the river (HR), GC content decreased from 0 to 16 days, and thereafter increased on and after 32 days. Although TG content did not change significantly from 0 to 76 days in HR, it decreased gradually during the sampling period and reached 0.08±0.01% on 76 days in HS. The values of TG in HS were significantly lower than HR on 10, 32, 62, and 76 days. In both HS and HR, RNA/DNA ratio fluctuated from 0 to 16 days. Beginning on day 32,

Fig. 1. Changes in glucose and tryglyceride content RNA/DNA ratio in a liver and mortality of hatchery-reared and wild juvenile masu salmon during the experiment. Bars indicate the standard errors. Asterisk represents statistical significance between hatchery-reared juveniles released into the river and starved hatchery-reared juveniles ($p < 0.05$).
●: starved hatchery-reared juvenile ■: hatchery-reared juvenile released into the river ▲: starved wild juvenile



RNA/DNA ratio showed a constant course. In WS, GC content did not change significantly during the starvation experiment. TG content (0.16±0.03 - 0.20±0.04%) and RNA/DNA ratio (1.44±0.19 - 1.47±0.17) on day 54 and day 70, however, were significantly lower than initial values. Dead HS juveniles were observed on and after 16 days, and mortality reached 54.6% from 62 to 76 days. While dead WS juveniles were found on and after 38 days, and mortality reached 35.6% from 54 to 70 days. TG values were similar in the latter half of the experiment. The appearance of dead juveniles coincided with the time when TG reached 0.2% in both HS and WS. We interpret these results to indicate that TG content is a useful index of severe starvation in juvenile masu salmon. The change in GC content during starvation was not similar between HS and WS, and values of RNA/DNA ratio in HS tended to be lower than in WS. Thus, it is necessary to investigate the causes of these differences to establish criteria to measure starvation in hatchery-reared and wild masu salmon.

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Distribution, Origins, Biology, and Ecology of Juvenile Steelhead (*Oncorhynchus mykiss*) in the Gulf of Alaska in Summer 1993–2000

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Keywords: Juvenile steelhead, sea surface temperature, growth, food habits, eddies

Published high-seas research vessel data (1955–1985) has shown that juvenile steelhead (*Oncorhynchus mykiss*) are widely distributed in offshore waters of the Gulf of Alaska (Burgner et al. 1992) by mid-summer of their first year at sea. We present new information on juvenile steelhead collected during summer research cruises of the T/S *Oshoro maru* in the central Gulf of Alaska, 1993–2000. Varied-mesh surface gillnets (2.45 km long, 6 m deep) were used to catch salmonids at fishing stations located at 1° latitude intervals along 145°W from 49°N to 56°N. A total of 134 juvenile (ocean age-.0) steelhead was caught over the 8-year study. Juvenile steelhead were distributed along the entire transect, but catches were highest in the area between 51°N–53°N, particularly at 52°N (Fig. 1). There was no apparent relationship between sea surface temperatures (SST) and distribution of juvenile steelhead. The highest catches were at 10°C, which reflects mean SSTs at the 52°N station (Fig. 2). Six coded-wire tagged juvenile steelhead, released from US Pacific Northwest hatcheries in April and recovered in July (1980, 1996–1998) along the transect, included three inland summer-run steelhead from the Snake R., Idaho, two winter-run steelhead from the Cowlitz R., Washington (lower Columbia R. tributary), and a coastal winter-run steelhead from the Salmon R., Washington (Queets R. tributary). Juvenile steelhead grow rapidly during their first summer at sea, and their mean body sizes in 1993–2000 (fork length (FL) = 332 mm; body weight (BW) = 395 g; n = 134 fish) were similar to those reported for 1955–1985 (FL = 337 mm, n = 245; BW = 391 g, n = 53 fish) (Fig. 3). There are no published detailed data on feeding habits of juvenile steelhead in offshore waters. We found that juvenile steelhead fed primarily on small squid (*Berryteuthis* spp.) and larval and juvenile fish (Fig. 4). The food habits data show considerable interannual variation, which may be related to changes in prey abundance or distribution of prey with respect to environmental conditions. Recently published data indicates that mesoscale (200–300 km) and small (< 200 km) eddies, observed every year along the 145°W transect, may strongly influence primary productivity and distribution of fish and their prey in this region (Onishi et al. 2000).

Fig. 1. The number of juvenile steelhead caught by gillnet sampling at fishing stations located at 1° -latitude intervals along 145°W in summer 1993–2000.

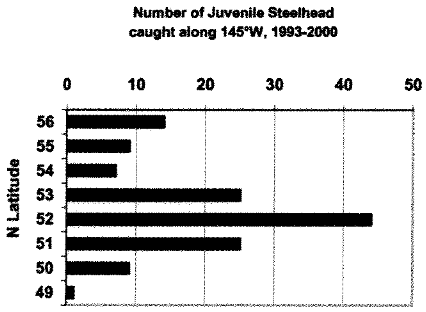

Fig. 2. The number of juvenile steelhead caught by sea surface temperature (SST, °C), and SSTs by latitude along 145°W in summer 1993–2000.

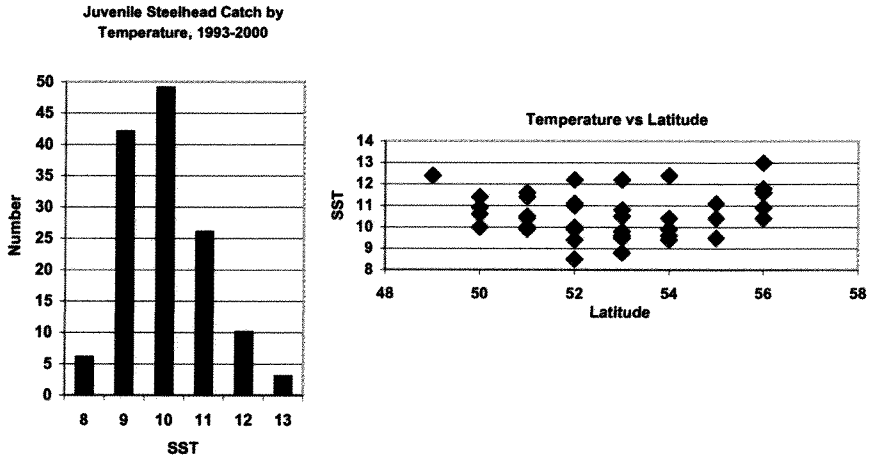

Fig. 3. Average length (mm) and weight (g) of juvenile steelhead caught along 145°W in summer 1994–2000. Sample sizes by year: 1994 = 13 fish, 1995 = 9 fish, 1996 = 29 fish, 1997 = 17 fish, 1998 = 27 fish, 1999 = 9 fish, 2000 = 29, 1994–2000 = 133 fish.

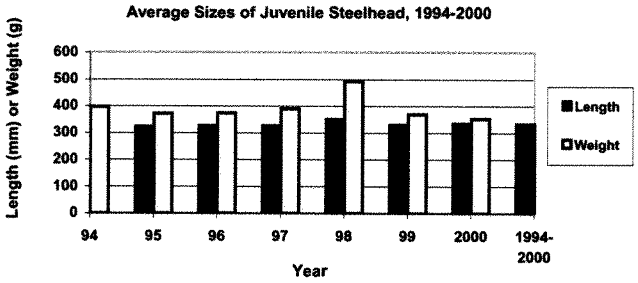

Fig. 4. Percentage composition (by volume) of major prey categories in stomach contents of juvenile steelhead caught along 145°W in summer 1994–2000. Sample sizes by year: 1994 = 12 fish, 1995 = 8 fish, 1996 = 29 fish, 1997 = 17 fish, 1998 = 24 fish, 1999 = 9 fish, 2000 = 27 fish. Pter = pteropod, Amph = amphipod, Euph = euphausiid, Poly = polychaete, Cope = copepod, Gel = gelatinous zooplankton, Unident = unidentified prey.

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Possible Effects of Sea Ice in the Southern Okhotsk Sea on the Survival of Pink Salmon Juveniles from Hokkaido and East Sakhalin

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* * *

Keywords: Pink salmon, survival, sea ice, Okhotsk Sea, climate change, North Pacific

During spring and early summer, pink salmon (*Oncorhynchus gorbuscha*) fry and juveniles from Hokkaido and East Sakhalin go to the sea and stay in coastal waters of the southern Okhotsk Sea (Takagi et al. 1981), which are covered with sea ice during winter and early spring. This paper examines the effects of sea ice in the southern Okhotsk Sea on the stocks of Hokkaido and East Sakhalin pink salmon (see Nagasawa 2000).

