

*NORTH
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TECHNICAL REPORT 7

Second International Workshop on Factors Affecting Production of Juvenile Salmon: Survival Strategy of Asian and North American Juvenile Salmon in the Ocean

**Edited by: Richard J. Beamish, Edward V. Farley, Jr., Jim Irvine,
Masahide Kaeriyama, Sukyung Kang, Vladimir I. Karpenko,
Toru Nagasawa, and Shigehiko Urawa**

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Second International Workshop on *Factors Affecting Production of Juvenile Salmon: Survival Strategy of Asian and North American Juvenile Salmon in the Ocean*

Sapporo, Japan, April 26-27, 2006

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Foreword

The Second International Workshop on Factors Affecting Production of Juvenile Salmon: Survival Strategy of Asian and North American Juvenile Salmon in the Ocean was held at the Conference Hall of Hokkaido University in Sapporo, Japan, on April 26–27, 2006. The Workshop was organized and sponsored by the North Pacific Anadromous Fish Commission (NPAFC). The Workshop Organizing Committee consisted of scientists from Canada, Japan, Republic of Korea, Russian Federation and U.S.A. All necessary arrangements were made by the NPAFC Secretariat in cooperation with the Organizing Committee.

Over 70 scientists, industry representatives, and fisheries officials attended the Workshop. There were 25 oral presentations including five national overviews, followed by a panel discussion, and 24 poster presentations. Extended abstracts of the oral and poster presentations are included in this Technical Report, which also contains opening remarks and short review of the workshop. The material presented in this Technical Report has not been peer-reviewed, and does not necessarily reflect the views of the NPAFC or the member countries. Some work may be preliminary. The material has been edited for clarity and publication purposes only.

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Opening Remarks

Pacific salmon are one of the most valuable fish resources in the North Pacific Ocean, playing important roles in the ocean and freshwater ecosystems, and also in economics and cultures of the Pacific Rim countries. The North Pacific Anadromous Fish Commission (NPAFC) was established under the Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean which entered into force on February 16, 1993. The main objectives of the NPAFC is promotion of the conservation of anadromous fish in the North Pacific Ocean and its adjacent waters, and the NPAFC serves as a forum for cooperation and coordination of scientific research and enforcement activities.

In 2000, the NPAFC organized the First Workshop on “Factors Affecting Production of Juvenile Salmon: Comparative Studies on Juvenile Salmon Ecology between the East and West North Pacific Ocean”, and the proceedings of this workshop were published in the NPAFC Technical Report No. 2. National review papers on marine investigations of juvenile Pacific salmon, presented at the workshop and later published in NPAFC Bulletin No. 3, emphasized the need for new research. As a consequence, the NPAFC Science Plan 2001-2005 included “Juvenile salmon research” as one of the three components that were a focus of our research activities. Since 2001, juvenile salmon research has been intensively carried out in various areas such as the coastal waters of the Okhotsk Sea, western and eastern Bering Sea, and the Gulf of Alaska by NPAFC member countries, accumulating new information using new techniques such as DNA stock identification, mass otolith marking, and acoustic tracking system.

Ocean production of salmon in terms of numbers of fish is closely linked with their early ocean survival. Recent reviews of national research on juvenile salmon show wide diversity of survival rates, growth, predation, etc. The fluctuations of many stocks and intermixing of stocks in the eastern and western North Pacific coastal waters has increased concern and interest in this critical period. Variations in early marine growth and survival are often related to climate-induced changes in distribution and abundance of predator and prey populations.

In order to increase our understanding of the processes that determine salmon population sizes and our ability to forecast stock sizes, I hope the workshop will provide us with a forum to exchange new scientific information, and develop new insights and future research directions about juvenile salmon in the North Pacific ecosystems. I am expecting your contributions to make the workshop valuable for us by providing your experiences and views. I wish you a pleasant stay in Sapporo and a productive meeting.

Shigehiko Urawa
Chair of the Workshop Organizing Committee

Canadian Coastal and High Seas Juvenile Pacific Salmon Studies

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Keywords: Juvenile Pacific salmon, marine survival, Strait of Georgia, southeast Alaska, west coast of British Columbia.

Canada maintains two programs that research the factors that regulate the early marine survival of juvenile Pacific salmon. Each year, approximately 100 days of ship time are used to survey juvenile rearing areas in the inside and outside waters off the coast of British Columbia. The expectations for the oceans research are that an understanding of the climate and ocean conditions that affect marine survival of Pacific salmon will lead to the development of forecasting models. Such models are needed to differentiate fishing and freshwater habitat effects on salmon production from ocean carrying capacity effects. Furthermore, Canada supports a salmon hatchery and artificial rearing program that releases an estimated 300 million individuals of all species into the ocean each year. Understanding the ocean impacts on these artificially reared Pacific salmon will help to optimize production and efficiency of the enhancement program. Understanding the impacts of hatchery-reared salmon on wild salmon is needed to protect wild salmon according to the commitments of Canada's wild salmon policy (Anonymous 2005). In the Strait of Georgia and in Puget Sound our studies focus on identifying the mechanisms that regulate the marine survival of hatchery and wild salmon. In Queen Charlotte Strait, we are assessing the impact of sea lice on salmon farming and on wild pink and chum salmon. Future work will focus on hatchery and wild salmon interactions that will explore ways to improve hatchery survival and provide more recreational fishing opportunities.

Surveys in the Strait of Georgia started in 1997 and occur in July and September. A standard track line is used. The trawl net (Beamish and Folkes 1998) is towed at five knots usually for 30 minutes. The net opening is 15 m x 35 m and the net is fished at different depths with the head rope set at 15 m intervals. In general, the effort is stratified by depth according to the relative abundance of juvenile salmon at these depths. An analysis of 2968 sets shows that most pink, chum and sockeye salmon (80–87%) are captured in the top 15 m. However, 78% of coho salmon are in the top 15 m and only 69% of chinook salmon are in the top 15 m (Table 1). In general 50% of our sets have been in the top 15 m and the remaining 50% extend to 60 m (head rope depth) and deeper. Our studies show that there is a relationship between the catch per unit effort of coho salmon and marine survival (Fig. 1) that is now used in forecasting coho salmon returns. The mechanism relates to the amount of early marine growth. Coho salmon that do not grow to a large enough size would not survive periods of energy deficit during the winter (Beamish et al. 2004). There also is a relationship between size and marine survival (Fig. 2). Thus in years when there is good growth, coho salmon are also abundant. Interestingly, this relationship appears to have disappeared in 2005 as the smaller catch per unit effort (CPUE) was also associated with larger fish (Figs. 1, 2). In years when coho salmon survival was largest, generally there were also large abundances of other species of juvenile Pacific salmon (Table 2), inferring that survival was high for all salmon species in those years. This was not true for 2005, where we observed the lowest juvenile coho survival but very large chum abundances. We also observed that the capacity to produce juvenile Pacific salmon may be related to the time of entry into the Strait of Georgia. In some years, such as 2005, chum salmon that entered the Strait of Georgia earlier than coho and chinook salmon had substantially

Table 1. Total effort and catch of juvenile Pacific salmon by depth for surveys conducted from 1997–2005.

Depth	Sets		Coho salmon		Chinook salmon		Chum salmon		Pink salmon		Sockeye salmon	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
0–15 m	1503	50.64	37572	77.45	44970	69.28	127088	86.98	46864	79.74	14854	85.70
15–30 m	669	22.54	7653	15.78	13060	20.12	16524	11.31	10984	18.69	1999	11.53
30–45 m	412	13.88	2629	5.42	5100	7.86	1676	1.15	431	0.73	390	2.25
45–60 m	190	6.40	495	1.02	977	1.51	439	0.30	191	0.32	71	0.41
60+ m	194	6.54	161	0.33	800	1.23	384	0.26	304	0.52	18	0.10
Total	2968	100	48510	100	64907	100	146111	100	58774	100	17332	100

Fig. 1. Relationship between catch per unit effort (CPUE) and marine survival estimates of hatchery coho salmon from 1997–2004. Projected marine survival for 2005 is shown.

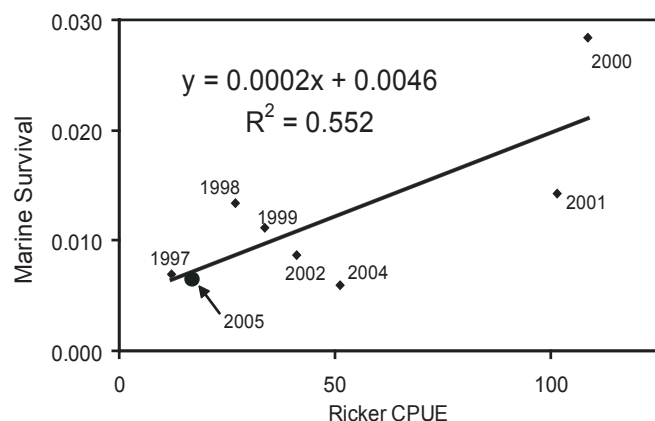
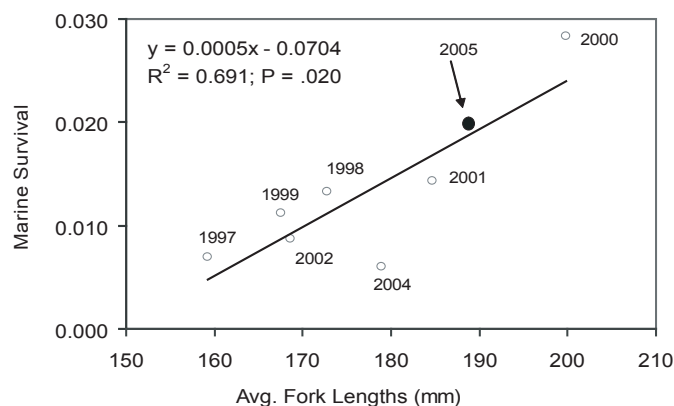


Fig. 2. Relationship between average fork length and marine survival of juvenile coho salmon in July surveys from 1997–2004. Projected marine survival for 2005 is shown.



higher abundances than coho and chinook salmon (Table 2). Other observations have been that juvenile pink and chum salmon remain in the Strait of Georgia through to September, which is much longer than previously reported. Most coho salmon leave Puget Sound in mid-August whereas coho salmon leave the Strait of Georgia towards the end of September. In recent years the Strait of Georgia has been very productive for pink, chum and sockeye salmon, resulting in record returns of adults (Fig. 3).

Our research on sea lice and Pacific salmon has documented sea lice levels on adult salmon (Beamish et al. 2006) as well as identified a possible life history strategy that enables one species of sea lice to be highly successful (Beamish et al. 2007).

Studies of offshore areas: The program on high seas salmon has been collecting juvenile Pacific salmon from the west coast of British Columbia to southeast Alaska since 1998 to assess the effects of ocean conditions and climate change on the distribution, migration, growth and survival of Pacific salmon, and to develop forecasting models of salmon returns to British Columbia. These surveys are normally conducted during spring/summer, fall, and winter and last two to four weeks. Fishing is conducted with a trawl net that is towed at the surface at 5 knots for 30 minutes. The fish samples are sorted by species and measured on board the ship. A skin sample is also collected for juvenile salmon to identify their stock of origin using microsatellite DNA (Beacham et al. 2001, 2006). A sub-sample

of the catch is preserved for various chemical and calorimetric analyses, and to examine their stomach contents. In addition to fish, temperature, salinity, surface nutrients, chlorophyll-a concentration and zooplankton are collected.

The working hypothesis of this research is that fast growth enhances the marine survival of salmon, either because fast-growing fish quickly reach a size that is sufficiently large to avoid predators, or because they accumulate enough energy reserves to better survive their first winter at sea, a period generally considered to be critical in the life cycle of salmon (Beamish and Mahnken 2001). The comparative approach is used to relate changes in salmon growth and bioenergetics to ocean conditions in two contrasting ocean domains: the west coast

Table 2. Abundance estimates (in millions of fish) for juvenile Pacific salmon in the Strait of Georgia. Abundances were derived using swept volume method (Beamish et al. 2000). Note that pink salmon are only estimated on even years.

Year	Coho salmon	Chinook salmon	Chum salmon	Pink salmon	Sockeye salmon
1997	1.65	4.73	1.97	-	7.30
1998	2.82	4.46	10.27	4.17	1.04
1999	3.42	3.88	7.42	-	1.33
2000	10.96	7.87	26.22	7.55	0.53
2001	9.27	5.84	11.80	-	1.62
2002	2.75	3.63	1.31	3.22	2.60
2003 ^a	-	-	-	-	-
2004	4.79	8.13	15.31	7.13	3.50
2005	0.82	1.66	17.48	-	0.48

^a No survey in 2003.

Fig. 3. Total adult pink salmon production (catch and escapement) to the Fraser River, 1957 to 2003. Reliable observations started in the mid 1950s.

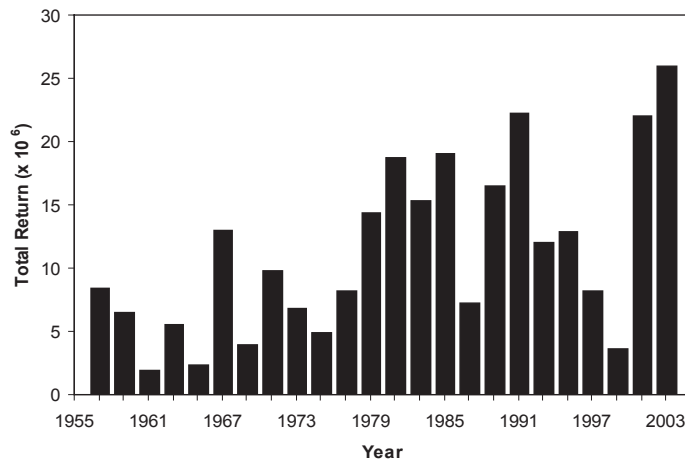


Fig. 4. Growth rates (May–October) of juvenile coho salmon off the west coast of Vancouver Island (triangles) and southeast Alaska (squares). The error bars are 2 X SE.

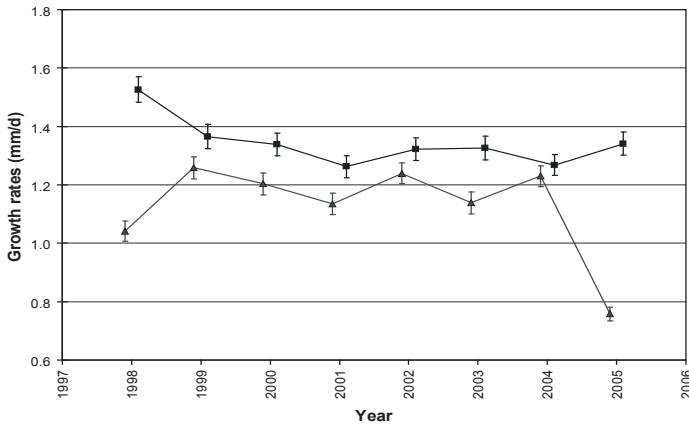
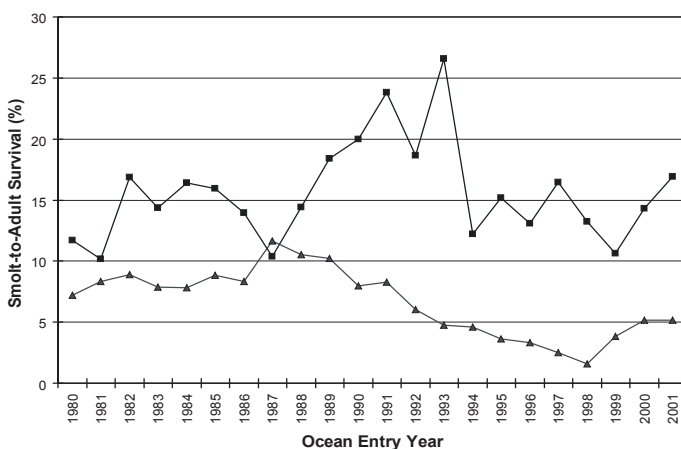


Fig. 5. Marine survival of coho salmon off southern British Columbia (triangles) and southeast Alaska (squares).



of Vancouver Island is located at the north end of the California Current System and is affected by up-welling, while southeast Alaska is located in the Alaska Coastal Current and is affected by down-welling (Ware and McFarlane 1989). In general, sea surface temperature, phytoplankton and zooplankton biomass are higher off Vancouver Island while nutrient concentration is generally higher off southeast Alaska.

Although ocean conditions appear to be more favourable to salmon growth off Vancouver Island, coho salmon growth rates and marine survival are generally higher in southeast Alaska (Figs. 4, 5). Our analyses indicate that regional differences in juvenile coho salmon are not attributed to differences in food consumption rates or temperature as juvenile coho salmon consume about 8–10% of their body weight per day in both regions. Simulations performed using a bioenergetics model indicate that juvenile salmon growth is not responsive to a change of 3°C in sea surface temperature, but that small changes in prey quality have large effects on the growth trajectory of juvenile salmon (Trudel et al. 2002; Beauchamp et al. 2007). This suggests that changes in the lipid content or composition of prey can have large effects on salmon growth, and that we need to have a better understanding of the factors affecting changes in prey quality at the base of the food chain. The comparative method used here may provide a useful approach for assessing the effects of ocean conditions and climate on juvenile salmon and to develop forecasting models for salmon survival.

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Research on the Early Life History of Chum Salmon in Korea

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Keywords: Out-migration, chum salmon, smoltification, stomach content, return rate

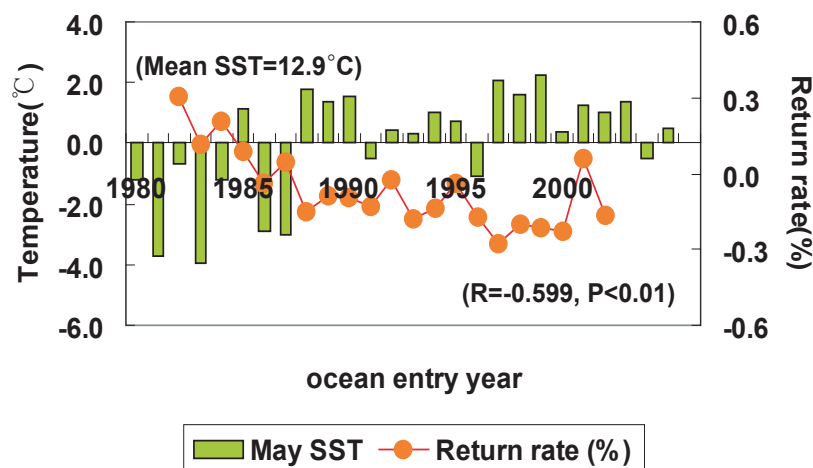
Pacific salmon are dominant fishes in the North Pacific Ocean and recent catches of salmon have been at historical high levels. Chum salmon have more than doubled during the past 20 years due to favorable ocean conditions, population management policies and artificial enhancement programs (Bigler et al. 1996). However, the marine survival rate of Korean chum salmon is quite low compared to other countries: ~1.5% in the 1990s and ~0.2% since 2000.

For the last four decades, Korea's chum salmon enhancement program has focused on improving the conditions of salmon stocks by artificially fertilizing eggs, raising fingerlings, and releasing them. We studied factors controlling the out-migration mortality of fingerlings with a view to improving return rates and consequently the status of Korean salmon. Since 1991, we have conducted follow-up investigations in river. Both biological and environmental data were collected in order to determine the behavior of fingerlings' out-migration and to investigate the source of early mortality during out-migration. Here we provide some preliminary results from these surveys, mostly from 2005, which summarizes duration and patterns of fingerlings' out-migration, stomach contents, and physical characteristics of the Namdae-cheon (river).

Water temperature in Namdae-cheon increased with time and exceeded 15°C after late April. These high temperatures may be unfavorable for the survival of juvenile chum salmon. Mean water temperatures (1980–2005) in the coastal waters near the mouth of Namdae-cheon were 9.8°C in April and 12.9°C in May. Return rates were negatively correlated with mean water temperatures of the coastal waters in April and May ($r = -0.485$, $p < 0.05$ in April; $r = -0.599$, $p < 0.01$ in May) (Fig. 1). Zooplankton biomass in the coastal waters was not correlated with return rates of Korean chum salmon. However, Seo et al. (2006) reported trends of zooplankton biomass were correlated with early growth of chum salmon. They concluded that food availability is more important than seawater temperature in determining chum salmon growth in the North Pacific, although it is not easy to decouple the effects of these factors.

Chum salmon fingerlings were released into Namdae-cheon in mid February and early March in 2005. Fingerlings caught before the first release were wild salmon. However most salmon caught originated from the Salmon Research Center. Wild salmon constituted 11.2% of the total catch. Catches of juvenile salmon increased after salmon release, peaked in mid-March, and gradually decreased. Salmon seemed to stay in Namdae-cheon about 30 days and then moved to the coastal area. Some salmon remained in the upper stream and grew up to over 7 cm body length.

Fig. 1. Interannual variability in water temperature at river mouths and chum salmon return rate to Namdae-cheon.



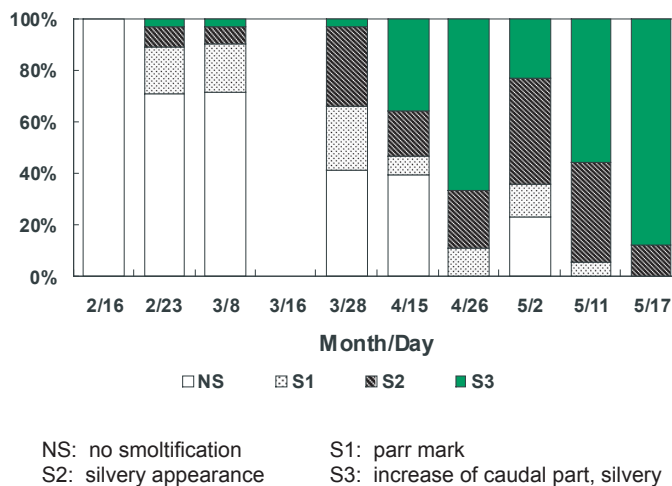
Smoltification is a series of physiological, morphological and behavioral changes that take place in juvenile salmon. Almost all salmon had smolted by late April, which corresponded with water temperature increases (Fig. 2). In addition, we analyzed stomach contents of chum salmon fingerlings. The majority of prey eaten were Diptera, which represented 92% of prey items by number and 41% by wet weight. Food items from the stomachs of juvenile salmon were compared with living organisms in the river. Juvenile chum salmon in Namdae-cheon do not appear to feed selectively.

There is very little information about the coastal and ocean distribution and migration of Korean chum salmon in the North Pacific Ocean. Coastal surveys are needed to improve our understanding of timing of out-migrations, early mortality rates, and coastal migration routes.

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Fig. 2. Degree of smoltification of juvenile salmon.



Russian National Overview of Juvenile Pacific Salmon Research during 2001–2005 Period

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Keywords: Juvenile Pacific salmon community, biomass, distribution, feeding behavior

The research of juvenile Pacific salmon's marine life period was an integral part of Russian EEZ ecosystem research programs during 2001–2005. During 2001–2005, studies on juvenile salmon's marine life period, which were initiated in early 1980s, were continued and new information was obtained from 19 research trawl surveys of TINRO-Centre, KamchatNIRO and SakhNIRO in the Far Eastern Seas.

Major results of research of juvenile salmon's marine life period can be summarized as follows:

1. During 2001–2005 TINRO-Centre continued to monitor upper epipelagic nekton communities' status, as well as interannual and seasonal dynamics of Pacific salmon in nekton communities (Temnykh 2004; Temnykh et al. 2004; Shuntov and Sviridov 2005; Shuntov and Temnykh 2005a). In the beginning of the present century, biomass of juvenile salmon and the ratio of Pacific salmon in overall fish biomass in the epipelagic layer of Russian EEZ increased.
2. The different areas of Russian EEZ were ranked in relation to juvenile salmon abundance, species composition and duration of feeding period. TINRO-Centre archival trawl surveys databases of the last 25 years were utilized for this ranking (Shuntov et al. 2003a, 2004a, 2005a, 2006a). It is the deep-water part of the Okhotsk Sea that is the major feeding ground of juvenile salmon within the Russian EEZ (Fig. 1). Despite the fact that the western Bering Sea is an important feeding ground of large-size Pacific salmon individuals during summer-autumn period, this area is of a low foraging importance for juveniles.
3. Data on the distribution of juvenile salmon in the Far Eastern Seas acquired during the last years and archival data from trawl surveys of TINRO-Center (Shuntov et al. 2003b, 2004b, 2005b, 2006b) was used to trace seasonal dynamics of juvenile salmon quantitative distribution in the Russian EEZ (Figs. 2–4). Comparisons of species-specific distribution patterns clarified the existing schemes of migration routes (Erokhin 2002; Temnykh 2004). New ideas on ecology of Pacific salmon juveniles during early marine period were

Fig. 1. Average biomass and duration of foraging period of Pacific salmon juveniles in different areas of the Russian EEZ during the autumn of 1980–2004.

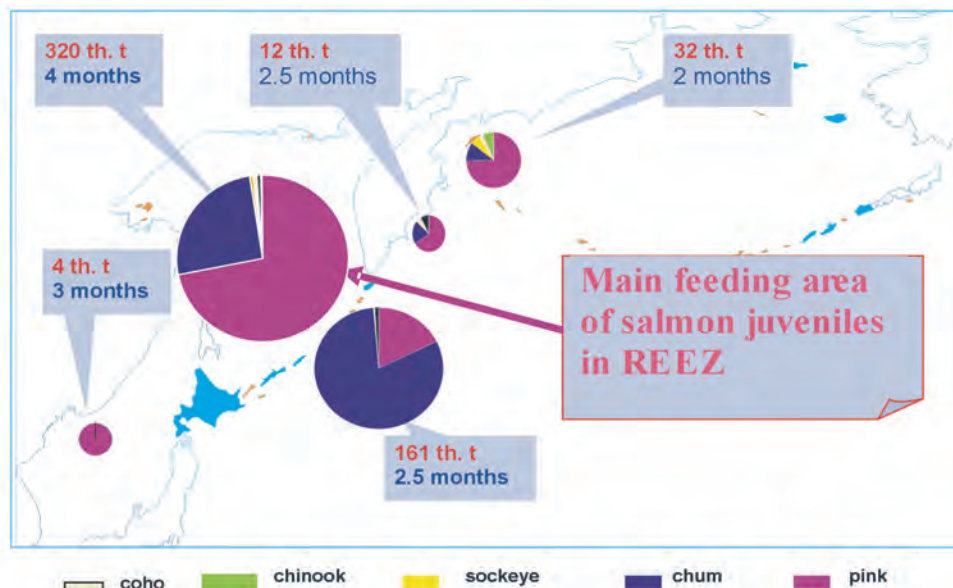
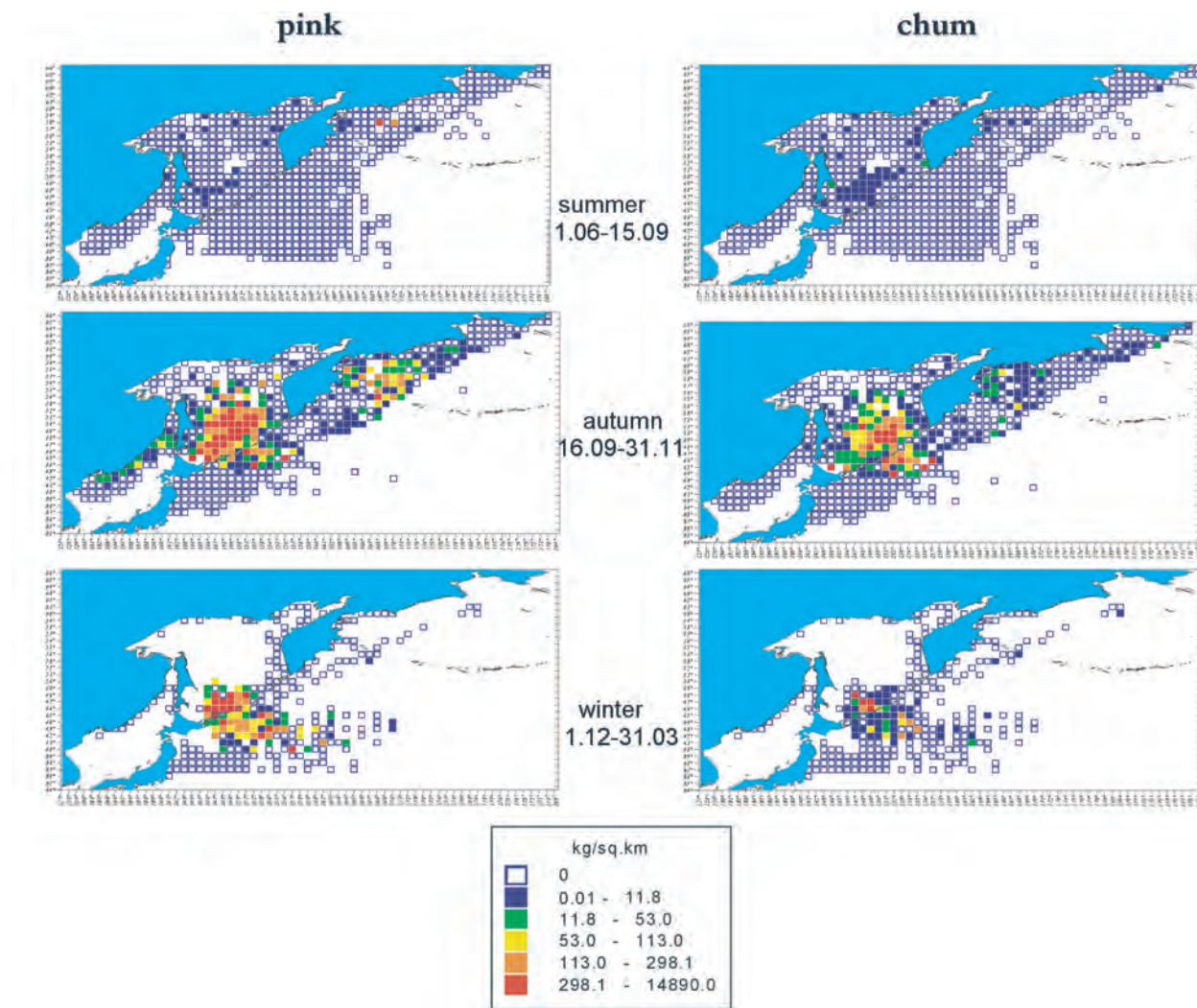


Fig. 2. Seasonal variation of pink and chum salmon (FL < 30 cm) biomass distribution patterns in different areas of the North Pacific Ocean, Bering Sea, Okhotsk Sea and Japan Sea.



developed (Shuntov and Temnykh 2005b).

4. The feeding activity and position of Asian juvenile salmon in trophic structure of the epipelagic zone of the Russian EEZ has been investigated (Maksimenkov 2002; Efimkin et al. 2004; Kuznetsova 2005; Volkov et al. 2005). The analysis of trophic structure of nekton communities and the role of salmon in these areas demonstrated that along with intraspecific competition, different salmon species may compete with other nekton species (Karpenko et al. 2002). However, critical analysis and published data did not support the idea that food rigidly limits Pacific salmon abundance (Maksimenkov and Smorodin 2004; Temnykh 2004; Kuznetsova 2005; Naydenko et al. 2005; Shuntov and Temnykh 2005a).
5. Data from juvenile pink salmon autumn surveys were utilized to improve annual forecasts of adult escapement into western Kamchatka and Sakhalin Rivers (Erokhin 2002; Erokhin et al. 2004; Karpenko et al. 2005; Shuntov and Temnykh 2005a). This was possible through two steps: estimation of overall abundance of juvenile salmon in offshore waters of Okhotsk and Bering Seas and discrimination of major groups of stocks from mixture marine juvenile salmon aggregations based upon scale pattern analysis (Temnykh 2004).

Future research on Pacific salmon in the ocean should focus on the determination of the carrying capacity of coastal and offshore waters for juvenile salmon, assessment of salmon mortality rates during early marine life period, and studying of mechanisms, which determine year-class strength of Pacific salmon (e.g., forage base, predators influence) (Shuntov 2005).

Fig. 3. Seasonal variation of chinook and coho salmon (FL < 30 cm) biomass distribution patterns in different areas of the North Pacific Ocean, Bering Sea, Okhotsk Sea and Japan Sea.

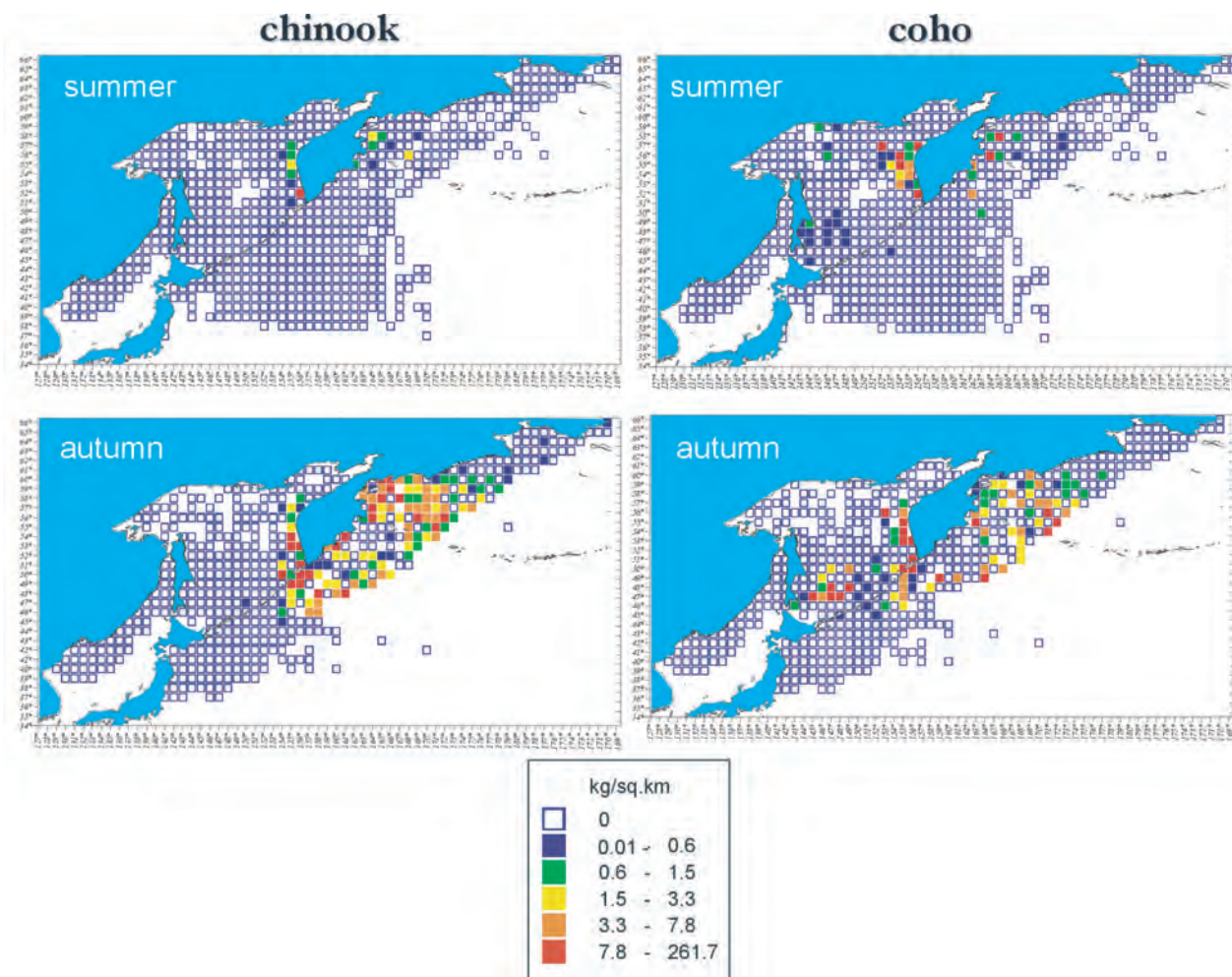
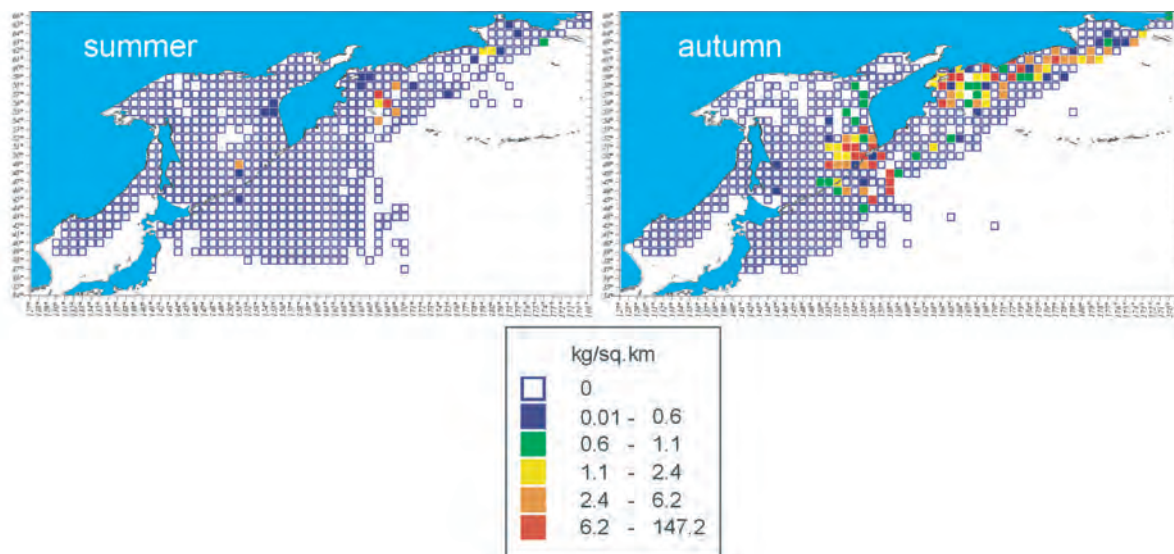


Fig. 4. Seasonal variation of sockeye salmon (FL < 30 cm) biomass distribution patterns in different areas of the North Pacific Ocean, Bering Sea, Okhotsk Sea and Japan Sea.



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Overview of Current Marine Juvenile Salmon Research by the United States

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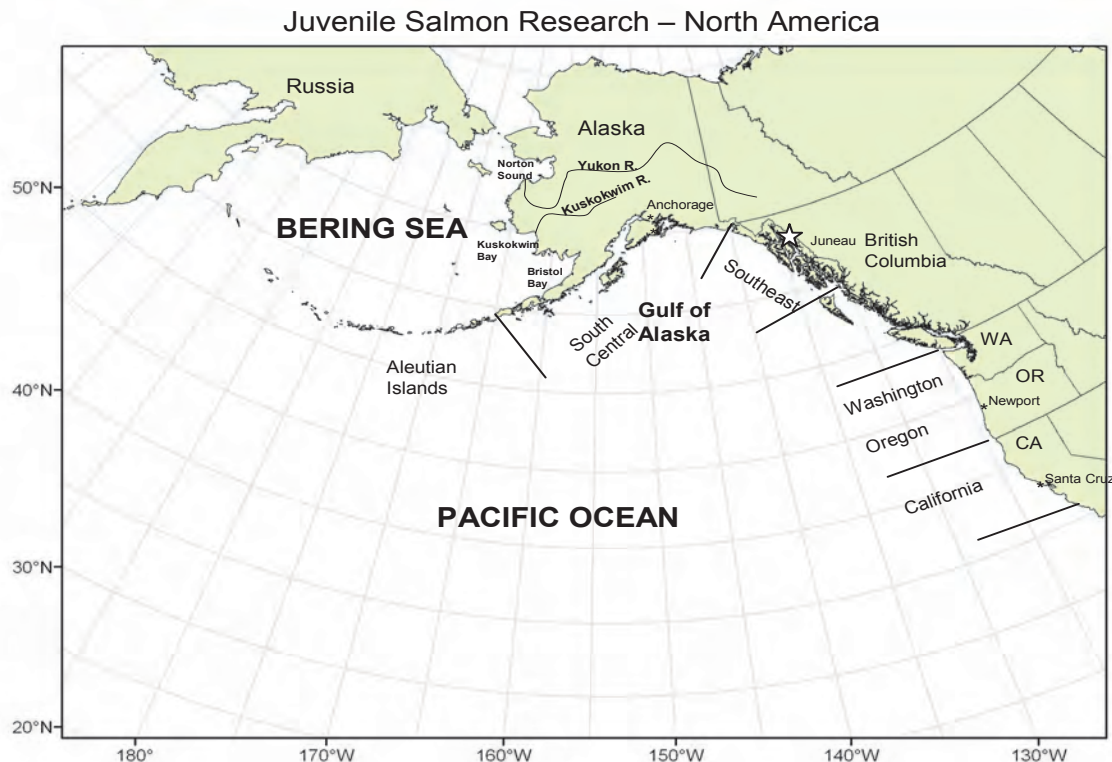
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Keywords: Juvenile Pacific salmon, migration, distribution, growth, survival, marine ecosystems, USA

A history of juvenile salmon research on Pacific salmon in coastal areas conducted by the United States (U.S.) was published by Brodeur et al. (2003). Presently, juvenile Pacific salmon research in the U.S. occurs in the coastal areas of all of the Pacific states: California, Oregon, Washington, and Alaska (Fig. 1). Major objectives of this research are to understand how dynamics in marine ecosystems influence migration, distribution, growth, and survival of juvenile salmon during their early ocean residence.

Several large-scale studies in coastal areas from California to Alaska are currently being conducted by the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), in collaboration with university and state scientists. Studies off California are operated by the Southwest Fisheries Science Center, Santa Cruz Laboratory in Santa Cruz, California and University of California Santa Cruz. Studies off Oregon and Washington are operated by the Northwest Fisheries Science Center, Newport Laboratory and

Fig. 1. Locations of marine juvenile salmon research in North America.



Oregon State University in Newport, Oregon. Studies in the Gulf of Alaska, Bering Sea and in the seaward migration corridors in the coastal waters of southeastern Alaska are operated by the Alaska Fisheries Science Center, Auke Bay Laboratory in Juneau, Alaska, in collaboration with Alaska Department of Fish and Game, University of Alaska Fairbanks, Bering Sea Fishermen's Association, and Yukon River Drainage Fishermen's Association. In addition to these large studies, smaller estuarine studies on juvenile salmon occur in northwestern Alaska in Kuskokwim Bay by the U.S. Geological Survey (Anchorage) and University of Alaska Fairbanks (Juneau), and, in Norton Sound by LGL Alaska Research Associates and Norton Sound Economic Development Corporation both headquartered in Anchorage (Fig. 1).

The estuarine studies on juvenile salmon in Alaska operate in shallow water and a variety of gear is used to capture salmon. A small trawl towed by two boats is used in Kuskokwim Bay. Fyke nets are utilized in Norton Sound to capture salmon.

The primary gear for capturing juvenile salmon at sea in the larger studies is a trawl towed near the surface. Studies in the Bering Sea and Gulf of Alaska utilize a larger trawl than the other studies. In the coastal studies, the trawls are towed perpendicular to the shore across four habitat types: near-shore, continental shelf, slope of the continental shelf, and oceanic water. Juvenile salmon migrate primarily along the continental shelf during their early life history. Studies in southeastern Alaska occur mainly in the channels and fjords protected by islands from the open ocean.

A variety of oceanographic observations are made from the vessels to support the juvenile salmon research. In addition, studies are underway on food habits, predator/prey relations, growth, bioenergetics and genetic stock identification of juvenile salmon.

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Overview of Juvenile Salmon Research in Japan from 2001 to 2005

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Keywords: Juvenile salmon, survival, stock identification, feeding, coastal waters, Okhotsk Sea

Major mortalities of chum and pink salmon may occur during the initial coastal life. Accordingly, their coastal life history studies are important to understand the survival mechanisms. The purpose of the investigation for the early sea life of juvenile salmon is to clarify mechanisms controlling population dynamics of the fishes.

Research on juvenile salmon in coastal waters began in 1967 in Japan. Since a historical review concerning the studies of the early ocean life of juvenile Pacific salmon in Japan was done by Mayama and Ishida (2003), the recent studies including ongoing ones are introduced in this paper.

There are several organizations conducting juvenile salmon surveys in Japan. The National Salmon Resources Center initiated a monitoring program at seven coastal areas around Hokkaido in the spring of 1994. The Hokkaido Fish Hatchery and the Iwate Prefectural Fisheries Technology Center researched at the Abashiri coast and the Touni Bay, respectively (Fig. 1).

After leaving Japanese coastal waters, Japanese chum salmon juveniles dwell in the Okhotsk Sea from summer to autumn (Urawa et al. 2001; Urawa 2004). To investigate the distribution of salmon juveniles in the Okhotsk Sea, Japan-Russia cooperative juvenile salmon surveys were conducted in the autumn of 2000 and 2002 (Fig. 2). In addition, small-scale surveys were carried out within the Japanese exclusive economic zone (EEZ) of the Okhotsk Sea in October 2004 and 2005 (Fig. 2).

According to a rise of sea surface temperature (SST), CPUEs of juvenile chum salmon and zooplankton wet weights increased, but the CPUEs decreased when SST increased over 12–14°C at the four stations of Ishikari Shari, Shiraoi and Shibetsu. Zooplankton wet weights decreased above 10°C at the three stations of Ishikari Shari and Shiraoi. Zooplankton biomass was more abundant in the Pacific coasts of Hokkaido than in the Japan Sea and Okhotsk Sea coasts. These observations suggest that juvenile chum salmon migrated after a decrease of prey organisms (Seki 2005).

Fig. 1. Map showing monitoring stations around the northern Japan.



Fig. 2. Map showing sampling stations in the Okhotsk Sea in 2002, 2004 and 2005.