During the period when the intensity of the Aleutian Low strengthened from 1977 to 1988, the sea ice area expanded in the Okhotsk Sea, coastal pink salmon catches declined in East Sakhalin and remained low in Hokkaido. The decline was not caused by offshore fishing because Japanese high seas salmon fisheries were banned in 1977. After the Aleutian Low weakened in 1989, the sea ice area sharply decreased in the Okhotsk Sea, and coastal pink salmon catches increased dramatically in these regions. In Hokkaido, the marine survival of pink salmon juveniles released from hatcheries similarly increased. Although long-term data on sea surface temperature (SST) are not available from these regions, fluctuations in coastal sea-ice related environmental conditions in the southern Okhotsk Sea appear to be associated with variations in the stock size of pink salmon. It is likely that juveniles have a higher mortality due to decreased SST in the Okhotsk Sea when the sea ice area expands, and also that the sea-ice cover affects the survival of fed, large-sized pink salmon juveniles from hatcheries.

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Response of Juvenile Masu Salmon, *Oncorhynchus masou* to Habitat Change, and Habitat Rehabilitation

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Keywords: Masu salmon, stream environments, habitat change, rehabilitation

Masu salmon is one of the most important commercial salmon in Hokkaido, however their landings have been decreasing since the 1970s in spite of the intensive enhancement programs. Masu salmon are dependent on freshwater environments because they live in streams for more than one year before they migrate to the ocean. However, the quality of freshwater environments has deteriorated due to man-made constructions, clear cut logging, and agricultural development, particularly since the 1950s. Accordingly, it is worthwhile to reduce the extent of stream degradation and to enhance fish habitat to restore our masu salmon resources.

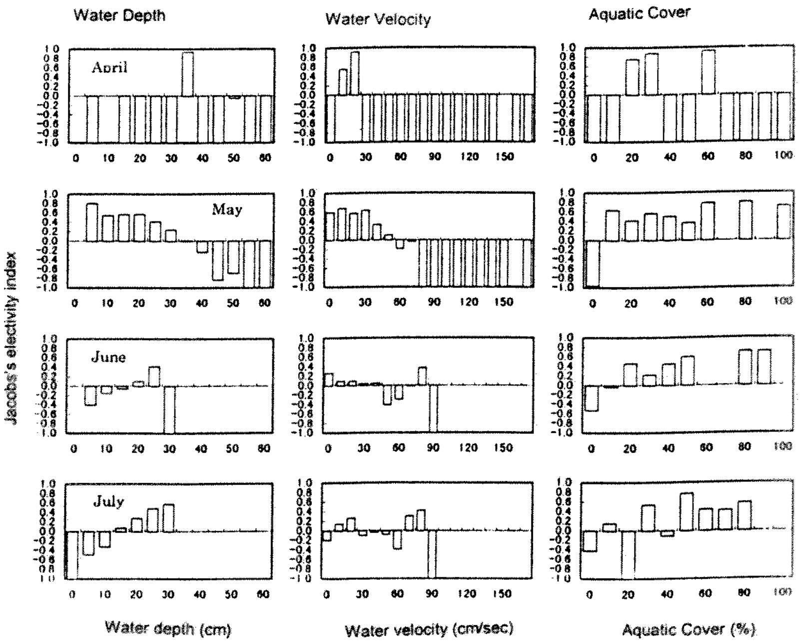
In recent years, we have studied juvenile masu salmon and their relationships with the freshwater environments in several streams to allow us to restore masu salmon habitat. In this report we summarize this work and review other recent studies on masu salmon responses to environmental changes including water temperature and stream structure, and habitat rehabilitation and enhancement.

When masu salmon fry emerge from their redds, they are very sensitive to stream flow changes, and most of them go downstream and/or remain at the spawning area. The first feeding period for salmonids is a critical time, and population dynamics during this period affect their survival and growth. Therefore, it is important to know what physical environments masu salmon fry select actively, and how these habitat preferences shift with growth.

Our studies were conducted in the upper reach of the Shakotan and Masuhoro rivers of Hokkaido. Study sites in both streams were divided into individual cells (one cell: 1 m × 1 m) to survey detailed environments. We captured masu salmon juveniles in each cell by electrofishing. After fish sampling was completed, habitat variables were measured for each cell, including depth of water column, water velocities, substrate composition (dominant substrate size), and percentage covers of overhanging and aquatic vegetation.

Shortly after masu salmon fry emerged in the Shakotan River, they distributed contagiously at submerged stream margins (Nagata et al. 1998a). Newly emerged fry favored low water velocity areas, particularly less than 30 cm/sec (surface velocity), 20 cm/sec (bottom velocity), and shallow water less than 30 cm. Masu fry favored habitats with dense cover of aquatic vegetation (Fig. 1). Aquatic cover decreases water velocity because energy is lost when water passes through the cover. Cover also provides security from predation.

Fig.1. Jacobs's electivity index (Jacobs, 1974) of water depth, water velocity and aquatic cover used by masu salmon from April to July in 1994. (from Nagata et al., 1998a).



A distinct shift in the distribution of masu salmon juveniles occurred from May to June. Although some masu juveniles remained in the habitat with low water velocity, shallow water, and dense cover even in June, others moved to new habitats with high water velocity, deeper water, and less cover. From May to June, masu salmon juveniles grew rapidly and most exceeded 4 cm in fork length. These studies support the view that summer habitat preferences of masu salmon juveniles are more variable as they become more competitive and require more food resources to grow.

Overwintering surveys in the Masuhoro River showed that masu juveniles shifted from the main channel to side channels. Overwintering juveniles favored lateral habitats with low water velocity, dense aquatic vegetation, and deep water in order to conserve energy (Suzuki et al. 2000).

Recently range land management has increasingly involved conservation and restoration of riverine environments because more attentions is being paid to the importance of rebuilding the natural ecosystem. As we showed for masu salmon, stream margins can make a unique contribution because they increase habitat diversity and provide rearing and refuge areas for juvenile masu salmon. Unfortunately, stream margins have been altered in many streams of Hokkaido by bank erosion and flood control measures. As stream margins, backwaters, and secondary channels are critical habitats for salmonids, it is essential to restore and conserve submerged areas.

We examined the relationship between masu salmon size and past stream temperature before early feeding to test the hypothesis that fish size at early feeding can be predicted by the past stream temperature. There are significant relationships between fish size and past stream temperature (Nagata, unpublished data), indicating that masu salmon fry in downstream areas with high past temperature tend to be larger than those in upstream areas and tributaries with low past temperature. However, high stream temperatures are not always desirable for masu salmon.

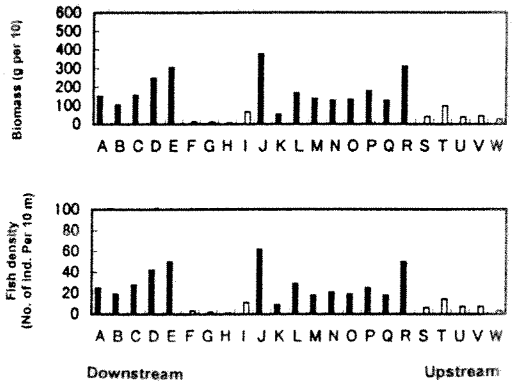
We also examined the influence of a loss of riparian vegetation on stream temperature, and resultant consequences on growth and survival of masu salmon juveniles (Nagata et al. 1998b). Five study stations along the Shakotan River were established to monitor changes in stream temperature, growth, condition factors, and population density of juvenile masu salmon in 1994 and 1995. The 1994 summer was so hot that stream temperature increased rapidly and exceeded 20°C in the middle reach with the least overhead cover. In contrast, the 1995 summer was cool and stream temperatures in the middle reach rarely exceeded 20°C. Masu salmon juveniles in the middle reach almost stopped growing, and their condition factor and population density also decreased from July to August in 1994. In contrast, masu salmon juveniles in the middle reach continued to grow and their condition factors increased from July to August in 1995. These results suggest that overhead cover by riparian vegetation contributes to maintaining low summer stream temperature that enables rapid growth of masu salmon juveniles during the summer.

Before smolting, masu salmon have to overcome severe winter conditions such as low water levels and shortages of food. Stocking experiments with different size groups of masu salmon juveniles showed that larger juveniles have higher survival during winter, presumably because energy supplies of large fish aid survival during times of cold water and shortages of food (Miyakoshi et al. 1999).