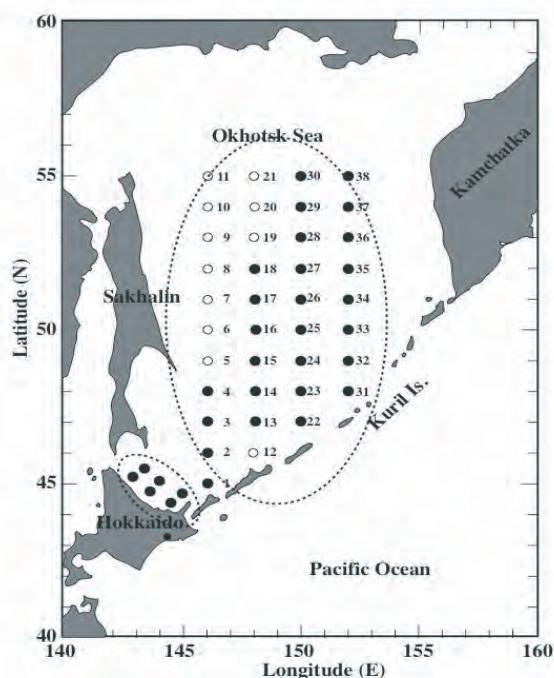
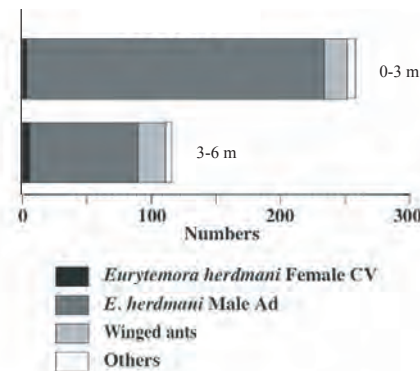


Table 1. Plan for number ($\times 10^3$) of otolith-marked salmon released from Japanese hatcheries, 1999–2007.

Released year	Chum	Pink	Masu	Sockeye
1999	3,958			
2000	14,503	985		
2001	19,030	2,820		
2002	40,747	2,572	33	
2003	65,199	2,980	30	
2004	64,783	3,078	32	
2005	72,345	1,373	1,567	
2006	123,475	2,200	2,198	200
2007	129,118	3,380	1,708	25

Fig. 3. Compositions of stomach content of juvenile chum salmon captured at two layers of 0–3 m and 3–6 m in the coastal waters near Shibetsu on 27 June, 2001.

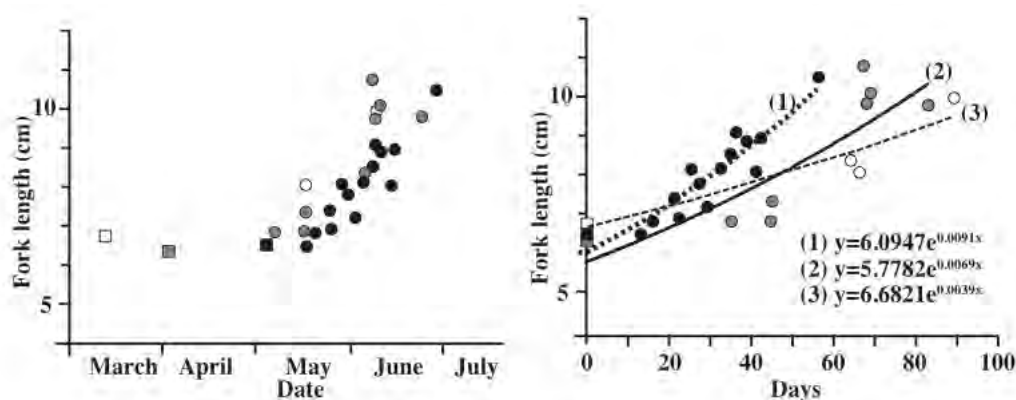
Zooplankton wet weight formed more than two peaks in three of five years from 1998 to 2002 in Shibetsu coastal waters, although in general the peak of zooplankton wet weight is once during spring in the coastal waters of Hokkaido. The zooplankton wet weight in 2001 exceeded three or four times than that of the other four years in Shibetsu (Seki et al. 2006). These results suggest that long-term coastal environment monitoring are necessary in each coastal areas.

Three zooplankton species of *Acartia longiremis*, *Pseudocalanus* spp. and *Evadne nordmanii* were dominated in the coastal waters off Shibetsu from spring to early summer. These three species had different distribution. Namely, *A. longiremis* was distributed near shore, *Pseudocalanus* spp. were distributed off shore and lower layer and *E. nordmanii* increased in late season and was distributed in upper zone. It seemed that the species avoided the duplications of the distribution to each other. Figure 3 shows stomach content compositions of juvenile chum salmon captured at the different layers of 0–3 m and 3–6 m in the coastal waters near Shibetsu. Three items of *Eurytemora herdmani* copepodite stage 4 female, adult male and winged ants were dominated in the stomach. Mainly, *E. herdmani* adult male occupied more than 75%. Number of stomach contents of juvenile chum salmon in the upper layer was two times more than that in the lower layer, due to difference in the distribution patterns of *E. herdmani* adult males. These results suggest that estimates of prey biomass have to consider both the distribution characteristics of prey organisms and fish.

The releasing of otolith marked fish started in 1999 in Japan. Only four million chum salmon fry were released in the first year. The number of otolith mark releases increased every year, and 128 million fishes of chum, pink, masu and sockeye salmon were released in the spring of 2006 (Table 1). Otolith marked chum salmon juveniles were captured in the wide area of the Pacific coast of Hokkaido. Because many fishes were captured in the west side of the released river mouth during the initial period, the migration of chum salmon juveniles might be affected by the current (in particular, Oyashio). Figure 4 shows temporal changes in fork length (left) and computed growth rates (right) of three different released groups of otolith marked chum salmon released in the Shizunai River in 2005. Although three groups were released every 20–30 days each other, the fork length of three groups were almost similar when released. When the growth rate was compared among the groups, the last released group grew much faster than other groups.

Chum salmon, pink salmon and arabesque greenling were dominated among fish captured by trawls in the Okhotsk Sea on October 14–27, 2002. A genetic analysis showed that the regional stock composition estimates of juvenile chum salmon was 37.6% Japan, 6.6% Sakhalin, 0.6% Premorye, 4.2% Amur River, and 49.7% northern Russian stocks (Urawa et al. 2004). The estimated stock composition was apparently different among the catching locations. The percentage of Japanese stocks was high in southern water, but low in northern water. The northern Russian stocks showed the opposite trends in their distribution. Sakhalin and Amur River stocks appeared in the western water. A similar result was obtained in 2000 (Urawa et al. 2006) and 2003 (Urawa et al. 2007). Nineteen otolith marked chum salmon released from three Japanese (Chitose, Shizunai and Ichani in Hokkaido) and three Russian (Bereznykovsky and Sokolovsky in Sakhalin, and Ozerki in western Kamchatka) hatcheries were found in the Okhotsk Sea (Urawa et al. 2004). Japanese marked fish ($n = 14$) were widely distributed in the waters south of 53°N. It was confirmed for the first time that Japanese chum salmon juveniles migrate even from the Pacific coast (Shizunai Hatchery) to the Okhotsk Sea. Four otolith marked fish released from two hatcheries in southern Sakhalin were caught in the western water near the island.

Fig. 4. Temporal changes in fork length (left) of otolith marked chum salmon released in the Shizunai River on 11 March (white), 1 April (gray) and 3 May (black) in 2005, and computed instantaneous growth rate of each group (right).



In summary, major mortalities of salmon may occur during the initial coastal life. The previous studies indicate that Asian juvenile salmon are abundantly distributed in the Okhotsk Sea during summer and fall in the first year of ocean life. The early life history studies in the coastal waters and the Okhotsk Sea are important to understand the survival mechanisms of salmon. To clarify mechanisms controlling population dynamics of juvenile salmon, we focus on the following research items:

- Feeding, growth, and survival of juvenile salmon;
- Seasonal distribution and migration of juvenile salmon; and
- Monitoring of ocean environments such as surface water temperature, salinity, primary production, and prey organisms.

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Juvenile Salmon: Migration Routes and Survival Results from the Demonstration Phase of the Pacific Ocean Shelf Tracking Project (POST)

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Keywords: Salmon, acoustic tracking, migration routes, mortality and survival

The Census of Marine Life and the Gordon and Betty Moore Foundation are helping to develop the Pacific Ocean Shelf Tracking Project (POST), a permanent continental-scale tracking array for the west coast of North America. This new tool for marine research can help provide an improved understanding of marine animal behavior and thereby facilitate better fisheries management. It can make available more precise data on such things as timing, rate and route of migration; differences in stock and species behavior, and the location of freshwater and marine mortality. The development of long-life modem-equipped (“wireless”) receivers means that it is possible to put in place a permanent year-round tracking array, which could potentially also include other sensors to supplement the tracking data with direct observation of changes in oceanic properties.

2004–2005 was a two year field demonstration, and used six 20 km long listening lines and several thousand acoustically tagged juvenile salmon (12–15 cm long) to test the concept. Detection rates for individual fish crossing 20 km long acoustic lines was approximately 95% in both years, meaning that only one fish in 20 was not detected as they crossed each listening line. As a consequence, very precise measurements of salmon biology (including survival) are now feasible.

The results demonstrate striking differences in marine migration pathways and survival even between different populations of the same fish species, as well as between species—and that these differences are measurable.

Data on two stocks of endangered sockeye salmon from southern British Columbia contained a number of surprises. They showed that a portion of the tagged fish from both Cultus and Sakinaw Lakes spent time in nearby Howe Sound before migrating north and that in both years a proportion of the Sakinaw fish left Georgia Strait by means of Juan de Fuca Strait rather than by the more obvious route through Johnstone and Queen Charlotte Straits.

Acoustic data from a line of 22 receivers across Queen Charlotte Strait suggests interesting variations in the way in which both species and stocks migrate, as well as differences in the migratory behavior of hatchery and wild components of the same stock. For example, wild steelhead from the Keogh River tended to fan out across Queen Charlotte Strait toward the mainland before turning north over the listening line, while most hatchery fish crossed the line nearer to Vancouver Island. Individual Sakinaw sockeye were repeatedly detected over a much longer period on the Queen Charlotte Strait line by comparison with Cultus sockeye which seemed thereby to be migrating more quickly.

Freshwater and early marine survival of most stocks studied was generally high, and indicates that substantial mortality must occur beyond the geographic range and period of time that the current POST array measures. Although survival rates generally seem to be stable between the two years, we observed a six-fold drop in the freshwater survival of Cultus Lake sockeye in 2005. Other stocks of salmon that also migrate out of the Fraser River showed no decline in 2005, and subsequent survival in the ocean of Cultus Lake sockeye was similar to that measured in 2004. Although the reason for the poor survival in 2005 is unclear, the key point is that it is now possible to measure these changes and isolate the parts of the life history affecting salmon conservation.

The array was able to measure both freshwater and marine survival for tagged fish by comparing the number leaving freshwater with those that subsequently migrated out of the Strait of Georgia ecosystem to the open ocean across the Queen Charlotte Strait and Juan de Fuca Strait listening lines, and provide detailed data on the speed of migration of individual fish. It should be noted that during the demonstration phase, sensors were removed from the water in September–October and they could not therefore detect and later movement to the open ocean of coho stocks like those from the Cheakamus and Nimpkish Rivers that maintain a period of initial residence in nearby salt water before further migration. The permanent lines being installed in 2006 will make such data available.

The development of POST promises a radical change in how scientific research can be conducted on salmon in freshwater or continental shelf waters. For example, it is now possible to contemplate direct experiments in the ocean of how different groups of marine fish respond (movement rates, survival) after “treatment” (e.g. sea lice burden or El Nino) or to measure seasonal movements of individual stocks of fish—of all species, not just salmon. This can change marine salmon research from a discipline based on a very limited observational capacity to one

based on direct experiment.

For further information, see www.postcoml.org.

Results of the Pioneering Studies of Pacific Salmon Early Marine Life on the Sakhalin Island Shelf

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Keywords: Juvenile pink salmon, abundance, growth, migration, coastal water, Sakhalin

The early marine life period of Pacific salmon is considered to be critical for the formation of their broodline numbers (Watanabe 2000). However, for a long time, this period was not investigated with research efforts concentrated in the offshore zone of far-eastern seas. It was believed that juveniles of the Sakhalin pink salmon stocks did not stay in the coastal zone for a long time. Migrations of 5–20 miles and more were thought to occur from the coast during the first days (Shershnev et al. 1982).

In 2002, SakhNIRO began a study of juvenile salmon in the Sakhalin-Kurile region from the board of R/V *Dmitry Peskov*. Since 2003, a pelagic trawl (54.4/192 m) with the fine mesh size insert in the codend was used to catch salmon. The net fished in an area of 0.17 km² during one half-hour. Calculations of juvenile pink salmon abundance were executed by the squares method assuming a trawl catch-ability coefficient of 0.1 for such small fish.

During June–July of 2002–2003, 337 trawl hauls were executed near the eastern Sakhalin and southern Kurile Islands. Juvenile salmon aggregations were not discovered on the shelf. In 2004, the survey area and schedule time were expanded. Waters around the southern Sakhalin were surveyed in June and July. During the cruise, 217 trawl operations were performed from 17 June to 31 July. Dense juvenile Pacific salmon aggregations were found in the Aniva Bay in the beginning of July. A total of 1671 juvenile pink, 425 juvenile chum, and 11 masu salmon were sampled (Shubin et al. 2005). We observed that juvenile Pacific salmon did not migrate from the inshore zone as early as previously believed.

In 2005, research efforts were concentrated in the Aniva Bay. Surveys were repeated three times. During the first lag (6–10 July), pink salmon catches varied from five to 2,867 and averaged 278 fish per haul. Juvenile pink salmon were mostly captured in the western Aniva Bay, above 34–36 m depths (Fig. 1). Chum salmon catches at five stations above the 30 m isobaths and deeper ranged from one to 133 fish per haul. In total, 3,700 juvenile salmon were captured. Frequency of occurrence in trawl catches was 56% for pink salmon and 16% for chum salmon. During the second lag (20–25 July), seven pink salmon juveniles were caught in the eastern Aniva Bay and 151 juveniles in the La Perouse Strait above 51–100 m depths. A single juvenile chum salmon was caught. During the third lag (11–18 August), juvenile salmon were not found in the survey area.

Pink salmon body lengths differed little between the stations of first survey lag, averaging 7.3 cm, and weighing an averaged of 2.94 g. The range of sizes indicated that investigated juveniles originated from the Aniva Bay rivers. Year-to-year comparisons revealed that the variability of pink salmon size indices was in a relatively narrow

Fig. 1. Pink salmon catch distribution in the Aniva Bay and the La Perouse Strait during the first (6–10 July, A) and second (20–25 July, B) lags of pelagic trawl survey.

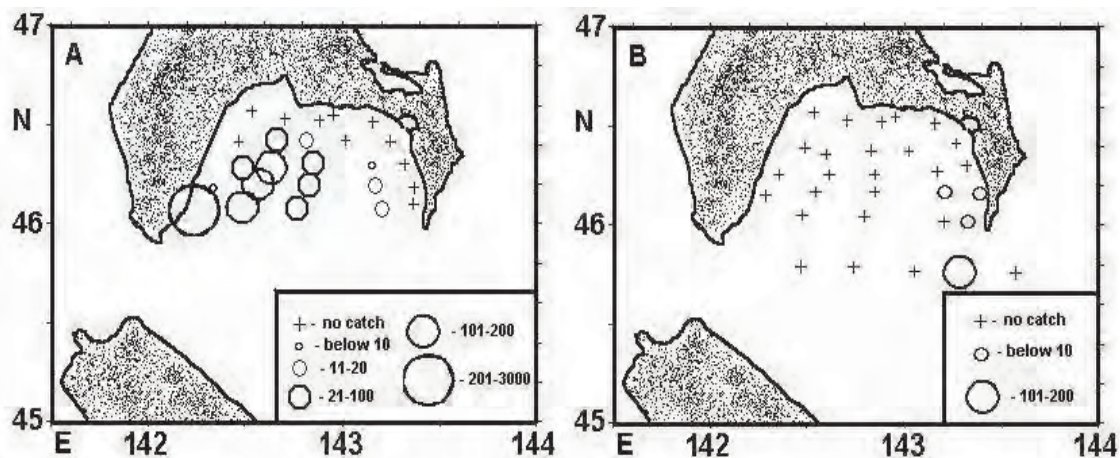
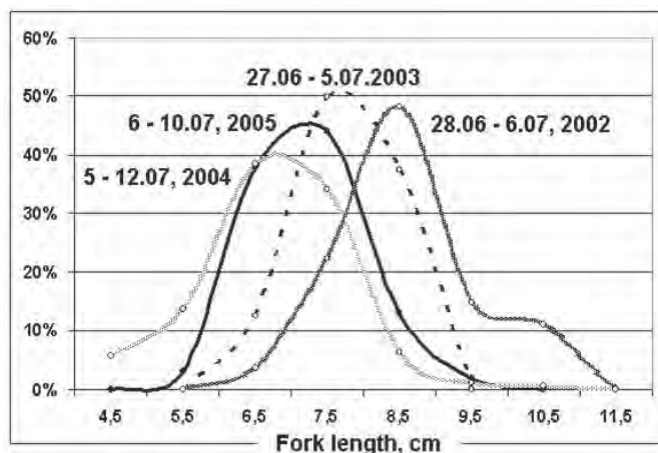


Fig. 2. Length distribution of pink salmon captured during the pelagic trawl surveys in 2002–2005. Dates of survey lags are indicated near the corresponding curves.



During first stage, total numbers of pink salmon juveniles were estimated at 51.6 million fish, with a distribution density of 16,353 fish/km². The total numbers of pink salmon brood from the Aniva Bay rivers were estimated during downstream migration at 219.3 millions in 2005. According to calculations, pink salmon mortality totaled about 76.5% of abundance during 1.5 months in the sea. This estimate may be too large because of the underestimation of juvenile pink salmon numbers in the Aniva Bay. Pink salmon mortality was estimated at 66.6–69.5% within approximately three months from marine environment entering to the autumnal survey in the offshore Okhotsk Sea in the 1990s (Radchenko 2001).

Pink salmon juveniles spend from 2.5 to 0.8 months in the narrow coastal zone out to the 30 m depth from April to early July, depending on the date they enter the marine environment. Their offshore migration did not occur gradually, in proportion to the growth of fishes, but simultaneously during several days. They all leave inshore waters independently from body size but related to the time of downstream migration. Juvenile pink salmon migration offshore coincided with a SST increase up to 14–15°C and with maturing pink salmon migration from the ocean.

Bycatch of pelagic fishes demonstrated significant variability during the survey. Thirty-one fish species from 19 families were captured in the trawl in the upper pelagic layer in Aniva Bay from 6 July to 18 August, 2005. Our survey identified changes in the specific composition and spatial distribution of the fish community. It demonstrated that juvenile pink salmon dwell in a very variable biological surrounding. The biological seasons changed more frequently in Aniva Bay than seasons identified by a calendar.

The tasks of future studies should be: the determination of an optimum timetable for a survey on the basis of the seasonal state of shelf fish community, estimation of the size and biological condition of juvenile salmon, pathways of migration for odd- and even years broodlines, gear improvement, and a quantitative examination of total number and productivity of broodlines.

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Distribution and Growth of Juvenile Chum Salmon in the Abashiri Bay, Eastern Hokkaido, in Relation to Sea Surface Temperature

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Keywords: Chum salmon, distribution, growth rate, stocking, timing

The number of chum salmon (*Oncorhynchus keta*) returns in Hokkaido, northern Japan, increased since 1970s. The recent high returns are supported by the improved stocking techniques and favorable oceanic conditions (Kaeriyama 1999). However, there are significant differences in the return rate of hatchery-released salmon depending on their spawning seasons or home regions within northern Japan.

To determine the optimal timing to stock hatchery-reared juveniles, we have conducted a research project along the Abashiri coast of the Okhotsk Sea since 2002 (Nagata et al. 2004; Nagata et al. 2005). A part of chum salmon juveniles were otolith-marked with alizarine complexone (ALC) before hatching, and were stocked in the Abashiri River in April or May 2002–2005. Several marked groups were stocked at different timings to examine the effects of stocking timing on distribution and growth of juveniles after ocean entry. In the Abashiri Bay, four transects (A–D; Fig. 1) in the costal waters, and three sampling sites were set on each transect at 1 km, 4 km, and 7 km from the shore. Marked and unmarked juvenile chum salmon were captured at these sites by a surface trawl in 2002–2005. Also, a beach seine has been conducted to capture salmon juveniles inhabited in the littoral waters (within 100 m from the shore; St. E in Fig. 1) in 2003–2005. Sampling in the coastal and littoral waters was repeated every ten days from late April to mid-July in each year.

While relatively high juvenile abundances were observed in the coastal waters from late May to mid-June in 2002 and 2004 when sea surface temperature (SST) ranged from 8 to 13°C, this temperature zones occurred only in June in 2003 and 2005 in the coastal waters (Fig. 2). When SST was below 8°C, marked juvenile chum salmon stocked in late April 2003 were not distributed in the coastal waters, and they appeared widely in the coastal waters when SST exceeded 8°C in June, along with the other marked group stocked in mid-May (Fig. 3). When SST was less than 8°C in the coastal waters, juvenile chum salmon were abundant in the littoral waters where SST was relatively higher. Marked fish stocked in late May 2004 and 2005 were distributed in the coastal waters immediately after stocking, and never captured in the littoral waters (Fig. 3), because SST in the coastal waters were near or

Fig. 1. Locations of sampling sites by surface trawl net (A–D transects) and beach seine (E). The arrow indicates release site of marked chum salmon.

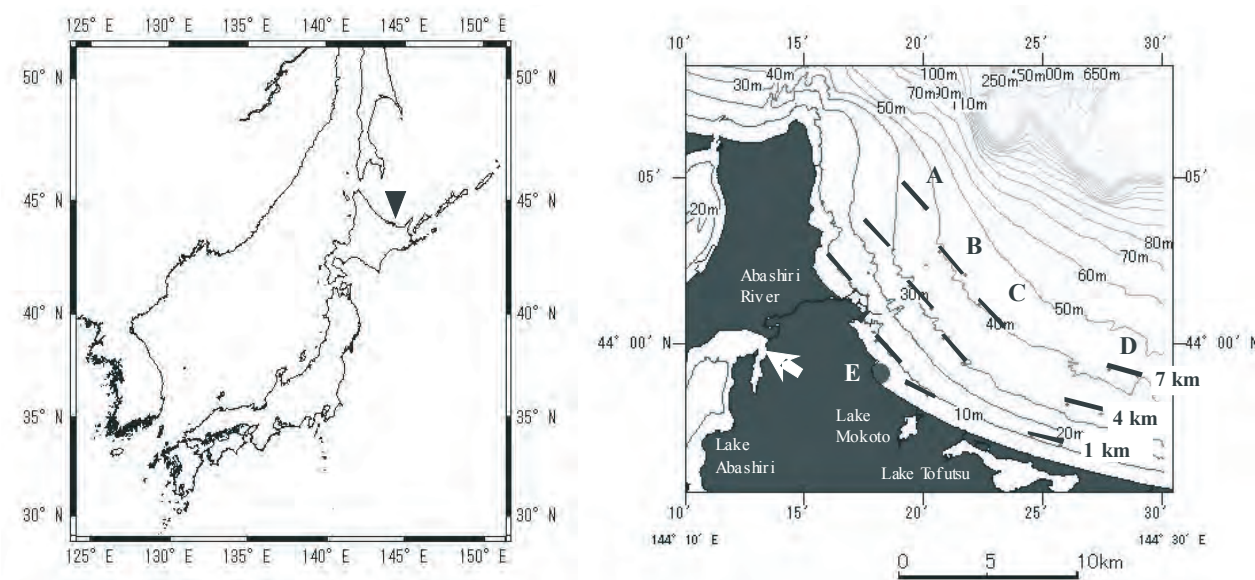
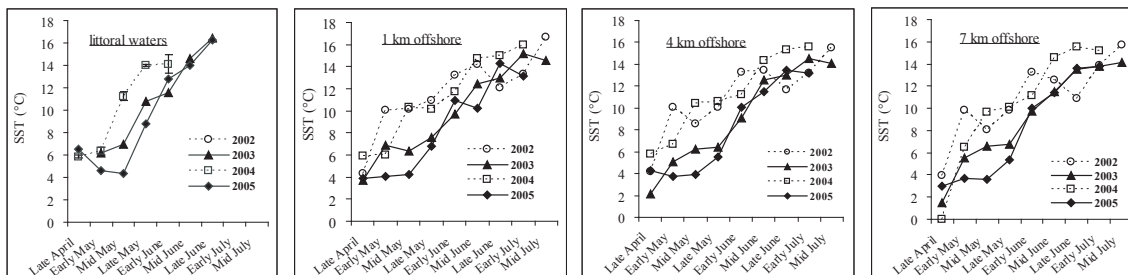
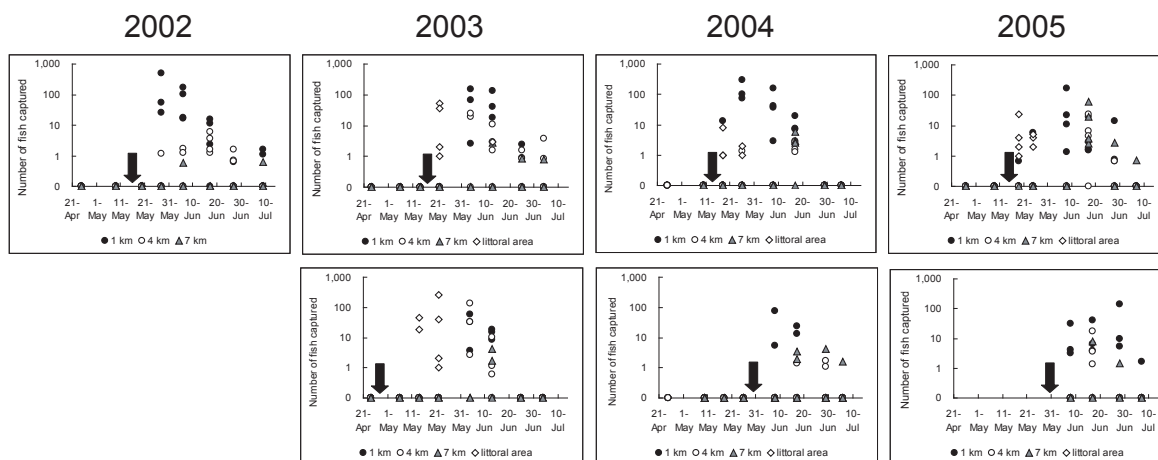


Fig. 2. Sea surface temperature at 1 km, 4 km, and 7 km off the Abashiri coast, 2002–2005.**Fig. 3.** Number of marked chum salmon captured by surface trawl (number of fish per 2 km towing) at 1 km, 4 km, and 7 km off the coast and beach seine (number of fish per 100 m towing) in the littoral waters, 2002–2005. The arrows indicate release dates for each marked group.

exceeded 8°C when they entered the ocean. These differences indicated that spatial distribution of juvenile chum salmon immediately after ocean entry was strongly affected by seawater temperature.

The specific growth rates (SGR) of marked juveniles released in mid-May was not correlated with SST. Also, SGR fluctuated within a season, and the trend was different from year to year. Seawater temperature might not be the critical factor to determine the growth rate of juvenile chum salmon in the coastal waters. High SST in May seems an advantageous condition for juvenile chum salmon, because it allowed fish to feed in the wide nursery areas. However, growth rates of juveniles should be related to abundance and structure of zooplankton community (Asami et al. 2005).

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A Summary of Juvenile Salmon Research along the Eastern Bering Sea Shelf by the Ocean Carrying Capacity Program, August–October (2001–2005)

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Keywords: Juvenile salmon, distribution, feeding, eastern Bering Sea

Mechanisms affecting marine survival of eastern Bering Sea salmon stocks are poorly understood due to the lack of basic biological information about the early marine life history of salmon in this region. Earlier studies of juvenile salmon migration in the eastern Bering Sea were generally focused within Bristol Bay (Straty 1974; Hartt and Dell 1986; Isakson et al. 1986). Information on juvenile salmon in the Arctic, Yukon, and Kuskokwim region is limited to a 1986 study of juvenile salmon that was restricted to a few sample stations around the Yukon River delta (Martin et al. 1986). Summaries of these studies can be found in Brodeur et al. (2003).

During the past five years (2001–2005), the Auke Bay Laboratory's Ocean Carrying Capacity program has conducted surveys of juvenile salmon along the eastern Bering Sea shelf. The goal of the Ocean Carrying Capacity program's juvenile salmon research along the eastern Bering Sea shelf is to understand mechanisms underlying the effects of environment on the distribution, migration, and growth of juvenile salmon in the eastern Bering Sea. Primary objectives of this work are: 1) determine the extent of offshore migrations of juvenile salmon from rivers draining into the eastern Bering Sea, 2) describe the physical environment of the eastern and northeastern Bering Sea shelf waters occupied by juvenile salmon, and 3) collect biological information on other ecologically important species. Summaries of the juvenile salmon surveys are reported in Farley et al. (2001, 2003, 2004, 2005).

In general, distributions of juvenile salmon along the eastern Bering Sea shelf vary between species. During our five year study, juvenile pink salmon were distributed further offshore during even years (Fig. 1a) and offshore and nearshore locations during odd years (Fig. 1b). The presence of juvenile pink salmon nearshore during odd years is likely due to dominance of the even year pink salmon returning to western Alaska. Juvenile chum, coho, and chinook salmon were generally distributed nearshore along coastal regions off the Yukon and Kuskokwim Rivers (Figs. 1c–e).

Fig. 1. Selected examples of distribution of juvenile salmon, described by the logarithm of catch per unit effort (number of juvenile salmon caught during a 30 minute trawl haul), for juvenile pink salmon during 2002 (a) and 2003 (b), juvenile chum (c), coho (d), chinook (e), and sockeye (f) salmon collected during August–October 2002 along the eastern Bering Sea shelf.

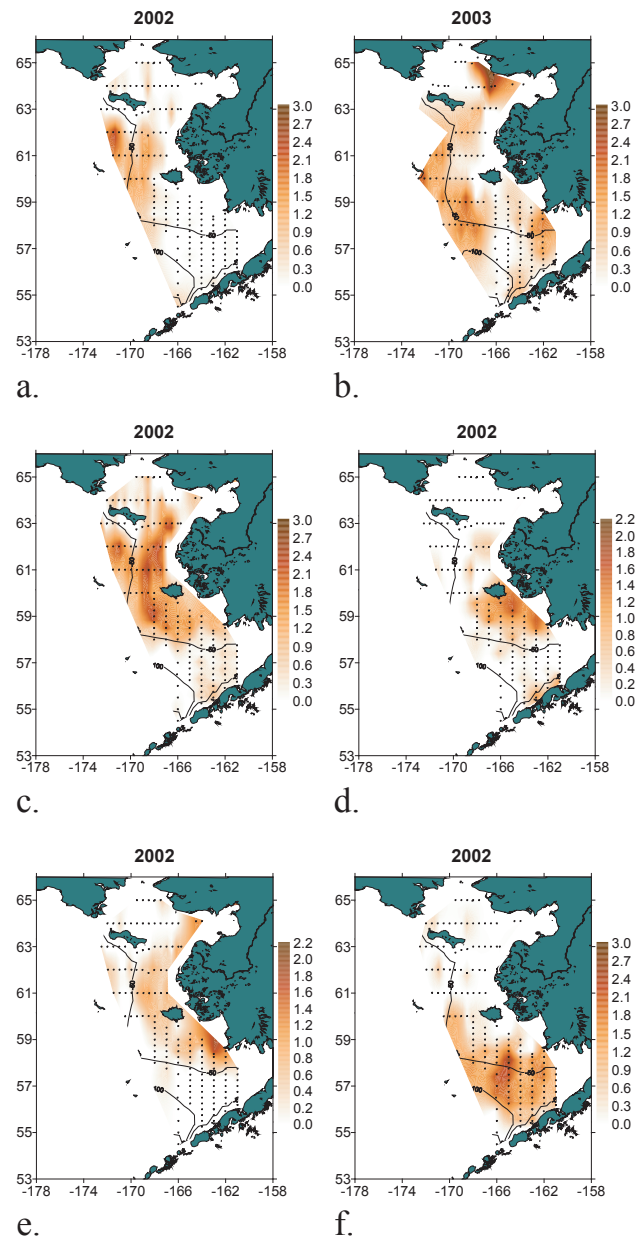
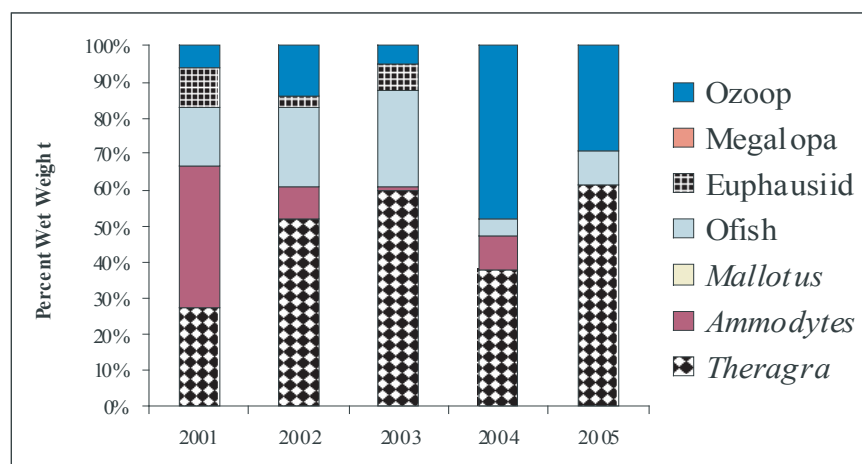


Table 1. Relative abundance (average catch per unit effort; 30 minute trawl haul) for juvenile pink, chum, sockeye, coho and chinook salmon caught along the eastern Bering shelf during August–October 2001–2005.

Year	Pink	Chum	Sockeye	Coho	Chinook
2001	0.9	2.0	35.1	0.6	.03
2002	4.2	29.8	49.5	2.7	2.1
2003	27.7	23.7	64.2	6.5	4.0
2004	13.1	12.2	36.4	2.5	3.4
2005	12.0	19.5	136.5	1.1	3.3

Fig. 2. An example of percent wet weight of prey for juvenile sockeye salmon caught along the eastern Bering Sea during August–September 2001–2005.

Juvenile sockeye salmon were generally distributed in offshore locations of the eastern Bering Sea shelf (Fig. 1f).

The relative abundance (the average of the catch per unit effort; catch of juvenile salmon during a 30-minute trawl haul) varied between years and species (Table 1). The relative abundance of juvenile pink, coho, and chinook salmon was highest during 2003. The relative abundance of juvenile chum salmon was highest during 2002 and 2003, and then declined during 2004. The relative abundance of juvenile sockeye salmon increased each year, declined during 2004, then greatly increased during 2005. Although it is too early to detect, the variability in juvenile salmon relative abundance during the last five years appears to be positively related to adult returns to western Alaska.

Other data collected during the survey indicate that fish, including age -0 pollock (*Theragra chalcogramma*), sand lance (*Ammodytes hexapterus*), and capelin (*Mallotus villosus*) dominated the diets of juvenile salmon along the eastern Bering Sea shelf during fall (Fig. 2). In addition, depth-averaged sea temperatures from a conductivity-temperature and depth device deployed at each fish station during our surveys have indicated that the temperature along the eastern Bering Sea shelf has increased during the five year period, especially in the nearshore areas.

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Seasonal Distribution and Migration of Juvenile Chum Salmon

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Keywords: Juvenile chum salmon, catch, distribution, abundance, migration, fork length

Data from epipelagic research surveys by TINRO-Centre in the southern Okhotsk Sea and western Bering Sea during autumn of 1991–2005 were utilized to analyze quantitative distribution, abundance and migrations of the juvenile chum salmon. The biological characteristics of the juvenile chum salmon in the Okhotsk and Bering Seas, as well as seasonal and interannual dynamics of growth were considered. The oceanographic conditions were reviewed along with the analysis of their influence upon redistribution and marine environment adaptations of juvenile chum salmon.

Our analyses indicated that in summer, juvenile chum salmon were distributed over the deep southern Okhotsk Sea basin in mid-July, while in the northern Okhotsk Sea, they remain within the inner shelf zone.

In the northern Okhotsk Sea, juvenile chum salmon begin their offshore migrations from the shelf zone during August, while in the south, juvenile chum catches may reach and even exceed 500 individuals per hour trawling. Transition of juveniles into open waters from various spawning areas proceeds in different directions. The major pool of juveniles migrate from the continental coast southward, while those from the southern regions distribute mainly northward (Fig. 1).

In the second half of autumn, juvenile chum salmon from the northern areas still continue their migrations into the southern deep basin (Fig. 2). At the same time, some juveniles migrate into the ocean through the Kuril passes, primarily through the southern and central deep-water De Vries, Urup and Boussole straits. Our data do not support the existence of intensive immigration of juvenile chum salmon into the ocean through the northern straits. The southern migration route seems to be more realistic, because in this case, young fish are able to take advantage of forage resources in the slowly cooling deep-water basin. Further more, spatial distribution of juvenile chum salmon in the southern Okhotsk Sea in December and January appears to support this idea. During these winter months, chum congregate immediately in front of the southern straits, through which young fish are going to enter the ocean (Fig. 2).

In the western Bering Sea, smoltification of chum occurs most intensively in June–July. Somewhat later, in August, chum juveniles born within the Anadyr drainage system enter the sea. In spite of the early downstream migration of juveniles, most fish after smoltification stay close to natal regions and continue to forage within relatively small areas.

During September, juvenile chum salmon start migrating from the Koryak coast and Karaginskyi Bay into the open western Bering Sea (Fig. 3). In October, juvenile chum salmon occur in the epipelagic western Bering Sea in both coastal and deep regions. Like in the southern Okhotsk Sea, the peak abundance of juvenile chum salmon is observed in October in the deep Bering Sea. However, the total abundance of juvenile chum salmon in the western Bering Sea is notably lower than in the Okhotsk Sea. Time of intensive exodus of juvenile chum salmon into the

Fig. 1. Spatial distribution of juvenile chum salmon catches during summer and autumn 1992–2005 (without “0 catch” CPUE in specimen/hour).

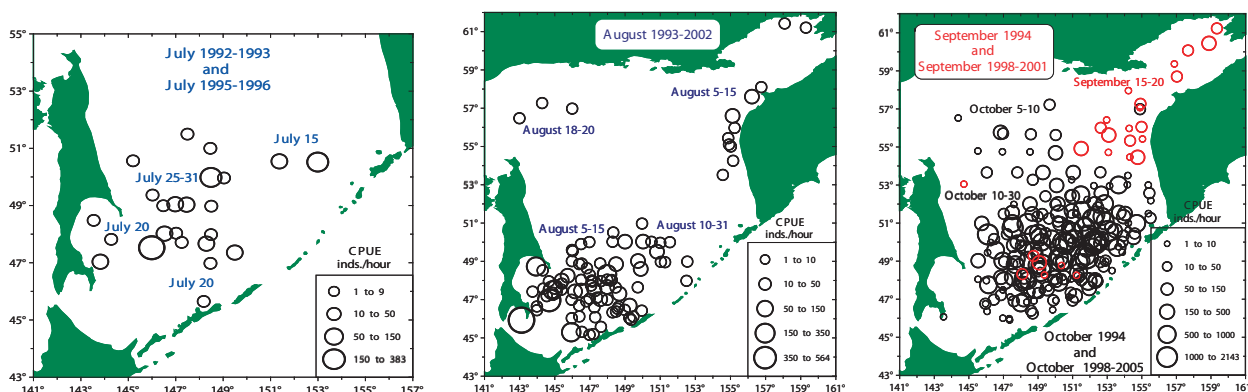
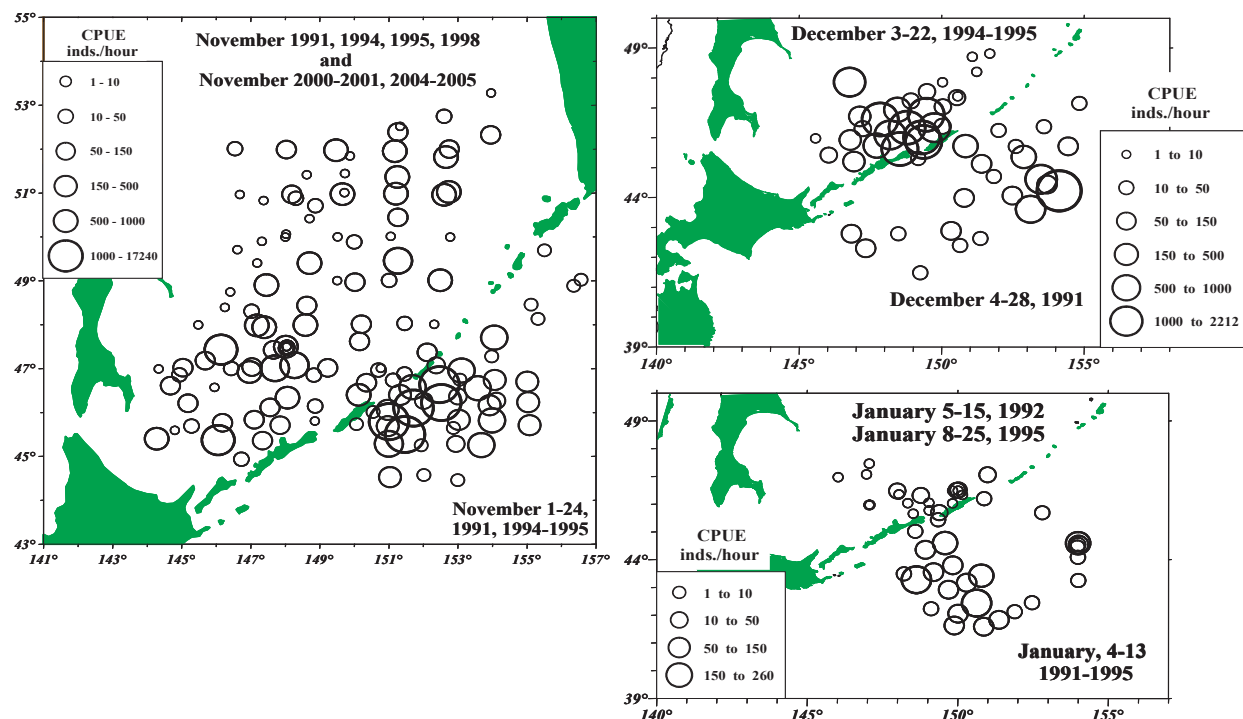
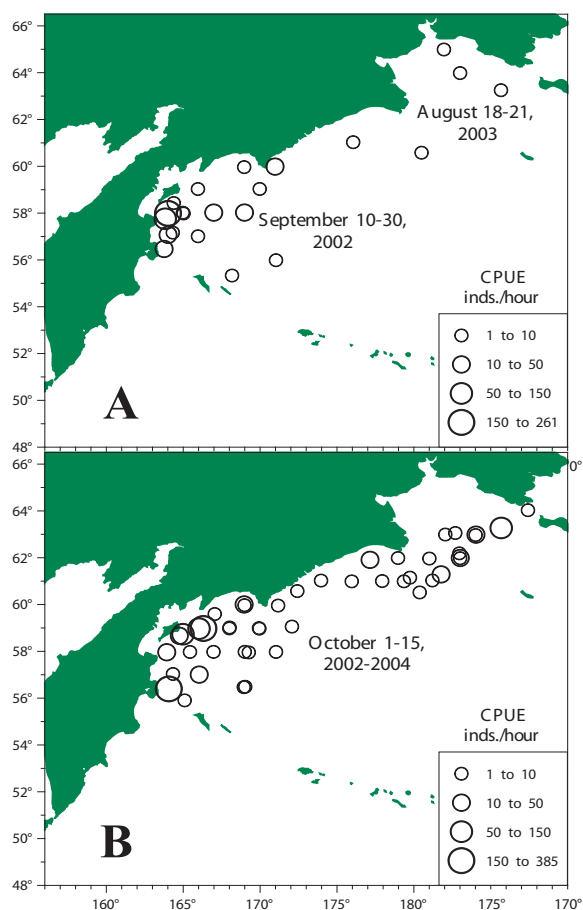
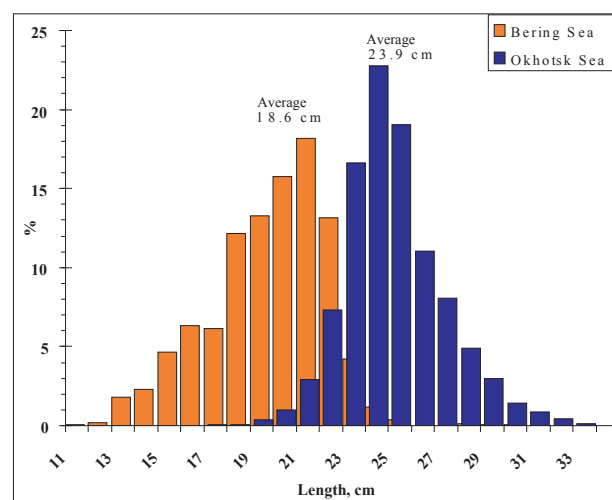


Fig. 2. Spatial distribution of juvenile chum salmon catches (specimen/hour) during autumn and winter 1991–2005.**Fig. 3.** Spatial distribution of juvenile chum salmon catches (specimen/hour) in the Bering Sea during August–October 2002–2004.**Fig. 4.** The fork length composition of juvenile chum salmon in the southern Okhotsk Sea and western Bering Sea during the autumn of 2002–2004.

ocean also differs in these two marine basins: the western Bering Sea chum salmon enter the ocean earlier than the Okhotsk Sea chum, and no juvenile chum salmon have ever been captured in the western Bering Sea in winter.

Juvenile chum salmon leave the Bering Sea through the western passes, primarily through Near Strait. Before entering the ocean, they stay for a while in the deep Commander Basin. However, they spend much less time there than young chum in the southern Okhotsk Sea and by early November, most of the

Fig. 5. Correlation between normalized CPUE values of juvenile chum salmon and sea surface temperature in the southern Okhotsk Sea (A), western Bering Sea (B), and western North Pacific Ocean (C) in 1991–2005.

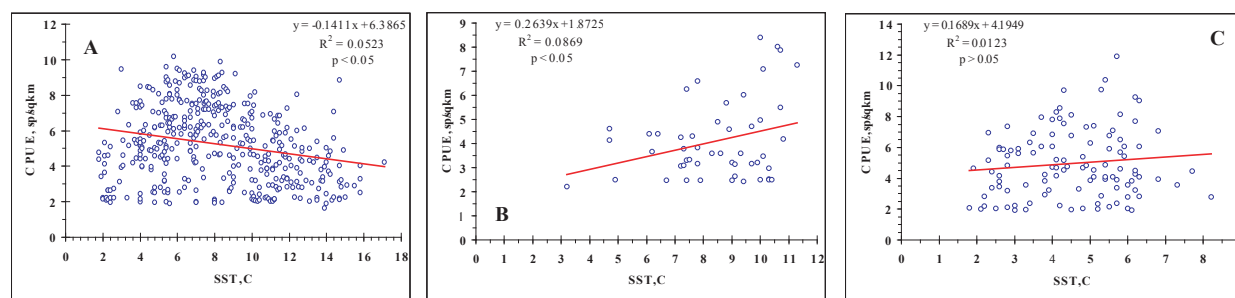
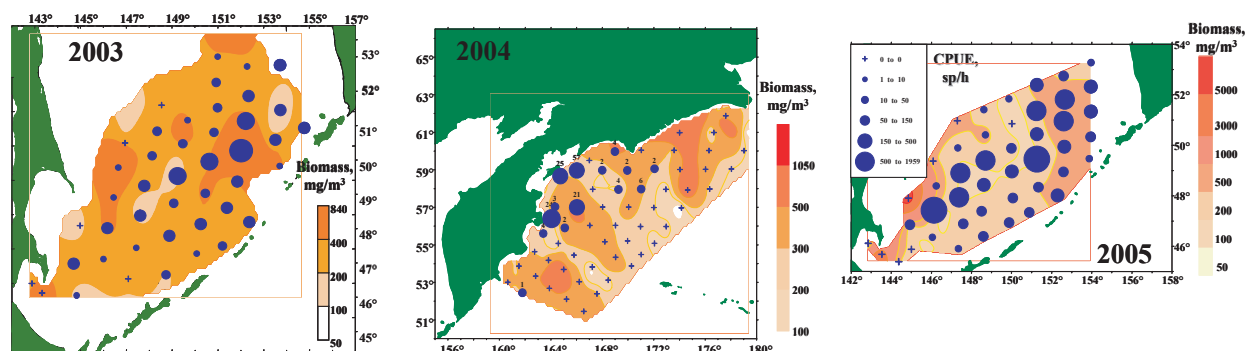


Fig. 6. Spatial distribution of juvenile chum salmon catches (per hour) and horizontal distribution of large-sized zooplankton biomass (mg/m^3) in the autumn of 2003–2005.



juveniles leave the western Bering Sea for the ocean.

Distribution patterns and size structure of chum juveniles in the southern Okhotsk and western Bering seas depend upon stock structure of these aggregations. In the southern areas, smoltification occurs earlier, and by the autumn, juvenile chum salmon tend to be larger there than in the northern areas (Fig. 4).

In the summer of 2002, the smallest chum salmon were observed in trawl catches off the southern Sakhalin, while larger fish were present in the southern deep basin. Mean length difference between juveniles from these regions reached 4 cm.

Notable seasonal changes in chum salmon body length have been observed within the southern deep basin in the Okhotsk Sea. In 1999, mean chum salmon length increased from 14.8 cm (mean weight 32.1 g) in August to 23.3 cm (mean weight 140.4 g) by October, or by 8.5 cm (108.3 g) in two months. Therefore, an individual fish gained about 1.8 g per day during that period.

Many researchers relate spatial redistribution and migrations of Pacific salmon to water temperature. For example, migrations of juvenile chum salmon from the shelf into the open sea are associated with a decrease in water sea surface temperature.

Long-term data do not reveal clear relationships between catches of juvenile chum salmon and sea surface temperature in any of the season during their forage migrations in the Far Eastern seas and adjacent Pacific Ocean. Most juvenile chum salmon occurred within the range of sea surface temperature from 1.8 to 17.1°C (Fig. 5). However, chum salmon were occasionally captured in Kuril waters at the negative temperature of -0.5°C.

In addition to the hydrological impact, chum salmon distribution and migrations are also undoubtedly influenced by forage conditions, as indicated by the biomass distribution of large-sized zooplankton, the major component of the diet of chum juveniles. Figure 6 shows that increased aggregations of zooplankton occur in areas where Pacific waters flow into the Bering Sea and form an anticyclonic gyre there. In the southern areas, the biomass of forage zooplankton was generally smaller, and hence, juvenile chum salmon were notably smaller in size. In the Bering Sea, similar patterns for distribution of young chum and forage plankton have been observed. In the Karaginskyi region, dense aggregations of juvenile chum salmon were associated with zooplankton-rich areas, and with large concentrations of hyperiids, their major prey.

Winter Distribution of Chum Salmon Related to Environmental Variables in the North Pacific

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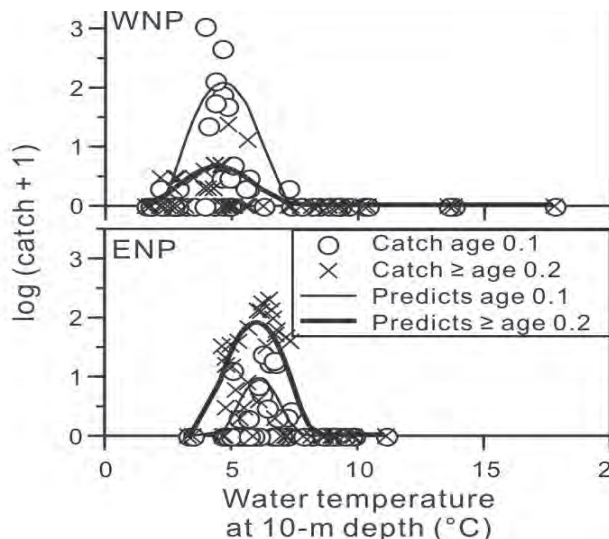
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Keywords: Spatial distribution, water temperature, growth-maximization hypothesis, zooplankton biomass

For many years, researchers have hypothesized that environmental factors are related to wintertime ocean distribution of chum salmon (e.g. Shimazaki and Nakayama 1975). In this paper, we analyzed relationships between latitude, temperature, and sea surface salinity, and the number of chum salmon caught during one-hour surface trawl operations. Data were collected during winter salmon research cruises by Japanese research scientists onboard the RV *Kaiyo maru* in the North Pacific (1992, 1996, 1998, and 2006) and Bering Sea (1998).

Fig. 1. Relationship between log-transformed catch of chum salmon caught in one-hour trawls and water temperature at 10-m depth. Fishing operations were conducted during winter in the western North Pacific (WNP; upper) and the eastern North Pacific (ENP; lower). Lines indicate the mean catch of young and older age chum salmon at temperatures predicted by a distribution model.



We constructed a chum salmon distribution model in which the number of salmon caught was a bell-shaped function of each environmental factor (latitude, temperature, or salinity), and trawl catches followed a negative binomial distribution with the mean predicted using a distribution model (i.e. we assumed an aggregate fish distribution). It was assumed that environmental factors did not affect trawl catch efficiency. We fit models to the catch data using the maximum likelihood method, and the best model fit was determined using the Akaike Information Criterion.

Results showed water temperatures in the surface layer in the western North Pacific (west of 180°; WNP) were cooler than in the eastern North Pacific (east of 180°; ENP) in winter. Young chum salmon experiencing their first winter at sea (age 0.1) were abundant in the WNP, and older-aged fish (\geq age 0.2) were abundant in ENP. Both groups of fish were distributed in a narrow latitudinal range, i.e. north-to-south, in the WNP, and in a wide latitudinal range in the ENP. In both areas, young and older-aged chum salmon were distributed in a narrow range of temperatures and in a wide range of salinities.

The best fitting model of observed catches of age 0.1 and older-aged chum salmon was a function of water temperature at the 10-m depth by area. The estimated temperature at the center of salmon distribution in the WNP was $4.67^{\circ}\text{C} \pm 0.70$ SD for age 0.1 fish and $4.48^{\circ}\text{C} \pm 1.03$ SD for older-aged fish. In the ENP the estimated temperature at the center of salmon distribution was $6.13^{\circ}\text{C} \pm 0.55$ SD for age 0.1 fish and $6.05^{\circ}\text{C} \pm 0.64$ SD for older-aged fish (Fig. 1). The estimated temperature ranges were similar for both age groups, although estimated ranges in the WNP were lower than in the ENP.

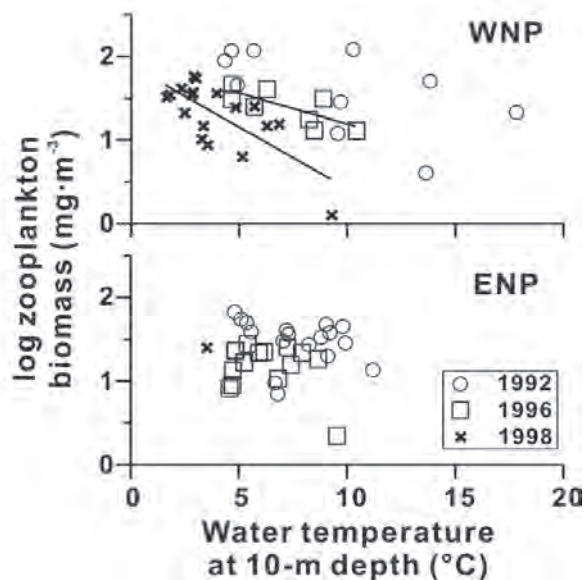
The estimated temperature range of chum salmon distribution in winter was lower than in summer ($6\text{--}11^{\circ}\text{C}$). This was consistent with a qualitative prediction of the growth-maximization hypothesis (GMH), which states that salmon select thermal habitats and have foraging behaviors that maximize growth rate (Rand 2002). The optimum temperature for salmon growth is lower at a lower ration level (Brett 1979). Therefore, we conclude the optimum temperature for growth of chum salmon should be lower in winter because zooplankton biomass collected at survey sites was about 10% lower in winter than in summer (Nagasawa 2000).

The GMH could explain the difference in temperature ranges of chum salmon distribution between the WNP and ENP. We reanalyzed zooplankton biomass from the 1992, 1996, and 1998 *Kaiyo maru* winter surveys (Nagasawa 2000). Although the mean zooplankton biomass was similar between the WNP and ENP (ANCOVA, $p = 0.160$), there was a significant increase in zooplankton abundance with decreasing temperature in the WNP in 1996 and 1998 (Fig. 2). In contrast, there was no relationship between zooplankton abundance and water temperature in the ENP. Therefore, chum salmon may be distributed in cooler waters in the WNP than the ENP in order to avail themselves to greater foraging opportunities in areas of higher zooplankton abundance.

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Fig. 2. Relationship between log-transformed zooplankton biomass and water temperature at 10-m depth in winter in the western North Pacific (WNP; upper) and the eastern North Pacific (ENP; lower). Lines indicate regression equations: $\log \text{ zooplankton biomass} = 1.94 - 0.0744 \text{ temp}$ ($R^2 = 0.558$, $p = 0.033$) in 1996 WNP, and $\log \text{ zooplankton biomass} = 1.89 - 0.147 \text{ temp}$ ($R^2 = 0.529$, $p < 0.001$) in 1998 WNP. Regressions were not significant ($p > 0.05$) in 1992 WNP, or during any year in the ENP.



Origins of Young Chum Salmon in the North Pacific Ocean during the Winter: Rapid Estimates by SNP Markers

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Keywords: Young chum salmon, winter distribution, genetic stock identification, SNP, mtDNA, western North Pacific

Information upon the marine distribution of chum salmon during the winter has been limited. In 1996 and 1998, Japanese scientists conducted winter salmon surveys and determined the stock origins of chum salmon caught in the North Pacific Ocean by allozyme analysis (Urawa and Ueno 1997, 1999; Urawa et al. 1997, 1998). In 2006 after a long gap, the research vessel *Kaiyo maru* winter cruise was conducted to examine the spatial distribution and biological status of salmon in the North Pacific Ocean (Fukuwaka et al. 2007).

DNA techniques provide significant advantage in sampling, sample handling, and the potential for improved resolution for stock identification of salmon. Of the various DNA markers, single nucleotide polymorphisms (SNPs) may be particularly appropriate for stock identification of chum salmon (Seeb et al. 2005). The objectives of the present study were to estimate the stock origins of chum salmon in the western North Pacific Ocean during the winter of 2006 using SNP and mitochondrial (mt) DNA microarray techniques, and to compare the accuracies of estimates by both methods.

We created a SNP baseline by 86 population samples collected throughout the range of chum salmon in Asia and North America. These populations represent most of the major lineages detected in the larger allozyme baseline used in previous NPAFC studies (Kondzela et al. 2002). Individuals were assayed for 30 nuclear SNPs and 6 mitochondrial SNPs using the 5' nuclease reaction previously reported by the US and Japan (Seeb et al. 2005; Smith et al. 2005).

One hour trawl operation was made in the surface layer (from the surface to about 50 m in depth) with 5 knots towing speed at 14 stations in the western North Pacific Ocean during January and February 2006 (Fig. 1). The pectoral fins were collected from young chum salmon (age 0.1; $n = 174$) and fixed in the 100% ethanol on the board. DNA was isolated from the fixed pectoral fins. The extracted DNA samples were assayed genetic variation for 36 SNPs and assigned to population of origin. For a comparison, we also analyzed the same samples using the mtDNA microarray technique (Moriya et al. 2004) and assigned them to population of origin using previously reported mtDNA baseline (Sato et al. 2004). We compared these results to allozyme-estimated stock compositions of young chum salmon caught in similar waters in 1996 and 1998 winters (Urawa and Ueno 1997, 1999).

Most young chum salmon were collected from a few stations along 165° E line in the western North Pacific Ocean (Fig. 1) (Fukuwaka et al. 2007). The stock composition of young chum salmon estimated by SNP analysis was 25.0% Japanese, 60.3% Russian, and 14.7% North American (mostly Alaskan) fish (Fig. 2). The mtDNA microarray analysis provided a similar estimate: 17.1% Japanese, 66.8% Russian, and 16.1% North American origins. The variation (90% confidence interval) of SNP estimate was low, compared with that of mtDNA estimate (Fig. 2). The

Fig. 1. CPUE distribution of young chum salmon (age 0.1) in the western North Pacific Ocean during the winter of 2006. CPUE means the number of catches per one hour trawl at 5 knots.

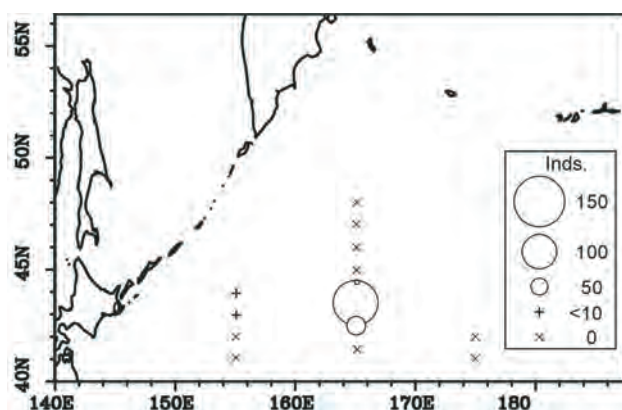


Fig. 2. Stock composition estimates of young chum salmon (age 0.1) caught in the western North Pacific Ocean during the winter of 2006 using SNP and mtDNA microarray techniques. Bars indicate 90% confidence of estimates.

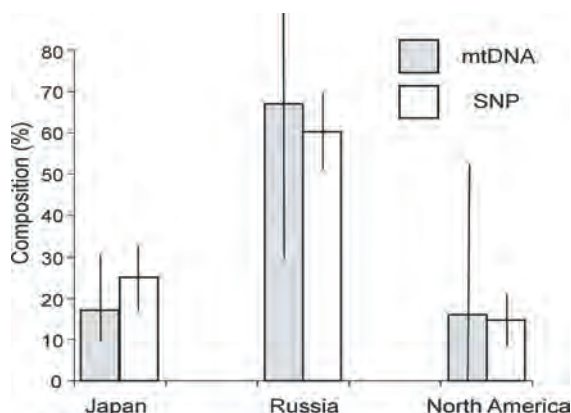
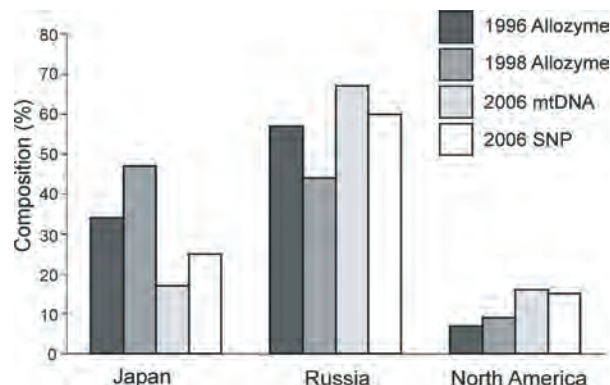


Fig. 3. A comparison of stock composition estimates of young chum salmon (age 0.1) caught in the western North Pacific Ocean during the winter of 1996, 1998, and 2006. The allozyme estimates in January 1996 and February 1998 were cited from Urawa and Ueno (1997, 1999).



SNP analysis used 30 nuclear loci and one mtDNA combined haplotype, while the mtDNA analysis used only one combined haplotype. It might be a reason for differences in variation of estimates by both methods. The stock composition estimates in 2006 winter were slightly different from those in January 1996 and February 1998: the proportion of Japanese stock was higher in 1996 and 1998 than 2006 (Fig. 3). It was impossible to estimate stock-specific biomass of chum salmon in the western North Pacific Ocean, because the survey area was limited by severe weather condition during the winter.

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Time and Spatial Distributions by Age Classes of Chum Salmon in the Central North Pacific and the Bering Sea

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Keywords: Chum salmon, Distribution, central North Pacific, Bering Sea

Chum salmon are widely distributed in the North Pacific and the Bering Sea from spring to autumn. It is known that the distribution for maturing chum salmon is farther north than that of immature chum salmon in spring (Nagasawa et al. 2005). However, why don't immature and maturing chum salmon migrate in the North Pacific and the Bering Sea together? To answer this question, we examined the time and spatial distribution of chum salmon by each age class in the central North Pacific and the Bering Sea.

To examine the time and spatial distribution of chum salmon by each age class, we used data obtained by Japanese salmon research vessels from 160°E to 170°W. The proportion of maturing and immature fish was calculated based on Takagi's maturity definition (Takagi 1961). CPUE is total catch in number per total effort in 30 tans of gillnets.

Figure 1 shows the histogram of CPUE of chum salmon for each of latitude. The predominant age of maturing chum salmon was 0.3 and the predominant ages of immature chum salmon were 0.1 and 0.2. Distribution of chum salmon shifted northward as the summer progressed. In May, chum salmon of age 0.1 to 0.3 were distributed from 43°N to 45°N. In June, distribution of age 0.1 chum salmon extended to 50°N. On the other hand, maturing chum salmon were distributed from 42°N to 63°N, indicating they had already entered the Bering Sea. Age 0.1 chum salmon were distributed in the Bering Sea from July to August. The distribution of age 0.1 chum salmon was less variable than that of maturing chum salmon. Thus, there were age differences structured in the distribution of chum salmon during spring to summer in the North Pacific and the Bering Sea.

Next, we calculated the migration speed from the position of the mode of distribution assuming the migration of the same stock. Estimated migration speed of maturing chum salmon was 0.68 m/s from May to June (Fig. 2). The speed of age 0.1 chum salmon was 0.27 m/s from May to August. Speed of maturing chum salmon was considerably faster than that of immature chum salmon, age 0.1 and 0.2. These estimated speeds corresponded to one fork length per second roughly. Assuming one fork length per second is the mean swimming speed of salmon, this result suggests that the time change of the distribution of chum salmon correlates with their swimming speed.

Total metabolic cost is a function of body weight, ambient temperature and swimming speed by (Beauchamp et

Fig. 1. Histogram of CPUE of chum salmon in each of latitudes. Black bars are maturing chum salmon and white bars are immature chum salmon.

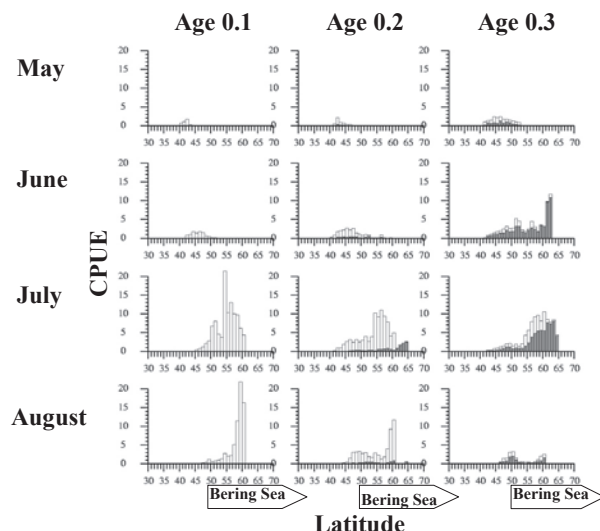
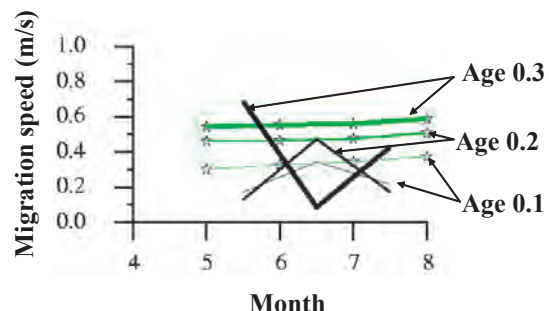


Fig. 2. Time series of monthly migration speed. Green lines are monthly averaged fork length.



al. 1989). The total metabolic cost was estimated from monthly averaged body weight, ambient temperature and swimming speed. Estimated total metabolic costs were dependent on their swimming speed mainly. The total metabolic cost of age 0.1 chum salmon was lower than that of maturing chum salmon from May to June. In June to July, the total metabolic cost of age 0.1 chum salmon was higher than that of maturing chum salmon. It is noted that the total metabolic costs of both immature and maturing salmon were relatively high before they entered the Bering Sea.

In order to reproduce the time change in distribution of chum salmon along latitude, we used the simple one dimensional model. The model which consisted of an advection and diffusion equation written as:

$$\frac{\partial F}{\partial t} = u \frac{\partial F}{\partial x} + D \frac{\partial^2 F}{\partial x^2} \quad (1)$$

where, F (number) is abundance of salmon; x (m) is latitude; t (s) is time; u (m/s) is northward swimming speed; and D (m^2/s^2) is horizontal diffusivity. In this model, u and D depend on fork length. We did not take into account salmon mortality in the model. It was assumed in the model that there was no passive transportation by current, the swimming direction of salmon was only northward, and there was no influence from other salmon stocks. The initial position of salmon in May was set at 40°N . Model parameters are listed in Table 1. Values of u and D that were similar to our observations were used in the model. The model was integrated by a time step of six minutes. After each model run, each age class was integrated for 30 days with no advection and same diffusion, then each age class was integrated for 120 days to obtain dynamics of salmon distribution.

The results of the model are shown in Fig. 3. Age 0.1 chum salmon arrived at 50°N in July, and age 0.3 chum salmon arrived at 50°N in June. The variance of distribution of age 0.1 salmon was smaller than that of maturing salmon. The model reproduced the northward shift of salmon as the summer season progresses. However, in the case of no advection, the model did not reproduce the observed chum salmon distribution. This indicates that the distribution from spring to summer is not well explained by random swimming only and instead indicates that chum salmon actively swim northward. Therefore, differences in age structured distribution of chum salmon from spring to summer is likely due to differences in their swimming speeds.

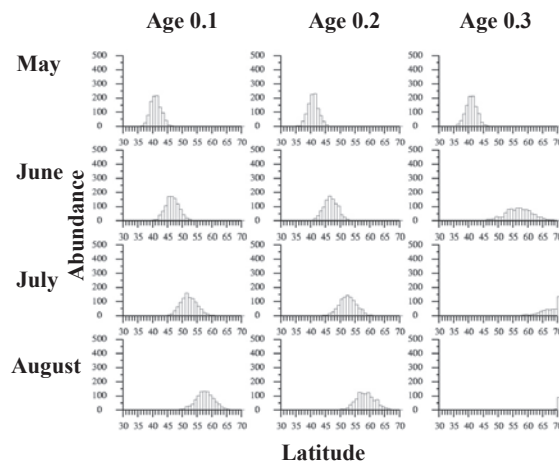
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Table 1. Model parameters.

Age	0.1	0.2	0.3
$u(\text{m/s})$	0.25	0.26	0.68
$D(\text{m}^2/\text{s}^2)$	5100	5500	39300

Fig. 3. Histogram of CPUE of chum salmon in each of the latitudes calculated by the model.



Spatial Patterns in Consumption Demand and Growth Potential of Juvenile Pink Salmon (*Oncorhynchus gorbuscha*) in the Gulf of Alaska

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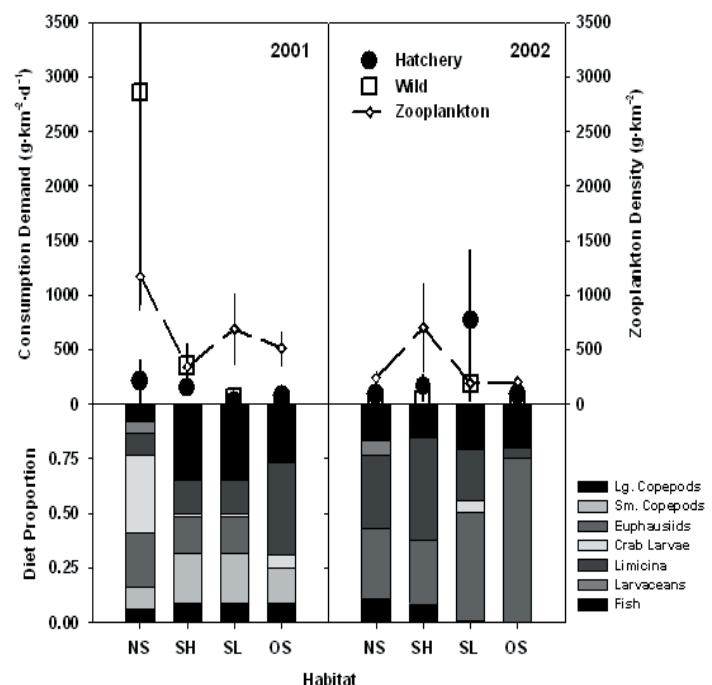
Keywords: Pink salmon, consumption demand, growth potential, Gulf of Alaska, marine survival, habitat

Salmon experience high mortality during early marine life, however, size-dependent mortality might be concentrated during specific life stages (Beamish and Mahnken 2001), and vary among regions (Mueter et al. 2002, 2005; Pyper et al. 2005). Survival of pink salmon during their marine residence appears to be determined in two stages, with the first stage characterized by high initial size-selective predation on juveniles as they enter the coastal regions (Parker 1965, 1968, Willette et al. 1999), and the second by significant size-selective mortality after the first summer growing season (Moss et al. 2005). Different stocks of fish will experience different conditions, as they inhabit different areas during different portions of their life cycle. However, each stock should respond to the same underlying mechanisms, and may express this two-stage mortality process differently. For pink and chum salmon, similar marine survival was reported for populations originating within regions (within 100–200 km) but differed among regions, suggesting that localized environmental processes operated similarly on early life stages in nearshore and coastal marine waters (Mueter et al. 2002, 2005; Pyper et al. 2005). Therefore, localized conditions affecting growth during the first summer in coastal shelf regions could determine the severity of over winter survival.

Average localized daily consumption estimates for wild juvenile pink salmon ($706 \text{ g} \cdot \text{km}^{-2} \cdot \text{d}^{-1}$, ± 371 standard error (SE)) were greater than for hatchery pink salmon ($127 \text{ g} \cdot \text{km}^{-2} \cdot \text{d}^{-1}$, ± 75 SE) during 2001, whereas, hatchery pink salmon were estimated to have consumed more prey ($203 \text{ g} \cdot \text{km}^{-2} \cdot \text{d}^{-1}$, ± 88 SE) than wild pink salmon ($60 \text{ g} \cdot \text{km}^{-2} \cdot \text{d}^{-1}$, ± 20 SE) during 2002, primarily because of differences in relative density. Daily prey consumption demand by wild juvenile pink salmon was greater than that estimated for hatchery stocks in nearshore and shelf habitats, but similar in magnitude with slope and offshore habitats during 2001 (Fig. 1). During 2002, daily prey consumption demand by hatchery and wild stocks were similar in nearshore, shelf, and offshore habitats, but estimates of prey consumption by hatchery stocks was greater in slope habitat than for wild stocks (Fig. 1).

Estimates of daily growth potential were greater during 2002 for each habitat across the Coastal Gulf of Alaska (CGOA) relative to 2001 (Fig. 2). Shelf and slope habitats were estimated to have the highest rates of potential growth during 2001, whereas the nearshore region ranked the lowest (Fig. 2). Averages of daily growth potential for a given habitat type during 2002 were relatively constant, but had a high degree of variability around the mean (Fig. 2). Densities of juvenile pink salmon

Fig. 1. Consumption demand by juvenile pink salmon at near shore stations (NS), over the continental shelf (SH), over the continental slope (SL), and offshore of the continental slope (OS) during July–August 2001 and 2002 Gulf of Alaska research cruises.



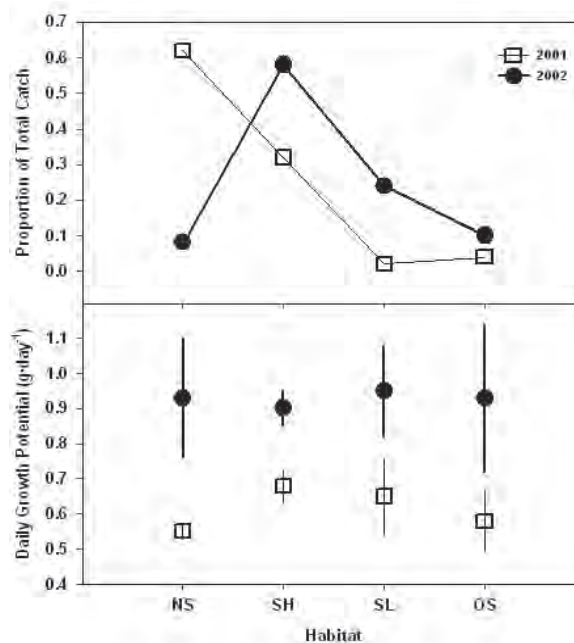
were greatest in nearshore regions and to a lesser degree shelf stations during 2001, whereas during 2002 densities were highest at shelf stations and to a lesser degree slope stations (Fig. 2).

Consumption demand on prey resources varied spatially. Growth potential was relatively low during 2001 and varied among habitats, where growth potential was relatively high and constant during 2002. Spatial differences in zooplankton abundance revealed that food limitation exists in some years and locations. Higher and more uniform estimates of daily potential growth across habitats during 2002 suggested that fish encountered less favorable growing conditions during 2001. During 2001 growing conditions were less favorable across the CGOA, with the largest abundances of juvenile pink salmon inhabiting the nearshore regions, which had the least favorable conditions for supporting growth. Daily growth potential for juvenile pink salmon inhabiting the CGOA increased from 2001 to 2002, as did marine survival for juvenile Prince William Sound (PWS) hatchery stocks. Total returns to PWS (hatchery and wild stocks combined) were greater in 2002 relative to 2001 by a factor of 2.21. This suggests that the daily growth potential metric has the ability to describe variation in marine survival. A large proportion of juvenile pink salmon were concentrated in nearshore habitats, which ranked the lowest in daily growth potential relative to other habitats during 2001, and average juvenile pink salmon body size and estimated consumption rates were lower in 2001 than 2002, thus, density dependent forces may have contributed to lower survival.

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Fig. 2. Top panel displays the proportional contribution of juvenile pink salmon catch by habitat, which is classified as either nearshore (NS), continental shelf (SH), continental slope (SL), or offshore of the continental slope (OS) during July–August 2001 and 2002 Gulf of Alaska research cruises. The bottom panel displays corresponding daily juvenile pink salmon growth potential estimates.



Distribution and Growth of Juvenile Pink Salmon in the Coastal Waters of Eastern Hokkaido Determined with Otolith-Marking

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Keywords: Distribution, growth, pink salmon, otolith-marking

In Hokkaido, northern Japan, although relatively constant numbers (approximately 140 million fish) of hatchery pink salmon juveniles have been released annually since the 1990s, even and odd year catches of pink salmon in coastal fisheries consistently differ. The reason(s) for this interannual pattern is unknown. There is little consistently gathered information on the ecology and status of pink salmon in Hokkaido although Morita et al. (2005) documented their population structure. It has been suggested that ocean conditions can limit salmon production and high mortality occurs during their early sea life (Parker, 1968; Mortensen et al. 2000). Consequently, we wished to improve our understanding of the early marine ecology of juvenile pink salmon with respect to their offshore movement and growth. We monitored the distribution and growth of juvenile pink salmon and environmental conditions off the Abashiri coast of the Okhotsk Sea beginning in 2002 (Ando et al. 2005).

Four transects were established (A–D; Fig. 1), each with three sampling sites 1 km, 4 km, and 7 km from the shore. Sampling occurred every ten days from late April to early July, 2002–2005. In coastal waters, we captured juvenile pink salmon using a surface trawl net pulled by two boats. We also beach seined littoral waters (St. E; Fig. 1) starting in 2003. Because juvenile pink salmon captured in the coastal or littoral waters of the Abashiri coast might include hatchery-origin fish released from several sites as well as naturally spawned fish, we designed an otolith-marking experiment in 2005 to survey the distribution and growth of juveniles of known origin. Of the 17.2 million juveniles stocked along the Abashiri coast, 2.6 million were otolith-marked in 200 ppm alizarin complexone (ALC) solution before hatching, and were stocked in the Abashiri River in late April 2005.

Distribution of juvenile pink salmon along the Abashiri coast was strongly affected by sea surface temperature (SST). In May 2003 and 2005 when SST was low ($< 8^{\circ}\text{C}$), many juveniles were captured by the beach seine (< 100 m from the shore), but not by trawl net in the coastal waters. In May 2002 and 2004 when SST was high ($> 8^{\circ}\text{C}$), many juveniles were captured by the trawl net in the coastal waters (> 1 km from the shore). In May 2005 when SST was the lowest in four years (Fig. 2), most marked juveniles were captured in the littoral waters, not in coastal waters (Fig. 3). The number of juvenile pink salmon captured 1 km off the shore rapidly increased in early June

Fig.1. Map showing the study sites of littoral area(E), 1 km, 4 km, and 7 km off the Abashiri coast (A–D). The arrow indicates release site of ALC marked juveniles.

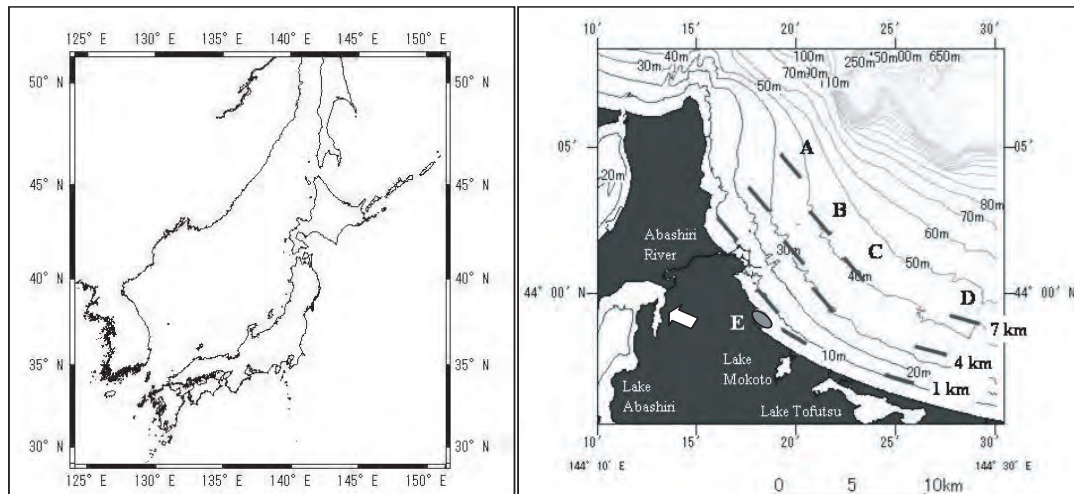
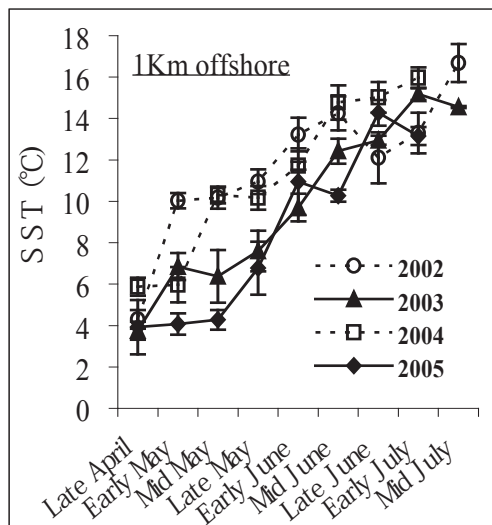


Fig.2. Changes in mean values with SD of SST in the 1 km offshore in the Abashiri coast of the Okhotsk Sea from 2002 to 2005.



when SST exceeded 10°C. Marked and unmarked juveniles showed a similar distribution pattern. In summary, the thermally dependent migration pattern that we found for unmarked pink salmon (including unknown origin fish) in 2002–2005 was consistent with that of marked juveniles released from the Abashiri River.

Mean fork lengths of pink juveniles captured in the coastal waters in cool years (2003 and 2005) were significantly smaller than those in milder years (2002 and 2004) (Fig. 4). This suggests that juvenile pink salmon in 2002 and 2004 utilized larger nursery areas and grew faster than juveniles in cool water years who tended to stay in littoral waters for longer periods. Annual variations in numbers of juvenile pink salmon captured in the coastal waters were greater than numbers of juvenile chum salmon (pink; 21,867 (in 2002)—3,870 (in 2005), chum; 72,024 (in 2002)—38,523 (in 2005)). The peak timing (late April) of stocking of pink salmon was about one month earlier than that (late May) of chum salmon, whereas the timing of disappearance of pink and chum salmon juveniles from the coastal waters was similar. In conclusion, since juvenile pink salmon stay in the littoral or coastal waters for a longer time than chum salmon, they may be more susceptible to ocean conditions, particularly low water temperatures after ocean entry. Interestingly, there was a clear correlation between the total number of juvenile pink salmon captured in the coastal waters and number of adults captured in the coastal fisheries the following year. These results suggest that cold coastal conditions would strongly affect the growth and survival of juvenile pink

Fig.3. Changes in CPUE (catch per unit of effort, number of juveniles per 2 km towing or per beach seine) of unmarked and ALC marked juveniles pink salmon captured in the littoral waters and 1 km, 4 km, 7 km offshore in 2005.

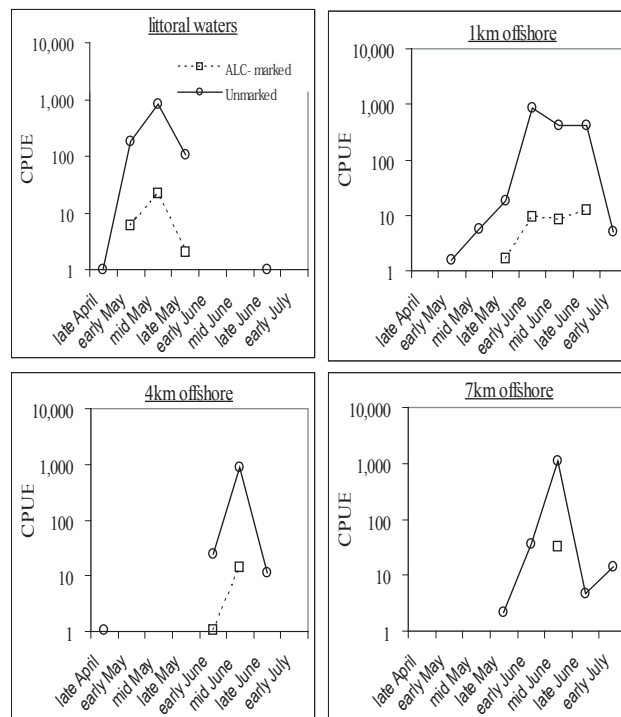


Fig.4. Mean fork length of unmarked juvenile pink salmon captured in the littoral waters and 1 km offshore from 2002 to 2005.

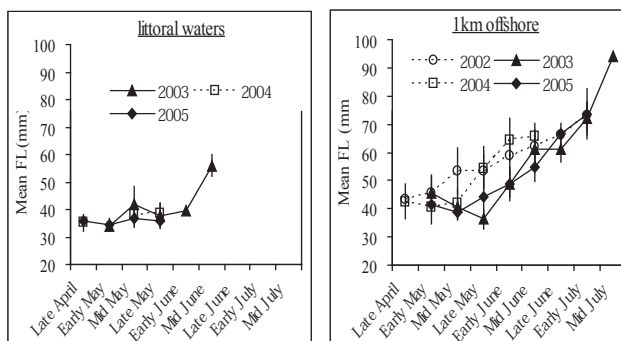
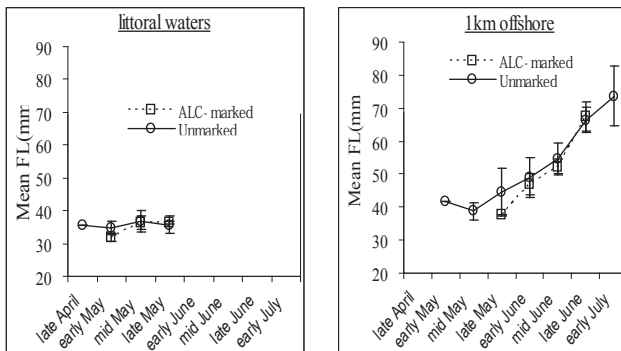


Fig.5. Mean fork length of unmarked and ALC-marked juvenile pink salmon captured in the littoral waters and 1 km offshore in 2005.



salmon in their early marine life, although inter-annual variations in numbers of naturally spawned fish may account for the variation of commercial catches. We plan to monitor the relationship between the early marine ecology and survival of pink salmon along the Abashiri coast with future marking experiments.

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Trophic Position of Pacific Salmon Juveniles in the Western Bering Sea Epipelagic Communities during Autumn

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Keywords: Juvenile Pacific salmon, zooplankton, consumption, prey, plankton community, Bering Sea

The major purpose of our study was the determination of the trophic structure of juvenile Pacific salmon in the epipelagic layer of the western Bering Sea during autumn.

2002–2004 data were collected on research vessels of TINRO-Centre. A total of 234 plankton and 255 trawl stations were made in the epipelagic zone (0–50 m), with stomachs from 11,078 fish taken for diet analyses. Standard methods, widely used in TINRO-Centre studies (Chuchukalo and Volkov 1986), were used for the analyses of fish stomach contents. We identified prey items, total prey weight and weight of each prey component from size categories of fish. Plankton was collected by Juday Net in the epipelagic layer (0–50 m) during day time and night time. All data were averaged for the regions: Commander Basin, western Aleutian Basin, Navarin regions, Karaginskyi, Olutorskyi and Anadyr Bays.

Fig. 1. Diet (%) of pacific pink, chum, sockeye juveniles in the western Bering Sea in autumn 2002–2004.

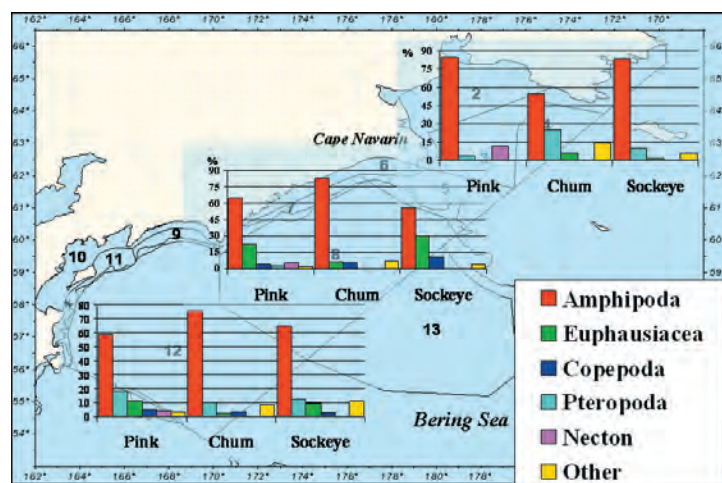
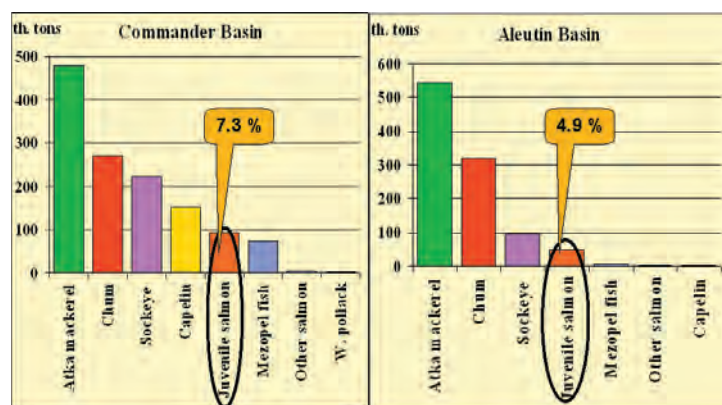


Fig. 2. Consumption of food by pacific salmon juveniles and by masses fish in the epipelagic layer (0–50 m) of the Commander and western Aleutian Basins in autumn 2004.



Juvenile Pacific salmon, originated from the Karaginskyi, Olutorskyi-Navarin and Anadyr areas migrate from shallow bays to the deep waters of the western Bering Sea to forage in these areas in autumn (Shuntov 1989, 1994). According to the database collected in the 2002–2004 trawl surveys, the autumn biomass of juvenile salmon ranged from 26.8 to 33.6 thousand tons (Temnykh et al. 2004; Temnykh 2005), accounting for no more than 1–3% of the total assessed biomass of the common fish species in the entire upper epipelagic western Bering Sea. Pink salmon dominated in numbers and biomass of all juveniles of Pacific salmon species.

During the transition from shallow to oceanic areas in September–November, juvenile salmon actively forage in the epipelagic waters of the western Bering Sea. The highest daily rations were observed for juvenile pink salmon (7.5–7.9% of body weight) and juvenile chum (7.0–7.9%). Daily rations of sockeye, chinook and coho salmon were lower (Efimkin 2003; Efimkin et al. 2004; Chuchukalo and Kuznetsova in press).

We estimated the seasonal weight of food consumed by juvenile salmon in the upper epipelagic layer of the western Bering Sea. Juvenile salmon utilized from 112–154 thousand tons of different zooplankton and nekton forage animals during autumn, while the major fish species consumed 6.4–8.9 million tons of forage animals.