The middle portion of the Shakotan River was modified from 1969 to 1975 to assist with flood control. The meandering channel was straightened, the river bed was protected by setting gabionades; river gradient was increased; and all riparian vegetation was removed. Unfortunately, the riparian forest in part of the clear cut area has not yet recovered. In addition to low juvenile salmon growth because of high water temperature during summer in the non-forested reach, there are few spawning and rearing sites for masu salmon in the channelized reaches.

Channel restoration work was carried out in the summer of 1996 to rehabilitate the spawning and rearing sites (Yanai 1997). As a result of this rehabilitation, stream habitats in the restored section became more complicated and diverse, containing pools, riffles, and runs instead of the previous simple structure. Thanks to these improvements, several masu and chum salmon redds have been found in the restored spawning section, particularly in the tail of plunge pools (Yanai 1997). Many masu salmon fry remained in the restored section. A greater biomass of masu salmon juveniles in summer was found in restored spawning and rearing sections than the unimproved sections, particularly in pools (Ohmori 1999, Fig. 2). In conclusion, stream changes using log dams and deflectors can contribute to habitat improvements for masu salmon, and are a useful habitat enhancement technique for masu salmon resources in natural streams.

Fig. 2. Biomass and fish density of masu salmon juveniles (0+) in improved (black histograms) and unimproved (white histograms) sections. Each unit represents 10-m distance except for M unit (5 m). A value in M unit was doubled (from Ohmori, 1999).



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Lipid Composition in Muscle and Liver Tissues of Chum and Pink Salmon Captured in the Gulf of Alaska during May, 1999

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Keywords: Lipid content, chum salmon, pink salmon, Gulf of Alaska, spring

The quantity of lipid has been used as a biochemical index of trophic condition in a variety of contexts for both freshwater and marine fish. In a previous paper, lipid content and fatty acids were studied to investigate trophic condition of chum and pink salmon in the North Pacific Ocean in winter (Nomura et al. 2000). There are no reports of trophic condition of salmonids in spring. A limitation of lipid research on salmonids in spring is the difficulty of collecting samples for analysis. A systematic trawl survey was conducted aboard the F/V *Great Pacific* in the Gulf of Alaska in May of 1999, and we report on the lipid content in white muscle and liver of salmonids in spring.

A total of 210 salmon (116 chum, 51 pink, 9 chinook, 10 coho, and 24 sockeye salmon), captured by trawl on the F/V *Great Pacific* in the Gulf of Alaska in May 1999, was used as spring samples. A total of 268 salmon (122 chum, 92 pink, 5 chinook, 16 coho, and 20 sockeye salmon, and 13 steelhead), captured by gillnet on the T/S *Oshoro maru* at 10 stations in the Gulf of Alaska in July 1999, was used as summer samples. The fork length (cm) and weight (g) of salmonids were measured, and used to calculate the condition factor (((Fork length (cm)3)/(Body weight (g)))x1,000). Tissue samples were frozen at -20°C until analyzed. Total lipids in the white muscle were extracted with chloroform/methanol (Folch et al. 1957) and measured gravimetrically, separated into polar lipid and neutral lipid fractions with Sep-Pak (Waters Co., MS, U.S.A.), and measured gravimetrically.

We compared the total lipid content of immature and maturing chum salmon captured in the Gulf of Alaska in spring. The means of total lipid in immature (n = 45) and maturing (n = 70) fish were 1.8% and 4.2%, respectively. There was a significant difference (P = 0.05) between the total lipids in white muscle in immature and maturing fish. In Fig. 1, total lipid content in white muscle of chum salmon is shown by ocean age. Total lipid content in age-.1 fish was low (< 2.3%, mean = 1.3%), and it was also low in age-.2 fish (< 5.5%, mean = 2.0%). In age-.3 fish, total lipid content was higher than in age-.1 and age-.2 fish (< 10.9%, mean = 3.9%). The total lipid contents in age- .3–.5 fish were significantly higher than those of age-.1–.2 fish.

Fig. 1. Total lipid content in white muscle in chum salmon caught in the Gulf of Alaska in spring by ocean age. Bars are means, and lines are SD

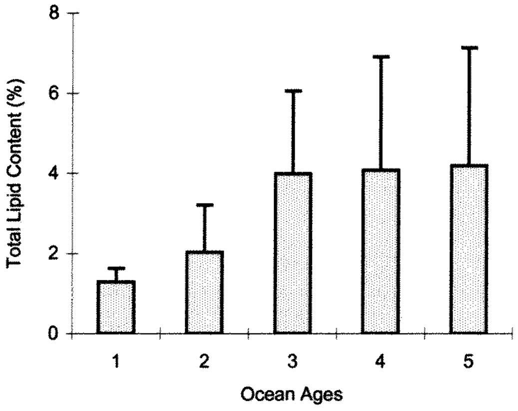


Figure 2 shows the correlation between total lipid content in white muscle and body weight by age of salmon caught in the Gulf of Alaska in spring. Salmon smaller than 1,000g in body weight had low lipid content in white muscle, and total lipid content increased with body weight for salmon weighing over 1,500 g.

In spring, lipid content in the white muscle in pink salmon was low (< 6.5%, mean = 2.7%). In summer, lipid content in white muscle (< 20.2%, mean = 7.2%) increased with body weight.

Total lipid contents in sockeye, chinook, and coho salmon, and steelhead captured in spring and summer are studied. In spring, all species had low lipid contents in white muscle, but lipid contents increased with body weight in summer, except for steelhead (< 11.0%, mean = 2.4%). There is no correlation between total lipid in liver and body weight in chum and pink salmon (Fig. 3).

Fig. 2. Correlation between total lipid content in white muscle and body weight in chum salmon caught in the Gulf of Alaska in spring by ocean age. Open circles are the age-.1 fish, closed circles are the age-.2 fish, open squares are the age-.3 fish, closed squares are the age-.4 fish, open triangles are the age-.5 fish and closed triangles are the age unknown fish of unknown age.

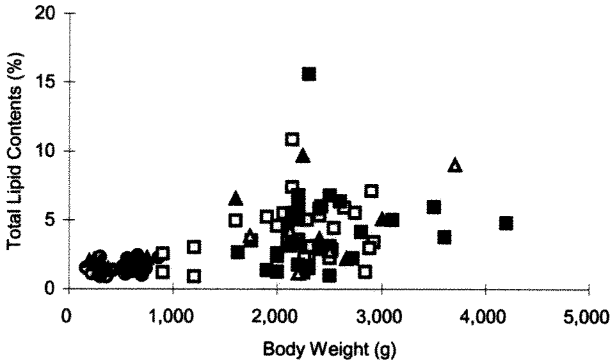
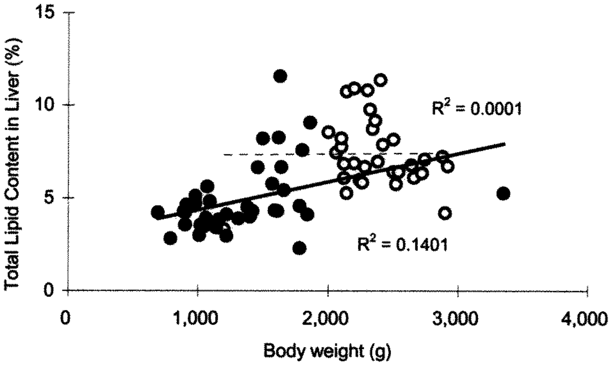


Fig. 3. Correlation between total lipid content in liver and body weight in chum salmon caught in the Gulf of Alaska in spring and summer. Open circles and dots are spring fish, and closed circles and line are summer fish.



In previous papers, we reported that lipid content of chum and pink salmon white muscle in winter is low (Nomura et al. 1999; Nomura et al. 2000). Young salmonids in spring showed very low lipid contents, the same as the low lipid contents observed in winter. The low lipid contents in white muscle in spring suggest that a starved condition, which was observed in winter, is prolonged into the spring in young fish in the Gulf of Alaska. We also showed that there is a significant difference in total lipid content in white muscle depending on maturity stage and age. It should be apparent that maturity stage is more significant than age in determining lipid levels. Sample sizes need to be much larger to adequately separate out the effects of age and maturity on total lipid content. We suspect, however, that investigation of lipid content in spring is important for estimation of survival and growth of high-seas salmonids.