Juvenile pink, chum and sockeye salmon preyed mainly upon the zooplankton. Amphipods, euphausiids and pteropods dominated in the diet of pink, chum and sockeye salmon (Fig. 1). Copepods, nektonic organisms and meroplankton were of much less importance as prey items. In the Gulf of Anadyr and Commander Basin, pteropods accounted for 10–18% of total prey weight and was much higher than in the western Aleutian Basin, where they accounted for less than 2.5% of food. The share of euphausiids in the juvenile salmon diet was higher in the western Aleutian Basin, where these crustaceans accounted for 22.3–30.1% of the pink and sockeye salmon diet, and 5.9% of the chum salmon diet. In the Commander region, euphausiids accounted for only 10.7–9.4% of all food consumed by pink and sockeye salmon and 2.5% of the chum salmon prey. Chinook and coho salmon preyed predominantly upon nektonic animals. This prey preference was associated with morpho-physiological features of these two salmon species. The plankton species, which accounted at most for 25.2–31.3% of food consumed by juvenile chinook salmon, were represented mainly by large crab larvae and rarely by large mature euphausiids (*Thysanoessa longipes*). There was a high proportion of euphausiids in the diet of juvenile salmon in the western Aleutian Basin. Pteropods and amphipods in the Commander Basin were associated with dense aggregations of these planktonic groups in a local plankton community.

Of all the prey species, salmon consumed mainly *Themisto pacifica* among amphipods and *T. longipes* among euphausiids. These two plankton species were also heavily preyed on by juvenile walleye pollock (*Theragra chalcogramma*), as well as by immature sockeye and chum salmon, atka mackerel juveniles, and by other fish. During our surveys there was a large biomass of juvenile walleye pollock in the northwestern Bering Sea (Shuntov et al. 2000; Starovoitov et al. 2004). The major forage areas for juvenile salmon were Olutorskyi-Karaginskyi region continental slope, Commander and western Aleutian Basins.

The overall amount of food consumed by fishes in the upper epipelagic layer in the Commander Basin totaled 1.3 million tons and in western Aleutian Basin, 1.0 million tons. Juvenile salmon consumed 7.3% of the total amount of all food consumed by all fish in the Commander Basin, and 4.9% in the western Aleutian Basin (Fig. 2). Thus, the role of juvenile salmon in the trophic structure of the epipelagic layer in the waters of the Commander and Aleutian Basins, as well as the nearby Olutorsky-Karaginsky shelf break areas, was more important than in the northwestern Bering Sea.

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Diurnal Feeding Rhythm of Plankton-Eating Salmon Juveniles in the Kamchatkan Waters of the Bering and Okhotsk Seas

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Keywords: Feeding rhythm, salmon juvenile, coastal and offshore waters, plankton, food requirements

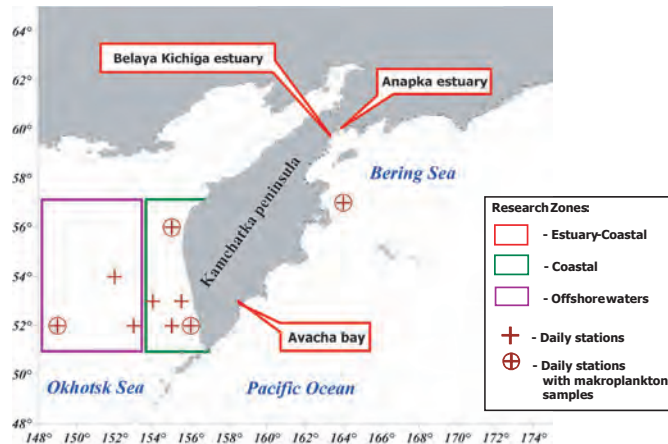
For estimation of food requirements of salmon juveniles was provided with regular 24-hour stations during coastal surveys to carry out from 1970s, and also with surveys in the offshore of the Bering and Okhotsk Seas from 1990s (Karpenko 1982, 1998). For the period mentioned there were accomplished more than 30 diurnal (24 hour) stations; the results more of half of this number have been used in this work (Fig. 1). The surveys were accomplished in the estuary-coastal zone (12 stations) and in the coastal-offshore waters (7 stations). Diurnal feeding by three Pacific salmon species (pink, chum and sockeye salmon) and the basis of food spectrum of these species, consisting of plankton organisms, was studied. To provide a comparison of feeding dynamics we also used results of studying food composition of the species mentioned, obtained in the course of standard juvenile trawl surveys. Stomachs of several thousand fishes of each species and also the composition of plankton in several 24-hour stations of some surveys were examined. We also used the data on the diurnal feeding rhythm of salmon juveniles in the other regions of Far East.

In the estuary-coastal zone of the Bering Sea the principle food of juvenile salmon (chum salmon) were *Lamproys korroensis* (24%), larval and juvenile fish (capelin, herring, sand lance, flounders; up to 36%) and also larval and imago insects (23%) emerged from the rivers. The part of the other organisms, including copepods, Harpacticoidae, mysids and etc., was small due to the substantial desalinization and dynamism of the coastal water zone. For 24 hours usually two (sometime three) maxima (morning and evening) and one minimum (night) of food consumption have been observed. In pink salmon the part of Harpacticoidae was usually higher, being compared to that in chum salmon, but the character of the diurnal dynamics of the amount of food in stomach was similar. The dynamics of the food composition and of the amount of food in stomach is determined by the high-low tide cycle, and it also relates to the density of fish stocks in the coastal zone. Salmon juveniles feed actively and fishes with empty stomachs were very rare. Similar food spectrum and diurnal feeding rhythm of salmon juveniles has been revealed in the other regions, including the estuary of the Bolshaya River, Avacha Bay and South-West Sakhalin (Ivankov et. al. 1999; Karpenko 1979; Shershnev 1975).

In the offshore waters of the Bering Sea in September the basis of juvenile salmon food spectrum consisted of *Themisto japonica*, euphausiids (both mentioned organisms for pink and chum salmon) and larval crabs (sockeye salmon), which in particular cases got substantially over 50% of food weight (Fig. 2). The food spectrum of chum salmon juvenile was the widest, and that of sockeye salmon juvenile, the narrowest; pink salmon took intermediate position. Chum salmon also consumed a high number of Oikopleura (up to 50%) and Chaetognatha (up to 15% of food weight). In this zone one maximum (over 200 %₀₀₀) (in the evening) and minimum (10 times less) (midnight) of food consumption can be observed.

In the Okhotsk Sea in September the food spectrum of juvenile salmon (plankton-eaters) normally includes less species of organisms, being compared to that in the Bering Sea. For example, in the coastal zone it was the narrowest and included mostly *Limacina helicina* and *Clione limacina*, their summary number usually taking over 80% of food weight (over 90% for chum salmon) (Fig. 3). Among the other organisms only juvenile fish (for chum and sockeye salmon), euphausiids and copepods (for pink salmon) played some role in feeding of salmon juveniles. Normally one (evening) food consumption maximum (over 150 %₀₀₀) and one (midnight) minimum (10

Fig. 1. Area of investigation.



times less) were observed. In the offshore waters of the Okhotsk Sea in September the food spectrum of juvenile salmon (pink and chum salmon) got extending, but the basis of the spectrum still consisted of hyperiids, euphausiids and Oikopleura, the summary number of mentioned organisms being in some cases over 90% of food weight. Two (day and night) local maxima of food consumption (up to 200 ‰ and more) and one (morning) minimum (about 15 ‰) were demonstrated. A similar diurnal rhythm of feeding and food composition of juvenile pink salmon was observed in November 2003 in the Japan Sea, where the basis of food consisted of hyperiids, and the maximum amount of food in stomachs was observed in the evening (more than 300 ‰) (Chuchukalo in press).

Plankton organisms undertake vertical migrations during 24 hours and create aggregations of different density, determining the removal by fish. The same vertical migrations are used by juvenile and adult salmon too. That creates a ground to determine the diurnal rhythm of feeding not only from daily surveys, but also from the by-catch of salmon in different time in the course of standard trawl surveys. Over the comparison of food composition and amount of food in stomach

Fig. 2. Diurnal feeding rhythm Pacific salmon juveniles, Offshore waters, Bering Sea, September 2002: A, pink salmon; B, chum salmon; C, sockeye salmon.

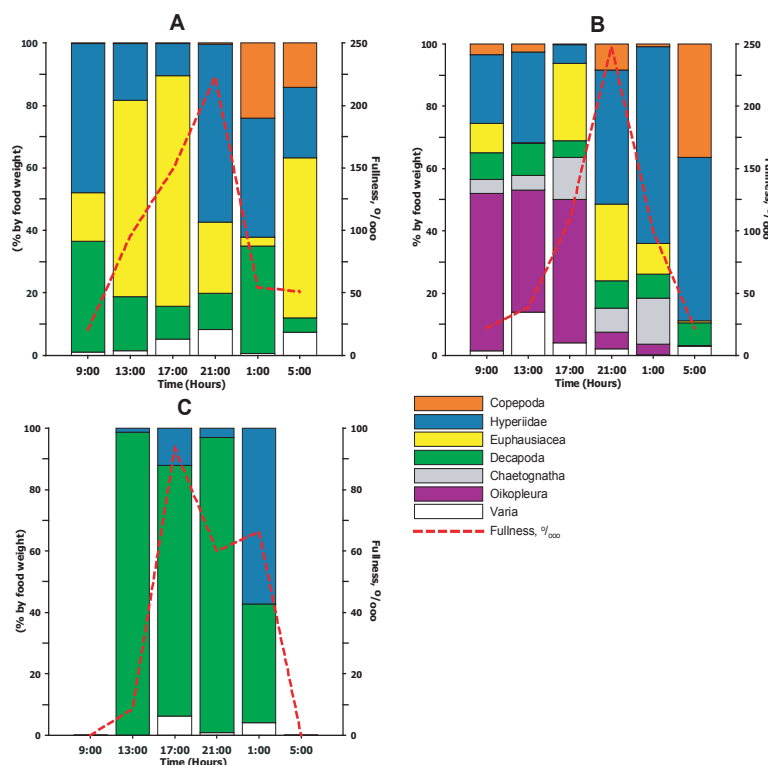


Fig. 3. Diurnal feeding rhythm Pacific salmon juveniles, Okhotsk Sea, September 1999: Coastal waters: A, pink salmon; B, chum salmon; C, sockeye salmon; Offshore waters: D, pink salmon; E, chum salmon.

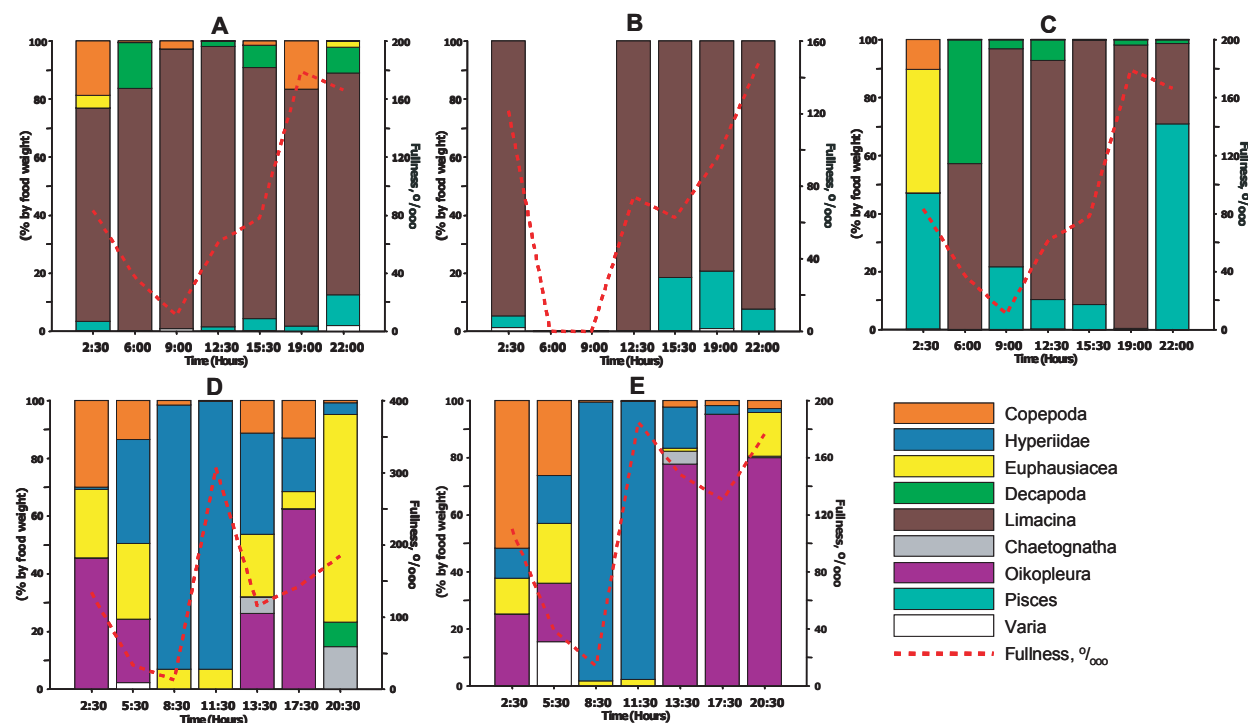


Table 1. Daily ration (% body weight) of plankton-eating juvenile salmon.

Area (species)	Year and month	Daily ration (% body weight)
Anapka estuary, Karaginsky Bay (chum)	1975–1993 mid July	6.7–16.5
Bering Sea (pink)	September 1998, 2002	6.5–9.3
Bering Sea (chum)	September 2002	5.9–6.8
Bering Sea (sockeye)	September 2002	7.0
Okhotsk Sea (pink)	September–October 1986–2001	5.9–13.2
Okhotsk Sea (chum)	September–October 1991–2001	4.9–10.5
Okhotsk Sea (sockeye)	September–October 1997–2001	6.0–7.7
Okhotsk Sea (pink)*	1985	5.5–7.2
	1994–2000	7.5–14.4
Okhotsk Sea (chum)*	1994–1998	6.8–7.3
Okhotsk Sea (sockeye)*	1994–2000	2.2–4.8

*Data from Chuchukalo (in press).

of juvenile salmon, the data collected with two methods—diurnal 24-hour surveys and regular juvenile surveys—demonstrated significant similarity characteristic for area of studies, what was observed both in the Bering Sea and in the Okhotsk Sea.

Different methods of studying of the diurnal rhythm of feeding allow assessing of food requirements of juvenile salmon directly or by inference, widely used by experts. The data from the daily rations of plankton-eating juvenile salmon make us to conclude, that on entering the sea the rations take 10–15% of juvenile body weight and go reducing gradually to 5–7% to the beginning of juvenile migration for wintering (Table 1). It also should be noted, that the daily ration of juvenile salmon with a short life cycle in the ocean (pink salmon) is usually higher, being compared to that of salmon, spending several years in the ocean (chum and sockeye salmon). Moreover, there are significant regional and seasonal variations of juvenile salmon food requirements by species.

The principle purpose of studying the diurnal rhythm of fish feeding consists in the estimation of food requirements, consumption and provision with food and also in the figuring out of the energy flows in the ocean communities with salmon membership. These all should be the principle directions either to use the data from the 24-hour survey stations.

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Diel Energy Consumption and Food Requirements by Juvenile Sockeye Salmon during Their Fall Migration in the Okhotsk Sea

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Keywords: Energy, consumption, energy expenditure, metabolism, activity coefficient, daily ration, total consumed energy, balance equation, growth, food requirements

During fall, migrating Pacific salmon juveniles live in marine waters near their natal river (Birman 2004). In Contrast to later periods in their marine life, during their fall migration, since hydrological characteristics are relatively stable, mortality is not high (Karpenko 1998). Consequently, during the fall migration, numbers of fish per generation in proportional to numbers later in salmon's marine life (Erokhin 2002). Thus, the principle role of the fall migration in the life cycle of Pacific salmon is their rapid growth and accumulation of energy resources, required later during wintering.

Since 1981 KamchatNIRO has conducted trawling researchers to study the biology of Pacific salmon juveniles during their fall migration in the waters adjacent to Kamchatka (September–October). These long-term studies demonstrated that during the migration from the coast of Kamchatka to offshore waters of the Okhotsk Sea, the daily growth and caloric content of juvenile pink salmon (*Oncorhynchus gorbuscha*) increased (Yerokhin and Shershneva 2000; Erokhin 2002; Erokhin and Shershneva 2007). This was found to be caused by the following reasons: with the distance from the coast of Kamchatka the summary biomass of macroplankton increases, consequently food supplies of plankton-eating species improved (Table 1); the intensity of feeding and the daily rations of juvenile pink salmon increased; the total caloric value of fish rations and surface water temperature increased; and the diel dynamics of juvenile salmon activity and feeding changed. As a result of differences in diel energy consumption and expenditure by juvenile salmon in different areas of the Okhotsk Sea, differences in their diel growth rates and energy accumulation occurs.

As known, most juvenile sockeye salmon (*O. nerka*) in the Okhotsk Sea inhabit the shelf over the south-west coast of Kamchatka. Thus, sockeye migrations westward are limited mostly within 150-mile coastal zone (Erokhin 1998; Birman 2004). At the same time, some sockeye salmon can also be found outside the shelf in the offshore waters of the Okhotsk Sea. Therefore, the offshore waters of the Okhotsk Sea also play some role in the fall migration of this species.

We determined the diel dynamics of food energy consumption and expenditure by juvenile sockeye salmon in different areas of the Okhotsk Sea. For our calculation we use by following parameters: weight and caloric content of fishes and their prey items; temperature; estimated standard metabolism indices; generalized diel fish activity dynamics (determined by information of diel feeding rhythm); and data on the ratio between sockeye salmon metabolism rates under different activities and the standard metabolism (Hoar et al. 1979).

Energy consumption for sockeye salmon in the different areas of the Okhotsk Sea were estimated based on the daily ration value and caloric content of prey items (Shershneva and Koval 2005). Total energy value of daily rations by juvenile sockeye salmon were 1.150 kcal/g (11.270 kcal/ind by wet weight) in the coastal waters and 1.270 kcal/g (15.113 kcal/ind by wet weight) in offshore waters (Table 1).

The energy expended by juvenile sockeye salmon for the total metabolism (Q , kcal/ind per day) was calculated from the equation:

$$Q = \sum_{j=1}^{24} a_j (0.36 \cdot W^{0.78} \cdot 4.8/q) \cdot 10^{-3} \quad (1)$$

where a = the “activity coefficient” or the ratio between metabolism for different types of activity and sockeye salmon standard metabolism (Hoar et al. 1979); 0.36 = the amount of oxygen consumed by sockeye per a unit of weight, ml O_2 /g of wet weight per hour (Brett 1965); W = the weight of fish (g); 0.78 = an index determining the speed of metabolism rate transformation in the course of sockeye salmon weight growth; 4.8 = the oxycaloric coefficient (cal); q = temperature correction to make the meaning of standard metabolism answering to a certain temperature according to the “normal curve” by Krogh.

Diel energy expended by sockeye salmon for the total metabolism calculated from equation (1) are 4.250 kcal/ind. for 140 g fish (i.e. from coastal waters) and 5.800 kcal/ind. for 170 g fishes (i.e. from offshore waters). In both cases expenditures use about 40% of total energy values of daily ration (C).

Table 1. The basic biological, chemical and energy indices of pink and sockeye salmon juveniles and environmental characteristics in the different areas of the Okhotsk Sea during the fall migration.

Characteristics	Coastal waters		Offshore waters	
	*Pink	Sockeye	*Pink	Sockeye
Biological and chemical indices of fish (by wet weight)				
Avg. weight, g	96.1–100.0	137.1–140.0	108.7–110.0	170.5–170.0
Avg. content of lipids, %	4.4	6.2	4.8	2.6
Avg. content of protein, %	13.2	12.4	14.2	24.1
Avg. content of water, %	79.4	79.0	78.1	68.6
Avg. content of ash, %	2.9	2.4	2.9	4.6
Min–Max daily ration, % by fish weight	5.9–9.4	6.0–7.7	8.0–13.2	7.0–7.0
Avg. daily ration, g	7.569	9.800	10.016	11.900
Avg. daily growth, % by fish weight	2.3	1.8	3.5	2.0
Avg. daily growth, g	2.280	2.520	3.358	3.400
Energy indices of fish (by wet weight)				
Avg. calorie content, kcal/g	1.084	1.290	1.186	1.608
Avg. calorie content of food, kcal/g	1.083	1.150	1.122	1.270
Total energy value of daily ration (C), kcal/ind	8.197	11.270	11.238	15.113
Total consumed energy (Q + P), kcal/ind	6.558	9.016	8.990	12.090
Energy expended for the total metabolism (Q), kcal/ind	4.230	4.250	5.107	5.800
Energy expended for the total metabolism (Q), % by total energy value of daily ration	51.6	37.7	45.4	38.4
Energy expended for the growth (P), kcal/ind	2.328	4.766	3.884	6.290
Energy expended for the growth (P), % by total energy value of daily ration	28.4	42.3	34.6	41.6
Avg. "activity coefficient" (a)	6.4	7.6	6.1	6.8
Environmental characteristics				
Avg. water temperature, °C		8.0	10.0	
**Avg. biomass of makroplankton (layer 0–50 m), mg/m ³		949.0	2963.5	

*Basis of data by V. G. Erokhin (2007)

**Data for September 1999

According to the balance equation (Winberg 1956; Shulman and Love 1999):

$$C = 1.25 (Q + P) \quad (2)$$

the total energy expended by juvenile sockeye salmon for growth (P) is 4.766 kcal/ind per day in coastal waters and 6.290 kcal/ind per day in offshore waters.

Analysis of sockeye salmon energy expenditure for 24 hours has indicated that during periods of maximum feeding activity in coastal waters (day time), energy expended by fishes can increase to 0.250 kcal/ind per hour and in the offshore waters (in the morning and evening), to 0.370 kcal/ind per hour (Fig. 1). In periods of minimal night activity, expenditure decreased to 0.040 and 0.060 kcal/ind per hour, respectively. Thus, in the coastal waters of West Kamchatka average value of diel energy expended by sockeye salmon for the total metabolism is 7.6 times higher than to the standard metabolism, and in the offshore waters of the Okhotsk Sea, it is 6.8 times higher (Table 1).

As shown, in waters adjacent to Kamchatka, the portion of energy expended by fishes for their total metabolism is higher and energy required for their growth is lower, compared with fish in offshore waters of the Okhotsk Sea. Moreover, sockeye salmon (like pink salmon) is mainly a plankton-eater, so it seems logical that the food supply for sockeye is better in the offshore waters of the Okhotsk Sea. Despite this fact, the fall migrations of most juvenile sockeye salmon occurs in the West Kamchatka shelf waters. It is known that sockeye salmon are more cold-resistant than other Pacific salmon. Brett (1971) demonstrated that effective food conversion by sockeye salmon was possible only in environments with lower temperature ranges than for pink salmon. Therefore, during migration in the Okhotsk Sea, juvenile sockeye salmon inhabit coastal waters of Kamchatka where water temperature are optimal for this species.

On the basis of the balanced equation (2) we calculated the diel food requirements of juvenile sockeye salmon during their fall migration. As follows from Fig. 2, at a daily ration of less than 3.5% (by fish weight), fish growth does not occur, as all the total consumed energy is expended for metabolism. Thus, the ration 3.5% is a "supporting ration". At a daily ration of 6.5%, approximately equivalent energy is expended for total metabolism and growth. With increases of daily ration more than 7%, the part of the total assimilated energy expended for metabolism is reduced, and the part of energy expended for the growth increases. Please note, for our studies, juvenile sockeye salmon daily rations more than 8% were not registered (Table 1). Thus, the ration 6–8% is an "optimal daily ration" for juvenile sockeye salmon and which is generally observed during the fall migration in the Okhotsk Sea.

Fig. 1. Diel dynamics of energy expended by juvenile sockeye salmon for the total metabolism in the coastal (A) and offshore (B) waters during the fall migration in the Okhotsk Sea.

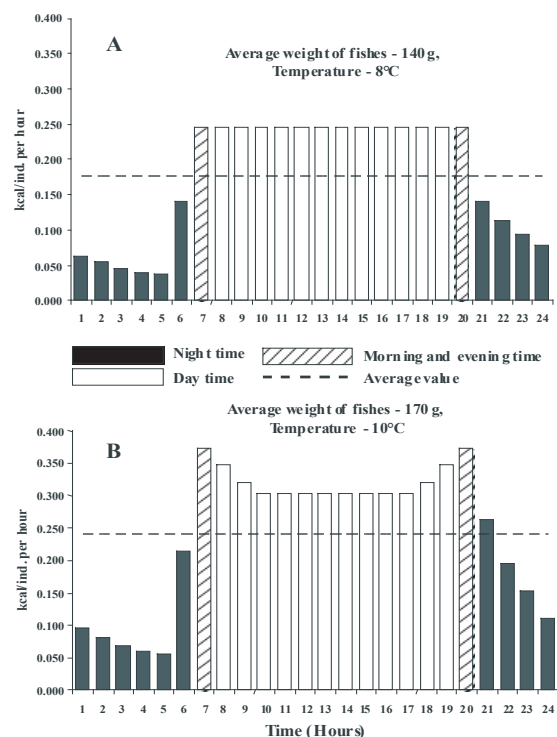
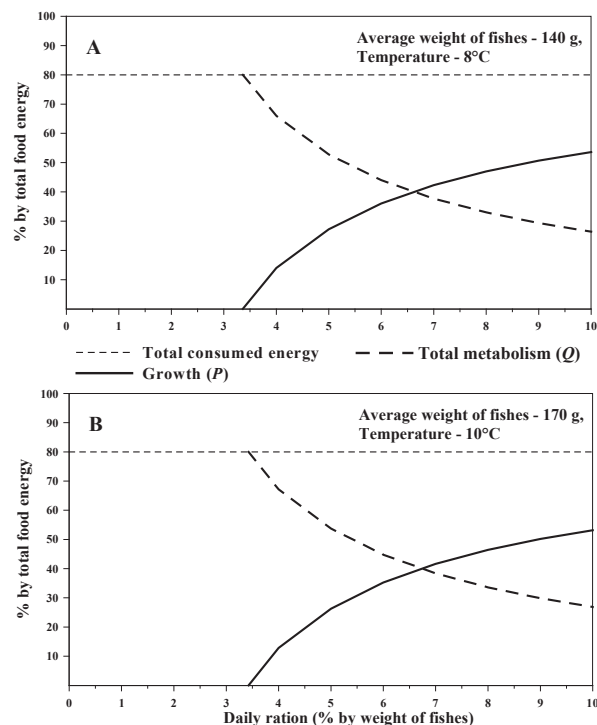


Fig. 2. Rate of total food energy expended by juvenile sockeye salmon for the total metabolism and growth with different daily rations in the coastal (A) and offshore (B) waters in the Okhotsk Sea.



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Foodweb Dynamics and Trophic Interactions Among Juvenile Pacific Salmon in the Bering Sea Ecosystem

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Keywords: Juvenile Pacific salmon, foodweb dynamics, trophic interaction, Bering Sea

Current literature suggests climate variability, fishing, carrying capacity, and nutrients as important forces driving the growth and survival during the early life stages of salmon in the ocean. There is still a major gap in our understanding of the foodweb dynamics and trophic interactions among salmonid and non-salmonid species in the marine ecosystems. We hypothesized that if the Bering Sea ecosystem is at its carrying capacity, we should see intense trophic interactions among species, rapid ontogenetic niche shifts as a function of size within species, and significant diet overlaps among species. As a part of BASIS project, we analyzed stable isotopes of N and C of over 8,000 samples for 5 salmon species, forage fish species and zooplankton collected over three years from 182 stations along north-south and east-west transects covering over 36,000 square miles of the Bering Sea ecosystem. We presented results showing significant inter-annual variability in diet overlaps and trophic interactions among salmon species, and trophic shifts within each of the species as a function of body size, which seemed to vary significantly from near-shore to off-shore zones, and discussed their implications for growth, survival and productivity of salmon.

Ocean Changes in the Strait of Georgia Indicate a Need to Link Hatchery Programs, Fishing Strategies and Early Marine Studies of Ocean Carrying Capacity into an Ecosystem Approach to Manage Coho Salmon

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Keywords: Climate change, coho salmon, hatcheries, Strait of Georgia

We studied the factors that affected the early marine survival of juvenile Pacific salmon in the Strait of Georgia since 1997 using a standard midwater trawl (Beamish and Folkes 1998) that is fished throughout the water column at 15 m intervals. A standard survey is shown in Fig. 1. The Strait of Georgia is perhaps the most important juvenile Pacific salmon rearing area off the west coast of Canada. Historically, about one third of all the salmon in the commercial catch originated from rivers around the Strait of Georgia and reared as juveniles in the strait. The Fraser River is the major river producing these salmon that enter the Strait of Georgia. The salmon from the Fraser River have traditionally been fished by Canada and the United States requiring a treaty and a joint management agency. The original commission that is now the Pacific Salmon Commission was established in 1937. The Commission has been responsible for maintaining accurate catch and escapement records for sockeye salmon and, up to a few years ago, for pink salmon. We used this information and records from the Department of Fisheries and Oceans to estimate the average annual number of juvenile Pacific salmon that reared in the Strait of Georgia from 1970 to 1979 and from 1996 to 2004. We estimated that there has been an increase in the numbers of juvenile pink, chum and sockeye salmon in recent years, whereas the numbers of juvenile coho and chinook salmon has not increased. The result has been a doubling of the dominance of pink, chum and sockeye over coho and chinook salmon. An example of the increased abundance of pink, chum and sockeye salmon is shown in the returns of adult pink salmon to the Fraser River (Fig. 2).

The reason for the switching of dominance appears to be related to changes in the Strait of Georgia in the timing of the initial spring production. Yin et al. (1997) related the timing of the beginning of production to the beginning of the freshet in the Fraser River in April. In Fig. 3, it is apparent that in recent years there has been a

Fig. 1. The Strait of Georgia showing the standard survey track.

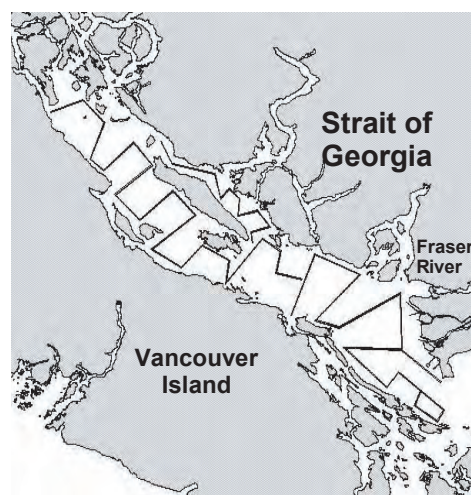


Fig. 2. Production of pink salmon in the Fraser River in odd-numbered years only. Virtually all adults return to the Fraser River in odd-numbered years.

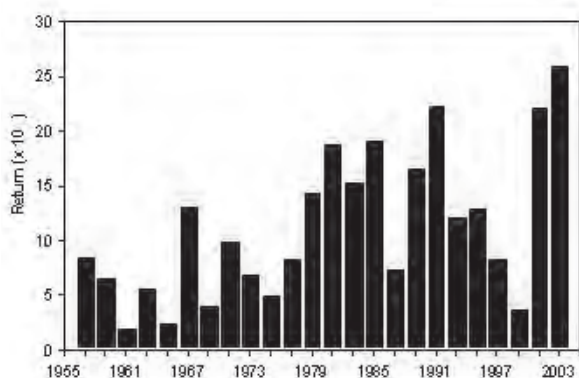
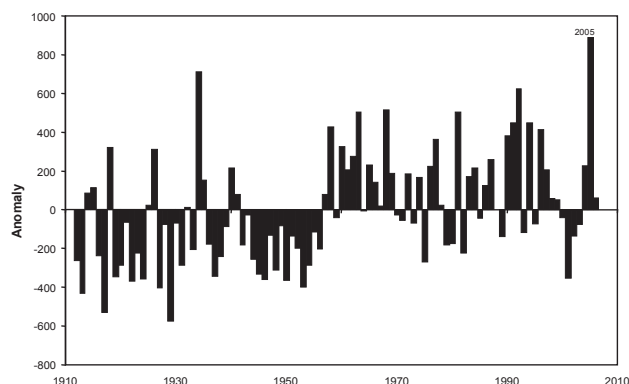


Fig. 3. Anomaly of the flow in the Fraser River from January to April. Note the anomaly in 2005 which is the largest in the data series.



trend to increased earlier flows, suggesting an earlier timing of the initial plankton bloom. A dramatic example of this relationship occurred in 2005. The amount of flow in April was the largest in ever recorded (Fig. 3), and evidence from other studies indicated an exceptionally early spring bloom (S. Allen, University of British Columbia, Vancouver, BC V6T 1Z4, Canada, personal communication). Our surveys in July found that abundances of juvenile coho and chinook salmon were the lowest in the study, but the abundances of chum salmon were the highest. Clearly, the chum salmon that entered the strait first and early in the year had exceptionally good survival, while coho and chinook that entered later in the year had exceptionally poor survival.

Ecosystem management can be considered in a number of ways. We propose that ecosystem management is management that appreciates the dynamic relationships among the key species and their environment. This means that managing coho salmon requires an understanding of the natural processes that affect coho production in the ocean. Our studies suggest that natural changes in the Strait of Georgia probably have advanced the date of plankton blooms which improved the production of species such as chum and pink salmon that entered the ocean early. However, many coho salmon that enter the Strait of Georgia are not really wild as they are produced in hatcheries (Fig. 4; Sweeting et al. 2003). We also know that most of these coho salmon are released into the strait about mid-May and that these release dates have remained fairly constant for about 25 years (Fig. 5). We know that since the mid-1980s there has been a rather constant release of around 10 million coho salmon from hatcheries and a declining marine survival of coho that in recent years is about one percent (Fig. 6).

A definition of a wild salmon used by Fisheries and Oceans Canada (Anon. 2005) is a salmon that spent their entire life cycle in the wild and originated from parents that were also produced by natural spawning and who continuously lived in the wild. Thus, on one hand, hatchery-reared coho salmon may not be able to adapt naturally to the ocean habitat changes to maintain historic high marine survivals; but on the other hand, their release times from hatcheries can be artificially manipulated to adapt to the changing timing of prey availability. As climate continues to change, it is apparent that future management of coho has to be flexible, adaptive and linked to physical

Fig. 4. Percentage of coho salmon produced in hatcheries (modified from Sweeting et al. 2003).

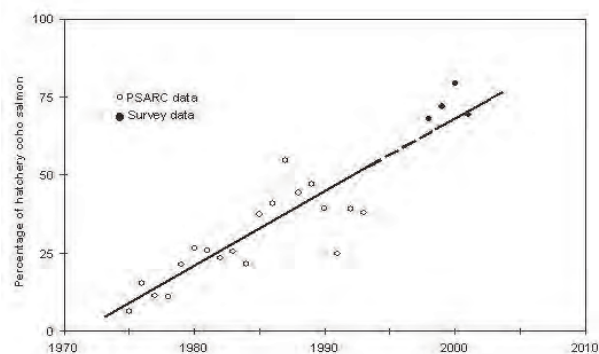


Fig. 5. Average date that 50% of all coho salmon produced in hatcheries were released into the Strait of Georgia.

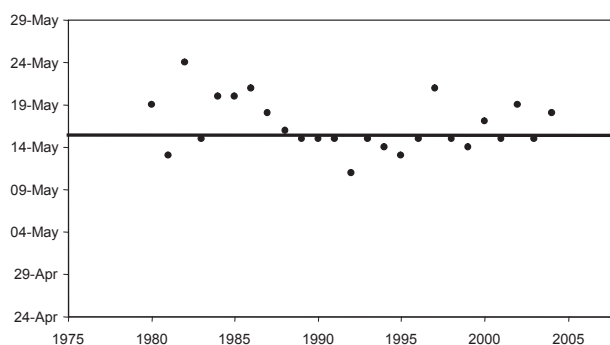


Fig. 6. Strait of Georgia coho salmon smolt production from hatcheries and marine survivals for brood years 1976 to 2001 (year of ocean entry is two years later in 1978 to 2003).

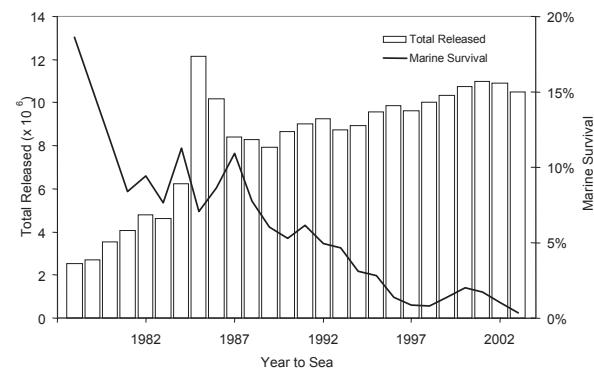
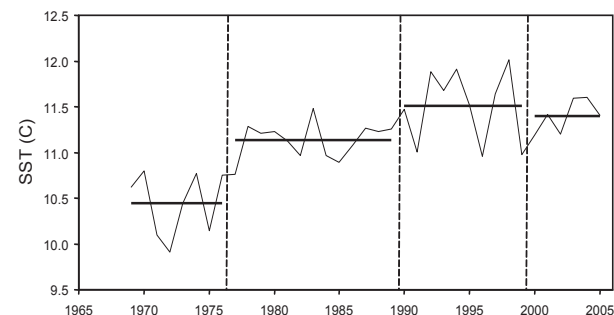


Fig. 7. Mean sea surface temperature in the central Strait of Georgia from 1969 to 2005. Vertical dashed lines represent regime shift years and horizontal solid lines indicate the average sea surface temperature determined at the Nanoose site (Beamish et al. 2004).



and biological conditions within the Strait of Georgia. We know that the Strait of Georgia is warming (Fig. 7) and that the warming occurs in trends that match regimes and regime shifts (Beamish *et al.* 2004). The physical and biological processes that regulate the timing and amount of primary production will be affected by this warming and associated changes such as river flow and atmospheric wind direction and intensity. The impacts on factors such as warming, regional winds, and Fraser River flows are unlikely to be linear, as these conditions respond in trends or regimes, and shift to new states quickly. Thus, future changes may follow a long-term trend, but these changes would occur on a decadal scale.

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Where, When, and How Does Mortality Occur for Juvenile Chum Salmon *Oncorhynchus keta* in Their First Ocean Year?

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Keywords: Juvenile, chum salmon, mortality, size-selective mortality, size-related mortality

Chum salmon (*Oncorhynchus keta*) migrate seaward as fry, and move from the coast of Hokkaido offshore by the end of their juvenile stage after completing ossification (Fig. 1; Kaeriyama 1986). Migration patterns of juvenile chum salmon can be summarized as (1) prior residence near the spawning area, (2) growth inversion in the river, (3) foraging and initial migration along the coast (Kaeriyama and Ueda 1998). Ishikari River juvenile chum salmon migrate to the Okhotsk Sea at 120 mm length by the end of June (Mayama and Ishida 2003). We investigated the relationship between growth and survival of juvenile chum salmon released from the Ishikari River in the first ocean life year to clarify critical mortality mechanisms affecting the life history strategy of chum salmon.

We analyzed 2,432 scales of female chum salmon collected in the Ishikari River during 1970–2001 except for 1973 and 1985. Scale distances and numbers of circuli from the focus to the inner edges of check (RcJ and Ros) and annuli (r1–r4) were measured by a scale image processor (Ratoc System Engineering Co.). Individual growth in fork length was back-calculated from the scale radius based on Kaeriyama et al. (in press). Data on sea surface temperature (SST) during 1950–2004 were provided by the Meteorological Agency of Japan as a monthly mean of 1° latitude and longitude blocks (25–49°N, 121–180°E) and satellite data from the NVHRR/NOAA (50–56°N, 145–155°E).

Analysis of Ishikari River chum salmon scales showed that younger adults grew faster than older fish in the first ocean life year (Fig. 2; $H = 26.22$, $P < 0.001$). In all age groups of salmon, growth during the first year increased in the 1990s. The number of circuli in the first year also increased in the 1990s despite no change in circulus intervals (Fig. 3). This growth increase occurred in the Okhotsk Sea, but not in the coast of Hokkaido (Fig. 4). In the Okhotsk Sea, the extent of ice cover decreased in the 1990s (Ustinov et al. 2002). The correlation map also showed that the ice cover area was negatively correlated with winter SST in the Okhotsk Sea (Fig. 5). Growth and circuli numbers of Ishikari River chum salmon at the first year was negatively correlated with sea ice concentration in winter (Fig. 6a, b), and positively correlated with SST during summer and fall in the Okhotsk Sea (Fig. 6c, d). The correlation map indicated that the growth anomaly of the Ishikari River chum salmon strongly positive-correlated with summer and fall SST in the Okhotsk Sea (Fig. 7). According to Merzlvakov et al. (2005), zooplankton biomass in the Okhotsk Sea has decreased since the 1980s. These results suggest that the growth of the Ishikari River chum salmon will be affected by SST in summer and fall and not by productivity

Fig. 1. The developmental stage of chum salmon in their early life period (modified from Kaeriyama 1986).

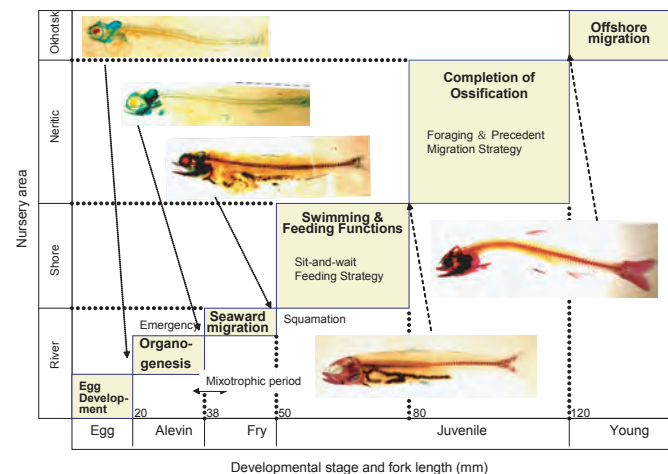


Fig. 2. Mean and standard deviation of growth (fork length, mm) at the first year of chum salmon by the age returning to the Ishikari River in 1970–2001. H, result of the Kruskal-Wallis test.

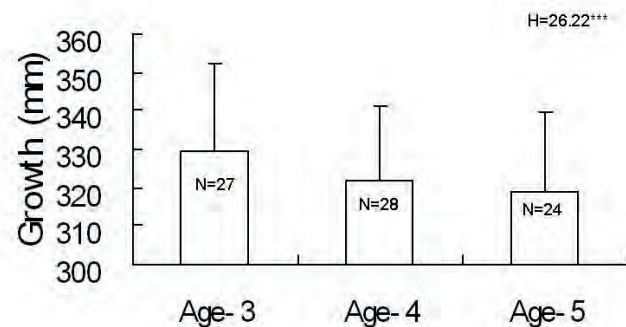


Fig. 3. Changes in mean and standard deviation of body growth (A), number and interval of circuli (B) at the first year of Ishikari River chum salmon in the Okhotsk Sea. A, age 3–5; B, age 4; I, circulus interval (μm); C, number of circuli.

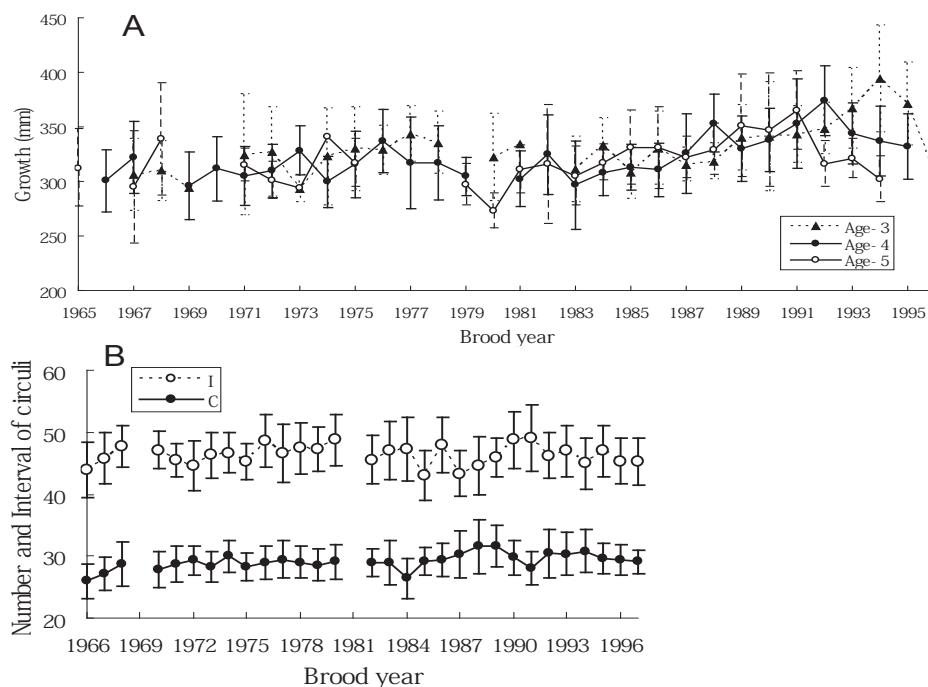


Fig. 4. Changes in mean and standard deviation of body growth at the first year for Ishikari River age-4 chum salmon in the coast of Hokkaido (Lc) and the Okhotsk Sea (Lo).

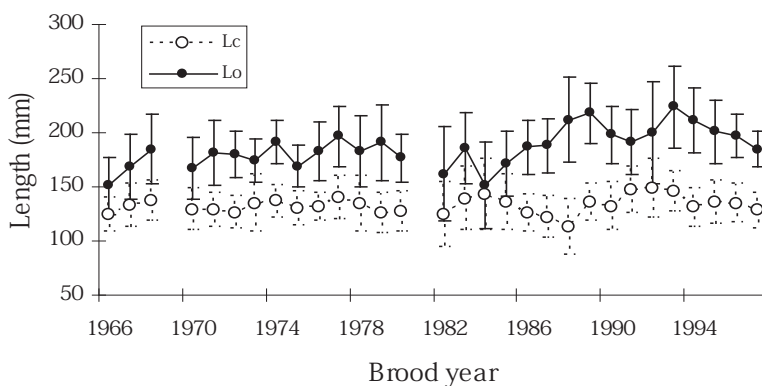


Fig. 5. Correlation map between 1° gridded sea-surface temperature in the winter (January–March) and ice cover area in the Okhotsk Sea during 1957–2004. Grey and white circles indicate positive and negative correlations, respectively.