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Southeast Alaska Coastal Monitoring for Habitat Use and Early Marine Ecology of Juvenile Pacific Salmon

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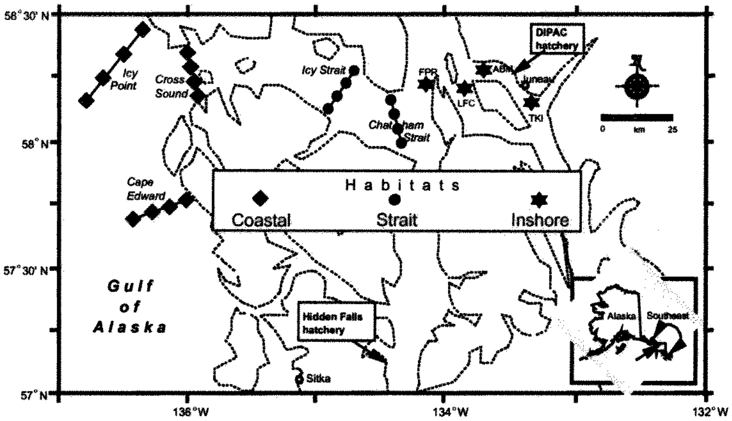
Keywords: Juvenile, salmon, marine, ecology, habitat, Southeast Alaska

The Southeast Coastal Monitoring (SECM) Project in Alaska was initiated in 1997 to study the habitat use and early marine ecology of juvenile (age-.0) Pacific salmon (*Oncorhynchus* spp). From May through October 1997–2000, biophysical parameters were sampled in inshore, strait, and coastal habitats along a primary seaward migration corridor used by juvenile salmon (Fig. 1). Up to 24 stations spanning 250 km were sampled five times annually. These habitats extend geographically from inshore localities near large glacial rivers to 65 km offshore in the Gulf of Alaska. Sampling was accomplished with a NORDIC 264 surface rope trawl fished from the NOAA ship *John. N. Cobb.*

Fig. 1. Stations sampled in inshore, strait, and coastal habitats of Southeast Alaska, May–September, 1997–2000.



Seasonal patterns in temperature, salinity, and zooplankton abundance were observed. In all habitats, surface (2-m) temperatures generally increased from May–July then declined from August–October. Surface temperatures increased more rapidly in inshore and strait habitats than in coastal habitats; temperatures were similar in all habitats in August, and by September–October the coastal habitats were warmest. Surface salinities in inshore and coastal habitats decreased from May–July, then increased from July–September. Salinity increased seaward, and was highest and most stable in coastal habitats. Zooplankton biomass in 20-m vertical plankton hauls was highest in inshore and strait habitats in May and June, then declined sharply from June–August. Zooplankton biomass was lower in coastal habitats compared to others, but varied less over the season. Therefore, juvenile salmon may follow migration cues of increasing seaward salinity and a seasonal decline in zooplankton biomass in inside waters.

Juvenile salmon were the dominant epipelagic fish in the catch during the trawl sampling. A total of 38,538 fish from 42 taxa were captured with 374 hauls. Five species of juvenile salmon comprised 65% of the catch, with pink (*O. gorbuscha*) and chum salmon (*O. keta*) each representing 29% of the catch. Of the remaining fish species captured, only three comprised > 5% of the catch: sablefish (*Anoplopoma fimbria*, 13%), Pacific herring (*Clupea harengus*, 8%), and capelin (*Mallotus villosus*, 7%). The biomass of these species may be underrepresented because their diel migration minimizes their diurnal occurrence near the surface.

Distribution of juvenile salmon varied by season and habitat. The catch rates of juvenile salmon were zero in May and highest in June and July for most species (Fig. 2). Among the habitats sampled, catch rates were highest in the straits, where declining abundance in August coincided with declining zooplankton biomass. In coastal habitats, catch rates of juvenile salmon declined with distance offshore; most juveniles were captured over the continental shelf within 25 km of shore.

Annual and seasonal differences in biophysical parameters were related to early marine growth of salmon. Warmer spring temperatures and higher zooplankton biomass occurred in El Niño years 1997–1998 compared to La Niña years 1999–2000. This was particularly evident in 1999, when decreased temperature and zooplankton biomass translated into lower apparent growth during June–July for pink and chum salmon in strait habitats (Fig. 3). Lower growth rates may increase mortality by making juveniles more vulnerable to size-selective predation or by decreasing their ability to compete.

Fig. 2. Average monthly proportion of cumulative catch of juvenile salmon (standardized for effort) sampled at stations in inshore, strait, and coastal habitats, May–September, 1997–2000.

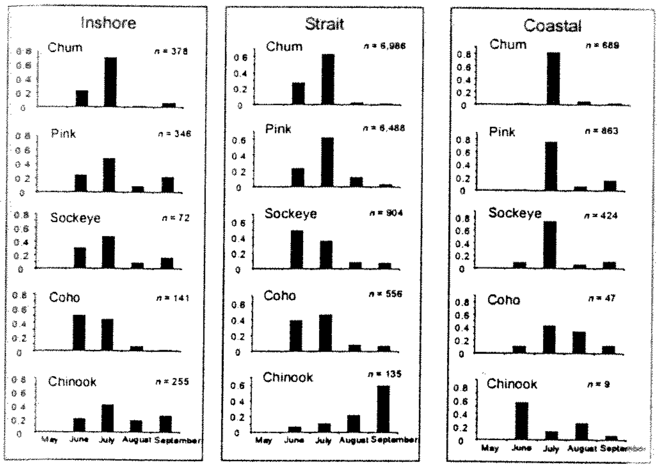
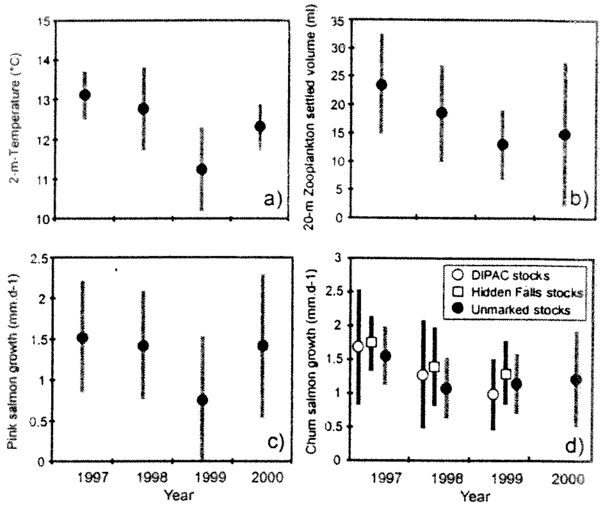


Fig. 3. Values (one SD about the mean) for: a) 2-m temperature, b) 20-m zooplankton settled volume, c) growth of juvenile pink salmon, and d) growth of juvenile chum salmon in strait habitats of Southeast Alaska, June–July, 1997–2000.

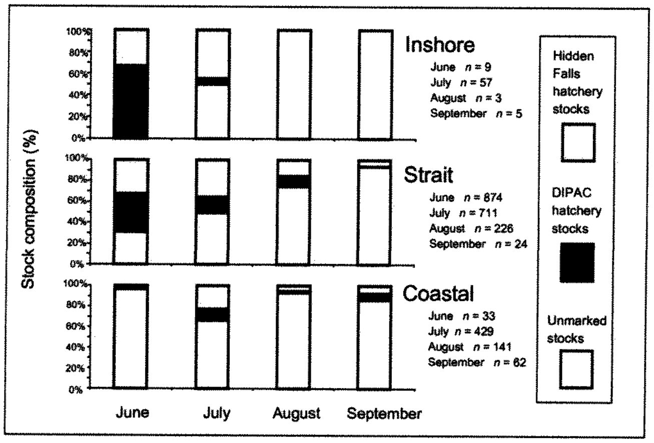


For pink salmon, early marine growth and abundance of juveniles may indicate year-class strength. Apparent growth of juvenile pink salmon in strait habitats from June–July and July–August was 1.4 and 1.3 mm.d-1 in 1998 compared to 0.8 and 0.7 mm.d-1 in 1999. Catch rates of juvenile pink salmon were also substantially higher in 1998 compared to 1999. Consequently, the harvest of adult pink salmon in Southeast Alaska was almost four times as high in 1999 (77.5 million) as in 2000 (20.2 million). Therefore, high marine survival may be predictable from high abundance of juvenile pink salmon and favorable growing conditions in strait habitats during early marine residence.

At-sea stomach analysis of potential predators indicated that predation on juvenile salmon occurred in five of the 19 fish species examined. Salmon occurred in 4% of the 876 stomachs examined. The percentage occurrence of salmon for each predator species was: 29% in age-1+ sablefish, 9% in adult coho salmon (*O. kisutch*), 8% in Pacific sandfish (*Trichodon trichodon*), 3% in spiny dogfish (*Squalus acanthias*), and < 1% in walleye pollock (*Theragra chalcogramma*). Predation on juvenile salmon by adult coho salmon and by spiny dogfish was observed in three of four years, by sablefish in two of four years, and by Pacific sandfish and walleye pollock in one of four years.

Data on origin of juvenile salmon show that fish in inshore and strait habitats are predominately of local origin, and are mixed with stocks of other regions when they enter the coastal waters of the Gulf of Alaska. Coded-wire tags were recovered from 34 (9%) juvenile chinook (*O. tshawytscha*) and 42 (4%) juvenile coho salmon. Over 90% (70) of the tagged juveniles were of Alaska origin, and were captured in inshore and strait habitats. Juveniles from the Columbia River (five chinook and one coho) were also recovered, only in coastal habitats. Marine migration rates of juvenile chinook and coho salmon averaged 1 and 3 km.d-1 for Alaska stocks, and 19 and 25 km.d-1 for Columbia River stocks. Otolith thermal marks were found in 985 (38%) of the juvenile chum and 57 (12%) of the juvenile sockeye salmon (*O. nerka*) sampled. All juvenile salmon with thermal marks were of Alaska hatchery origin, except one fish from British Columbia captured in the coastal habitat. In inshore and strait habitats in June and July, Alaska hatchery chum salmon comprised 50–100% of the total chum salmon catch; in coastal habitats, they comprised 5–35% (Fig. 4). No pink salmon were sampled for otolith marks because marking rates were low for this species.

Fig. 4. Seasonal stock composition of juvenile chum salmon based on thermal mark recoveries in inshore, strait, and coastal habitats of Southeast Alaska, June–October, 1997–2000.



Long-term ecological monitoring of key juvenile salmon stocks, in several regions of the North Pacific Rim and encompassing a variety of environmental conditions, is needed to understand the relations of habitat use, marine growth, and hatchery-wild stock interactions to year-class strength and ocean carrying capacity.

Handling Time and Profitability of Food in Juvenile Chum Salmon: Effects of Fish Size, Food Size, and Satiation

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Keywords: Handling time, optimal foraging, fish size, food size, satiation, chum salmon

As a first step toward understanding the size selective foraging of juvenile chum salmon by the optimal foraging approach, handling time and profitability of food were measured by feeding experiments with an artificial food, and the effects of fish size, food size, and satiation were examined.

The experiment was conducted five times when juvenile chum salmon grew to the target fork lengths (FL), of 40, 50, 60, 70, and 90 mm (Table 1). Juveniles were held individually in aquaria (30 x 60 x 30 cm) under natural photoperiod. The water temperature was maintained at 10.5°C. The fish were fed to satiation each day on a specified size of food (a commercial dry pellet). The food size offered on a given day was randomly chosen from the size range applicable to that size fish. Each trial was recorded by a video camera so that handling time could be estimated.

Handling time was defined as the time taken for swallowing one food pellet after it was captured. Average handling time (h_t) per individual was estimated from

$$h_t = f T_f + T_{su},$$

where f is the average number of failures preceding a successful feeding, T_f is the average time spent per failed feeding, and T_{su} is the average time spent per successful feeding. f was estimated by $(1-S)/S$, where S is the proportion of attacks that resulted in success (Bence and Murdoch 1986).

Table 1. Average fork length (FL), number of fish examined, and size of food offered in each experimental group of juvenile chum salmon.

	Group				
	40	50	60	70	90
FL (mm)	45.5	57.8	68.0	77.4	96.2
No. of fish	4	4	5	5	5
Food size (mm)					
0.86	○				
1.20	○	○			
1.80	○	○	○	○	
2.03	○	○	○	○	○
2.58		○	○	○	○
3.68			○	○	○
4.38					○

To examine the effect of the average handling time was estimated at low and high levels of satiation. The handling time at high satiation level was derived from the data of $n/n_t > 0.5$ where n is the nth food taken in a feeding sequence and n_t is the total number of food consumed in a trial.

The profitability of food to a fish was indicated by handling cost (handling time/mg dry weight of food). The cost of handling in a given fish size was computed from the following relationships:

handling time, food size, and gape size (see Fig. 1);

gape size (GS) and fish size (FL): $GS = 0.24FL^{0.754}$; and

dry weight (DW) and size (L) of food: $DW = 0.614L^{2.62}$.

Handling time increased exponentially with increasing relative food size (food size/gape size) in each size group at both satiation levels (Fig. 1). The relationships differed significantly between size groups of 40–50 mm and 60–90 mm at the low satiation level (ANCOVA, $F_{4,86} = 11.78, p < 0.001$) and the high satiation level (ANCOVA, $F_{4,86} = 13.62, p < 0.001$). Handling time was prolonged significantly as juveniles approached satiation in the 40–50 mm group (ANCOVA, $F_{4,61} = 14.92, p < 0.001$) and the 60–90 mm group (ANCOVA, $F_{4,117} = 19.62, p < 0.001$).

Handling cost was inversely related to food size, suggesting that larger food particles are more profitable for juvenile chum salmon (Fig. 2). In the course of growth from 40 mm to 60 mm FL, juveniles began to feed more efficiently on a broader range of food particle size. Satiation raised the regression curves, and improved the fit. This implies that juveniles would benefit by intensifying food size selectivity during the course of satiation.

The size (50–60 mm FL) at which juvenile chum salmon change handling time and handling cost is remarkably consistent with the size when they develop from fry to fingerling, move from littoral to more pelagic habitat, and broaden their prey size in the ocean (e.g., Okada and Taniguchi 1971; Kaeriyama 1989).

Fig. 1. Relations between handling time and the ratio of food size to gape size at low (A) and high (B) satiation levels in juvenile chum salmon. Solid curves indicate regression curves for the groups of 40 and 50 mm: (A) y = 2.31 exp(5.30x); (B) y = 4.42 exp(4.55x). Bold-solid curves indicate regression curves for the groups of 60, 70 and 90 mm: (A) y = 2.21 exp(3.88x); (B) y = 4.31 exp(3.03x).

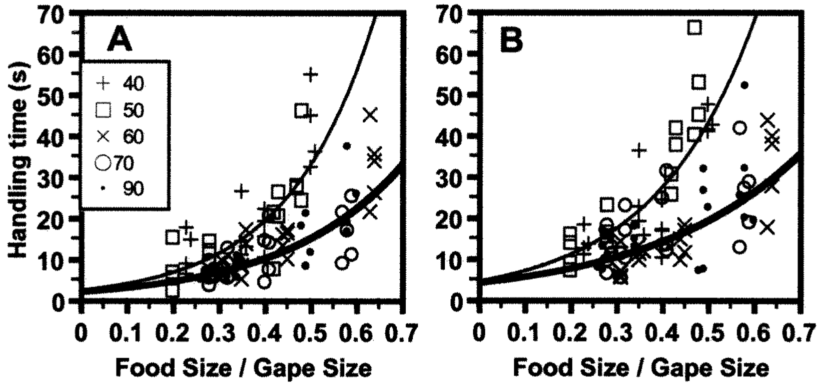
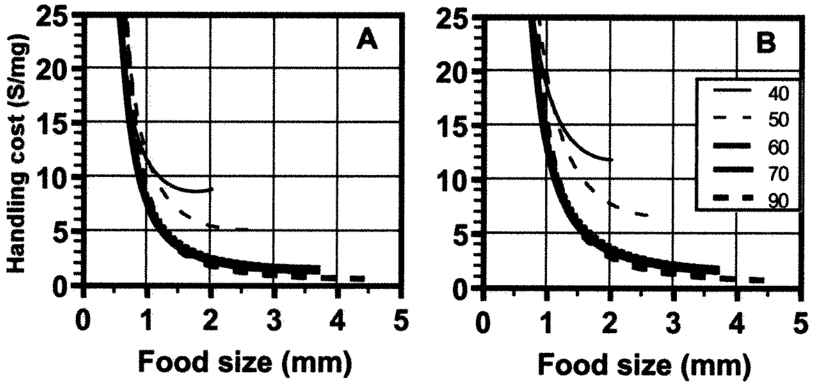


Fig. 2. Relations between handling cost (handling time/milligram dry weight of food) and food size at low (A) and high (B) satiation levels in juvenile chum salmon. Fish size (mm, fork length) for the curves is indicated in the legend. Each curve ends at the maximum food size that the fish is capable of handling.



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Monitoring the Juvenile Pink Salmon Food Supply and Predators in Prince William Sound

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* * *

Keywords: Pink salmon, mortality, predators, food supply, acoustic survey

The survival of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound (PWS) is a function of the availability of large calanoid copepods (genus *Neocalanus*) and the abundance of predators, especially walleye pollock (*Theragra chalcogramma*) and Pacific herring (*Clupea pallasi*) (Willette et al. 1999a,b). The Prince William Sound Science Center, with support from the Oil Spill Recovery Institute (OSRI), in cooperation with the Alaska Department of Fish and Game and the Ship Escort/Response Vessel System (SERVS), initiated a program in FY00 to begin monitoring spring predator and prey densities along the primary pink salmon out-migration path.