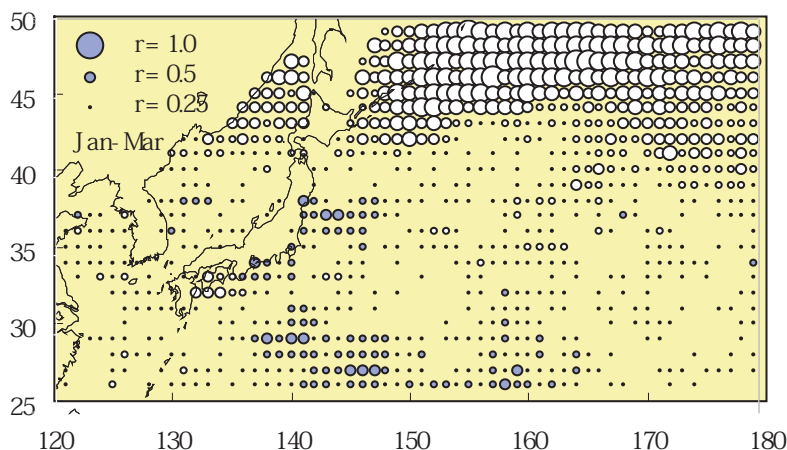


Fig. 6. Annual changes in anomalies of growth (Lo) and circuli number (Co) and sea ice concentration (SI; a and b), and the sea surface temperature (SST) during summer (c) and fall (d) in the Okhotsk Sea for age-4 chum salmon returning to the Ishikari River.

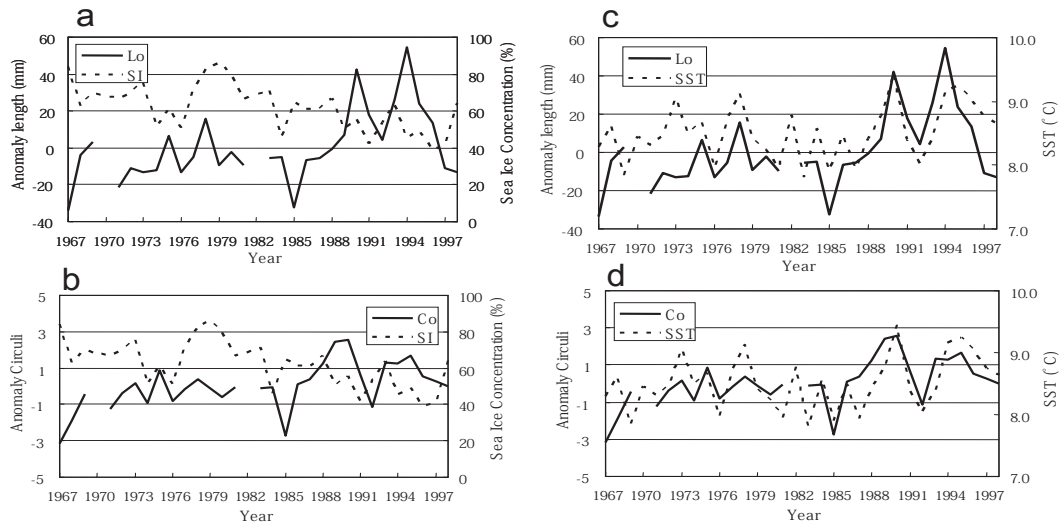


Fig. 7. Correlation map between 1° gridded sea-surface temperature in July–December and growth anomaly of the Ishikari River chum salmon in the Okhotsk Sea during 1957–2004. Grey and white circles indicate positive and negative correlations, respectively.

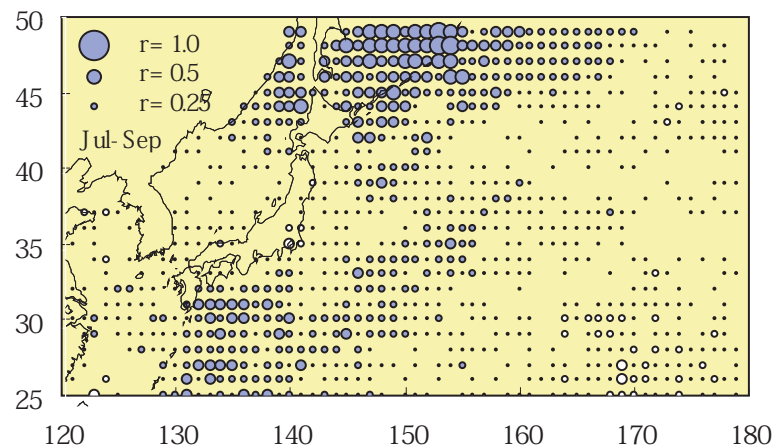


Table 1. Result of stepwise multiple regression analysis in return rate of Hokkaido chum salmon population on body size (g) at the release and growth of the Ishikari River chum salmon in the age 1.

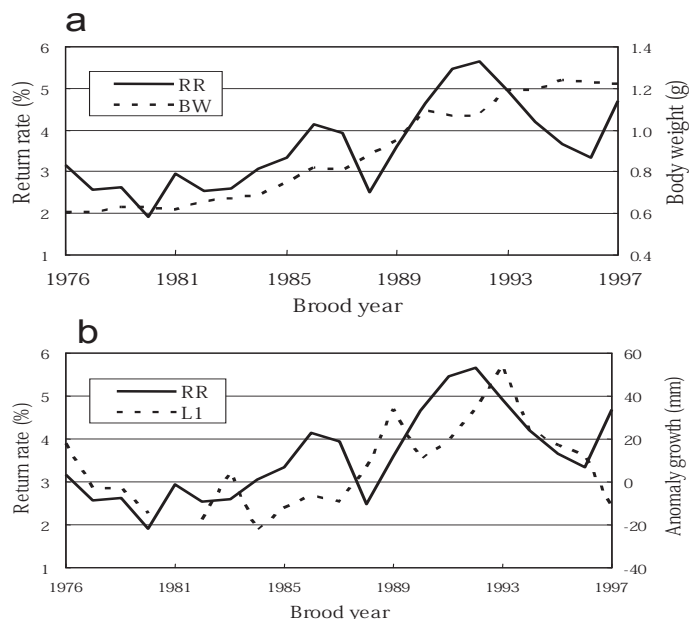
Variable	Slope	Partial Correlation	T	P
Body size at release	3.010	0.653	3.339	0.004
Growth in the Okhotsk Sea	0.024	0.434	1.866	0.082
Growth in the coast	-0.010	-0.112	0.437	0.668
Number of circuli in the Okhotsk Sea	-0.391	-0.425	1.817	0.089
Constant	0.965		1.235	0.236

$r^2 = 0.617$, $df: n1 = 4, n2 = 20$, $F = 6.046$, $P = 0.004$, $AIC = 50.763$

trends, relating to the sea ice concentration in the Okhotsk Sea.

The marine survival from fry to adult for chum salmon ranges from 0.3% to 3.2%, with a mean of ~1.8% (Salo 1991). There are two hypotheses on the period of critical mortality in the Pacific salmon: (1) Size-selective mortality in the early marine life period (Healey 1982) and (2) Size-related mortality over the first marine fall and winter relating to the sufficient growth by the end of the first marine summer (Beamish et al. 2004, Moss et al. 2005). Return rates of hatchery salmon measure the survival from release to return. The return rate of Hokkaido chum salmon is significantly correlated with mean body size at release (Fig. 8a) and the growth of the Ishikari River salmon in the Okhotsk Sea (Fig. 8b). However, the result of step wise multiple regression analysis in return rate on

Fig. 8. Changes in anomaly of growth at the first year (L1) of the Ishikari River chum salmon, mean body weight (BW) at the release, and return rate (RR) of Hokkaido chum salmon.



body size at release and growth in the Okhotsk Sea showed that the mortality of Ishikari River chum salmon would be higher at the seaward migration in the spring than in the first winter (Table 1).

In conclusion, 1) Larger chum salmon, which have the higher growth rate and energy metabolism in the Okhotsk Sea, migrate more rapidly than others. 2) In the Okhotsk Sea, chum growth increased in the 1990s, in association with increased SST during summer and fall, and decreased in areas of dense sea ice. 3) Chum salmon have 2 periods of critical mortality: (a) their early marine life (immediately after seaward migration), and (b) their first winter in the ocean. 4) The critical mortality of chum salmon will be higher in the early marine life than in the first winter. 5) The survival of Ishikari River chum salmon can be accurately predicted by the body size at release from hatchery and the growth in the Okhotsk Sea.

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Linkage between Early Ocean Life and Adult Returns of Chum Salmon in the Strait of Nemuro, Japan

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Keywords: Juvenile chum salmon, adult returns, zooplankton abundance, Nemuro Strait

A fundamental premise of population dynamics is that the mortality at an early life stage greatly affects brood-year strengths (e.g. Wootton 1998). This premise is probably true for some chum salmon populations in Japan because fluctuations in marine survival for chum salmon within a brood-year frequently show regional similarities. The fluctuations are thought to be related to coastal ocean conditions at the time of their sea entry (Saito 2002). In a previous study, however, since only SST data were analyzed as a variable indicating ocean conditions, it was unclear how coastal ocean conditions affected the survival of chum salmon. A juvenile survey has been carried out in Nemuro Strait, Japan, from late May to mid July in 1999–2002 (i.e., 1998–2001 brood-year stocks) to improve the understanding of the mechanisms regulating the abundance of juvenile chum salmon in coastal waters. Nemuro Strait is a narrow passage of water connecting the Sea of Okhotsk and the Pacific Ocean.

Six transect lines were set perpendicular along the coast of Shiretoko Peninsula from Shibetsu to Rausu. Each transect had a maximum of eight survey points with the distance from shore being 0.05, 0.25, 0.5, 1, 2, 4, 6, and 8 km, respectively. At each survey point, juvenile salmon were collected using one of two types of purse seine nets; one was 150 m long and 10 m depth and the other was 40 m long and 4 m depth. The latter, smaller net was mainly used at the survey points located in the shallow, near shore areas (< 0.5 km from shore). A NORPAC net was towed from 10 m depth to the surface at the survey points along two of the six transect lines to assess food conditions for juvenile salmon. Fixed transect lines for zooplankton sampling were established. In this paper, we compared the abundance, growth, condition of juvenile salmon and zooplankton abundance among the four study years and evaluated whether the abundance of the juveniles could be linked to the abundance of adults that returned at age 0.3.

The number of purse sein nets ranged from 46 to 117 operations per year (mean 92.2 operations/year). The year-to-year variation in the number of seines was due to weather or gear trouble. The mean density of juveniles was significantly higher (0.20 fish/m²) in 2001 compared to 1999 and 2002 (0.01 and 0.04 fish/m², respectively). Juvenile chum salmon occurred densely within inshore areas (< 1 km from shore) until early June, migrated offshore in late June and left from the study area up to mid July. This seasonal pattern of distribution was almost identical among the study years. Growth rates during coastal residence, estimated from back-calculated length based on otolith increments, were 10–17% higher for juveniles in 1999 and 2001 than those in 2000 and 2002. Analysis of fish condition was evaluated using the weight-length relationship proposed by Vila-Gispert and Moreno-Amich (2001) and revealed that fish collected in 2001 were in slightly better condition than fish caught in the other years, especially 1999 and 2000. As a consequence, juvenile salmon collected in 2001 (2000 brood-year stock) were

considered as the most successful among the four brood years studied. The success of the 2000 brood-year stock was probably the result of the zooplankton abundance in 2001, which was four to five times higher from mid May to late June in 2001, compared with that in the other years. The dominant species of zooplankton were *Pseudocalanus* spp. and *Acartia longiremis*. This dominance was an almost common feature during the study period.

In fall 2005, the 2001 brood-year fish that entered seawaters in 2002 returned to the Nemuro Strait as age 0.3 adult fish. Their returns enabled us to compare the status of 1998–2001 brood-year stocks at the adult stage. Interannual comparisons in age 0.3 adults revealed that the number of the 2000 brood-year stock (7 million; year-to sea in 2001) was the least abundant among the four brood-year

Fig. 1. Relationship between the number of age 0.3 adult chum salmon returning to the Nemuro Strait, Japan (bars) and mean density of juvenile salmon at their coastal residency (line) for 1998–2001 brood-year stocks.

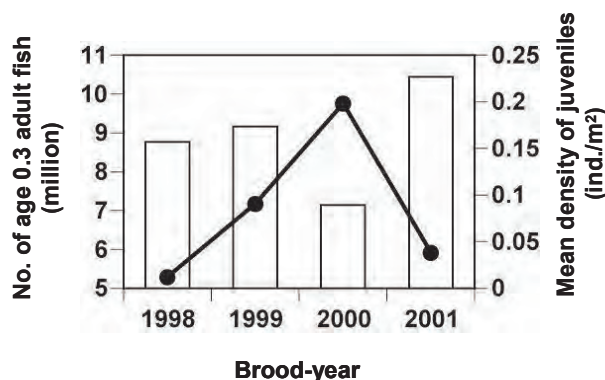
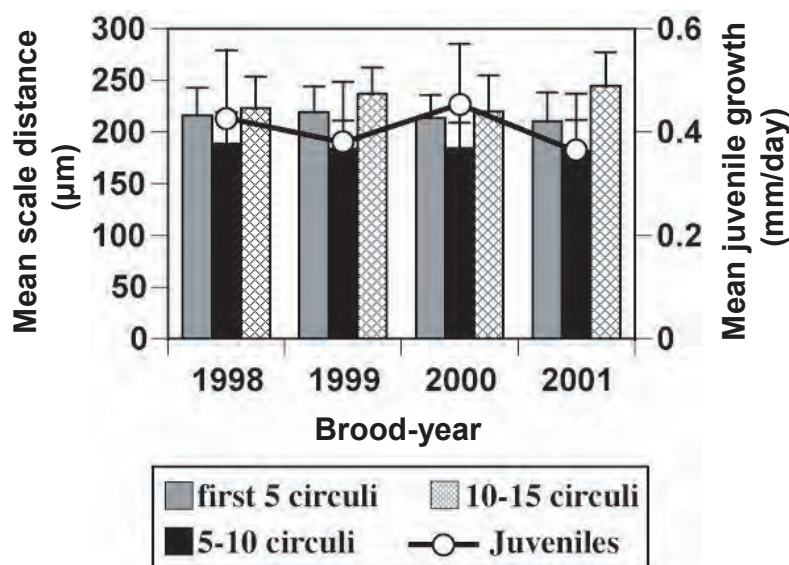


Fig. 2. Relationship between mean scale distance for age 0.3 adult chum salmon returning to the Nemuro Strait (bars) and mean juvenile growth during their coastal residency (line). The scale distance up to the first 5 circuli, that between 5th and 10th circuli, and that between 10th and 15th circuli were averaged for 100 fish per brood-year stock. Juvenile growth was estimated from back-calculated length based on otolith increments. Error bars indicate 1 SD.



stocks (range: 7–10 million). This was completely opposite to the results of our stock assessment at the juvenile stage (Fig. 1). Furthermore, the first year growth of returning adult fish, estimated with scale circuli spacings, showed little evidence that the 2000 brood-year stock had higher growth rates than the other brood-year stocks at the juvenile stage (Fig. 2). Although the reason for the discrepancy between juvenile and adult stages was unknown, we speculated that the spatial and temporal heterogeneity of juvenile distribution might bias our evaluation of juvenile status. Kaeriyama (1986) reported that juvenile chum salmon attaining 80 mm or more in fork length start migrating offshore. However, almost all juvenile salmon collected during our juvenile survey were less than 80 mm in fork length, suggesting that offshore migration had not occurred yet. If one tried to evaluate brood-year strengths at the juvenile stage, such offshore migrating fish also would have to have been monitored. This study suggested that a juvenile survey limited to small coastal areas may be difficult for forecasting the future adult returns using only the results of such juvenile survey.

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Overwinter Mortality and Energy Depletion in Juvenile Pacific Salmon Off the West Coast of British Columbia and Alaska

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Keywords: Winter, size-selective mortality, energy density, lipids, coho salmon, Chinook salmon, *Oncorhynchus*

Winter is generally considered a critical period in the early life of fish. As prey productivity and water temperature are typically lower during this season, it is commonly believed that food consumption rates of juvenile fish are greatly reduced over winter and insufficient to meet their energy demands. As a consequence, fish are expected to rely on the energy reserves accumulated during the growing season to fuel their metabolic functions during the winter months. Thus, fish with low energy reserves at the end of the growing season may be expected to experience higher mortality over winter. Smaller and slow growing fish are believed to be particularly vulnerable to winter conditions due to their lower lipid reserves. In addition, because laboratory experiments have consistently showed that mass specific metabolic rates decreased with size, we may expect that energy depletion over the winter months would be higher in smaller fish. The objectives of this study were to examine the winter ecology of juvenile salmon, and to test the hypotheses that overwinter mortality and energy depletion are higher in smaller salmon (Beamish and Mahnken 2001).

Fig. 1. Distribution of juvenile coho salmon and Chinook salmon off the west coast of British Columbia and southeast Alaska during fall and winter.

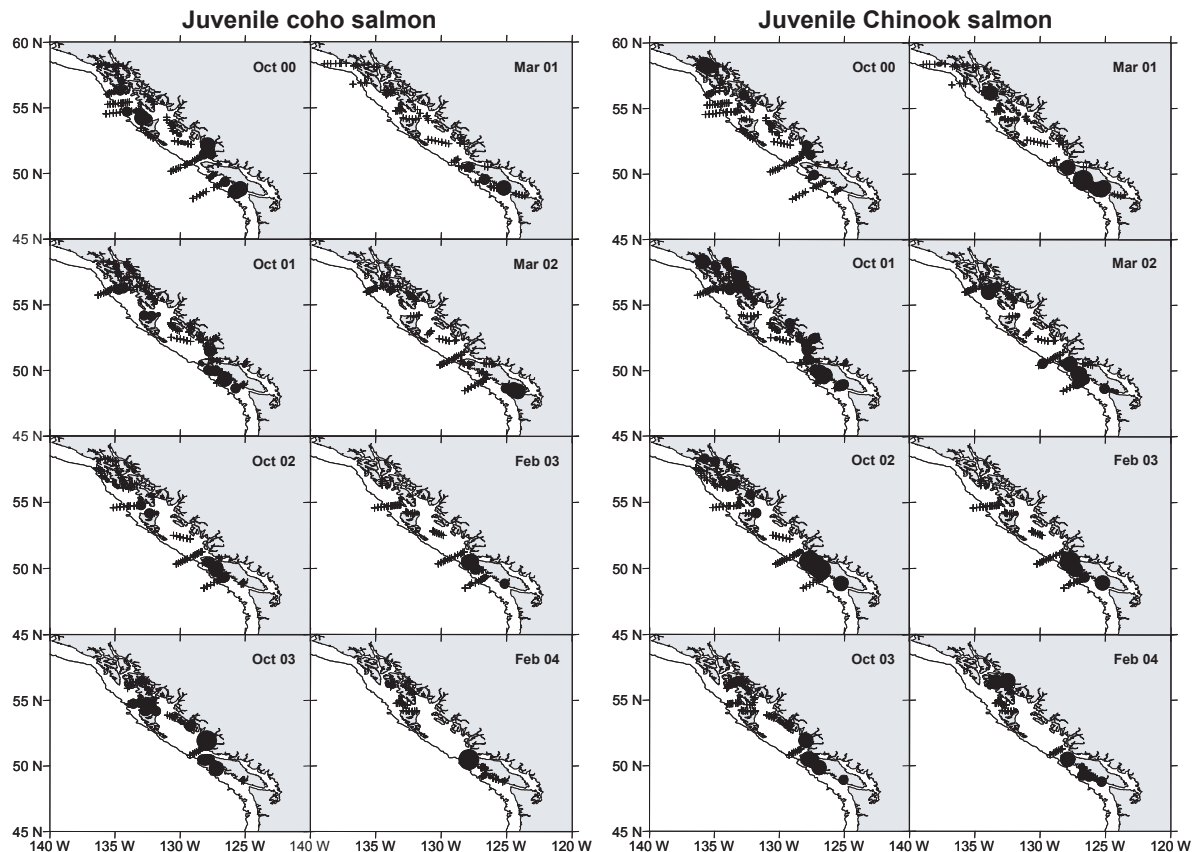
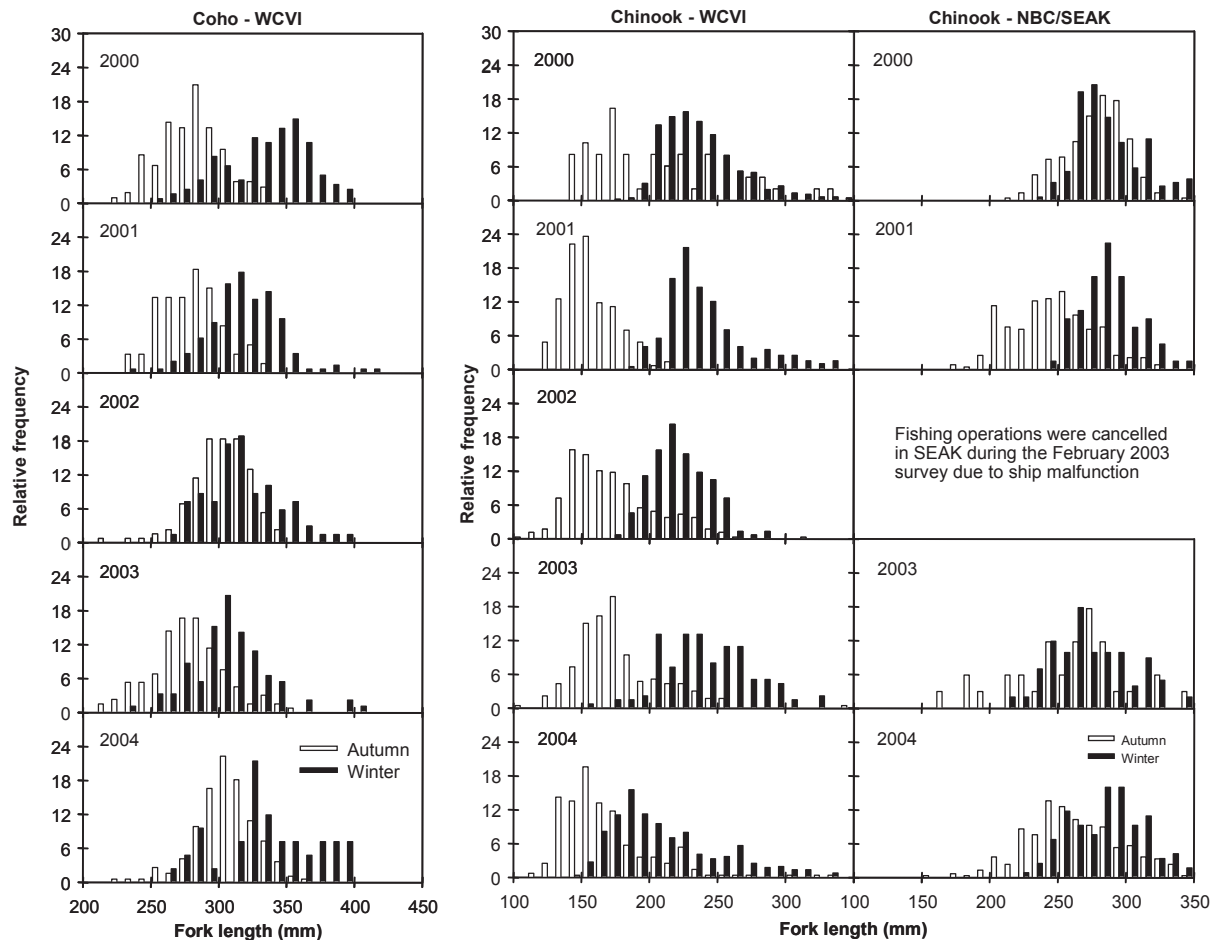


Fig. 2. Size frequency distribution of juvenile coho salmon and Chinook salmon caught off the west coast of Vancouver Island (WCVI) and southeast Alaska during fall (NBC/SEAK) and the following winter.



We collected juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) off the west coast of Vancouver Island and southeast Alaska during October–November 2000–2003 and February–March 2001–2004 using a rope trawl towed at the surface at five knots for 30 minutes. Juvenile salmon were identified, measured and weighed onboard the ship. All the Chinook and coho salmon were systematically examined for coded-wire tags. Otoliths and scales were removed for age determination. Skin samples were taken and preserved in 95% ethanol for DNA stock identification (Beacham et al. 2001, 2006). Juvenile salmon were then stored individually in pre-identified plastic bags and frozen for subsequent analyses.

The stomach contents were removed in the laboratory once the fish were thawed, weighed, and preserved for prey identification. The carcasses were dried to constant weight at 60°C, and ground. Energy density was measured directly on a subsample of the fish. For the remaining fish, we estimated the energy content by converting percent dry weight into energy density (Trudel et al. 2005, in press).

Size-selective mortality was assessed by comparing the mean and variance of fall and winter sizes. Mean size and the variance are expected to increase and decrease, respectively, over winter as a result of size-selective mortality against smaller fish. Overwinter energy depletion was tested by comparing the slope of the relationship between energy density and size for fish that were collected during fall and winter. As smaller fish were expected to utilize a larger fraction of their energy reserve over the winter period, the slope and intercept of the relationship between energy density and size were expected to be higher and lower, respectively, for fish collected during winter.

Juvenile Chinook salmon and coho salmon were caught throughout the study area during fall (Fig. 1). In contrast, with the exception of very few fish, juvenile coho salmon were exclusively caught off the west coast of Vancouver Island during winter (Fig. 1). In addition to the west coast of Vancouver Island, juvenile Chinook salmon were also caught in large quantities in Sumner Strait, southeast Alaska, during winter. DNA analyses indicated that the same populations were sampled during fall and winter (Trudel et al. 2004).

Mean size and the variance of size were generally higher during winter than during fall for juvenile Chinook salmon and coho salmon collected off the west coast of Vancouver Island (Fig. 2). In contrast, the mean size and variance of size was higher and lower, respectively, during winter than during fall for juvenile Chinook salmon in southeast Alaska (Fig. 2). Thus, size-selective mortality was only apparent for juvenile salmon in southeast Alaska, and may suggest that size-selective mortality may regulate the dynamics of salmon at northern latitudes, but not at southern latitudes.

Energy density increased with fish size during fall, but not during winter for juvenile salmon collected off the west coast of Vancouver Island and southeast Alaska. Thus, contrary to our expectations, energy depletion was higher in larger rather than in small salmon, possibly because larger salmon grew at a faster rate, as indicated by the increase of mean and variance of juvenile salmon size off the west coast of Vancouver Island over the winter period. Alternatively, field metabolic rates may be higher in larger fish. Although standard metabolic rates are generally higher in smaller fish under laboratory conditions, activity and foraging costs scale positively with size in fish under field conditions (Trudel and Rasmussen 2006), suggesting that weight specific metabolic rates increase with size in fish. Further effort will be required to evaluate the importance of overwinter mortality and lipid dynamics in juvenile salmon.

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Coastal Migration and Survival of Juvenile Chum Salmon Estimated from Laboratory Analysis their Maximum Sustainable Swimming Speed

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Keywords: Chum salmon, juvenile salmon, coastal migration, swimming speed

Chum and pink salmon migrate to the sea during their early juvenile stages. Previously, it was believed that Japanese chum salmon juveniles migrate east along the sub-arctic boundary (Yonemori 1975). However, recent investigations involving the recapture of otolith marked fish (Ueno 1998; Urawa et al. 2004) and genetic stock identification (Urawa et al. 2001) revealed that Japanese chum salmon juveniles migrate to the Okhotsk Sea.

When migrating to the Okhotsk Sea, the swimming performance of juveniles may be important. In this study, water velocity was adjusted in a circulating tank (SOC-10, Japan Aqua Tech Co. Ltd.) and the effect on swimming performance of chum salmon juveniles was observed. The swimming chamber was 600 mm long x 300 mm wide x 330 mm deep (Fig. 1).

Figure 2 shows the relationship between fish size and endurance time. Linear relations with different slopes by each velocity were found. For juveniles ≤ 80 mm in fork length, except for recently emerged fry (36–38 mm), the maximum sustainable speed (U_{max}) was about 7 FL/s (specific speed based on fork length (FL)).

The value 7 FL/s is higher than others have reported. For example, Brett (1964) showed 2.8 FL/s as a maximum sustainable speed for 10 cm sockeye juveniles. Our results suggest that juvenile chum salmon heading for the Okhotsk Sea have a maximum speed of 50 cm/s, or 1.8 km/h, or 1 knot without any effects from currents. However, the Oyashio Current off Hokkaido in the Pacific side flows primarily southward along the Kuril Islands, in the opposite direction of juvenile chum migrating northward. Current data are available from the Japanese Coast Guard's Oceanographic Data Center (http://www1.kaiho.mlit.go.jp/KANKYO/KAIYO/qboc/index_E.html). From these data, west of the Cape Erimo, a strong westward current is typical during May and June when the juvenile chum salmon migrate to the ocean in this area. Figure 3 shows the results of recovery of otolith thermal marked chum juveniles since 2000. Though almost all fish were caught near the mouth of the river where they were released, a few were caught far to the west, especially those released from the Shizunai and Tokachi rivers.

Considering the swimming ability of young chum salmon, many fish entering the sea in this region might be transported westward by ocean currents. Migrating against the current would take additional energy and time to travel to the Okhotsk Sea, and may result in fish being transported to areas where they would experience high mortalities. Thus it is important to better understand current patterns in coastal and offshore waters to clarify the mechanism of migration and survival of juveniles.

Fig. 1. SOC-10, a circulating tank for measuring swimming capacity (Japan Aqua Tech Co. Ltd.).

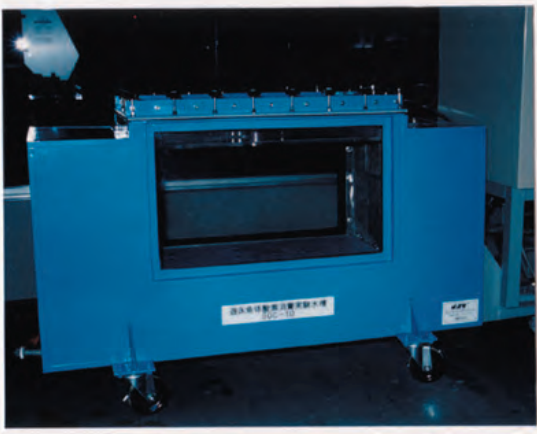


Fig. 2. Swimming capacity of chum salmon (40–80 mm in fork length, FL) expressed in specific flow speed (multiple of FL per second).

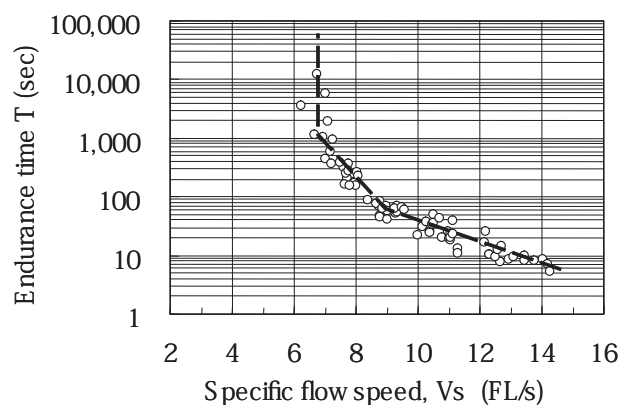
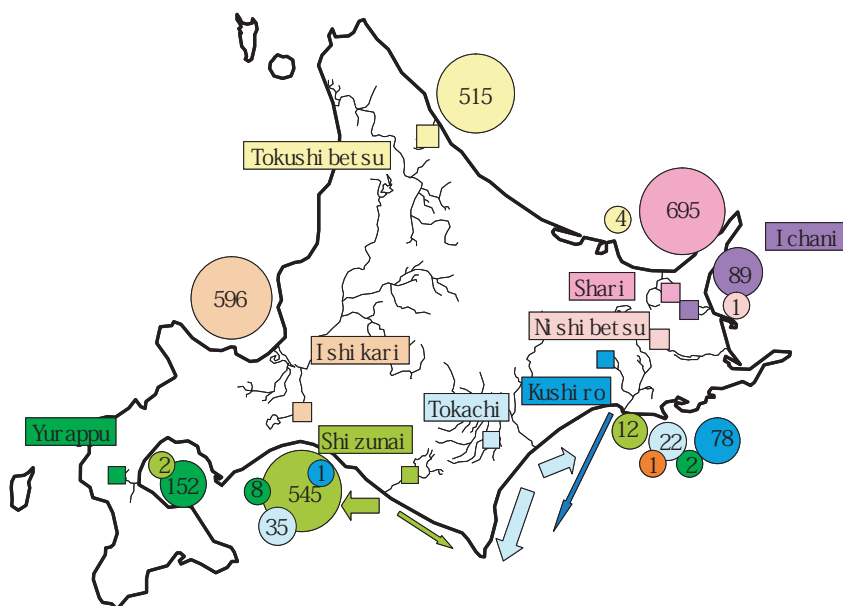


Fig. 3. Distribution of otolith marked juvenile chum salmon caught in coastal waters in 2000–2005. The figure was revised from Nara (2006), adding the results of coastal research in 2000–2004.



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Genetic Stock Identification of Chum Salmon in the Summer Bering Sea 2004

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Keywords: Chum salmon, mitochondrial DNA, haplotype, genetic stock identification, DNA microarray

Stock identification of Pacific salmon is an important component for their population research and management. Molecular techniques are an effective tool for genetic stock identification (GSI) of salmon (Ferguson et al. 1995). Moriya et al. (2004) developed a DNA microarray technique for rapid and accurate identification of single nucleotide polymorphisms in the mitochondrial (mt) DNA control region of chum salmon. Sato et al. (2004a) reported that the DNA microarray technique was useful to identify the regional origins (Japan, Russia or North America) of high-seas chum salmon. In this study, we estimated stock composition of chum salmon caught in the Bering Sea and its adjacent waters using the mtDNA microarray technique.

Chum salmon were collected during the Bering/Aleutian Salmon International Survey (BASIS) research cruise of RV *Kaiyo maru* from June 17 to July 16, 2004. One hour surface trawls were conducted at a towing speed of 5 knots in the Bering Sea and along the eastern Aleutian Islands (50°30' to 58°00'N, 170°00'W to 175°00'E; Fig. 1). We caught a total of 1,669 chum salmon by 25 surface trawls. Blood samples were collected from each chum salmon and immediately frozen until analysis. DNA was extracted from the frozen blood samples in the laboratory using PUREGENE™ DNA isolation kit (Gentra System, Minneapolis, MN), and mtDNA haplotype of each fish was detected using DNA microarray (Moriya et al. 2004). Regional stock contributions were estimated with a conditional maximum likelihood algorithm using the Statistics Program for Analyzing Mixtures (SPAM version 3.7b). We employed the baseline data set of 48 chum populations in the Pacific Rim (Sato et al. 2004b).

Chum salmon were widely distributed in the Bering Sea and eastern North Pacific Ocean, and they were relatively abundant in the central Bering Sea (north of 54°N, between 175°E and 175°W; Fig. 1). About 90% of chum salmon were immature (Fig. 2). The estimated stock compositions of immature chum salmon showed that Asian (Japanese and Russian) stocks were widely distributed in the survey areas of the Bering Sea (Figs. 3 and 4). Russian stock was relatively abundant in the western water, while Japanese stock was abundant in the northeastern water (Fig. 4). Previous GSI studies indicated that Japanese chum salmon was predominant in the Bering Sea during the autumn of 2002 and 2003 (Sato et al. 2004a; Urawa et al. 2005a,b). These results support a stock-specific ocean migration model that Japanese chum salmon feed mainly in the Bering Sea during the summer and autumn (Urawa 2000, Urawa et al. 2004).

Fig. 1. Number of chum salmon caught by 1-h trawl (CPUE) in the Bering Sea and North Pacific Ocean near the Aleutian Islands in June and July 2004.

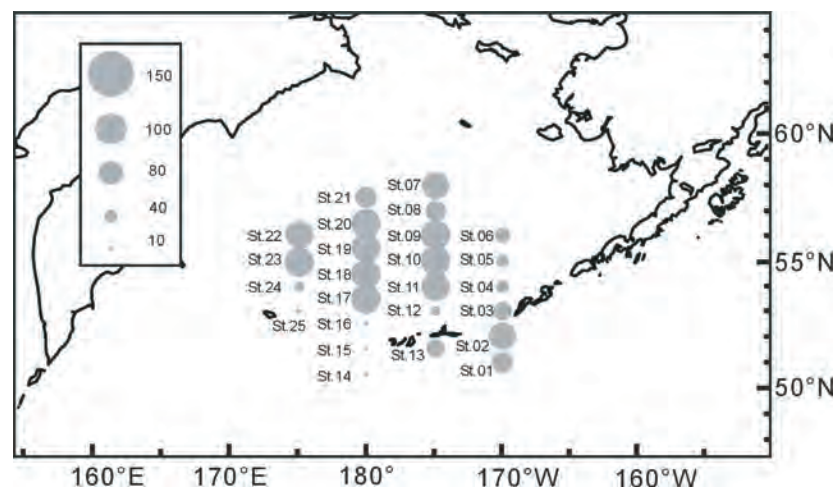


Fig. 2. Composition (%) of maturing and immature chum salmon caught in the Bering Sea and North Pacific Ocean in June and July 2004.

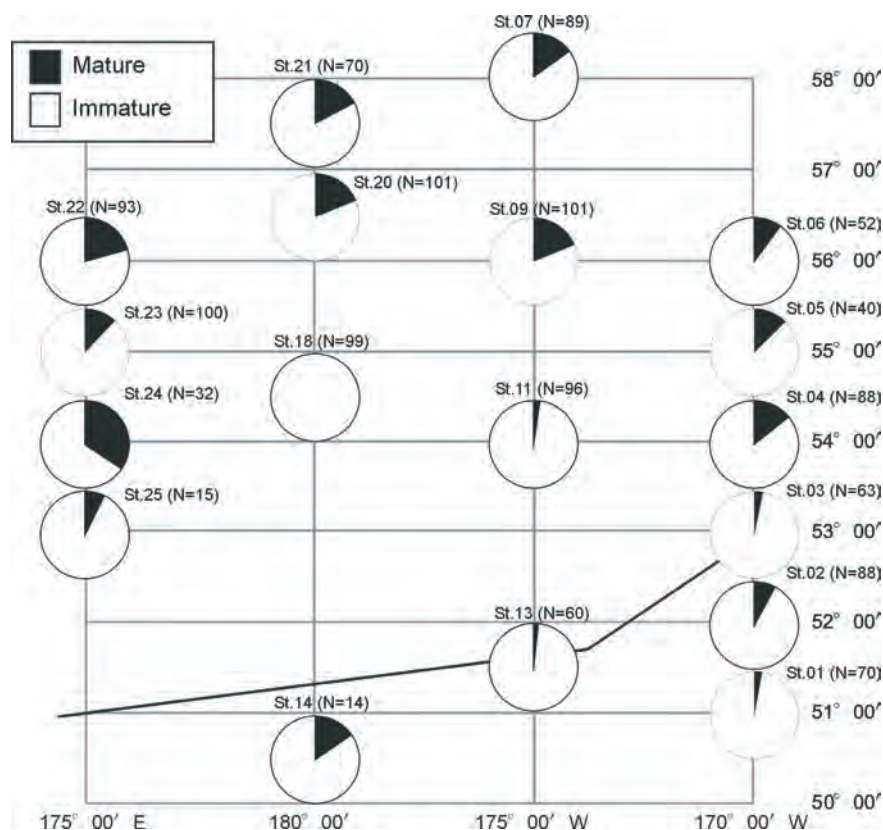


Fig. 3. Genetic-estimated stock composition (%) of immature chum salmon caught in the Bering Sea and North Pacific Ocean in June and July 2004.

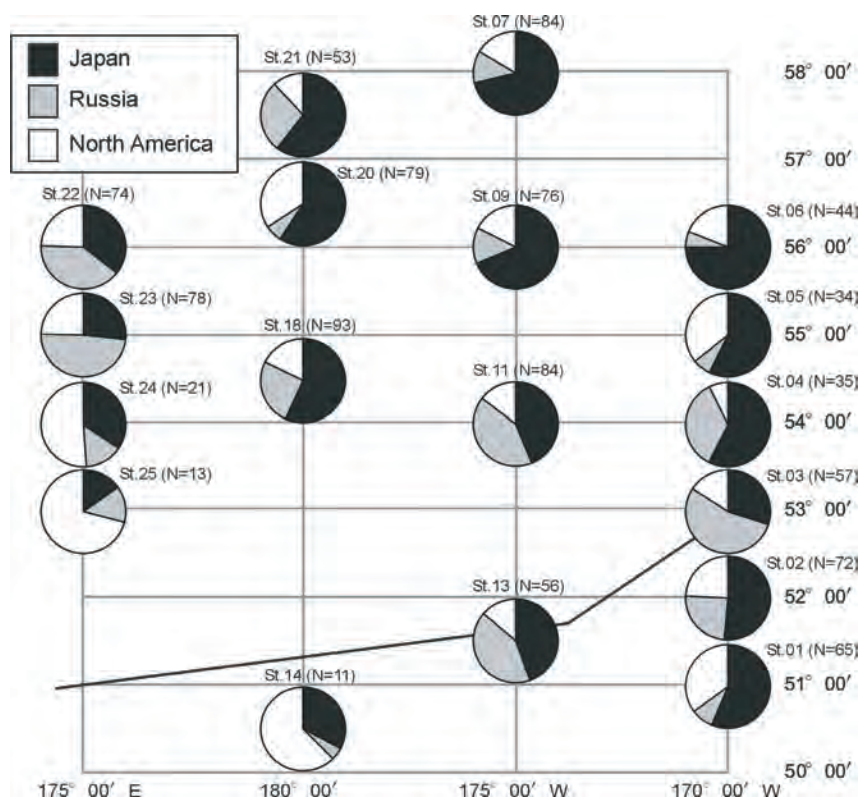
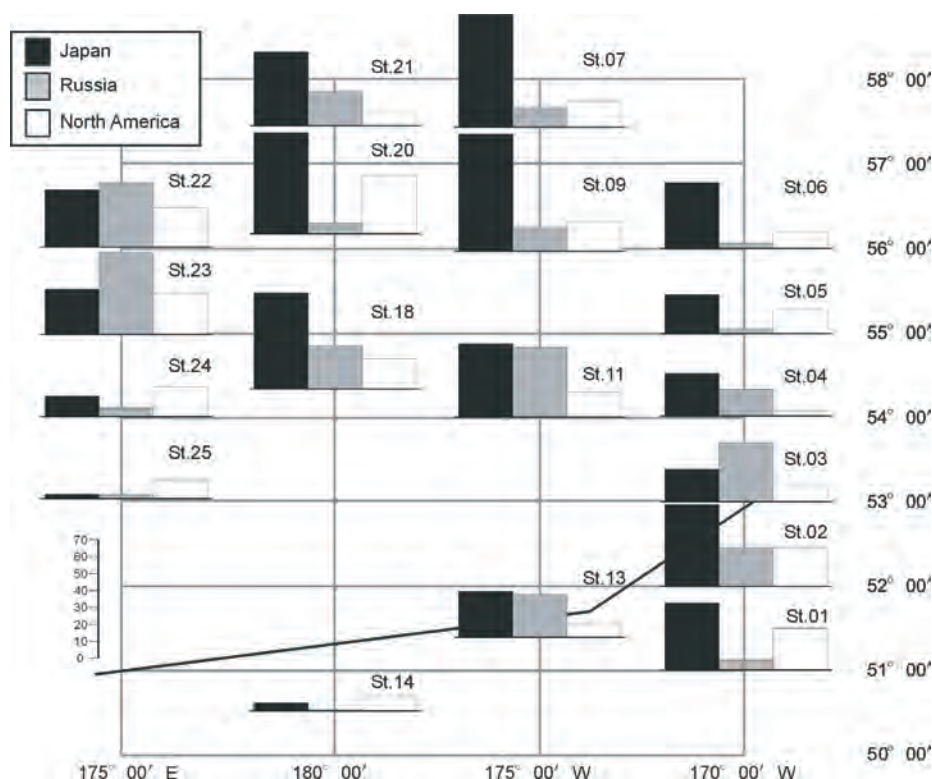


Fig. 4. Genetic-estimated CPUE of immature chum salmon by stock origin in the Bering Sea and North Pacific Ocean in June and July 2004. CPUE means number of catches per 1-h trawl.



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Influence of Water Salinity on the Physiological Status and Distribution of Juvenile Chum Salmon in the Estuary of the Ola River of the Northeast Coast of the Okhotsk Sea

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Keywords: Juvenile chum salmon, otoliths, physiological status, morphology of blood, osmotic resistance, erythrocytes

Identification of individual fishes by their specific features, natural or artificial markers, is the basis for differentiating between individual populations and fish groups in mixed stocks. The significant number of thermally marked fish released from the Ola Salmon Hatchery gives us an opportunity to conduct a large-scale research of various salmon stocks on the basis of their identification at any stage of their life cycle.

One of factors contributing to survivability of juvenile salmon during their migration from fresh water to the ocean is their ability to adapt to increasing water salinity. Osmoregulatory mechanisms of juvenile chum salmon begin to form during the freshwater period at the presmolt stage and reaches a significant level of development at the smolt stage prior to their migration into the ocean. Results of the work performed in 2003–2005 have indicated that juvenile salmon in the Ola River estuary (Fig. 1) mix with wild fish beginning from the middle of June. The stock abundance dynamics during seaward migration is influenced by habitat conditions. The analysis of different hydrological and hydro chemical parameters allowed us to determine that the main abiotic factor from which the distribution of juvenile salmon depended was water salinity. The dynamics of changes in catch volumes in the estuary represents distributional pattern for chum fry from the time of their seaward migration until their subsequent journey to the coastal regions of the ocean.

During July significant numbers of juvenile salmon were found in the pre-estuary part of the river and also in the estuary of the Ola River in the areas of oligohaline and mesohaline types (Fig. 2). Such distribution is connected with the active migrations of juvenile salmon during the period of high growth rate and gradual adaptation to the conditions of increased salinity and the influence of great quantity of hatchery-released salmon. The otolith microstructure analysis allowed us to differentiate hatchery released juvenile salmon in the mixed aggregation and also their distribution regularity in the estuary (Fig. 3). Hatchery juveniles were found in the inner part of the estuary in small numbers. To get into the north-western and north-eastern parts of the estuary water area, juvenile chum salmon have to migrate for long distances through the head tide zones. We believe hatchery-released salmon

Fig 1. Survey stations within the Ola River estuary.



Fig 2. Average number of juvenile salmon caught in the Ola River estuary in July.