We collected volume backscatter measurements during three cruises in May 2000, using a three-frequency acoustic system (38 kHz, 120 kHz and 420 kHz) along a systematic line-transect survey. The survey design consisted of twelve transects extending along the main basin of PWS from Bligh Island to the Hinchinbrook Entrance and twelve more transects along the primary pink salmon out-migration corridor west and north of Knight Island, extending to Perry Island. This design was based on several criteria: (1) coverage of the historic area of juvenile pink salmon out-migration and hatchery locations, (2) contrast between the western out-migration route and the eastern side or main basin of Prince William Sound, and (3) an area that could be covered within a two-day survey. Transects were designed to be able to contrast near-shore and offshore areas as well as north/south trends. Periodic station data provided zooplankton composition and salinity/temperature profiles. The zooplankton sampling was a 50-m vertical tow using a 0.335-mm 0.5 m-ring net, following procedures of Cooney et al. (1995). Temperature and salinity data were acquired using a SeaBird Electronics Model 19.03 CTD. The three survey dates were May 3–4, May 12–13, and May 22–26.

The acoustic data were analyzed using standard echo integration techniques (Thorne 1983a,b). The plankton samples were analyzed to determine both size and frequency of the major components following procedures outlined in Kirsch et al. (2000). Acoustic backscattering cross-sections for the various zooplankton components were used to estimate abundance. Most values for the acoustic backscattering cross-sections were obtained from previous observations and scattering models (Stanton et al. 1994, 1996; Wiebe et al. 1997; Kirsch et al. 2000; G.B. Steinhart, 1558 Stanford Rd, Columbus, OH 43212, personal communication). Values for the remaining were estimated by forward problem analysis (Holliday and Pieper 1980; Wiebe et al. 1997). Fish densities were estimated from the 120-kHz data. The fish component to the scattering was estimated by thresholding the acoustic returns at –40 dB (G.B. Steinhart, 1558 Stanford Rd, Columbus, OH 43212, personal communication). A generalized acoustic cross-section equivalent to –32 dB/kg was used to estimate fish biomass from the thresholded returns (Thorne 1983b).

The ratios of volume backscatter from the upper 50 m among the three frequencies were sensitive to the relative components observed in the plankton net samples (Tables 1–2). Overall, the large bodied copepods, primarily *Neocalanus*, were the dominant zooplankton by weight, 73% in Knight Island/Perry Passage and 58% in the main basin. These copepods also dominated the 420 kHz backscatter, 80% in Knight Island/Perry Passage and 64% in the main basin (Fig. 1), were a major factor in the scattering at 120 kHz, and were detectable even at 38 kHz. At the beginning of May, the biomass of large copepods was high in the southern portion of Knight Island Passage (between Knight Island and Chenega Island), and was lower in the northern

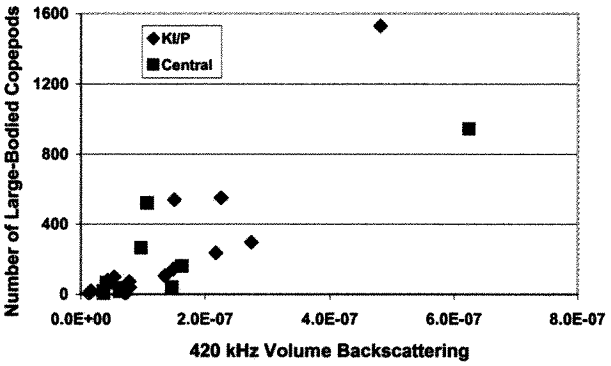
Table 1. Characteristics of plankton net samples in Knight Island (KI)/Perry Passage (P), and the main basin of Prince William Sound (Main).

	% Biomass Composition					Length (mm)		
Location	Small copepods	Large copepods	Oikopleura	Pteropod	Other	Large Copepod	Pteropod	Euphausid
KI/P	19.8	73.2	4.5	0.1	2.5			
Main	35.6	58.4	1.0	0.7	4.2			
Average	27.8	65.8	2.6	0.3	3.5	3.80	1.48	3.26

Table 2. Scattering characteristics of various components in plankton net samples.

	Volume Backscattering		Target Strength (dB)			
Frequency	KI/P	Main	Large Copepods	Small Copepods	Pteropods	Oikopleura
420	1.4E-07	1.4E-07	-97	-113	-95	-107
120	2.5E-07	1.3E-07	-98	-120	-95	-94
38	1.7E-07	6.0E-08	-102	-150	-115	-95

Fig. 1. Relation between 420 kHz volume backscattering and plankton net catches of large copepods in Knight Island Passage and the main (central) basin of Prince William Sound, May 2000.



portion (Perry Passage). As the month progressed, the biomass increased and the distribution shifted north (Fig. 2). During the first half of May, lower abundance was consistently found along the western edge of Knight Island Passage, and was associated with a surface lens of less saline water (Fig. 3). As the peak in abundance moved north, the distribution shifted slightly toward the center of the passage, but still remained low along the western edge. Fish abundance in Knight Island/Perry Passage was much lower than in the central basin at the beginning of May (Fig. 4). The fish abundance in Knight Island/Perry Passage increased at the end of May, while that in the central basin decreased.

The dominance by large copepods simplified the estimation of the various zooplankton components. This result was expected from previous observations (Kirsch et al. 2000), and was one of the reasons for the timing of the study. In addition to the simple composition, backscattering coefficients from the major components are all well documented for 420 kHz (Kirsch et al. 2000), and reasonably well documented for 120 kHz (Steinhart et al. unpublished ms). The differences between the Knight Island/Perry Passage and the main basin provided power to a forward problem analysis to estimate the backscattering cross-section of the other components at 120 and 38 kHz.

Fig. 2. Changes in large copepod abundance and distribution in Knight Island/Perry Passage during May 2000 estimated from 120 kHz.

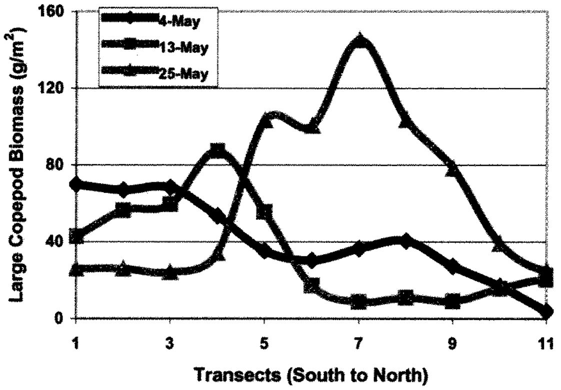
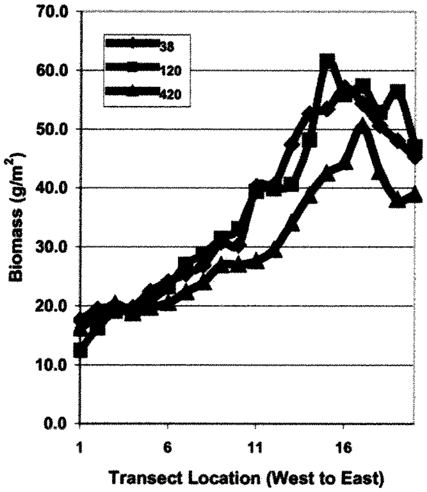
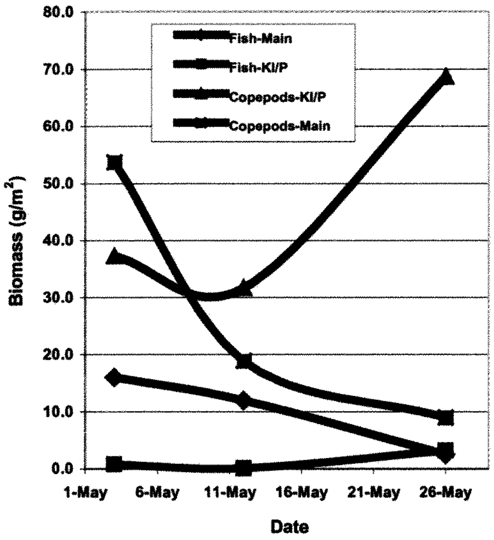


Fig. 3. West to east distribution of large copepod biomass in Knight Island/Perry Passage during the first half of May 2000, estimated from each of three frequencies.