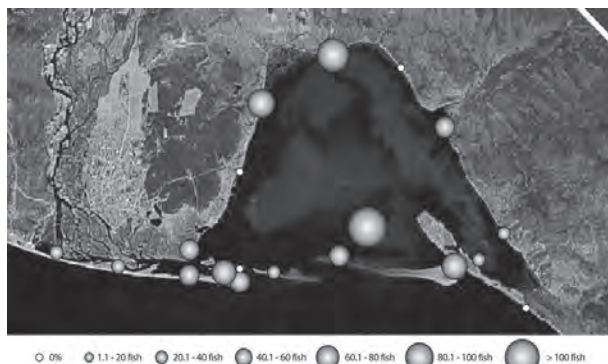


Fig 3. Distribution of otolith-marked salmon juveniles in the Ola River estuary in July.



Fig. 4. Erythrocyte quantity per mm² of juvenile chum salmon blood (1x10⁶) from different salinity areas.

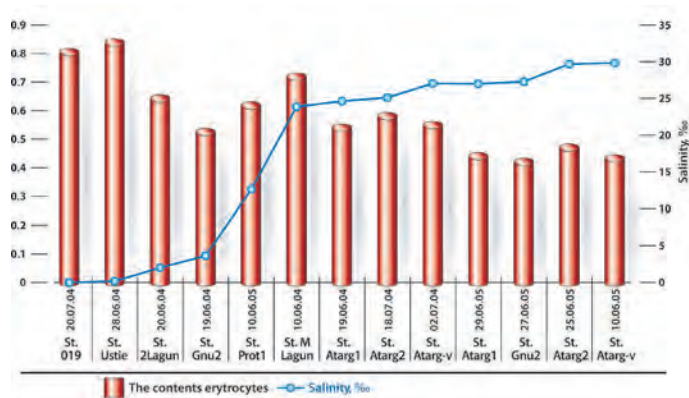
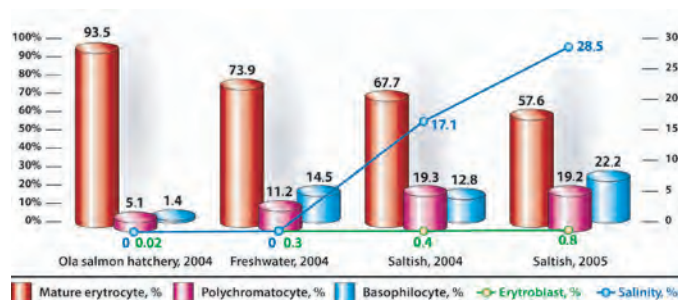


Fig. 5. Mature and young forms of erythrocyte correlation of juvenile chum salmon.



increase of the number of young erythrocyte forms, either polychromatophil or basophil. Such a large quantity of young erythrocytes and blast forms indicates the erythropoiesis increase.

Thus, in the process of adaptive reactions to increasing water salinity, new erythrocyte production increases along with a decrease in volume unit. This fact, from our point of view, can be explained by the intensive degeneration of the old erythrocyte forms which have not adapted to the changed concentration of ions inside the fish body when entering salt water and great quantity of degenerated erythrocyte data received from the blood smears of juvenile salmon from the areas of variable salinities also supports the above. Additional proof of intensive degeneration of adult erythrocytes of juvenile salmon is the results of our osmotic erythrocyte resistance investigation. This parameter's evaluation was carried out with the help of being able to determine the sodium chloride solution concentration under which the osmotic erythrocytes' cover is being degenerated, e.g. we observed hemolysis.

We took solution concentration into account, under which the process of hemolysis began, e.g. some part of erythrocytes degenerated, and also the concentration under which all erythrocytes entirely degenerated. Figure 6 shows that juvenile chum salmon erythrocytes from different areas with sea salinity started to degenerate under the sodium chloride solution concentration of 0.5% and entirely degenerated under the sodium chloride solution concentration of 0.42 %, while erythrocytes of freshwater salmon could tolerate a greater concentration of the solution. According to these results we can come to the conclusion that osmotic erythrocyte resistance in juvenile salmon from brackish water areas is lower.

The hematologic indexes, characterizing the immune system and determining compensatory body abilities, are the structural elements of fish white blood cells—lymphocytes (they are responsible for the humoral immunity and antibodies production), neutrophils (represented by juvenile neutrophils and segmented neutrophils) and monocytes which are responsible for phagocytal functions at different stages of the immunal reaction in fish. When going from freshwater areas into the brackish areas, some portion of lymphocytes decrease while some portions of monocytes and juvenile neutrophils increase (Fig. 7). Such types of responses of immune system are typical for juvenile salmon, during the evolutionary process. Under stress-factors, we see changes in the metabolism and respiratory systems, which help fish to survive in a given stress situation, but at the same time these changes can cause illnesses within fish. In this connection we can explain the increase of some forms of juvenile neutrophils and segmented neutrophils as they take part in the phagocytosis on the first stage of the adaptive reaction of fish and that is why

may be not able to overcome such long distances because of their low physical and physiological status. That is why hatchery salmon are characterized by passive migration, first in the zones of freshwater currents of the Ola River and then in the zones of the ebb current along the islands of the southern part of the estuary flowing into the open sea.

To evaluate the changes taking place in the respiratory system of juvenile chum salmon during smoltification, we conducted research on erythrocyte quantity of juvenile salmon taken from different areas of the Ola River estuary with different salinities. As the level of water salinity increased the erythrocyte quantity of juvenile chum salmon decreased (Fig. 4). This is due to the fact that oxygen transportation in salt water moves faster than in fresh water and to the degeneration of part of the erythrocytes. Erythrocytes increased with the physical response to the stress-factor. Thus, we believe that not only is general erythrocyte evaluation important but also the analysis of the mature (e.g. old) and young forms of erythrocytes to which polychromatophil, basophilic and blast forms are related. The most distinct reaction to increasing water salinity is the decline of mature erythrocytes and accordingly the

Fig 6. Osmotic erythrocyte resistance of juvenile chum salmon parameters from different areas having different salinity.

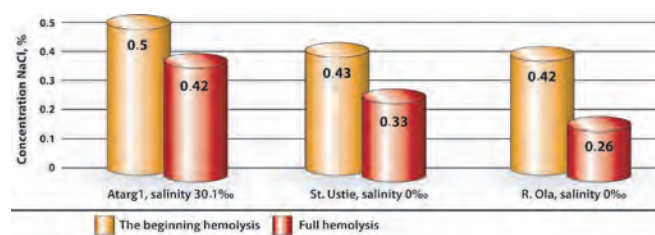


Fig. 7. Fish white blood parameters of juvenile chum salmon at different stages of smoltification.

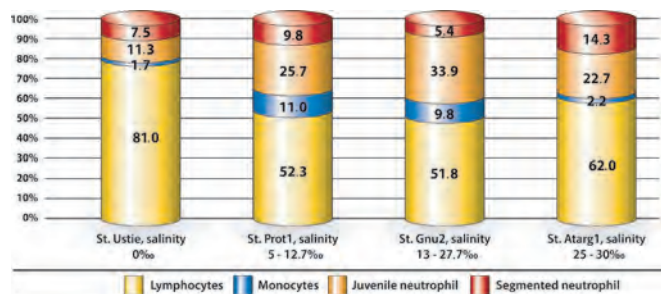
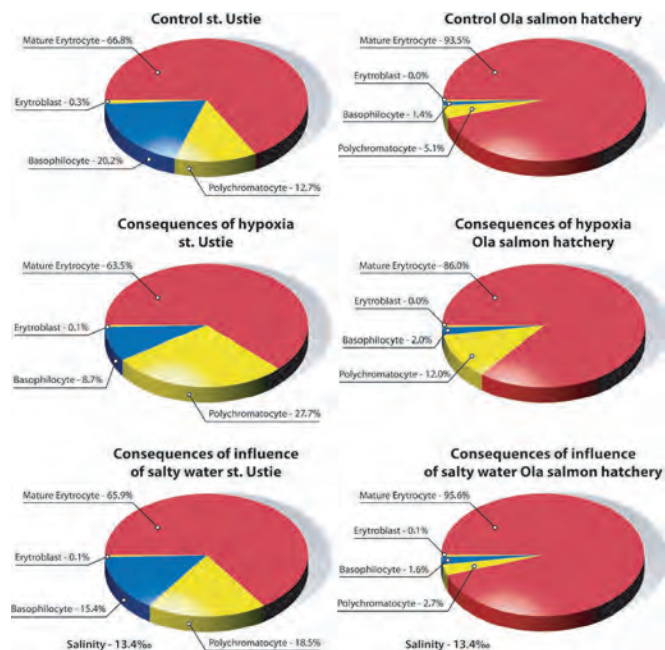


Fig. 8. Changes in the “red” blood cell structure of juvenile chum salmon in the course of experiment.



on the organs of the hematoses response of wild and hatchery-raised salmon was totally different. While the mature erythrocyte portion of wild salmon remained the same, hatchery-raised salmon stopped producing juvenile forms of erythrocytes and “red” blood cells consisted mainly of mature, the oldest erythrocytes. Such a correlation of erythrocyte forms is the index of inconsistency of the ability of the body to adapt. After the influence of salt water the white blood cell index of “wild” juvenile salmon slightly changed, but thrombocyte quantity increased two-fold which is a normal adaptive reaction to salinity increase. Juvenile neutrophils of hatchery raised salmon abruptly increased, while thrombocytes portions decreased by five times. In the course of the experiment the removal was noted only within hatchery raised salmon at 33%.

they are consumed in the first place.

Under continuing stress, which can be observed when fish are in the zone of increased salinity for a long time, the accumulation of suboxidal products in the location of the inflammation occur, and become the reason for juvenile neutrophils and segmented neutrophils becoming less active and their place being taken by monocytes. Thus, monocytes are being activated at the second stage of phagocytosis, and that is why they exist in great numbers in the blood of juvenile chum salmon from the areas with different salinity and practically are not seen in smoltified juvenile salmon from the areas with high salinity (Fig. 7).

To reveal the regularity of the blood elements of wild and hatchery born salmon we conducted a two stage experiment: 1) under the conditions of hypoxia in fresh water; and 2) under the conditions of increased water salinity. Equal quantities of wild juvenile salmon, found in Ustye, and hatchery-born salmon were placed into equal concentration of fresh water. For two days salmon hatchlings were contained in such conditions without additional aeration. Diurnal temperature oscillations were varied from 5°C to 12°C, oxygen from 3.3 to 4.0 mg/l. After that, all the hatchlings were placed into concentrations of sea water with the following parameters: salinity = 13.4‰, oxygen = 4.4 mg/l, temperature = 12.3°C. Hematologic tests were conducted at the beginning of the experiment as a background (22 June 2004), after two days of oxygen starvation (24 June 2004) and after keeping the hatchlings in salt water (26 June 2004).

Hematologic changes of red blood cell dynamics are shown on the diagram (Fig. 8). Comparing the background of red blood parameters of wild and hatchery born juvenile salmon showed that wild fish have a higher number of erythrocytes, basophilocytes and polychromatophiles; existence of the blast cells is noted. Juvenile hatchery raised salmon have the highest concentration of mature erythrocytes of 93.5%. After two days of starvation and lack of additional aeration (24 June 2004) both wild and hatchery raised salmon had a decrease in the quantity of erythrocytes. Thus, physiological reaction of both wild and hatchery raised salmon was the same, e.g. the activation of erythropoiesis occurred. After remaining in salt water, the effect

Genetic Stock Identification of Juvenile Chum Salmon Caught in the Okhotsk Sea During the Fall of 2003

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Keywords: Juvenile chum salmon, genetic stock identification, distribution, Okhotsk Sea

Juvenile chum salmon (*Oncorhynchus keta*) are abundantly distributed in the Okhotsk Sea during the fall season (Ueno 1997; Melnikov et al. 1999a, 1999b; Lapko and Glebov 2001; Volvenko 2003). The first genetic stock identification (GSI) study suggested that the Japanese stock was dominant among juvenile chum salmon caught in the southern Okhotsk Sea (45–49°N, 145–152°E) in October 1993 (Urawa et al. 1998, 2001). On the other hand, Russian stocks were dominant in the southwestern water (46–51°N, 146–150°E) in October 2000 (Urawa et al. 2006). Urawa et al. (2004) estimated the stock origins of juvenile chum salmon caught in the wide areas of the Okhotsk Sea (45–55°N and 146–152°E) in October 2002 using allozyme and otolith marks, and confirmed that the stock composition was different among the sampling locations.

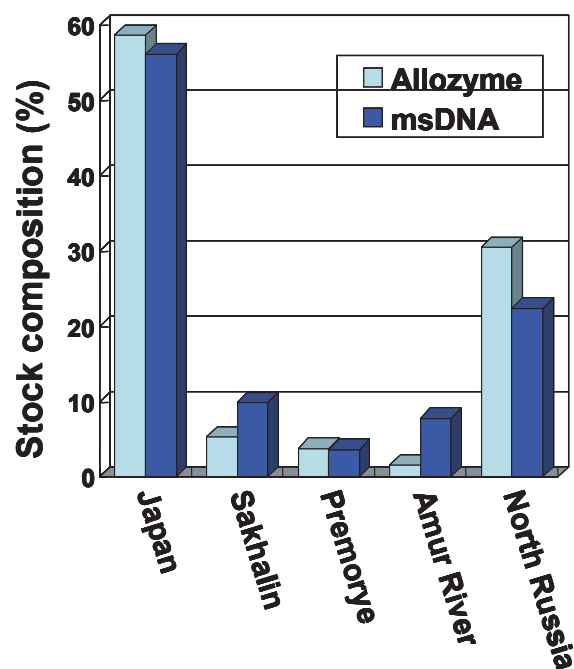
In the present study, the origins of juvenile chum salmon caught in the Okhotsk Sea during the fall of 2003 were estimated by using allozyme and microsatellite DNA variations. A total of 361 juvenile chum salmon (age 0.0) was caught at eight stations (51–55°N and 148–155°E) by a surface trawl net of a Russian research vessel between September 27 and October 17, 2003 (Table 1). Tissue samples (heart, liver and muscle) were collected from each fish, and frozen on board.

Samples were examined for protein electrophoretic variation on horizontal starch gels using standard procedures described by Aebersold et al. (1987). Alleles were compared and standardized for 20 polymorphic loci. We used an Asian baseline data set (43 stocks/20 loci) reported by Winans et al. (1994), Wilmot et al. (1998) and Urawa et al. (2006). Estimates of stock contributions were made with a conditional maximum likelihood algorithm using the Statistics Program for Analyzing Mixtures (SPAM version 3.7, Debevec et al. 2000). Standard deviations and 90% confidence intervals were estimated by 1,000 bootstrap resamplings of the baseline and mixture samples. Estimates were made to individual stocks and then pooled to regional stock groups: Japan, Sakhalin, Premorye, Amur River, and northern Russia (Magadan/Kamchatka/Anadyre).

Table 1. Juvenile chum salmon caught in the Okhotsk Sea in the fall of 2003 for genetic stock identification.

Station	Latitude	Longitude	Date	Number of samples
1	51°31'N	155°00'E	Sep-27-2003	50
2	51°01'N	152°00'E	Sep-29-2003	50
3	51°00'N	149°00'E	Sep-30-2003	50
4	52°59'N	148°02'E	Oct-06-2003	36
5	52°53'N	152°00'E	Oct-07-2003	44
6	55°00'N	147°59'E	Oct-13-2003	50
7	55°01'N	151°57'E	Oct-15-2003	30
8	55°00'N	155°00'E	Oct-17-2003	51
Total				361

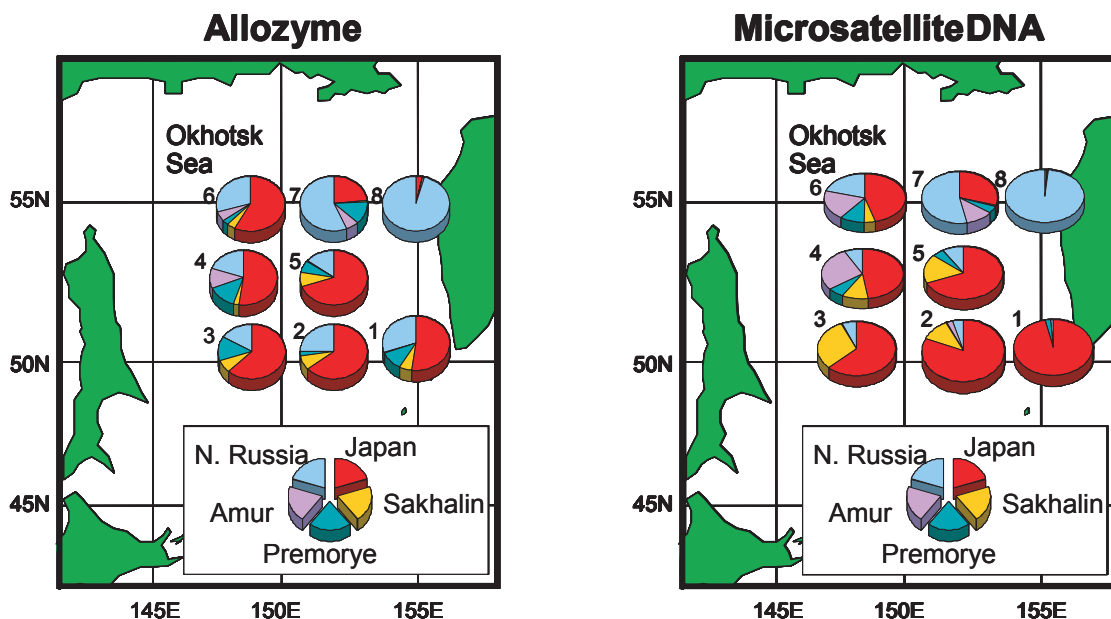
Fig 1. A comparison of regional stock composition (%) of total mixtures of juvenile chum salmon estimated by allozyme and microsatellite (ms) DNA analyses. Both analyses showed that the Japanese stock was predominant in the Okhotsk Sea in the fall of 2003.



In addition, surveys of variation at 13 microsatellite loci were conducted: *Ots3*, *Oke3*, *Oki2*, *Oki100*, *Omy1011*, *One101*, *One102*, *One103*, *One104*, *One111*, *One114*, *Ssa419*, and *OtsG68* (Beacham et al. 2004). Genotypic frequencies were determined for each locus in each sample and SPAM version 3.7 was used to estimate stock composition of the mixed-stock samples. Analysis of the mixed-stock sample was conducted with a baseline of 25 Russian populations and 26 Japanese populations (Beacham et al. unpublished data).

Both allozyme and microsatellite DNA analyses showed similar estimates of stock composition for all juvenile chum salmon samples: 59% and 56% for Japan, 5% and 10% for Sakhalin, 4% and 4% for Premorye, 2% and 8% for Amur River, and 31% and 22% for northern Russia stocks, respectively (Fig. 1). The estimated stock composition was different among the sampling locations (Fig. 2). Japanese chum salmon were predominant in southern waters, while northern Russian stock (mainly western Kamchatka) was predominant in the northeastern waters. In comparison with the 2002 results (Urawa et al. 2004), the distribution of Japanese and Russian stocks shifted to the northern water in the fall of 2003, maybe because of warmer water temperatures in 2003. Thus, the distribution pattern of juvenile chum salmon within the Okhotsk Sea may be different among years. It is highly important to continue the monitoring program for juvenile salmon in the Okhotsk Sea including accurate stock identifications in order to understand the population status and dynamics of Asian chum salmon.

Fig 2. Regional stock composition (%) of juvenile chum salmon estimated by allozyme and microsatellite DNA analyses. The stock composition was different among the sampling locations: the Japanese stock was predominant in the southern waters and the northern Russia (west Kamchatka) stock dominated in the northeastern waters.



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Seasonal and Annual Changes of Oceanographic Condition during Early Ocean Life of Chum Salmon in the Coastal Waters of Okhotsk Sea, Eastern Hokkaido

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Keywords: Oceanographic condition, temperature, salinity, nutrient, chlorophyll-a, sea ice, Soya Warm Current

Two different currents affect oceanographic conditions in southern part of the Okhotsk Sea along the Hokkaido coast. In winter the East Sakhalin Current characterized by low temperature and salinity flows along the Hokkaido coast with sea ice. In summer the Soya Warm Current (SWC) characterized by high temperature and salinity flows southeastward from Soya Strait along the coast. In spring, these current systems are replaced, so that the temperature, salinity and nutrients change extremely. These extreme changes in the oceanographic conditions may affect the early marine survival of juvenile chum salmon. We investigated to clarify the relationship between seasonal and annual fluctuations of oceanographic condition and early ocean life of chum salmon. Physicochemical and biological conditions were examined every 10 days from April to July in 2002–2005 at 12 stations in the coast of Abashiri Bay, eastern Hokkaido (Fig. 1). Water temperature and salinity profiles were measured by using memory STD at all stations. Water samples in each depth (0, 10, 20, 30 and 40 m) were collected with Van Dorn Bottles for nutrients and chlorophyll-a analyses at two stations off the mouth of the Abashiri River (Stations B1 and B3).

Changes in water temperature (°C), salinity (PSU), nutrient concentration ($\text{NO}_3 + \text{NO}_2$: $\mu\text{g-atom/L}$), and chlorophyll-a concentration ($\mu\text{g/L}$) at Station B1 (off 1 km) and B3 (off 7 km) are shown in Fig. 2. There were large annual fluctuations in sea surface water temperature and salinity in May, when juvenile chum salmon stayed around Stations B1 and B3. The physicochemical conditions extremely fluctuated every year owing to three seasonal environmental factors: 1) retreat timing of sea ice; 2) nutrient supplement from oceanic or terrestrial area; and 3) predominance timing of the SWC (salinity > 33.5 psu). Sea ice disappeared in late March in 2002, 2004 and 2005, but in late April in 2003 (Table 1). The maximum concentrations of chlorophyll-a (> 8 $\mu\text{g/L}$) were observed soon after sea ice disappearance, suggesting that retreat timing of sea ice might influence the timing of phytoplankton bloom. The high nutrient concentrations were observed after chlorophyll-a peaks except for 2003, suggesting that the nutrients were constantly supplied from another area to the bay (Fig. 3). Especially in 2005, it seemed that the Dichothermal Water (temperature < 2°C) containing high nutrient concentrations flowed into the bay from offshore areas.

From May to June, the SWC became predominant in the bay, and simultaneously “low temperature and low salinity” condition shifted to “high temperature and high salinity” condition (Fig. 4). Since the SWC is driven by a difference in sea level between the Japan Sea and Okhotsk Sea (Aota 1984), the sea level difference between Wakkanai and Abashiri is used as an index of the strength of SWC. The salinity profiles in this study indicated the predominance of SWC when the sea level difference has become to increase, although those timings were different every year. The condition shifted drastically in 2003 and 2005, but gradually in 2002 and 2004, depending upon the water temperature in April and the predominance timing of SWC. These results suggested that the early ocean life of juvenile chum salmon may be affected by annual fluctuations in the coastal oceanographic conditions between spring and summer. In the coastal waters of eastern Hokkaido, chum salmon juveniles were abundant when

Fig. 1. Map showing the study sites 1 km, 4 km, and 7 km off Abashiri coast in the Okhotsk Sea.

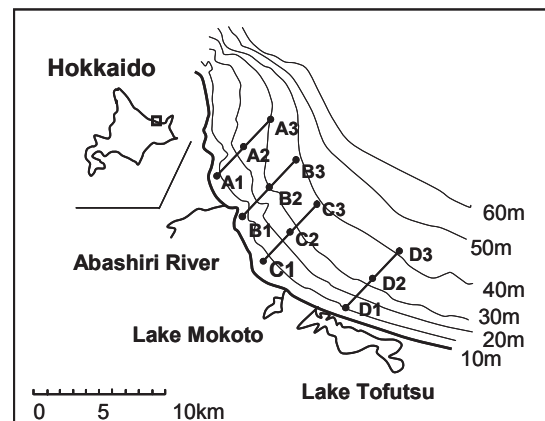


Fig. 2. Changes in water temperature (°C), salinity (psu), $\text{NO}_3 + \text{NO}_2$ concentration ($\mu\text{g-atom/L}$), and chlorophyll-a concentration ($\mu\text{g/L}$) at Station B1 and B3 between April and July in 2002–2005.

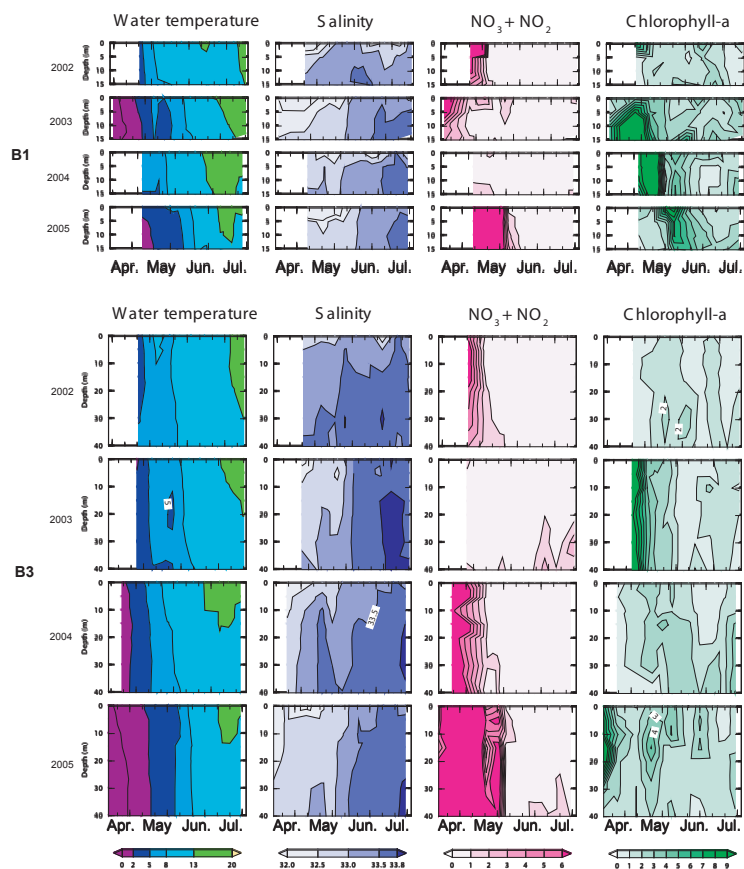


Table 1. Sea ice period and the last day of the sea ice period at Abashiri in 2002–2005 (data source: Japan Meteorological Agency).

year	sea ice period	the last day of the sea ice period
2002	89	25-Mar
2003	108	29-Apr
2004	54	24-Apr
2005	60	26-Mar
30 year average (1971–2000)	87	16-Apr

Fig. 3. Changes in $\text{NO}_3 + \text{NO}_2$ concentration ($\mu\text{g-atom/L}$, averaged in euphotic zone), and chlorophyll-a concentration ($\mu\text{g/L}$, averaged in euphotic zone) in time scale from the last day of the sea ice at Station B3 in 2002–2005.

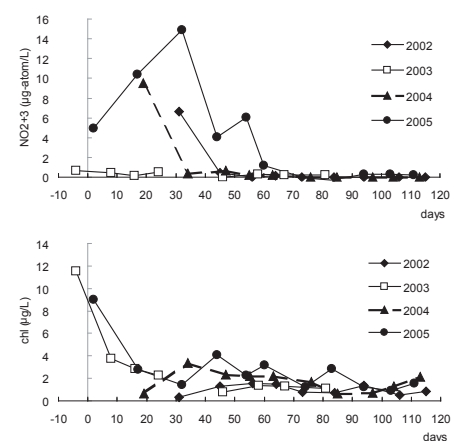
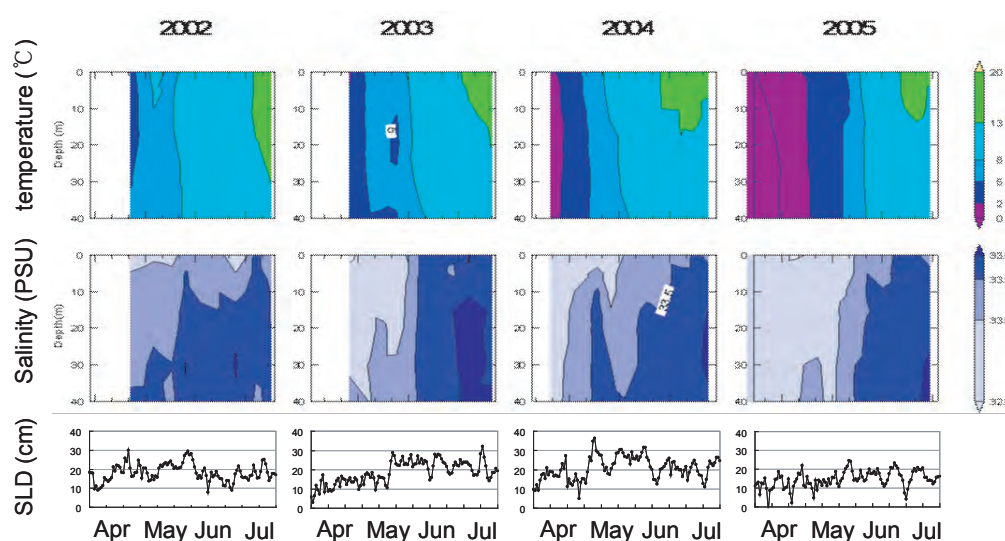


Fig. 4. Changes in water temperature (°C and salinity (psu) at Station B3 and sea level difference between Wakkanai and Abashiri (cm) in 2002–2005.



water temperature was 8–13°C (Nagata *et al.* 2005), and the cold water zooplankton utilized by salmon juveniles was abundant when salinity was less than 33.5 psu (Asami *et al.* 2005). The duration of favorable oceanographic conditions for chum juveniles might be longer in 2002 and 2004 than in 2003 and 2005.

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Growth Pattern and Seawater Tolerance of Precocious Male Sockeye Salmon

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Keywords: Sockeye salmon, precocious male, growth pattern, seawater tolerance

Sockeye salmon (*Oncorhynchus nerka*) exhibit one of the most complex life-history patterns among all salmonid species; maturing at ages ranging from 2–5 years post fertilization. Each year, the sockeye salmon enhancement program of the National Salmon Resources Center in Japan produces a significant number of male fish that precociously mature (PM) at age-2. PM's can be further classified in two phenotypes; the predominant one remains in freshwater until reproduction while the other migrates to the ocean and resides for several months before returning to the spawning grounds to reproduce. Previous studies of salmonids have demonstrated that the rate of PM is significantly influenced by growth rate at specific times of the year (Lundqvist 1980; Berrill et al. 2003). This study investigated the effects of alteration in growth rate in the winter and spring on the prevalence of PM and compared seawater adaptation between immature (I) and PM hatchery sockeye salmon.

Juvenile sockeye salmon were divided (50 fish per treatment) into one of three feeding treatments (A–C) and fed rations (% body wt/day) as follows: Treatment A (1% November–March and 3% March–May), Treatment B (3% November–January and 1% January–May), and Treatment C (3% November–May). Fish were monitored monthly for growth in fork length (FL) and at the end of the experiment in May the rate of PM in each treatment was determined by designating all males with a gonadosomatic index (gonad wt/body wt X 100) greater than 0.15% as PM. Seawater adaptation was examined in May in a subset of 30 fish (I and PM) by measuring plasma sodium concentration after a 24-hour seawater challenge test at 33 ppt. Furthermore, gill Na^+/K^+ -ATPase activity was measured in May in a second subset of 20 fish (I and PM) maintained in freshwater. Growth rates corresponded with feeding rates in all treatments with FL increasing in all groups from approximately 11 cm in November to 17.1, 16.1, and 18.4 cm, in treatments A, B, and C, respectively. PM rates were 50% in treatment A, 80.3% in treatment B, and 79.2% in treatment C. The plasma sodium concentration was 167.5 mM for PM (n = 9) and 155.0 mM for I or smolts (n = 21). The mean gill Na^+ , K^+ -ATPase activity was 8.6 $\mu\text{mol Pi/mg pro/h}$ for PM (n = 6) and 13.6 $\mu\text{mol Pi/mg pro/h}$ for I or smolts (n = 14).

These results suggest that rapid growth in winter has a stronger influence on PM rate than rapid growth in spring and PM's are less seawater tolerant than I (smolts) in the spring.

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Feeding Behavior of Pacific Salmon Juveniles in the Northern Okhotsk Sea during the Summer and Autumn of 1994–2000

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Keywords: Juvenile salmon, diet composition, daily ration

In the epipelagic layer (0–200 m) of the northern part of the Okhotsk Sea, the major nekon species are walleye pollock (*Theragra chalcogramma*), Pacific herring (*Clupea pallasii*), capelin (*Mallotus villosus*), northern smoothtongue (*Leuroglossus schmidtii*), and lesser salmonids and cephalopods (juvenile squids). These species serve as key elements in energy/substance flows (Shuntov et al. 1993; Lapko 1994). Biomass changes of Pacific salmon are caused by their foraging and prespawning migrations. The major species are pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) among Pacific salmon (Lapko 1994). The biomass of Pacific salmon in summer is higher than the biomass of Pacific salmon juveniles in autumn, because most Pacific salmon are prespawning individuals.

In the summer of 1997, juvenile pink salmon (10–20 cm in fork length) preyed upon juvenile fishes and squids in coastal waters (Survey Areas 1–3 and 7), whereas in open waters (Area 6) zooplankton dominated in their diets (Fig. 1). In the Shelikhov Bay (Area 1) Pacific herring was the dominant food item, while in other areas (North Western Kamchatka, Area 7) juvenile walleye pollock and squids were key prey. Juvenile chum salmon (10–20 cm) fed mainly on juvenile walleye pollock and Pacific sand lance (*Ammodytes hexapterus*), while only in the Shelikhov Bay (Area 1) they preferred Hyperiidea (Fig. 1).

In September and October, stomach contents of juvenile pink salmon were variable: Hyperiidea, Pteropoda, Euphausiacea, Copepoda and crabs megalopa were dominant food items. In 1994, juvenile pink salmon consumed 3,161 tons of forage species per day. In 1998–2000, their daily consumption decreased from 952 tons to 35 tons (Fig. 2). This might be explained not only by a decrease in the juvenile biomass, but also by a reduction of the daily ration from 8.5% (in 1998) to 4.5% of body weight (in 2000).

In the September and October of 1994 and 1998, the daily food consumption of juvenile chum salmon ranged

Fig.1. Survey Areas and diet composition (%) of juvenile pink and chum salmon in the epipelagic layer of the northern Okhotsk Sea in summer.

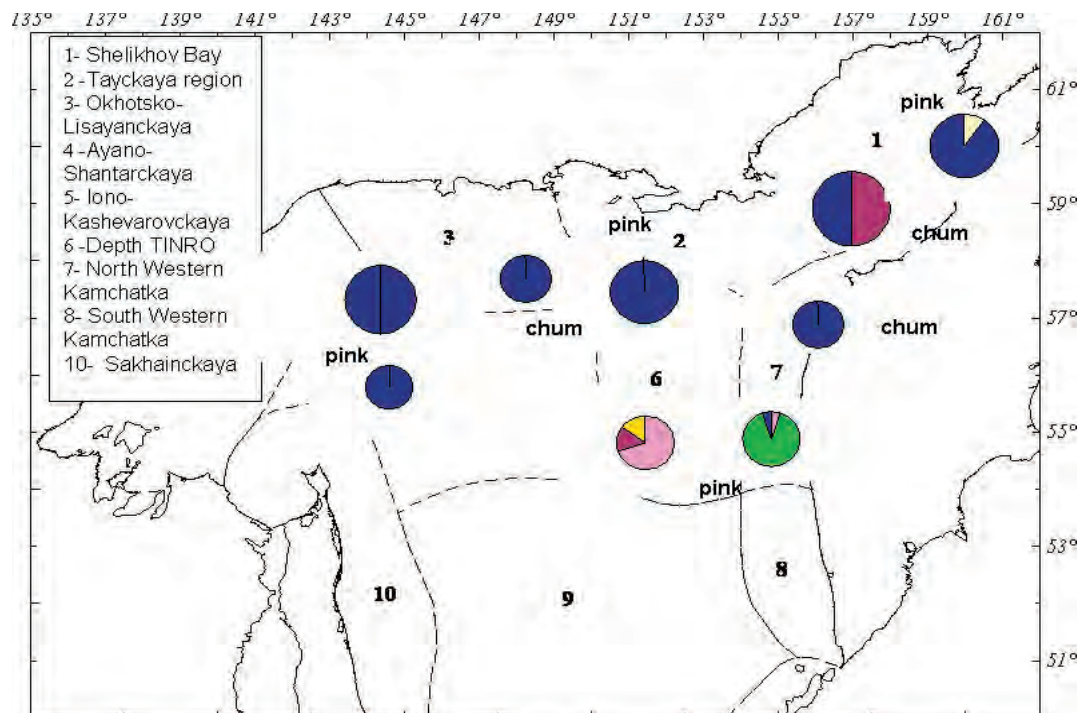


Fig. 2. Diet composition and daily ration (tons) of juvenile pink salmon in the epipelagic layer of the northern Okhotsk Sea during the autumn of 1994 and 1998-2000.

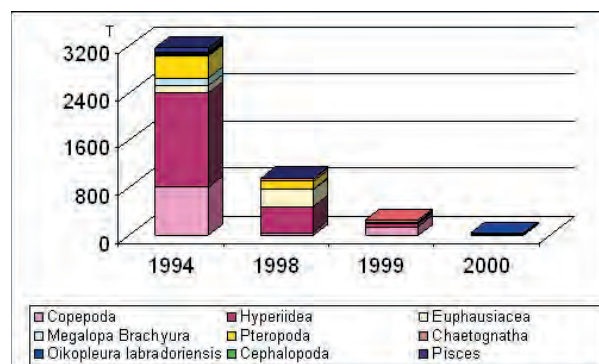


Fig. 3. Diet composition and daily ration (tons) of juvenile chum salmon in the epipelagic layer of the northern Okhotsk Sea during the autumn of 1994, 1998 and 2000.

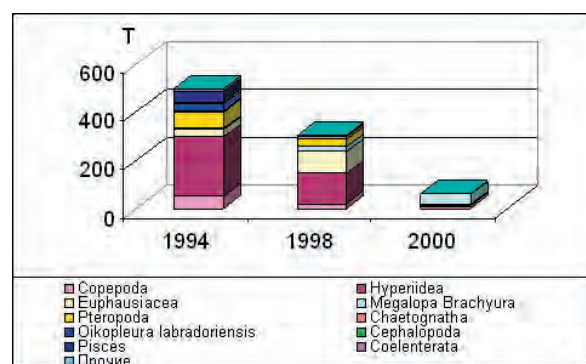


Fig. 4. Diet composition and daily ration (tons) of juvenile sockeye salmon in the epipelagic layer of the northern Okhotsk Sea during the autumn of 1994, 1998 and 2000.

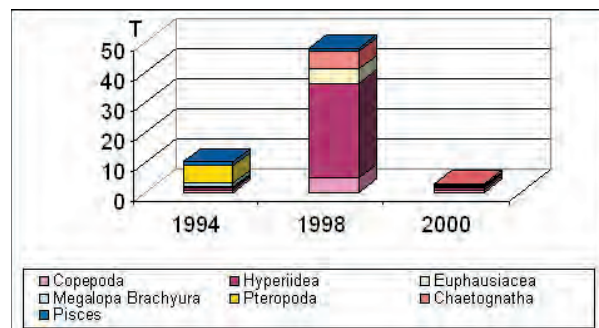


Fig. 5. Diet composition and daily ration (tons) of juvenile coho salmon in the epipelagic layer of the northern Okhotsk Sea during the autumn of 1994, 1998 and 2000.

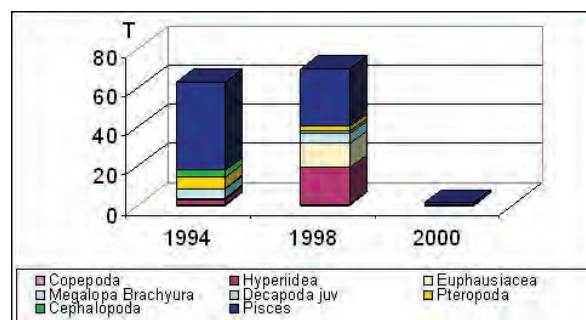
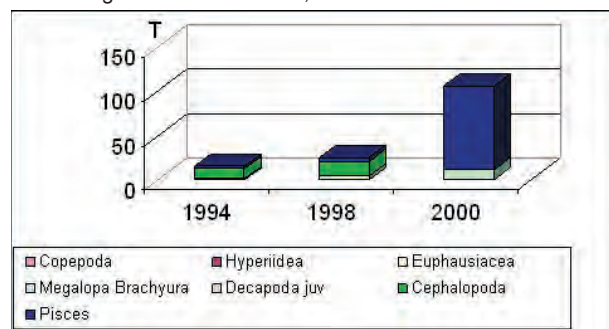


Fig. 6. Diet composition and daily ration (tons) of juvenile chinook salmon in the epipelagic layer of the northern Okhotsk Sea during the autumn of 1994, 1998 and 2000.



between 494 and 304 tons, whereas in 2000 it was 27 tons (Fig. 3). Fifty percent of the daily diet of juvenile chum salmon (10–30 cm) was composed of Hyperiidea, while consumption of Euphausiacea was lower. Pteropoda were a dominant food item in 2000. Nekton constituted about 40% of the diet in 1999. Like juvenile pink salmon, the biomass of juvenile chum salmon decreased and the daily diurnal ration decreased from 7.3% (in 1994) to 4.2% (in 2000).

In the autumn of 1994, Pteropoda, crabs megalopa and juvenile walleye pollock were dominant food items of juvenile sockeye salmon (*O. nerka*)(15–30 cm). Juvenile sockeye salmon biomass increased in 1998 and the consumption of forage species totaled

47.5 tons per day, with Hyperiidea being the most dominant (67.7%)(Fig. 4). In 2000 it was significantly lower (2.9 tons) with Copepoda and Hyperiidea being dominant food items. In 1994 and 2000 the daily ration was lower (2.2% and 3.9% of body weight, respectively) compared to 1998 (4.8%).

During summer and autumn, juvenile coho salmon (*O. kisutch*)(20–35 cm) and juvenile chinook salmon (*O. tshawytscha*)(20–30 cm) fed on juvenile walleye pollock, Pacific sand lance, capelin, Pacific herring, and Pleuronectidae, as well as upon juvenile squids (Figs. 5 and 6). Zooplankton constituted up to 20–25% of food weight in diet of juvenile coho salmon. Major prey groups were Euphausiacea, Hyperiidea, Copepoda and crabs megalopa. In waters of the western Kamchatka, juvenile chinook salmon consumed primarily juvenile squids (63.4%). For juvenile coho and chinook salmon, feeding activity was observed during the daytime period. Minimal feeding occurred in the morning. In 1998 average daily rations of juvenile coho and chinook salmon was 5.1% and 4.5% of body weight, respectively.

Fish species were basic food components of juvenile masu salmon (*O. masou*) (20–30 cm), with capelin,

Table 1. Diet composition (% of food weight) of juvenile masu salmon in the epipelagial of the northern Okhotsk Sea during summer and autumn.

	Summer	Autumn					
	1997	1994	1998				2000
	Areas 6–7	Areas 5–7	Area 10	Area 5	Area 7	Area 8	Area 8
Folk length of fish (cm)	20–35	20–30	30–40	30–40	25–35	25–35	25–35
Copepoda	-	3.0	-	-	0.1	-	-
<i>Neocalanus plumchrus</i>	-	2.8	-	-	0.1	-	-
<i>N. cristatus</i>	-	0.2	-	-	-	-	-
Hyperiidea	-	-	-	-	-	2.6	8.0
<i>Themisto japonica</i>	-	-	-	-	-	2.6	6.0
<i>Primno macropa</i>	-	-	-	-	-	-	2.0
Euphausiacea	-	9.2	-	-	-	0.9	-
<i>Thysanoessa raschii</i>	-	1.1	-	-	-	0.9	-
<i>T. longipes</i>	-	8.1	-	-	-	-	-
Megalopa, Zoea Brachyura	-	32.5	-	-	9.7	-	-
Cephalopoda	-	10.8	-	-	-	-	6.0
Pisces	100.0	44.5	100.0	100.0	90.2	96.5	86.0
<i>Theragra chalcogramma</i>	60.0	44.5	-	-	-	39.0	50.0
<i>Mallotus villosus</i>	-	-	-	-	34.0	-	-
<i>Ammodytes hexapterus</i>	40.0	-	-	-	-	-	-
Pleuronectidae larvae	-	-	100.0	-	51.2	-	-
Pisces larvae	-	-	-	-	-	57.5	-
Pisces unidentified	-	-	-	100.0	5.0	-	36.0
Stomach fullness index ($^0/_{000}$)	284	61	68	27	234	157	176

Table 2. Diet composition (% of food weight) of juvenile Dolly Varden in the epipelagial of the northern Okhotsk Sea during summer and autumn.

	1992		1994		1997	
	Area 7	Area 8	Areas 7–8		Area 3	
Folk length of fish (cm)	30–40	30–40	20–30	30–40	20–30	30–40
Copepoda	1.7	-	-	-	-	-
<i>Themisto japonica</i>	79.3	52.9	76.3	89.0	-	-
<i>Primno macropa</i>	-	-	1.1	2.5	-	-
<i>Thysanoessa longipes</i>	-	-	20.0	-	-	-
<i>Thysanoessa</i> sp.	0.6	1.5	-	4.0	-	-
Megalopa Brachyura	16.6	0.7	-	1.5	-	-
<i>Limacina helicina</i>	0.1	11.6	0.1	0.1	-	-
<i>Clione limacina</i>	-	-	2.5	1.4	-	-
Chaetognatha	-	33.3	-	-	-	-
<i>Hemilepidotus</i> sp.	-	-	-	1.5	-	-
<i>Theragra chalcogramma</i>	1.7	-	-	-	100.0	-
Insecta	-	-	-	-	-	100.0
Stomach fullness index ($^0/_{000}$)	123	89	116	90	407	42

Table 3. Daily consumption (thousand tons) of forage species of nekton in the epipelagical northern Okhotsk Sea during summer–autumn period of 1997–2000.

	<i>Theragra</i> <i>chalcogramma</i>	<i>Clupea</i> <i>pallasii</i>	<i>Mallotus</i> <i>villosus</i>	<i>Leuroglossus</i> <i>schmidtii</i>	Salmonidae	Cephalopoda (squids juv.)	Other fish species	Total	
								th. tons	%
Plankton, total	135.7	92.3	34.7	13.1	0.8	2.1	4.1	282.7	91.7
Euphausiacea	66.9	37.7	16.3	4.4	0.2	1.2	0.9	127.5	41.4
Hyperideia	25.2	9.8	2.4	2.6	0.3	0.7	0.9	41.9	13.6
Copepoda	27.9	35.7	11.6	5.3	0.0	0.1	0.3	80.9	26.2
Chaetognatha	1.0	1.0	2.0	-	0.0	0.0	0.0	4.1	1.3
Other zooplankton	14.7	8.1	2.4	0.8	0.2	0.1	2.0	28.3	9.2
Nektobentos and bentos, total	5.2	0.3	0.0	0.0	0.0	-	1.4	6.9	2.2
Nekton, total	15.5	1.0	0.2	0.0	0.8	0.1	1.0	18.7	6.1
Squid	0.6	0.1	0.0	0.0	0.1	0.1	0.2	1.1	0.3
Fish	14.9	1.0	0.2	0.0	0.7	0.0	0.8	17.6	5.8
Ground total	156.4	93.6	34.9	13.1	1.6	2.2	6.5	308.3	100.0
% of total consumption	50.8	30.4	11.3	4.2	0.5	0.7	2.1	100.0	

juvenile walleye pollock and Pacific sand lance being most dominant (Table 1). However, in the autumn of 1994, crab magalopa were also dominant in food items of juvenile masu salmon. In summer, a significant amount of hyperiids were observed in their diet. Hyperiids were also dominant food items for Dolly Varden (*Salvelinus malma*) (Table 2). Euphausiids, pteropods and megalopa crabs were significant parts of their diet. Dolly Varden had a similar feeding as juvenile pink and sockeye salmon, because they fed mainly on hyperiids.

In summary, walleye pollock and Pacific herring were major consumers of zooplankton and nekton in epipelagic layer (0–200 m) of the northern Okhotsk Sea (Table 3). Among Pacific salmon, pink and chum were most abundant. In the late 1990s, the daily food consumption decreased both in juvenile pink salmon (from 3.2 in 1994 down to 1.0 thousand tons in 1998) and juvenile chum salmon (from 0.5 down to 0.3 thousand tons). Although juvenile pink and chum salmon had a high diurnal ration in autumn, their share in the overall biomass of nekton species in epipelagic layer was insignificant. A share of food consumed by Pacific salmon was as low as 0.5% in autumn and 0.6% in summer among the total food consumption (Kuznetsova 2005), because large salmon migrated for spawning. In summer, a significant share of juvenile Pacific salmon diet was attributed to nekton, while in autumn, Pteropoda, Euphausiacea, Hyperideia, Copepoda and crabs megalopa were dominant food items. Predatory salmon species consumed primarily squids and fishes. Pacific salmon, due to their low biomass and short period of stay in the northern Okhotsk Sea, do not play significant role in the total food consumption.

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Temporal Changes in Physiological Condition of Juvenile Chum Salmon and Zooplankton Biomass in a Coastal Water of the Okhotsk Sea

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Keywords: Juvenile chum salmon, coastal water temperature, growth, RNA/DNA, zooplankton

Japanese chum salmon (*Oncorhynchus keta*) are distributed along the coastal waters of Hokkaido for several weeks before their offshore migrations. Their survivals in the initial coastal life may be influenced by various factors. The aim of our research is to evaluate effects of coastal water temperature and zooplankton biomass on the physiological condition of juvenile chum salmon in a coastal water along the Okhotsk Sea.

Surveys were conducted in a coastal water near the Shari River, eastern Hokkaido (43°55'N, 144°38'E; Fig. 1) between May and July, 2004 and 2005. The sampling stations were set in 1, 2, 4, and 5 km offshore from the Shari River mouth. Zooplankton were collected with simultaneously multiple layer horizontal tow net (LH net; mesh size 1.0 mm; 1 m × 1 m mouth square; towed at 2 knots) at 3 and 15 m depths at 1 and 4 km offshore (stations 1 and 4) in 2005. The zooplankton samples were fixed with 10% seawater formaldehyde, and species compositions were determined at the laboratory. A surface trawl net (4.5 m × 6.6 m) was towed at 2 knots for 30 min at all four stations in 2004 and 2005. Captured juvenile chum salmon were immediately deep frozen with dry ice and stored at -80°C. Fork length (FL) and body weight were measured for each fish, and the instant growth coefficient (IGC) was calculated by a formula: $IGC = \ln(L_t) - \ln(L_0) / T$, where L_0 , FL (mm) at initial day; L_t , FL after t days; T , progress days. In addition, RNA/DNA ratio in the white muscle of fish was determined using Schmit-Thanhauser-Schneider method.

Surface seawater temperature (SST) gradually increased during May and June in both years, but the initial SST

Fig. 1. Sampling stations where juvenile chum salmon and zooplankton were collected.

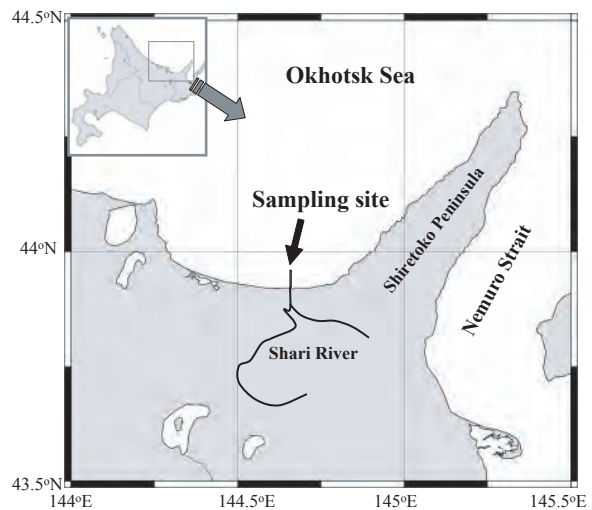


Fig. 2. Temporal changes in surface seawater temperature (SST) in the coastal water of Shari between May and July in 2004 and 2005.

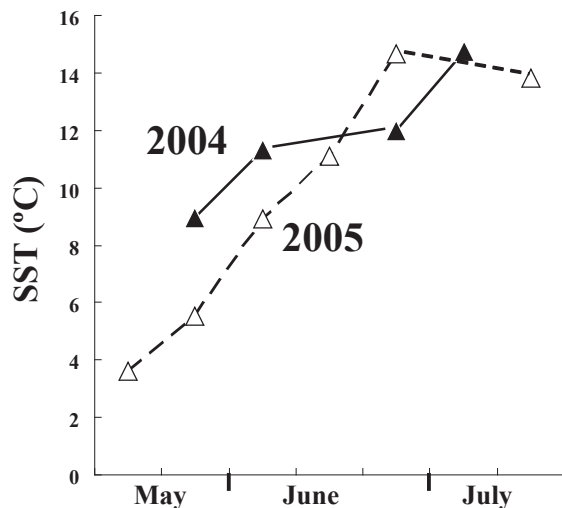


Fig. 3. Temporal changes in number of juvenile chum salmon captured by 30 min trawl in the coastal water of Shari between May and July in 2004 and 2005.

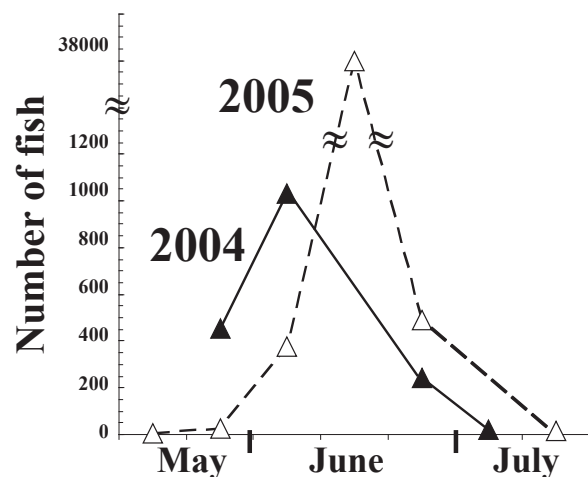


Fig. 4. Temporal changes in fork length frequencies of juvenile chum salmon captured in the coastal water of Shari between May and June in 2004 and 2005.

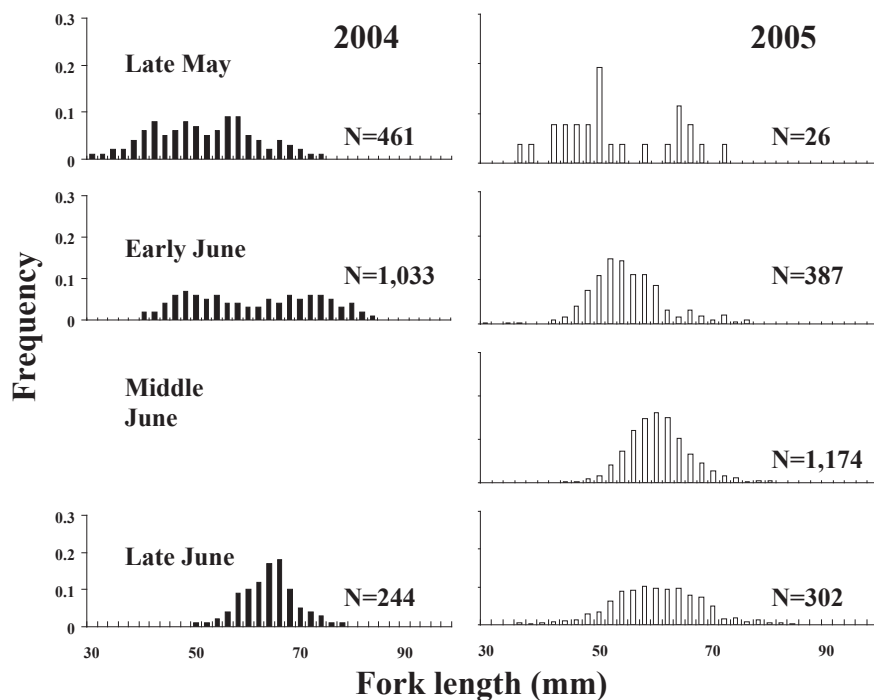


Fig. 5. Temporal changes in mean RNA/DNA ratios in the white muscle of juvenile chum salmon captured in the coastal water of Shari between May and July in 2004 and 2005. Vertical Bars, one standard deviation; *significant difference compared with same period at $p < 0.05$; ** significant difference at $p < 0.01$.

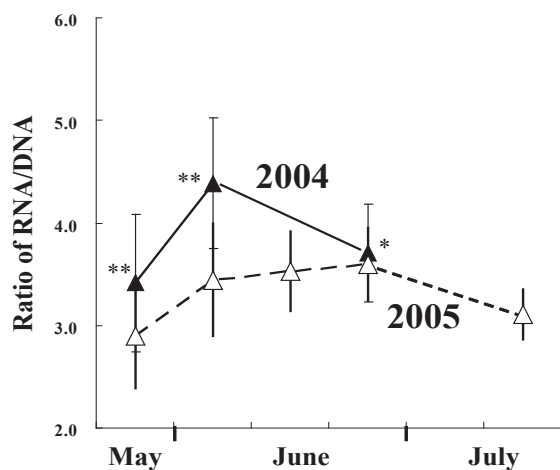
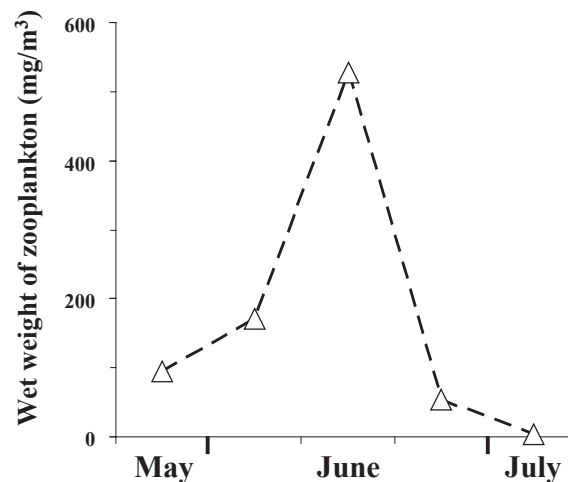


Fig. 6. Temporal changes in mean wet weight (mg/m^3) of zooplankton collected with LH net at 3 m deep in the coastal water of Shari between May and July in 2005.



was higher in 2004 than in 2005 (Fig. 2). Most chum salmon juveniles were captured near the shore when SST was 8–11°C. The number of captured fish was low in May, peaked in June and decreased to zero by mid July when SST was over 14°C (Fig. 3). The peak of fish abundance looked a slightly different in timing between 2004 and 2005, but it was uncertain because of no survey in the mid June of 2004. The fork length of captured fish varied depending on the sampling date (Fig. 4). The instant growth coefficient of fish was higher in 2004 (0.0098) than in 2005 (0.0042). The mean RNA/DNA ratio in the muscle of fish captured between May and early June was also significantly higher in 2004 than in 2005 (Fig. 5). The mean wet weight (mg/m^3) of zooplankton in the surface water showed a peak in the mid June of 2005 (Fig. 6), coinciding with a peak of fish abundance. The results suggest that seawater temperature might affect the growth and physiological condition of juvenile chum salmon as well as zooplankton production in the coastal water.

Comparison of Feeding Pattern of Pacific Salmon between the Western Subarctic Gyre and the Gulf of Alaska in Summer 2005

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Keywords: Pacific salmon, feeding pattern, Western Subarctic Gyre, Gulf of Alaska, summer 2005

Pacific salmon (*Oncorhynchus* spp.) is one of the keystone species in the North Pacific Ocean ecosystem. Their feeding ecology is influenced by the oceanic environment such as ENSO event (Kaeriyama et al. 2000, 2004), inter- and intra-specific interaction such as density-dependent effect (Tadokoro et al. 1996; Kaeriyama et al. 2000, 2004; Ruggerone et al. 2003), and also population dynamics of prey animal community (Shiomoto et al. 1997), because salmon are opportunistic feeders (Kaeriyama et al. 2000). The evaluation of feeding ecology of Pacific salmon is useful for understanding on prey-animal community structure in the North Pacific Ocean. In this study, we examined the feeding pattern of Pacific salmon in the Western Subarctic Gyre (WSG) and the western Gulf of Alaska (GA) in summer 2005 to understand their feeding ecology.

Sockeye (*O. nerka*), chum (*O. keta*), pink (*O. gorbuscha*), and coho salmon (*O. kisutch*) were collected by non-selective research gillnets and angling aboard T/V *Oshoro Maru* (1,396 MT), Hokkaido University, at seven stations in the North Pacific Ocean during early July (three stations in the WSG, 45–50°N, 165°E) and late July (four stations in the GA, 45–47.5°N, 165°W) in 2005 (Fig. 1). Their fork length (FL, mm), whole body weight (BW, g), and stomach content weight (SCW, g) were measured aboard. Stomachs were collected and preserved in a 10% formalin-seawater solution. Condition factor (CF; $BW / FL^3 \times 100$) was calculated as relative growth between fork length and body weight. Stomach contents were classified to 12 taxa to the lowest identifiable taxon using a dissecting microscope, counted, and weighed by species. Stomach contents were evaluated in terms of stomach content index (SCI; $SCW / BW \times 100$), as well as a modified index of relative importance (IRI) method (Pinkas et al. 1971; Kaeriyama et al. 2000). The Shannon-Wiener index (H') was used to estimate diversity of stomach contents

Fig. 1. Locations collecting Pacific salmon in the North Pacific Ocean in summer 2005. WSG, Western Subarctic Gyre; GA, Western Gulf of Alaska.

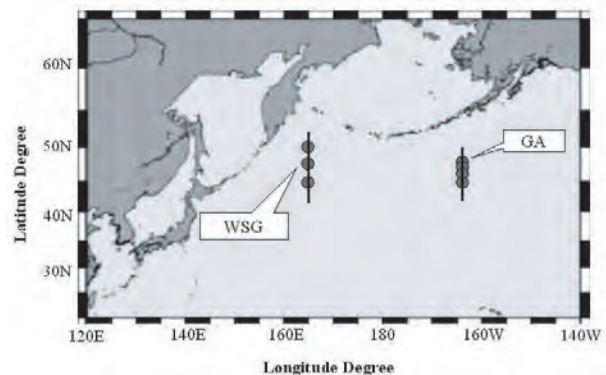
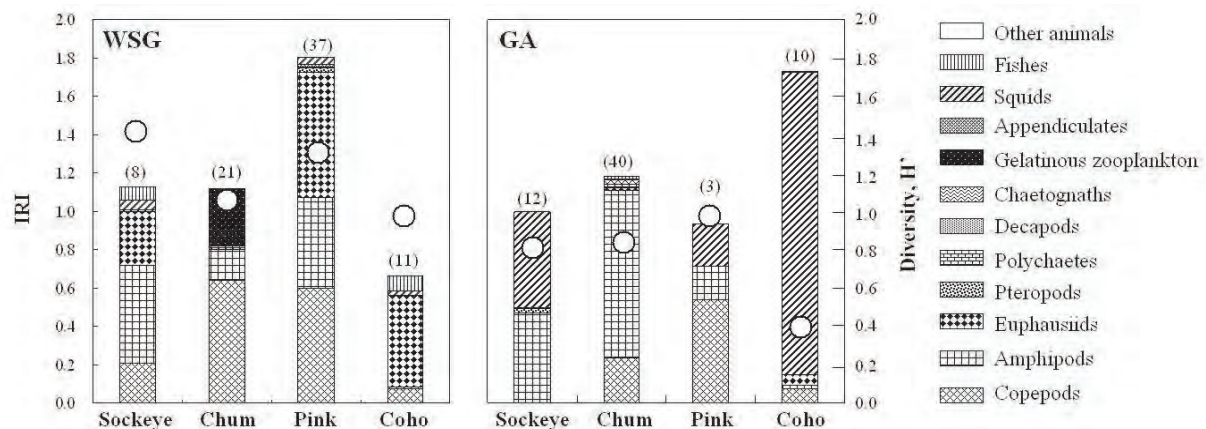
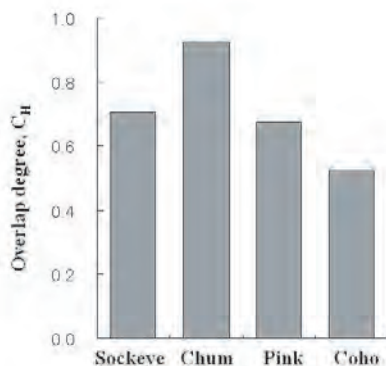


Fig. 2. Stomach contents of Pacific salmon in the WSG and the GA in the summer of 2005. The IRI indicates a modified index of relative importance (Pinkas et al. 1971; Kaeriyama et al. 2000). Open circles show the stomach content diversity. Parenthetic numerals show the number of samples.



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Fig. 3. Overlap degree of stomach content of Pacific salmon between the WSG and the GA during the summer of 2005.



(Colwell and Futuyama 1971). A simplified Morishita's index (C_H) was also used to estimate similarity of their stomach contents between the WSG and the GA (Horn 1966). The Student's *t*-test and the Mann-Whitney U-test were used to compare biological characters of salmon between the WSG and the GA. Significance in all tests was accepted at the $P = 0.05$ level.

Sockeye and pink salmon mainly fed on amphipods, copepods, and euphausiids in the WSG, while amphipods, copepods, and squid in the GA. Chum salmon mainly consumed copepods, gelatinous zooplankton, and amphipods in the WSG, and copepods and amphipods in the GA. Only chum salmon fed on gelatinous zooplankton (Fig. 2). Food of chum salmon mostly overlapped between both areas (Fig. 3). CF and SCI of coho salmon were higher in the GA than those in the WSG (Figs. 4 and 5). Coho salmon mainly fed on euphausiids in the WSG, and squids (mainly *Berryteuthis anonychus*) in the GA (Fig. 2). Pacific salmon except for chum salmon

had more-diverse preys in the WSG than in the GA. They also fed on more squids in the GA than in the WSG (Fig. 2). Thus, the food habit of Pacific salmon may differ between the WSG and the GA in the North Pacific Ocean. Coho salmon was also the most nektonic-feeder, and followed by sockeye, pink, and chum salmon. Coho salmon often feeds on larger micronektonic prey such as fishes and squids, while sockeye, chum, and pink salmon feed on zooplankton (Kaeriyama et al. 2004). Primary production in the WSG are higher than those in the GA (Mackas and Tsuda 1999). Sugimoto and Tadokoro (1997) also indicated zooplankton biomass in the WSG was higher than in the GA. Therefore, these suggest that the difference of oceanic environment including prey animal community in both the WSG and the GA may cause a diverse feeding pattern of Pacific salmon in the North Pacific Ocean.

Fig. 4. Comparison of condition factor (CF) of Pacific salmon between the WSG (open bar) and the GA (closed bar) in the summer of 2005 (*t*-test: NS; $p > 0.05$; *, $p < 0.05$; ***, $p < 0.001$; -, a few samples). Parenthetic numerals show the number of samples.

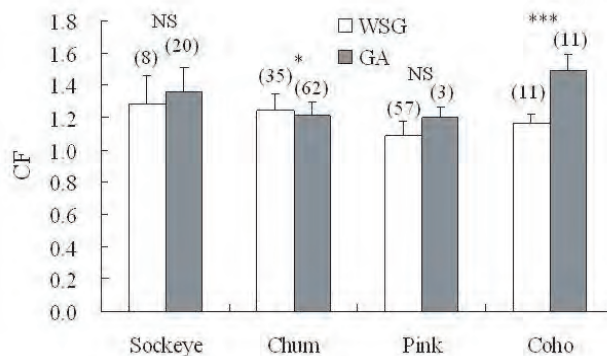
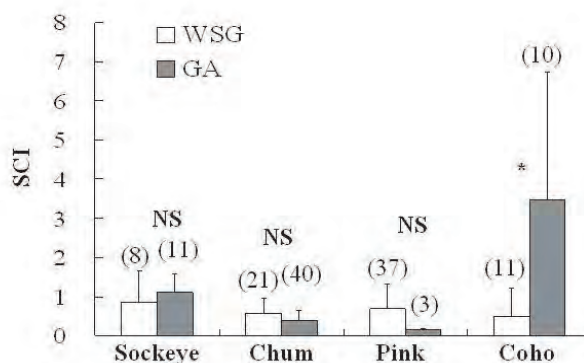


Fig. 5. Comparison of stomach content index (SCI) of Pacific salmon between the WSG (open bar) and the GA (closed bar) in the summer 2005 (*u*-test: NS; $p > 0.05$; *, $p < 0.05$; -, a few samples). Parenthetic numerals show the number of samples.



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Spatial Distribution and Feeding Interactions between Chum and Pink Salmon Juveniles in the Coastal Water of the Okhotsk Sea in the Eastern Hokkaido

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Keywords: Chum salmon, pink salmon, interaction, distribution, feeding

In Pacific salmon, chum and pink salmon go to the sea soon after they newly emerge and spend several weeks near shore before moving offshore. Our previous studies (Ando et al. 2005; Nagata et al. 2005) showed chum and pink salmon juveniles were captured together within 7 km offshore in the Okhotsk Sea. As their diet compositions are very similar (Okada and Taniguchi 1971), social competition between chum and pink salmon for habitat and feeding may occur in the coastal water.

We examined potential interactions between chum and pink salmon juveniles in terms of spatial distribution and food habit in the Abashiri Bay along the Okhotsk Sea coast of Hokkaido. Salmon juveniles were captured by a surface trawl net from 1 km to 7 km off the coastal water and by a beach seine in the littoral water, respectively (Fig. 1). CPUEs (catch per unit effort) of littoral and coastal waters were calculated as number of captured fish per beach seine and per 2 km towing, respectively. We examined an interspecific association between chum and pink salmon with a Point Correlation Coefficient (PCC) (Poole 1974) and an interspecific overlapping between two species with Morisita's C_s (Morisita 1959) using CPUEs data in the coastal water. While the PCC ranges from -1 to +1, with +1 showing preference for the same environment, the Morisita's C_s ranges from 0 to +1, with +1 indicating perfect overlapping. In the laboratory, we measured fork length (FL), body weight (BW) and stomach content weight (SCW), and calculated stomach content index (SCI) as $SCI = (SCW / BW) \times 100$. Prey items in each stomach of both species were counted and identified to species whenever possible. We used Kimoto's C_π (Kimoto 1967) as a similarity index of stomach content composition between two species. This similarity index ranges from 0 to +1, with +1 indicating high similarity between two species on diet composition.

According to the results of CPUEs, most of both chum and pink salmon juveniles after seaward migration directly moved to the 1km offshore when SST (surface seawater temperature) in the coastal water exceeded 8°C in May 2004, in contrast they densely aggregated in the littoral water when SST was below 8°C in May 2003 (Fig. 2). In spite of these different dispersals of juvenile salmon depending on thermal conditions, the values of PCC and C_s between chum and pink salmon in the coastal waters were relatively high when CPUEs in both years were high (Table 1). These results suggest that they lived together and preferred the same environment in the Abashiri Bay.

Mean stomach content indices (SCIs) for both chum and pink juveniles in the 1 km off for two years were relatively high in May, but sharply decreased in June and July (Fig. 3). While the SCIs of chum salmon in the 4 km off were relatively high from mid May to early June, those of pink salmon were maintained to be low except mid June 2003. SCIs of both chum and pink salmon in the 7 km off were relatively high from mid May to late June 2004, but those in both species in 2003 were relatively low. In the littoral waters, SCIs of juveniles with high CPUEs in May 2003 were significantly lower than those in 2004 with less CPUEs.

Chum and pink salmon juveniles consumed mainly copepods, cladocerans and appendicularians. The values of C_π in the coastal water were variable not only among different sized juveniles but also among times (Table 2). The

Fig. 1. Maps showing the study sites of the littoral area (E), 1 km, 4 km and 7 km off the Abashiri coast (A-D) in the Okhotsk Sea.

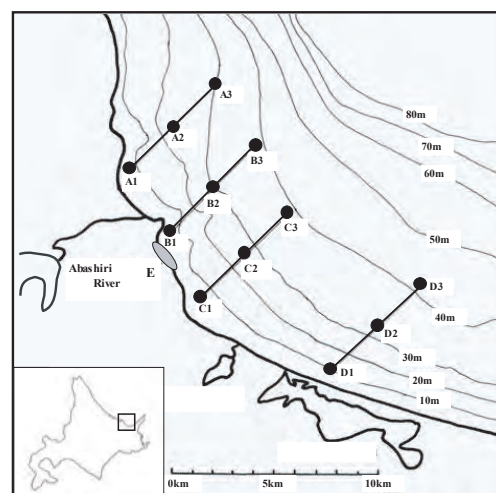


Fig. 2. Changes in CPUE (catch per unit effort, the number of juveniles per 2 km towing or per beach seine) of juvenile chum (top) and pink (bottom) salmon captured at the littoral sites (beach seine) and the 1 km off the Abashiri coast (trawl net) in the Okhotsk Sea from 2003 to 2004.

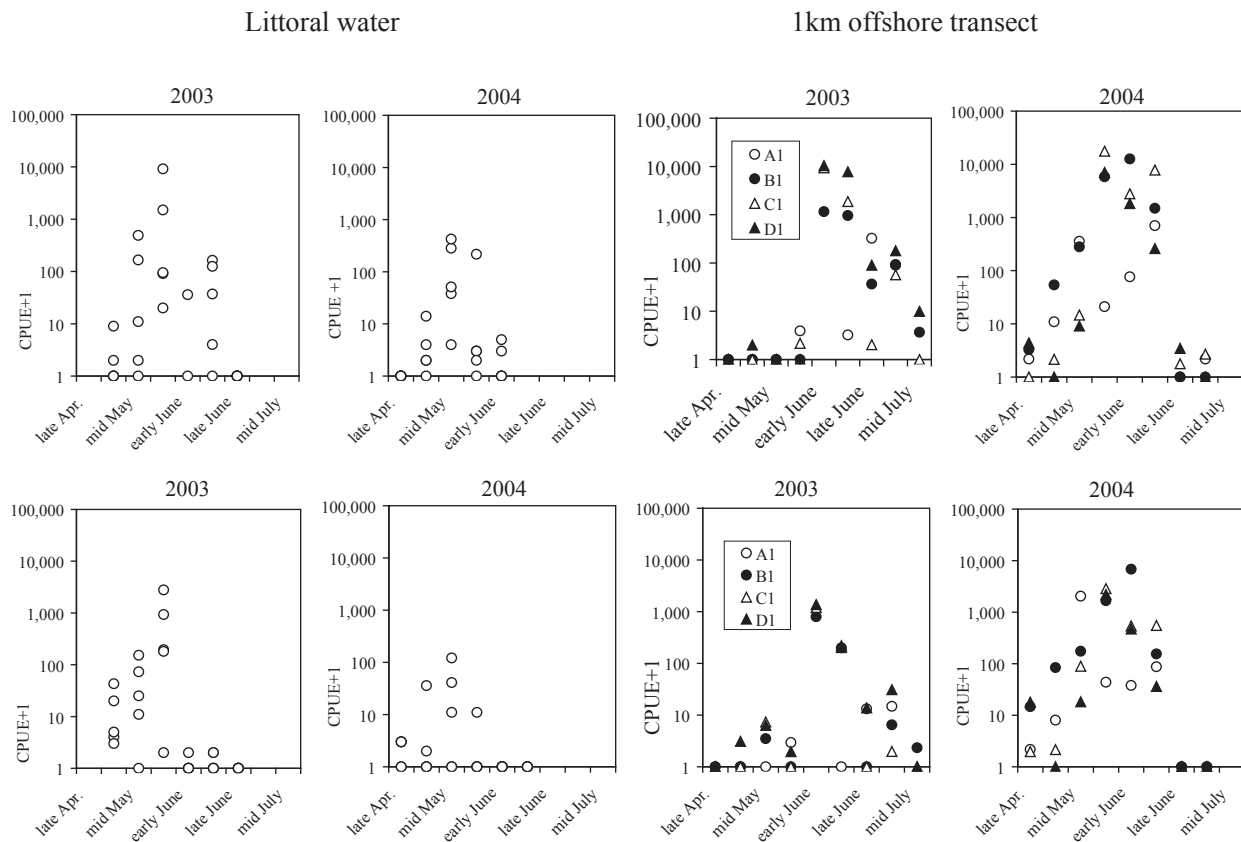


Table 1. Interspecific association (PCC) and overlapping (C_o) between chum and pink salmon juveniles in the coastal water from 2003 to 2004.

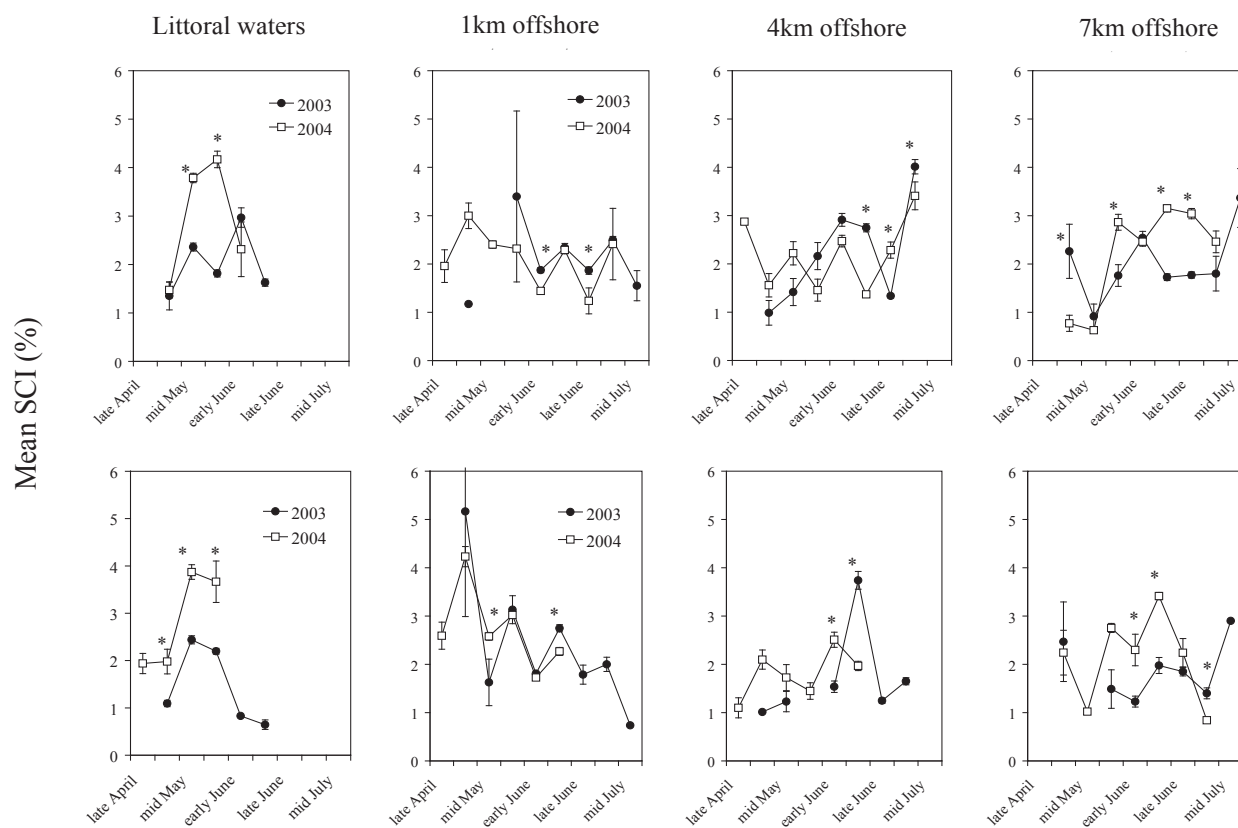
PCC	early May	mid. May	late May	early June	mid. June	late June	early July
2003	0.478	0.000	0.125	1.000	0.522	0.674	0.522
2004	0.408	0.241	1.000	0.674	1.000	0.258	0.083
C_o	early May	mid. May	late May	early June	mid. June	late June	early July
2003	0.588	0.186	0.608	0.924	0.716	0.734	0.726
2004	0.980	0.805	0.948	0.977	0.814	0.608	0.054

values were relatively high when CPUEs of both species were high and their fork lengths were ranged from 50 mm to 69 mm. The C_π values in the littoral water were relatively lower than those in the coastal water when CPUEs were high. While pink juveniles tended to consume smaller animals such as *Pseudocalanus* spp., chum juveniles had a tendency to consume larger animals such as *Neocalanus* spp.

Chum-pink salmon competition for feeding is known to occur in the early life (Salo 1991). Okada and Taniguchi (1971) showed when chum and pink salmon juveniles reached to 55 mm in fork length, the maximum size of diet eaten by juveniles changed rapidly from a small-size group less than 1.3 mm to a large-size group (1.3–3.8 mm). As our study also showed that similarity indices of juveniles whose fork length was 50–69 mm in the coastal water were higher than those of other size class, social competition between chum and pink salmon juveniles may be getting greater when both juveniles grew over 50 mm in fork length. It is concluded that there is a potential competition between chum and pink salmon juveniles for the habitat and food requirements during the early ocean life of juvenile salmon in the coastal waters.

Table 2. Comparison of Kimoto's C_m , as a similarity index of diet composition between chum and pink salmon juveniles in the littoral and coastal waters from 2003 to 2004.

Location	Size class (mm)	2003							2004					
		early May	mid. May	late May	early June	mid. June	late June	early July	early May	mid. May	late May	early June	mid. June	late June
Littoral	30-39	0.34	0.02	0.99	0.70				0.55	0.17	0.37			
	40-49	0.35	0.27	0.96						0.12	0.97			
	50-59		0.45	0.47		0.19				0.23				
	60-69		0.38			0.24								
1 km off	30-39				0.01				0.45	0.56	0.75			
	40-49			0.08	0.87	0.67	0.48		0.71	0.42	0.75	0.67	0.96	
	50-59	0.79			0.76	0.86	0.79	0.32	0.58	0.50	0.74	0.70	0.82	
	60-69				0.67	0.75	0.66	0.93		0.70	1.00	0.99	0.96	
	70-79					0.98		0.97			0.50	0.99	0.98	
	80-89					0.88		0.27				1.00	0.24	
4 km off	30-39								0.17	0.98			0.27	
	40-49				0.61	0.15			0.57	0.14	0.60	0.73	0.99	
	50-59				0.59	0.68	0.91		0.69		0.69	0.96	0.69	
	60-69				0.62	0.67	0.99	0.96			0.98	0.77	0.80	
	70-79					0.30	1.00	0.59			0.58	0.08	0.31	
	80-89					0.76	0.98	0.30						
7 km off	30-39				0.37						0.09	0.67		
	40-49				0.46						0.66	0.99	0.53	
	50-59				0.79	0.90	0.87				0.75	1.00	0.61	
	60-69					0.85	0.36					0.93	0.81	
	70-79					0.56	0.76	0.26				0.94	0.66	
	80-89						0.01	0.07				0.93	0.19	

Fig. 3. Changes in mean values with S.E. of stomach content indices (SCIs, stomach content weight x 100 / body weight) of chum (top) and pink (bottom) salmon juveniles captured at the littoral water and the 1 km, 4 km and 7 km off the Abashiri coast in Okhotsk Sea from 2003 to 2004. *A significant difference between two years at $p < 0.05$.

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Trophic Linkages of Juvenile Chum Salmon in the Okhotsk and Bering Seas during the Last Decade

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Keywords: Feeding, prey organisms, stomach contents, consumption, stomach fullness index

One of the most important features of salmon (*Oncorhynchus* spp.) ecology is their feeding behaviour and trophic linkages during their marine life history stage. Studies of salmonids in the marine environment are usually focused on population dynamics and life history characters. However, there are only a small number of publications dealing with feeding behaviour and juvenile salmon food web dynamics within the subarctic zone of the Pacific Ocean. The purpose of this paper is to examine juvenile chum salmon feeding behaviour and to define the total consumption of prey organisms by juvenile chum salmon in the southern Okhotsk Sea and the western Bering Sea. The data come from trawl surveys that were conducted in the upper epipelagic layer of the southern Okhotsk Sea

Fig. 1. Survey areas and diets of juvenile chum salmon in the southern Okhotsk Sea during the autumn of 1998–2005.

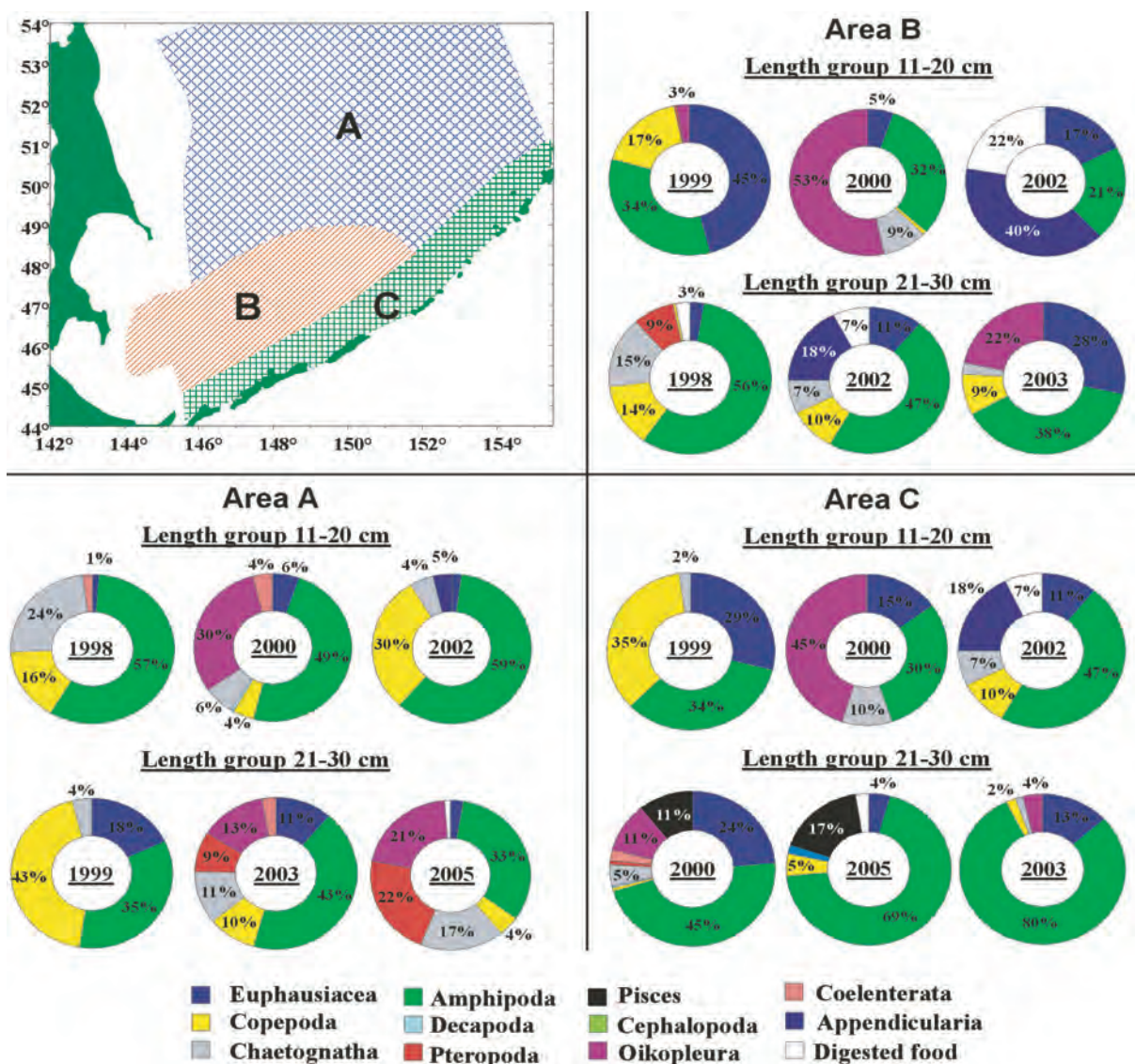
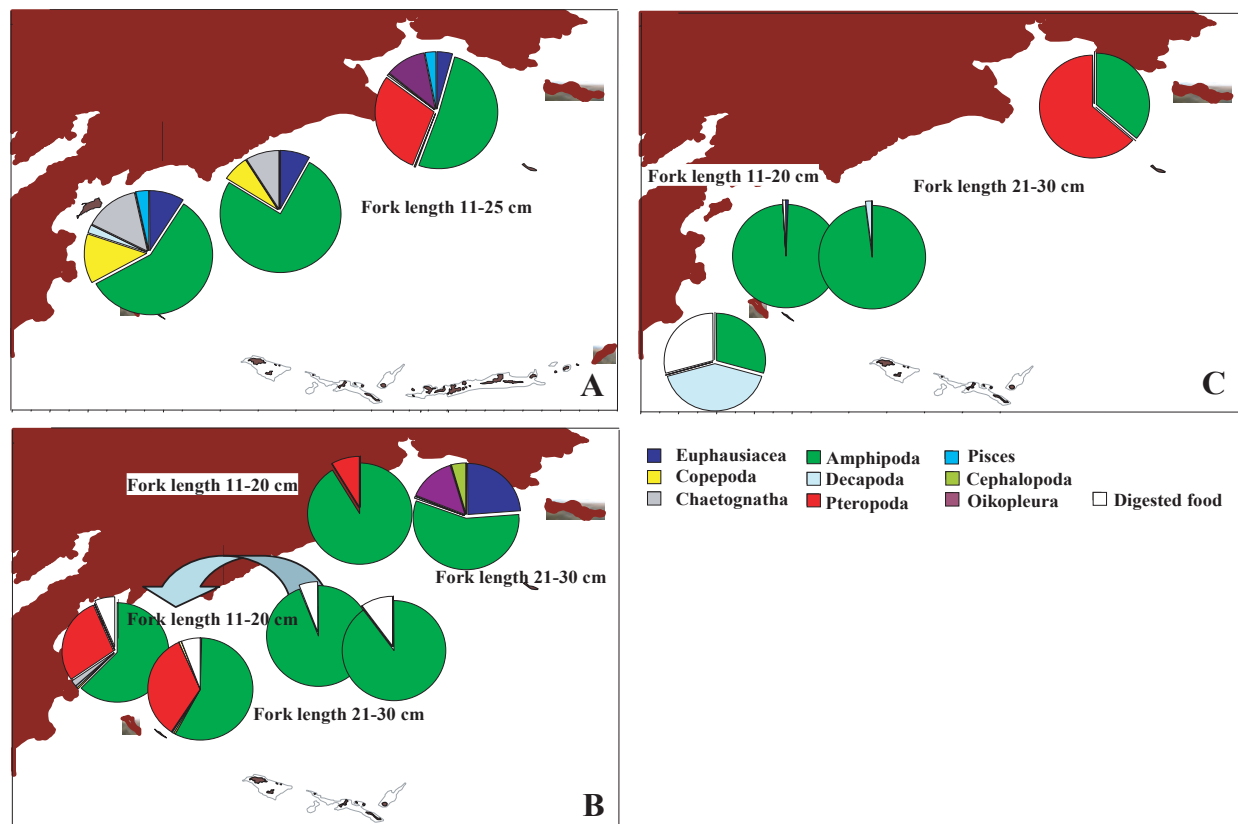


Fig. 2. Diets of juvenile chum salmon in the western Bering Sea in the autumn of 2002 (A), 2003 (B) and 2004 (C).**Table 1.** Daily prey consumptions by juvenile chum salmon in the southern Okhotsk Sea.

	1998	1999	2000	2002	2003	2005
Composition of prey (tons)						
Euphausiacea	213.6	980.0	391.5	223.4	299.5	182.0
Amphipoda	1992.0	2066.5	1049.2	1115.5	842.9	1208.6
Copepoda	655.2	2096.7	142.5	366.5	171.0	61.1
Decapoda	11.7	5.0	14.7	-	-	2.4
Chaetognatha	642.3	158.2	45.6	238.3	160.0	181.8
Pteropoda	382.0	2.4	2.4	1.6	110.9	104.4
Polychaeta	-	-	-	-	-	9.8
Oikopleura	103.4	-	775.8	-	280.5	817.2
Appendicularia	-	-	-	357.2	-	-
Coelelerata	-	21.0	38.6	-	37.8	0.0
Pisces	6.1	0.0	25.1	-	-	306.0
Cepahopoda	87.7	12.8	-	-	-	-
Digested food	48.8	-	405.1	58.2	-	259.2
Daily consumption of prey (tons)	4142.8	5342.5	2890.5	2360.8	1902.7	3132.6
Average SFI (‰)	111.5	181.2	134.1	90.8	138.4	88.2
Number of stomachs processed	444	791	746	404	417	159
Average length of chum salmon (cm)	24.0	22.8	22.0	23.8	23.5	22.9
Average weight of chum salmon (g)	116.3	205.4	116.2	156.4	150.2	138.3
Daily ration (% of body weight)	4.5	4.2	4.7	4.1	5.3	4.8
Biomass of chum salmon (tons)	92063	127202	61499	57620	35900	65262

Table 2. Daily consumption of prey by juvenile chum salmon in the western Bering Sea.