Densities along the west side of the passages were low throughout the month. This observation may have implications for the juvenile salmon, since most hatchery release areas are along the west side. The low abundance of zooplankton along the west side was associated with a lens of less saline water from freshwater run-off. Willette et al. (1999a,b) hypothesized that juvenile salmon survival was improved when multiple storm events occurred in Prince William Sound during spring. The reason for the improved survival was speculated to be the prolonged spring zooplankton bloom that results from storm events. However, our detailed information on the zooplankton distribution suggests an alternative hypothesis, namely,

Fig. 4. Changes in biomass of large copepods and fish in Knight Island/Perry Passage and the main basin of Prince William Sound during May 2000.



that lack of storm events allows a salinity gradient to be established on the west side. The salinity gradient could either directly depress zooplankton abundance or alter the current regime so that zooplankton are advected to the eastern side. May 2000 was characterized by unusually calm conditions.

While the zooplankton distributions appear to be unfavorable for juvenile salmon growth, the lack of predators in Knight Island/Perry Passage would seem to favor juvenile salmon survival. This study is the first detailed monitoring of fish abundance during this time period, but previous studies suggest higher fish densities (Steinhart et al. unpublished ms). One predator, herring, is at historic lows (Thorne 2000), while the pollock remained primarily in the central basin until the end of the month. Future monitoring of this type should allow estimation of the relative importance of food supply and predator abundance on the juvenile salmon survival.

The goal of the OSRI zooplankton-monitoring program is to develop and apply a cost effective approach to estimation of pink salmon food supply and predator abundance. The observations from this study provide a valuable initial data framework to examine juvenile salmon survival. An understanding of the complex environmental conditions that govern juvenile salmon survival will only be obtained by long-term acquisition of this type of information. The results of this study demonstrate that the three-frequency acoustic system, supported by plankton net samples and CTD measurements, can provide a viable methodology, combining high quantification with the extremely high sampling power that is required to obtain sufficient detail in a reasonable time and cost framework.

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Survivorship of Juvenile Chum Salmon Released from Hokkaido, Japan: Independence of the Density Effect

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Keywords: Juvenile survival, rate of spawner, density effect

For the last couple of decades, chum salmon returns to northern Japan have reached the historically highest level. This is due to the success of the salmon hatchery programs in Japan (Kaeriyama 1996; Hiroi 1998). However, some reports noted the possibility that the growth of chum salmon has decreased (Kaeriyama 1989; Ishida et al. 1993). This paper describes the extent of the effect of density of juvenile chum salmon on their population dynamics.

Records of return and release of chum salmon in five regions around Hokkaido were collected for year classes from 1950 to 1994 by the National Salmon Resources Center. The number of survivors at each age was derived from iterative backward calculation by using the equation, $N_t = (N_{t+1} + R_t)e^M$ (N_t, the number of survivors at the beginning of age t; R_t, the number of fish returned at age t; M, coefficient of natural mortality in the period of ocean residence, postulated to be stable). M was calculated as $2.5/T_{max}$ (T_{max}, maximum age of return), proposed by Tanaka (1960) and cited in Watanabe (1999). The maximum age of return was 6 in regions A and C, and 7 in other regions. The survival rate of one-year-old juveniles was the percentage of N_1 to the number of juveniles released. The rates of change in juveniles released and one-year-old survivors were calculated as the percent ratio between the number juveniles released (or survivors) in each year class and the average number released (or survivors) from 1950 to 1961 year classes. As the salmon resource enhancement program in Hokkaido was started in 1962, the average shows the level of release and survival before the start of the program. From the values of N_t and R_t, the rate of spawners in total survivors at each age was calculated as $100R_t / (N_{t+1}+R_t)$.

The numbers of one-year-old survivors and spawners reached the maximum level in the year classes after the mid 1980s in all the regions. The survival rate of one-year-old salmon and the return rate also reached the highest levels in the corresponding year classes (Fig. 1). The rates of change in the number of one-year-old survivors in the year classes after 1970 far exceeded those of juveniles released. The percentage of age two- and three-year old spawners decreased in the year classes after the end of 1960s (Fig. 2). The maximum age of return increased in recent year classes.

The rise in juvenile survival and increase in the return of spawners to Hokkaido is due to the success of the salmon resource enhancement program. Maturation of chum salmon may have lagged with increase in the juvenile survival.

Survival of juvenile chum salmon released from Hokkaido is possibly independent of the density of juvenile salmon, or the number of juveniles released may not be high enough to cause an increase in the density effect. However, the decrease in the rate of the spawners at age and the increase in the maximum age of return suggest that the slowdown of growth of chum salmon in the period of ocean residence is an effect of increased density.

Fig. 1. Numbers of juveniles released, spawners returning, and 1-yr.-old survivors. A, coast along Okhotsk Sea; B, Nemuro Strait; C, east coast of Pacific Ocean; D, west coast of Pacific Ocean; E, Coast along Sea of Japan. ◁; calculated from provisional figure.

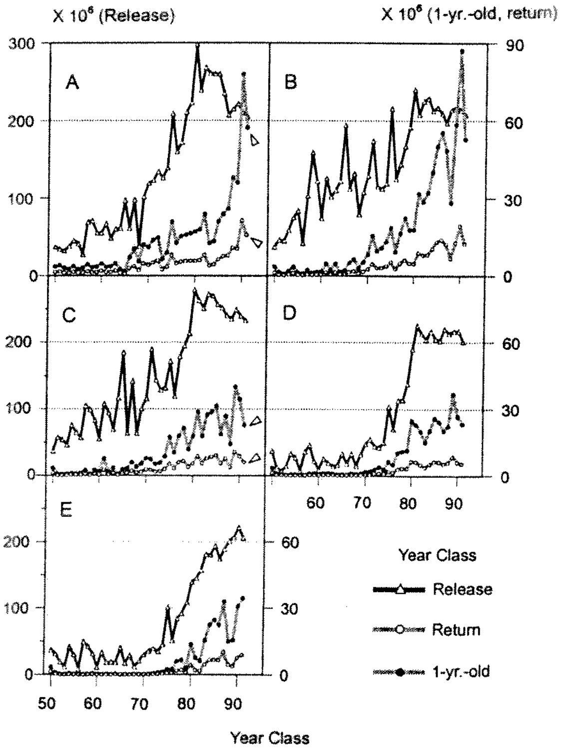
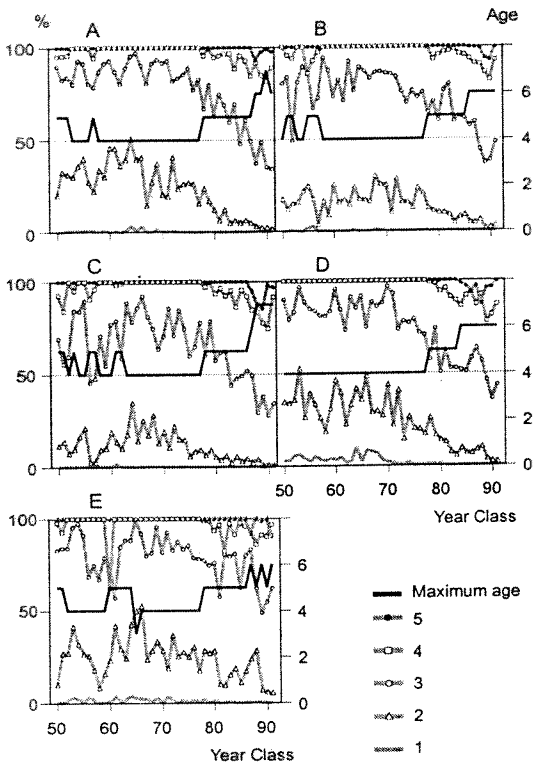


Fig. 2. Percentages of spawners in total survivors at age and maximum ages at return.



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III. Workshop Review

In 1998, the North Pacific Anadromous Fish Commission (NPAFC) organized the Workshop on Climate Changes and Salmon Production. The evidence presented at the workshop suggested strong connections between climate change and subsequent changes in marine productivity and salmon production. Salmon production takes place in freshwater and marine ecosystems, and the marine ecosystem is divided into coastal and offshore ecosystems or juvenile and immature/maturing stages. Therefore, it was scientifically logical to examine biological processes in the juvenile stage in much more detail. In 2000, the NPAFC and the North Pacific Marine Science Organization (PICES) organized a 1-day Workshop on Factors Affecting Production of Juvenile Salmon: Comparative Studies on Juvenile Salmon Ecology between the East and West North Pacific Ocean.

The review of past juvenile salmon studies was the first part of the workshop. It was recognized that Pacific salmon are primarily a marine species, and that there is still much to learn about the factors regulating their abundance. We also recognized that it is necessary to continue monitoring in standard areas and to organize a new investigation on biological interactions of enhanced and wild salmon stocks. It is also necessary to examine more fully the role of ocean physics and biology in determining salmon production. There were many scientific papers on juvenile salmon research on both sides of the North Pacific Ocean, but there were not comprehensive and complete review papers. Therefore, after the workshop the NPAFC decided to publish the salmon juvenile review papers in a consistent format for easy comparison. These review papers will be published in NPAFC Bulletin No. 3.

Several studies indicated that the mortality of juvenile salmon in coastal waters was much higher than the subsequent ocean mortality. Also it was reported that the most critical issues, such as abundance of preferred foods, environmental conditions, and abundance of competitors and predators determined survival of juvenile salmon. There were differences in some critical issues between the east and west North Pacific Ocean. For example, predation by seabirds had a greater effect on survival of juvenile salmon than predation by fish in coastal waters in Japan, but the predation by fish such as spiny dogfish and river lamprey was important for juvenile mortality in coastal waters in Canada. Further comparisons of critical issues between the east and west North Pacific Ocean will deepen our understanding of biological process of juvenile salmon production.

An extensive field survey showed that bottom-up processes affected the spring zooplankton bloom and thus influenced juvenile salmon growth rates and foraging behavior. But it also indicated that top-down processes were modified through size-selective predation on juvenile salmon and by altering the timing of a shift from planktivory toward piscivory among major predators on juvenile salmon. This was a good example of an ecosystem study for juvenile salmon. The development of mechanistic numerical bioenergetic-foraging models that incorporate interactions between juvenile salmon and their principal prey and predators are needed. Such models will provide an invaluable tool for formalizing our understanding of juvenile salmon ecology and can provide insights into system function that may not be directly observable. Several migration models were also presented at the workshop. The descriptive migration models will contribute to when, where, and how our research should be concentrated in the future. Also the numerical migration model will contribute to simulation of the effects of several factors such as climate change and enhancement. The model approach in conjunction with field surveys, and vice versa, should be promoted in the future.

General discussions focused on ocean distribution and migrations, factors affecting survival and growth, and the role of the NPAFC and PICES future research on juvenile salmon. Several research areas for understanding ocean distribution and migrations were pointed out such as estimation of plankton abundance as juvenile food resources, investigation of biological switches of salmon migration, and archival tags as a new technology in future studies. Also, factors affecting survival and growth, use of climate and oceanographic changes, and salmon response to these changes should be examined in the future. International collaboration is essential to solve these issues.

Yukimasa Ishida
Chairman of the NPAFC Committee
on Scientific Research,
Chairman of the Workshop Organizing Committee

APPENDIX 1

Program of the Workshop

REVIEW PRESENTATIONS *(To be published in NPAFC Bulletin No. 3)*

Review of juvenile salmon research conducted by Canada
R.J. BEAMISH, I. PEARSALL, and D.W. WELCH

Japanese studies on the early ocean life of juvenile salmon
H. MAYAMA and Y. ISHIDA

Review of Russian marine investigations of juvenile Pacific salmon
V.I. KARPENKO

Research conducted by the United States on the early ocean life history of Pacific salmon
R.D. BRODEUR and J.H. HELLE

Review of juvenile Atlantic salmon investigations in the marine environment
N. Ó MAOILÉIDIGH

ORAL PRESENTATIONS

A migration model of Japanese chum salmon during early ocean life
S. URAWA, Y. UENO, Y. ISHIDA, L.W. SEEB, P.A. CRANE, S. ABE, and N.D. DAVIS

A synthesis of research on early marine ecology of juvenile Pacific salmon in Southeast Alaska
W.R. HEARD, J.A. ORSI, A.C. WERTHEIMER, M.V. STURDEVANT, J.M. MURPHY, D.G. MORTENSEN, B.L. WING, and A.G. CELEWYCZ

Anomalous mass downstream migration of age 0+ chinook salmon juveniles (estuary of the Bolshaya River, West Kamchatka) – ***(not presented)***
V.N. LEMAN and V.V. CHEBANOVA

Early sea mortality of chum salmon juveniles in open coastal waters of Japan Sea
M. FUKUWAKA and T. SUZUKI

*Seabird predation on juvenile chum salmon around the river mouth of a salmon propagation river
H. KAWAMURA and S. KUDO

Predation-based mortality on juvenile salmon in the Strait of Georgia
R.J. BEAMISH and C.M. NEVILLE

The relationships between Pacific salmon juveniles during fall feeding migration in the Sea of Okhotsk
V.G. YEROKHIN – ***(not presented)***

Ecological processes influencing mortality of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska
T.M. WILLETTE, R.T. COONEY, E.V. PATRICK, G.L. THOMAS, and D. SCHEEL

Monitoring of salmon smolt numbers in the Khabarovsk region
V.A. BELYAEV and S.F. ZOLOTUKHIN

POSTER PRESENTATIONS

Effects of ocean currents on juvenile chum salmon migration
T. AZUMAYA and Y. ISHIDA

Effects of water temperature and day length on seawater tolerance of yearling sockeye salmon (*Oncorhynchus nerka*)
M. BAN

*Forecasting coho salmon survival off the Pacific Northwest
J.F. COLE, G.W. BOEHLERT, and L. DE WITT

Factors affecting distribution, migration, and growth of juvenile sockeye salmon in the Eastern Bering Sea (July and September 1999)
E.V. FARLEY, Jr., C.M. GUTHRIE III, B.L. WING, M.D. ADKISON, E.C. MARTINSON, and J.H. HELLE

Smolt abundance and age at maturity of sockeye salmon – ***(presented, but not submitted for publication)***
S. MCKINNELL

*Analysis of glucose and triglyceride content and RNA/DNA ratio in a liver for evaluation of starvation status in hatchery-reared and wild juvenile masu salmon, *Oncorhynchus masou*
N. MISAKA, T. KOYAMA, S. MIZUNO, and N. KASAHARA

*Distribution, origins, biology, and ecology of juvenile steelhead (*Oncorhynchus mykiss*) in the Gulf of Alaska in Summer 1993-1999
K.W. MYERS, R.V. WALKER, R.L. BURGNER, and G. ANMA

Possible effects of sea ice in the southern Okhotsk Sea on the survival of pink salmon juveniles from Hokkaido and East Sakhalin
K. NAGASAWA

Response of juvenile masu salmon, *Oncorhynchus masou* to habitat change, and habitat rehabilitation
M. NAGATA and S. YANAI

Lipid composition in muscle and liver tissues of chum and pink salmon captured in the Gulf of Alaska during May, 1999
T. NOMURA, H.R. CARLSON, K.W. MYERS, C. KONDZELA, and J.M. MURPHY

Southeast Alaska coastal monitoring for habitat use and early marine ecology of juvenile Pacific salmon
J.A. ORSI, M.V. STURDEVANT, J.M. MURPHY, D.G. MORTENSEN, B.L. WING, A.C. WERTHEIMER, and W.R. HEARD

Fresh-water and marine survival and sockeye salmon generation abundance in Dalneye Lake, Kamchatka – ***(not presented)***
E.G. POGODAYEV

Peculiarities of forming process of juvenile sockeye salmon biological characteristics in Paratunskiye Lakes (Kamchatka) depending on conditions of rearing – ***(not presented)***
E.G. POGODAYEV

A coastal research program for ecology and habitat of juvenile salmonids in the Nemuro Strait, Hokkaido – ***(not presented)***
J. SEKI, I. SHIMIZU, T. SAITO, K. WATANABE, and O. HIROI

Genetic analysis of development mortality in oiled and unoiled lines of pink salmon – ***(not presented)***
W.W. SMOKER, R. HEINTZ, A.C. WERTHEIMER, and S.D. RICE

Handling time and profitability of food in juvenile chum salmon: effects of fish size, food size, and satiation
T. SUZUKI

Individual growth and life-history divergence of juvenile masu salmon (*Oncorhynchus masou*) in a northern Japanese stream – ***(not presented)***
T. TAKAMI, T. AOYAMA, M. NAGATA, M. MIYAMOTO, S. OHKUBO, and H. KAWAMURA

*Assessment of food availability and predator abundance along a juvenile pink salmon out-migration corridor in Prince William Sound, Alaska
R.E. THORNE

Survivorship of juvenile chum salmon released from Hokkaido, Japan: independence of the density effect
K. WATANABE

*The title was changed for this publication.

APPENDIX 2

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	Dolores Garza
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