	2002	2003	2004
Composition of prey (tons)			
Euphausiacea	11.9	6.2	0.5
Amphipoda	93.0	137.5	118.2
Copepoda	12.4	0.8	-
Decapoda	1.9	1.0	2.9
Chaetognatha	13.7	1.4	-
Pteropoda	20.2	51.0	6.0
Polychaeta	-	2.2	-
Oikopleura	-	280.5	817.2
Appendicularia	7.6	3.5	-
Coelelerata	-	0.8	-
Pisces	5.1	-	-
Cephalopoda	-	1.0	-
Digested food	-	9.6	1.1
Daily consumption of prey (tons)	165.8	214.9	128.8
Average SFI ($\%_{000}$)	234.7	124.7	158.3
Number of stomachs processed	186	172	190
Average length of chum salmon (cm)	18.2	20.5	19.6
Average weight of chum salmon (g)	66.6	94.7	85.0
Daily ration (% of body weight)	7.5	7.0	7.9
Biomass of chum salmon (tons)	2210	3070	1630

and western Bering Sea during the late 1990s and early 2000s.

Stomach contents of juvenile chum salmon were examined within two groups according to body size 11 to 20 cm and 21 to 30 cm. The samples included up to 25 stomachs of the same body size group, selected from catches and processed without any prior fixation. Stomach samples were weighed to the nearest gram and stomach contents separated by dominant taxa. The stage of food digestion was evaluated using five-step scale. The stomach fullness index (SFI) was calculated as the relation of food mass in the stomach, divided by fish body weight times 10,000. The daily food intake was estimated as the sum total of all prey consumed in a given period of time. The amount of processed stomachs at separate years is represented in tables showing food consumption.

Our study indicated that chum juveniles smaller than 20 cm in length, and longer than 20 cm preferred amphipods of *Themisto* genus almost across the entire area surveyed (Figs. 1, 2). In the southern Okhotsk Sea, these size groups of chum salmon preyed on amphipods, as well as on appendicularians, oikopleuras, chaetognaths, euphausiids, and copepods. Besides zooplankton, chum preyed on small fishes in area "C" (Fig. 1).

In the northern Bering Sea, *T. libellula* dominated the diet of chum, while in the other regions, *T. pacifica* were the primary prey (58–98% of the total stomach content weight) of juvenile chum salmon. In 2004, pteropods *Limacina helicina* were dominating (64%) stomach contents of chum juveniles only in the center of the Anadyr Bay. As in the Okhotsk Sea, chaetognaths, euphausiids, copepods and decapod larvae were among major prey components in the diet of chum juveniles in the Bering Sea.

The mean index of stomach fullness (SFI) was about 88–181 $\%_{000}$ in the southern Okhotsk Sea and 125–235 $\%_{000}$ in the western Bering Sea, indicating that chum juveniles were actively feeding.

In the southern Okhotsk Sea, the daily consumption of the zooplankton and nekton species ranged from 1,903 to 5,343 tons, and in the western Bering Sea, it ranged from 129 to 215 tons (Tables 1, 2). As expected, amphipods accounted for the greater portion of the chum diet: 843–2,067 tons in the Okhotsk Sea, and 93–118 tons in the Bering Sea. In the Okhotsk Sea, the daily consumption of euphausiids reached 980 tons, copepods 2,097 tons, oikopleuras 817 tons and chaetognaths 642 tons, and only in autumn 2002, great amount of appendicularians, 357 tons, have been consumed.

In the Bering Sea, these zooplankton groups were preyed by juvenile chum salmon in considerably smaller quantities (Table 2), likely due to the lower biomass of juvenile chum in western Bering Sea stocks. Pteropods were less important prey and in autumn of 2003: chum juveniles consumed about 51 tons of these molluscs.

In the autumn, daily ration of chum juveniles reached 7.9% in the Bering Sea, being much higher than in the Okhotsk Sea, where it did not exceed 4.8% of the fish body weight.

Bioenergetics Model of the Japanese Chum Salmon (*Oncorhynchus keta*) Growth

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Keywords: Bioenergetics model, chum salmon

A reduction of body size of Japanese chum salmon (*Oncorhynchus keta*) was observed in the 1990s. In order to investigate causes of body size reduction, a bioenergetics model was developed for immature and maturing chum salmon. We assumed that sea surface temperature (SST) and prey zooplankton density were possible factors to reduce fish body size. Information on SST and prey zooplankton density in waters along the migration route of Japanese chum salmon (Urawa 2000, 2004; Azumaya and Ishida 2004) were obtained from the World Ocean Database (WOD) 2001 (O'Brien et al. 2002) and North Pacific Ecosystem Model Used for Regional Oceanography (NEMURO) embedded in 3-D physical model (Aita et al. 2007).

NEMURO (Fig. 1) was developed by PICES Model Task Team (Megrey et al. 2002). In this model, silicate is included as a nutrient as well as nitrogen, and ontogenetic vertical migration is applied to Copepoda (ZL in Figure 1). If it is embedded into a Global model, however, there are some technical difficulties. Figure 2 shows the time dependent features and anomalies of annual average plankton biomass and primary production, where PS, small phytoplankton (flagellate); PL, large phytoplankton (diatom); ZS, small zooplankton (foraminifera); ZL, large zooplankton (copepod); ZP, zooplankton predator (krill and jelly fish). After the regime shift, the biomass of phytoplankton and zooplankton and nutrient concentration increased dramatically as did primary production, except for ZS which increased slightly.

Our bioenergetics model (Fig. 3) was based on models for Pacific herring (*Clupea pallasii*) and Pacific saury

Fig. 1. North Pacific Ecosystem Model for Regional Oceanography (NEMURO) developed by PICES Model Task Team.

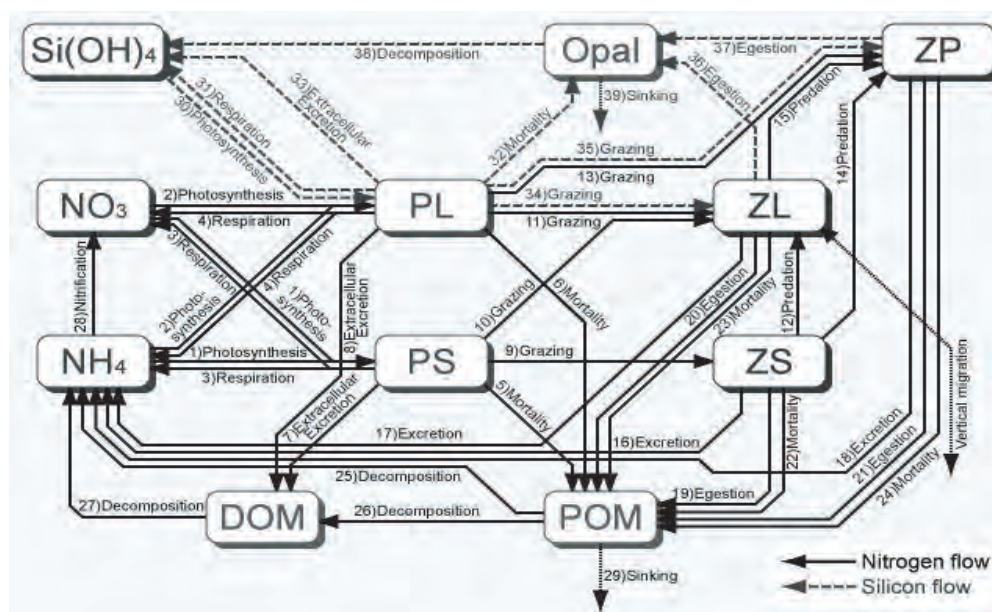


Fig. 2. Time dependent features of anomalies of annually averaged PS, PL, ZS, ZL, and ZP biomass, nitrate and silicate concentrations, and primary production in the upper 150 m in 6 regions of the Bering Sea (after Aita et al. 2007).

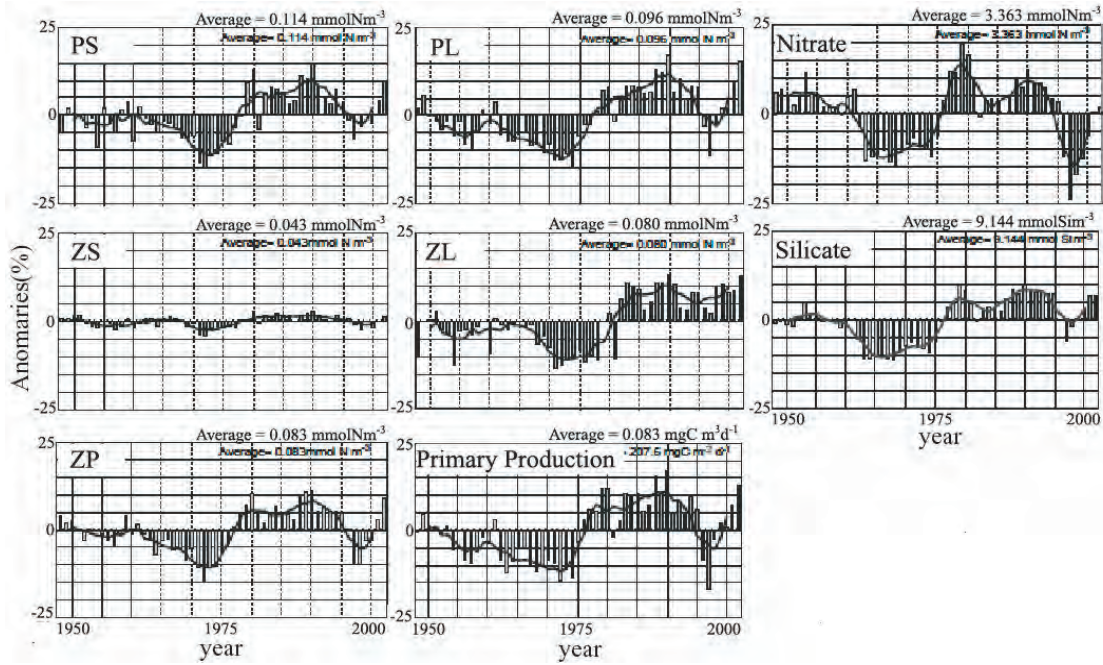


Fig. 3. The governing equation of chum salmon bioenergetics.

$$\frac{dW}{W \cdot dt} = [C - (R + SDA + F + E)] \cdot \frac{CAL_z}{CAL_f}$$

where

W : wet weight of fish (wwg)

t : time(day)

C : consumption ($\text{g prey} \cdot \text{g fish}^{-1} \cdot \text{d}^{-1}$)

R : respiration or losses through metabolism ($\text{g prey} \cdot \text{g fish}^{-1} \cdot \text{d}^{-1}$)

SDA : specific dynamic action ($\text{g prey} \cdot \text{g fish}^{-1} \cdot \text{d}^{-1}$)

F : egestion or losses due to feces ($\text{g prey} \cdot \text{g fish}^{-1} \cdot \text{d}^{-1}$)

E : excretion or losses of nitrogenous excretory wastes ($\text{g prey} \cdot \text{g fish}^{-1} \cdot \text{d}^{-1}$)

CAL_z , CAL_f : caloric equivalent of zooplankton ($\text{cal} \cdot \text{g zooplankton}^{-1}$) and fish ($\text{cal} \cdot \text{fish}^{-1}$)

$$C = C_{\text{MAX}} \cdot C_p \cdot f_c(T)$$

where

C_{MAX} : the maximum specific feeding rate ($\text{g prey} \cdot \text{g fish}^{-1} \cdot \text{d}^{-1}$)

C_p : prey density dependence function for consumption

$f_c(T)$: temperature dependence function for consumption

Fig. 4. Schematic view of the three oceanic spatial domains and the numbers of life stages of Japanese chum salmon simulated in the model. The three domains correspond to the western North Pacific, Bering Sea, and eastern North Pacific Ocean.

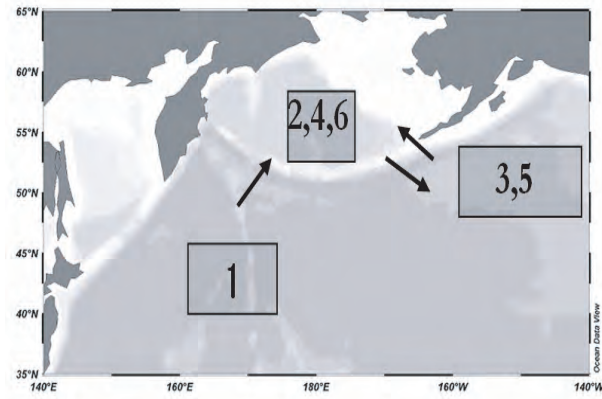


Table. 1. Life stages of Japanese chum salmon in the bioenergetics model.

Stage	Ocean age	Period	Region
1	0-1	12/1-5/31	W. North Pacific
2	1	6/1-11/30	Bering Sea
3	1-2	12/1-5/31	E. North Pacific
4	2	6/1-11/30	Bering Sea
5	2-3	12/1-5/31	E. North Pacific
6	3	6/1-10/31	Bering Sea

Fig. 5. Temperature dependent function ($f_c(T)$) for stage-1 (thin line), stage -2, 4 (bold line), and stage 3, 5 (broken line).

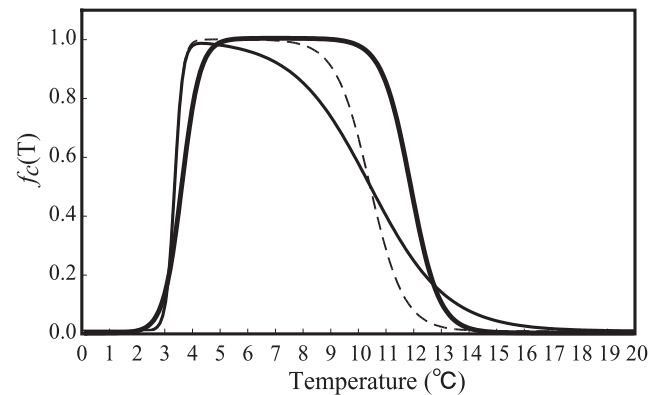


Fig. 6. Simulated body size growth of 1972 and 1991 year classes of chum salmon for cases of control (a), constant prey density with time dependent temperature (b), and constant temperature with time dependent density (c).

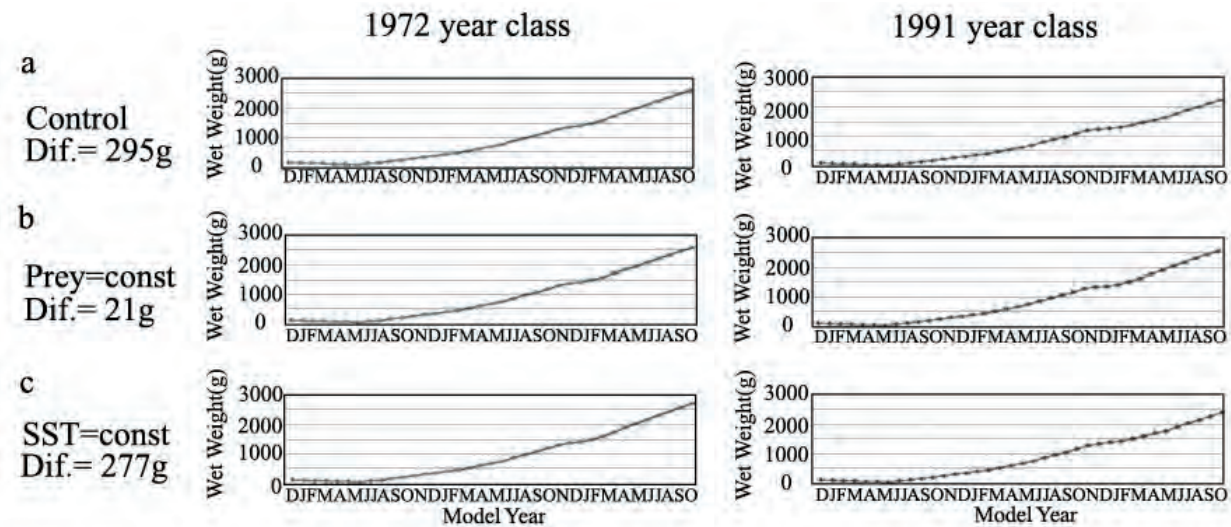
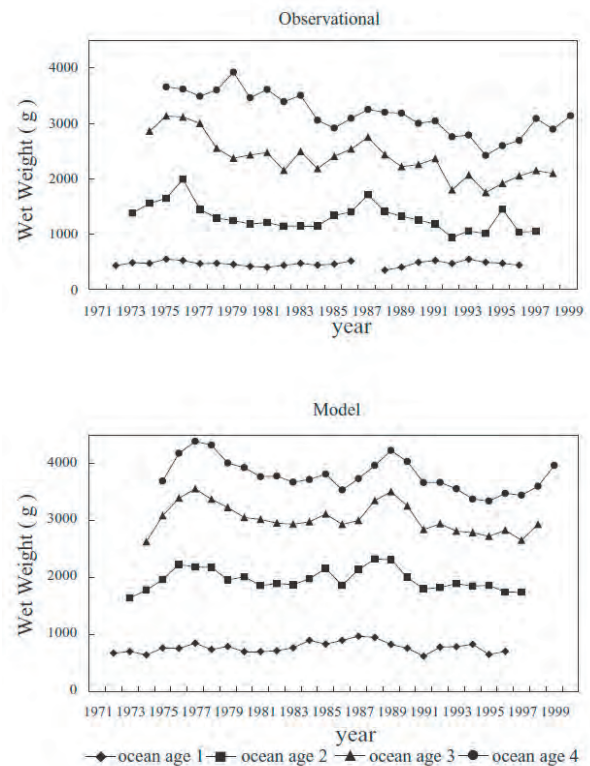


Fig. 7. Time dependent features of $f_c(T)$ (a) and Cr (b) in the equation of consumption for 1971 (open circles) and 1991 (closed circles) year classes of chum salmon.

Fig. 8. Time dependent body size of chum salmon in the Bering Sea in the summer of 1971-1999.



(*Cololabis saira*) (Mergrey et al. 2002), using respiration and consumption terms of Ware (1978), Beauchamp et al. (1989) and Trudel et al. (2004). According to Kaeriyama et al. (2004), we used only ZP as a zooplankton predator. The mean period of foraging ocean migration of chum salmon was supposed to be 3 years, thus the life stage was divided into six stages: three stages each for summer and winter (Table 1, Fig. 4). The model reproduced the body size of 1972 and 1991 year classes of chum salmon. We assumed optimum SST for chum salmon in each box and made $f_c(T)$ (Fig. 5).

The zooplankton density of NEMURO, represented in nitrogen unit ($\text{mol N} \cdot \text{L}^{-1}$) and simulated results converted into wet weight (Aita et al. 2007), was too small compared with WOD 2001 (O'Brien et al. 2002). Then, we adjusted the NEMURO value (ZL) (wet weight $\text{g} \cdot \text{m}^{-3}$) as 0.104 using observational data of WOD 2001, and

converted ZP also with the same ratio.

Reproduced wet weight of the 1972 year class was larger than that of 1991 year class (Fig. 6a). The prey density, especially prey zooplankton density during winter in the Gulf of Alaska, was found to influence the body size of ocean age 3 rather than SST (Figs. 6b,c, 7). The simulated results of time dependent features showed a coincident with observations in the Bering Sea (Fig. 8). The growth of ocean age 1 chum salmon did not affect the body size of ocean age 3 or 4 fish, but the body size of ocean age 3 fish was related to that of ocean age 4 fish. These results suggest that the size reduction of Japanese chum salmon in 1990s might be partly affected by prey zooplankton density.

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Trophic Status of Young Ocean Chum Salmon Estimated by Lipid Analysis

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Keywords: Total lipid content, chum salmon, immature, North Pacific Ocean, Bering Sea

Understanding the trophic status of chum salmon in the ocean is important to estimate their growth and survival potential in the ocean. Total lipid (TL) content is a good indicator of trophic status. Carnivorous fish, including salmonids, have a limited ability to utilize carbohydrates and so dietary lipids are an important energy source for them (Watanabe 1982). Although numerous lipid studies have focused on cultured fish that consume artificial food, few studies have measured lipid content of salmon caught in the high sea (Nomura et al. 2000, 2001, 2002, 2004). Lipid content determination for salmon during their high-sea migration can give an estimate of their trophic status and growth potential (Nomura et al. 2000, 2001).

Chum salmon were caught by surface trawl in the spring (May) of 1999, as well as summer (June–July) and fall (September) 2002–2004 in the Gulf of Alaska, Bering Sea and North Pacific Ocean (Table 1). Fork lengths (FL, cm) and body weights (BW, g) were measured from a sample during the survey. After measuring, these fish were frozen whole (–30°C). Other chum salmon were frozen (–30°C) and subsequently thawed prior to measuring lengths and weights in the laboratory. Scales were collected for age determination and a fillet was carefully removed from the fish. The white muscle was removed from the fillet and homogenized in a food processor. Approximately 10 g of the homogenized white muscle was collected, weighed, and kept frozen at –30°C until further analysis.

The frozen white muscle was thawed and homogenized with 60 ml of methanol and 120 ml of chloroform to extract lipids (Folch et al. 1957). The homogenate was filtered through lipid-free paper into a glass vessel. The crude extract was then mixed in a separator funnel with chloroform, methanol, and water in the volumetric proportions 8:4:3. The lower phase was collected and the solvent was evaporated with a rotary evaporator. The extracted lipid was measured gravimetrically.

Spring samples; TL 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-1 and age-3 fish, total lipid content was higher than age-1 and age-2 fish (< 10.9%, mean = 3.9%). The total lipid content in age-3–5 fish was significantly higher than that of age-1–2 fish.

Summer and fall samples; A total of 660 chum salmon muscle samples from immature fish caught during the summer (June–July) and 622 samples from the fall (September) were analyzed. Average TL content in the white muscle of immature ocean age-1 summer-caught chum was 1.8% (n = 48), 2.1% (n = 89), and 2.4% (n = 118) in 2002, 2003, and 2004, respectively (Fig. 1). Average TL content in the white muscle of immature ocean age-1 fall-caught chum was higher: 7.3% (n = 180) in 2002 and 5.2% (n = 198) in 2003 (Fig. 1).

Average TL content in the white muscle of ocean age-2 summer-caught chum salmon was 5.1% (n = 69), 4.4% (n = 103), and 4.2% (n = 125) in 2002, 2003, and 2004, respectively (Table 1, Fig. 1). The TL in ocean age-2 chum salmon increased to 11.7% (n = 122) and 8.5% (n = 83) in fall 2002 and 2003. Average TL content observed in each age group during fall was significantly higher than that observed in fish of the same age group collected during

Table 1. Number of fish sampled by ocean age in the Gulf of Alaska in the spring of 1999, and North Pacific Ocean and the Bering Sea in the summer and fall of 2002–2004.

Season	Year	Ocean age					Total
		1	2	3	4	5	
Spring	1999	16	15	33	30	5	99
Summer	2002	48	69	24	5	0	146
Fall	2002	180	122	18	3	0	323
Summer	2003	89	103	40	1	0	233
Fall	2003	198	83	17	1	0	299
Summer	2004	118	125	32	6	0	281

summer.

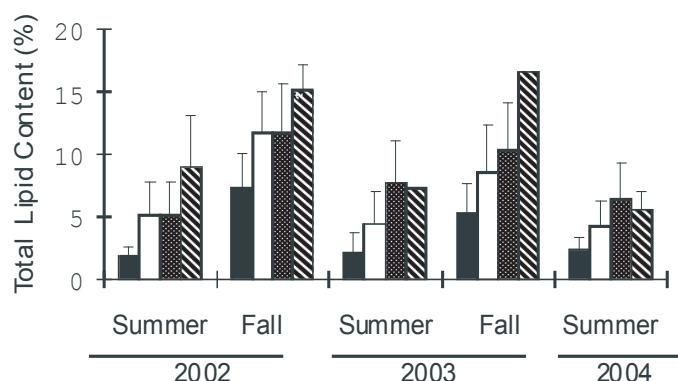
Our results clearly demonstrate that young (ocean age-1) chum salmon have lower lipid levels than older salmon, but the starved condition observed in winter and spring (winter TL content = 1.1% and spring TL content = 1.4% in female and 1.2% in male chum salmon; Nomura et al. 2000, 2001) does not occur in this age-group during summer and fall.

During their ocean migrations, salmon use energy for movement, metabolism, and growth (Crossin et al. 2003). Lower lipid content in young chum salmon as compared to old fish indicates either inadequate intake of dietary lipid, utilization of their lipid for growth, or a combination of these conditions. We hypothesize that during the summer, energy expenditures for growth in ocean age-1 chum salmon takes priority over lipid storage. During fall the reverse occurs, and lipids are stored at the expense of growth, which promotes survival during winter. If this hypothesis is true, then growth to avoid size-selective predation (Ricker 1964, 1976; Weatherly and Gill 1995) may not occur throughout the year, particularly in the fall when consumption rates may be high. Reduced food availability and high predation in the late summer and fall may critically limit sufficient lipid storage for salmon, particularly young fish, reducing overwinter survival.

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Fig. 1. Total lipid content in white muscle of immature chum salmon caught in the Bering Sea in summer (June–July) and fall (September) 2002–2004 by ocean age. Bar height is the mean, and line length is one standard deviation. Solid bar, ocean age-1; open bar, ocean age-2; stippled bar, ocean age-3; and slanted line bar, ocean age-4.



Influence of Sea Ice on Spring Phytoplankton Production and Foraging Period of Juvenile Salmon in Nemuro Strait

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Keywords: Okhotsk Sea, Nemuro Strait, sea ice, spring bloom, juvenile salmon

The Okhotsk Sea is an important summer nursery for Japanese juvenile salmon (Mayama and Ishida 2003). Juvenile salmon migrate through coastal waters around Hokkaido to the Okhotsk Sea in the spring. They rear in the Okhotsk Sea through the summer and autumn, migrating to the Pacific Ocean for overwinter (Urawa et al. 2001). Sea ice dynamics influence the biological production of the Okhotsk Sea, thus are important to the growth and survival of juvenile salmon (Asami et al. 2005).

Nemuro Strait, located along Shiretoko Peninsula and Kunashiri Island, eastern Hokkaido is a marginal sea of the southwestern Okhotsk Sea. The fisheries production in this strait is high and large salmon home to the waters around Nemuro Strait each year. Nemuro Strait is ice covered in the winter same as the Okhotsk Sea. There is considerable information on the relationship of sea ice to biological productivity in the Bering Sea (McRoy and Goering 1974; Alexander 1980; Schandelmeier and Alexander 1981; Alexander and Niebauer 1981; Niebauer and Alexander 1985; Niebauer et al. 1990; Niebauer 1995; Stabeno et al. 1998; Saitoh et al. 2002). There is little information on the relationship of sea ice and biological productivity in the Okhotsk Sea (Ohshima et al. 2001; Okunishi et al. 2005).

We investigated the Nemuro Strait to clarify the variability of spring biological production after the retreat of sea ice and the function of sea ice in coastal waters. Six sampling stations were located from 0.5 km to 8 km off Rausu and Shibetsu in northern Nemuro Strait (Fig. 1). Oceanographic observations were conducted on board the chartered vessels *Rausu maru* of Rausu Fisheries Cooperative Association and *Hakucho* of Shibetsu Fisheries Cooperative Association, between the period before sea ice reached the coasts of Nemuro Strait (January) and after sea ice retreated from Nemuro Strait (July), from 1998 to 2003. The observations under sea ice were conducted aboard the icebreaker *Teshio maru* of the Japan Coast Guard in 1999. Water temperature and salinity were measured with an Alec Memory STD. Transparency was measured with a Secchi disk. Water samples were collected from surface to a depth of 200 m (0 m, 5 m, 10 m, 20 m, 30 m, 50 m, 75 m, 100 m, 150 m, and 200 m) with a Rigo B sampler and filtered with a Whatman GF/F filter. Nutrients (nitrate, phosphate and silicate) concentrations were measured using spectrophotometers (Flow Injection Analyzer 5002 and Hitachi 100-60). The filters were extracted with 100% methyl alcohol (Otsuki et al. 1987) and chlorophyll a concentration measured with a Turner AU10 fluorometer. Accumulated ice concentration in the Okhotsk coastal area of Hokkaido was provided by the Sea Ice Laboratory of Hokkaido University, Mombetsu City.

Accumulated ice concentrations on the Okhotsk coast of Hokkaido were highest during 2000 and 2001, and lowest in 1998 (Fig. 2). However, sea ice retreated from the coastal waters in the middle of March in 1998, 2000 and 2001, one month earlier than 1999. Peak chlorophyll a concentrations in the surface layer (upper 10 m) off Shibetsu and Rausu occurred in the middle April of 1998, 2000 and 2001.

A chlorophyll a peak was not observed in 1999 during the retreat of the sea ice (Fig. 3). On the other hand, a strong phytoplankton bloom occurred in late March when sea ice began to retreat in 1998, 2000 and 2001. A mixed layer developed and a peak zooplankton biomass was observed in late June 2001 (Seki et al. 2006).

Nutrients and chlorophyll a concentrations were determined to examine the relationship between sea ice and the phytoplankton bloom in 1998 and 2003. Nutrients (nitrate, phosphate and silicate) concentrations in Nemuro Strait were higher during the period of ice cover than before or after. The concentrations of nitrogen, phosphorus and silica were 6.8 $\mu\text{mol/l}$, 0.9 $\mu\text{mol/l}$ and 18.3 $\mu\text{mol/l}$, respectively before ice cover. During the period of ice cover, the concentrations of nitrogen, phosphorus and silica were 11.2 $\mu\text{mol/l}$, 1.0 $\mu\text{mol/l}$ and 23.0 $\mu\text{mol/l}$, respectively. The ratio of nutrients in the water column under sea ice was similar to the Okhotsk Intermediate Cold Water (Maita

Fig. 1. Satellite image of the ice-covered Okhotsk Sea, showing the research area in Nemuro Strait. This NOAA image was produced by Kitami Institute of Technology.

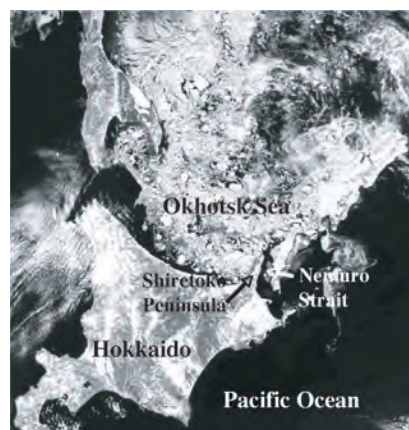


Fig. 2. Accumulated ice concentrations off the Okhotsk coast of Hokkaido in 1998–2001. The accumulated ice concentration indicates an extent (%) of coastal areas covered with sea ice for each year.

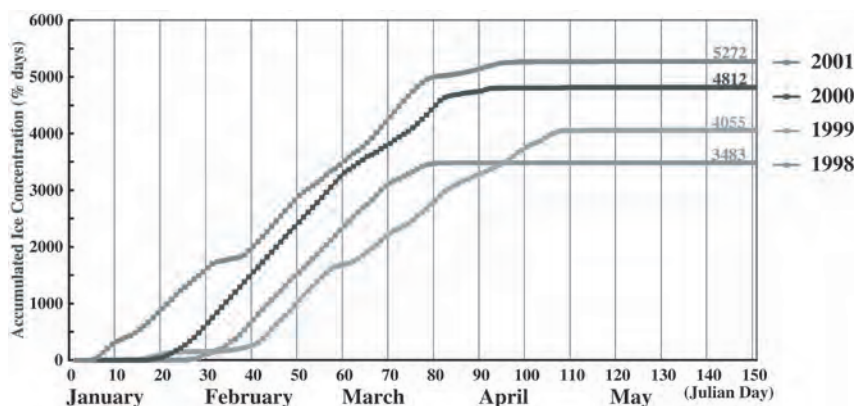
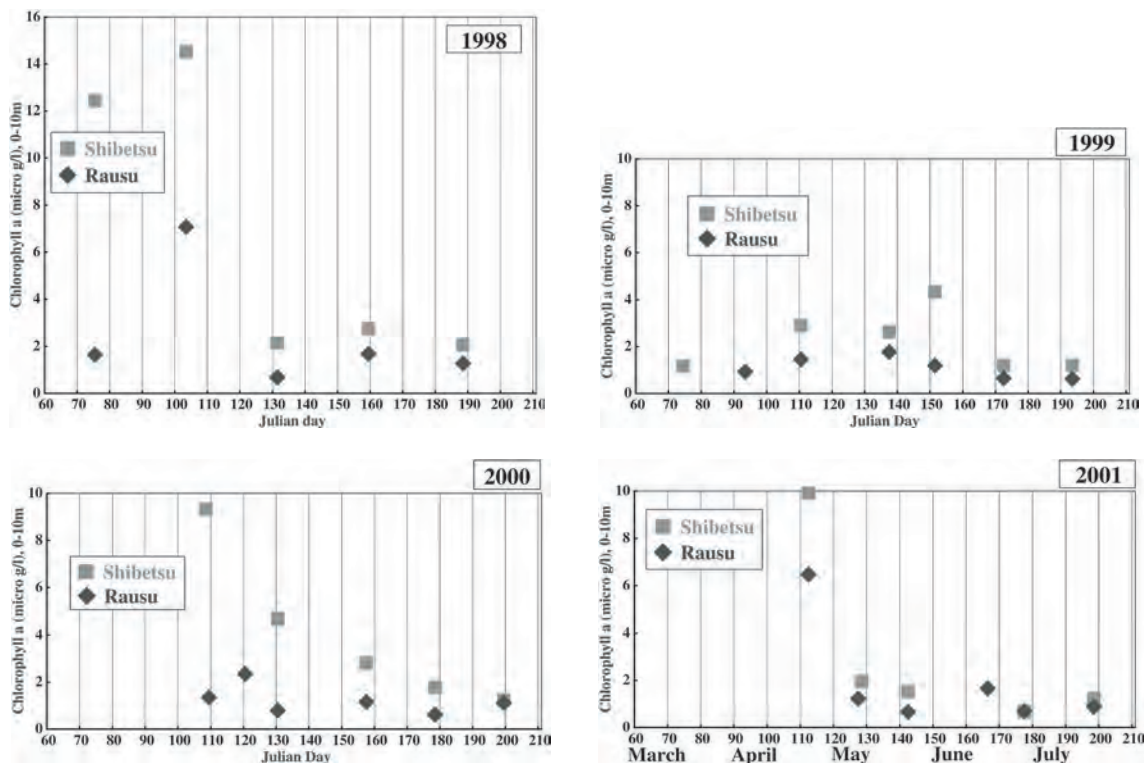


Fig. 3. Average concentrations of chlorophyll a in the surface layer (upper 10 m) off Shibetsu (west of Nemuro Strait) and Rausu (east of Nemuro Strait) after sea ice retreated in 1998–2001.



1986). After sea ice retreated nutrient concentrations decreased and chlorophyll a concentrations increased.

Volume of East Sakhalin Current Water was maximum between December and January (Itoh and Ohshima 2000; Itoh *et al.* 2003). It is believed that the water mass under sea ice originated from Okhotsk Intermediate Cold Water and brought high concentration of nutrients. These nutrients were utilized by phytoplankton blooms during the sea ice retreat period (Shimizu and Aota 2000).

Chlorophyll a concentrations were measured in northern Nemuro Strait during the 2002 sea ice retreat. Spring phytoplankton blooms were classified as ice edge bloom, open water bloom and under ice bloom. Ice edge phytoplankton blooms occurred in the salinocline formed during melting at the sea ice margin. Open water blooms occurred in the thermocline resulting from increased solar radiation and the rise of water temperature in open water after the sea ice retreat. In the Nemuro Strait, the ice edge bloom was larger than the open water bloom. The same was observed in the Okhotsk Sea during satellite remote sensing (Matsumoto *et al.* 2002).

The integrate value of the spring phytoplankton bloom differed among the years. A strong peak bloom occurred in 1998, but was not observed in 1999 (Fig. 4). The sea ice retreated in early March in 1998 and in late April in

Fig. 4. Vertical profiles of chlorophyll *a* at Rausu stations in Nemuro Strait on April 14, 1998 and April 21, 1999.

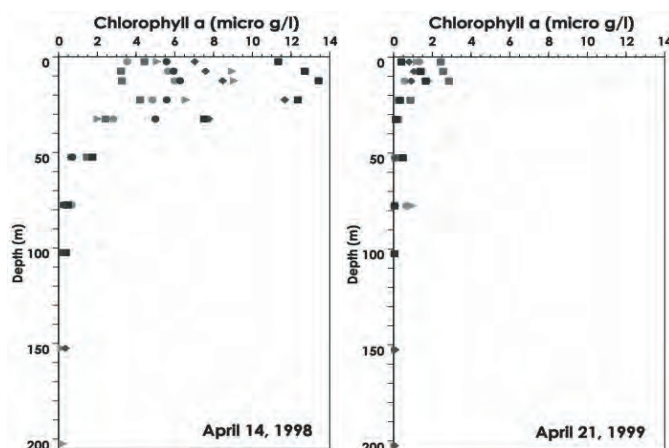


Fig. 5. Vertical profiles of sigma-t at Rausu stations in Nemuro Strait on April 14, 1998 and April 21, 1999.

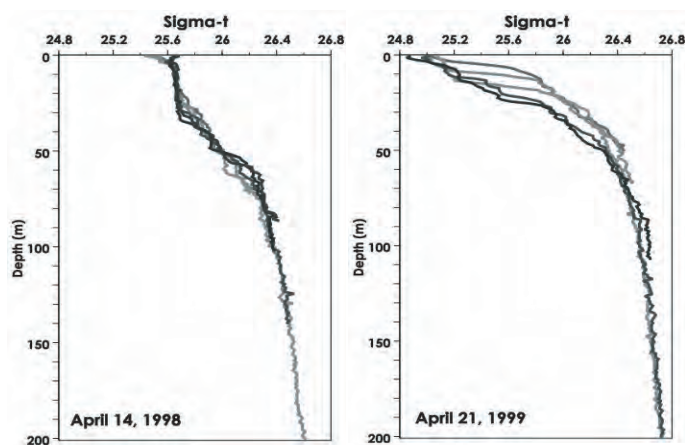
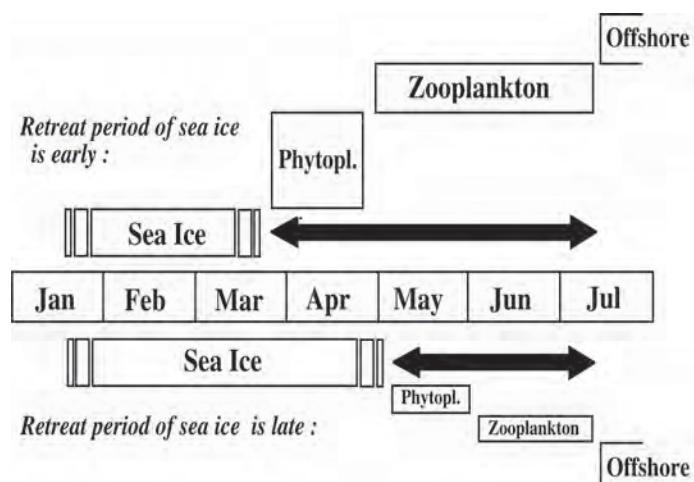


Fig. 6. Image of relation between retreat timing of sea ice and foraging period of salmon juveniles in the coastal waters of Nemuro Strait. The foraging period of salmon juveniles becomes longer and zooplankton biomass increases larger when sea ice retreats earlier.



1999, and the period of retreat was longer in 1999 than in 1998. The integrated value of the spring bloom was influenced by physical factors during the sea ice retreat period. The relationships between magnitude of the spring bloom and critical depth, nutrients, temperature and density were examined (Shimizu and Aota 1999; Shimizu *et al.* 2001). The surface density gradient (pycnocline) was more pronounced in 1999 than 1998, and the depth of the mixed layer was shallower in 1999 than 1998 (Fig. 5). Variation of density structure of a water mass triggered a phytoplankton bloom. This suggests that the thickness of the mixed layer influences the integrate value of the phytoplankton bloom after the sea ice retreats in Nemuro Strait.

In 1999, the nutrient concentrations in the water column in May were lower than in April. The decrease in silicate and nitrate was especially remarkable. Carbon content corresponding with the nutrient decrease in the periods from March to April in 1998 and April to May in 1999 was integrated using Redfield ratio (C:N:P = 106:16:1) and C: Chl.*a* ratio (= 30) (Strickland and Austin, 1960). Estimated value of chlorophyll *a* was 5.3 to 7.0 $\mu\text{g/l}$ in 1998, about equal to the observed value of 6.97 $\mu\text{g/l}$. Estimated value of chlorophyll *a* in 1999 was 1.19 to 3.0 $\mu\text{g/l}$, also about equal to the observed value of 1.77 $\mu\text{g/l}$. The nutrients under sea ice were utilized by later production in 1999.

The coastal water mass observed in Nemuro Strait changed though the influence of Soya Warm Water between late June and middle July. Chum salmon juveniles also migrated from Nemuro Strait to the Okhotsk Sea in late June and middle July. The feeding period of juvenile salmon in the year when the retreat of sea ice was late, was shorter than in the year of short ice retreat period in Nemuro Strait (Fig. 6). On the other hand, in the southeastern Bering Sea, spring blooms occurred later in the cold water influenced by storms in the years when sea ice retreat was early (Hunt *et al.* 2002). Although our results differ from the hypothesis for the Bering Sea, they demonstrate that spring blooms were influenced by oceanographic conditions during the period of sea ice retreat. Nutrient value of secondary production was influenced by the primary production after sea ice retreat. That is to say, the magnitude of the phytoplankton bloom after sea ice retreat influences the biomass of the zooplankton community during the early ocean life of juvenile salmon.

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Coastal Seawater Temperature during Early Ocean Life of Chum Salmon Measured by Satellite Remote Sensing and Its Effect on Their Return Rates in Eastern Hokkaido

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Keywords: Satellite remote sensing, sea surface temperature, return rate, chum salmon

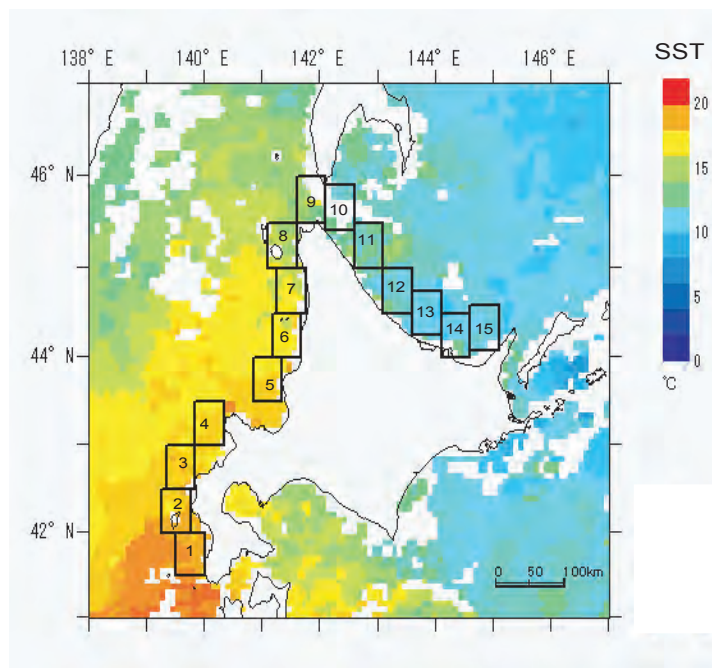
Many chum salmon populations are currently maintained by hatchery program in Japan. Egg-to-fry survival is improved by the hatchery technologies, and the early marine phase is thought as a critical period for hatchery-reared chum salmon when the mortality is highly variable. Recent researches in the Abashiri Bay, eastern Hokkaido, reported that the distribution of juvenile chum salmon shortly after ocean entry was strongly affected by coastal environmental conditions (Nagata et al. 2005; Miyakoshi et al. 2007), and ocean conditions greatly varied among years (Sawada et al. 2007). We hypothesized that coastal seawater temperature affected the distribution and survival of juvenile chum salmon in this region. The satellite remote sensing has been developed as an effective tool in oceanography research (Laurs and Polovina 2000). We began a study using the satellite remote sensing to analyze the relationship between coastal sea surface temperature (SST) and return rates of chum salmon stocked along the coast of the Okhotsk Sea, eastern Hokkaido.

The AVHRR/NOAA data (spatial resolution: 9 km, eight-day composite) distributed by NASA JPL PO-DAAC PATHFINDER database were used to measure SST in the coastal areas. The maximum SST were extracted from 9 coastal boxes ($0.5^\circ \times 0.5^\circ$), consecutively spaced at 0.5° latitudinal intervals between 41.5°N and 46.0°N in the coastal waters of the Sea of Japan and 6 boxes, consecutively spaced at 0.5° longitudinal intervals between 142°E and 145°E in the coastal waters of the Okhotsk Sea (Fig. 1). Each box covers an area within approximately 40 km of the coastline. The SST data from eleventh eight-day period (mean from 22 to 29 March) to twenty-sixth period (mean from 20 to 27 July) from 1991 to 2001 were processed. Using the periodical maximum SST in 1997 (low survival year) and 2001 (high survival year), isopleths of coastal SST were drawn (Fig. 2). To evaluate the timing

of release from hatcheries, the Sea of Japan and the Okhotsk Sea coasts were divided into three geographical regions, respectively, and numbers of juvenile chum salmon released were totaled by each region. Dates of beginning, end, and 50% of total fish stocked were plotted on the isopleths of coastal SST. Using the SST in the east coast (No. 13–15 in Fig. 1) of the Okhotsk Sea, the relationship between SST and return rate was analyzed by the simple linear regression.

By comparing the coastal SSTs in 1997 and 2001, coastal SST in the Okhotsk Sea was lower ($< 8^\circ\text{C}$) and did not reach the optimum SST range ($8\text{--}13^\circ\text{C}$) for residence of juvenile chum salmon by late May in 1997, while the coastal SST exceeded 8°C by late May in 2001 (Fig. 2). The timing of juvenile chum salmon stocked from hatcheries was earlier in 1997 when SST was lower. The discrepancy in the timings of stocking and optimum coastal SST period may affect the return rate of chum salmon stocked in the two years. By analyzing the SST and return rates of chum salmon stocked in 1991–2001, the relationship between timing of SST first

Fig. 1. Locations of coastal areas ($0.5^\circ \times 0.5^\circ$) where sea surface temperature data were extracted from satellite data.

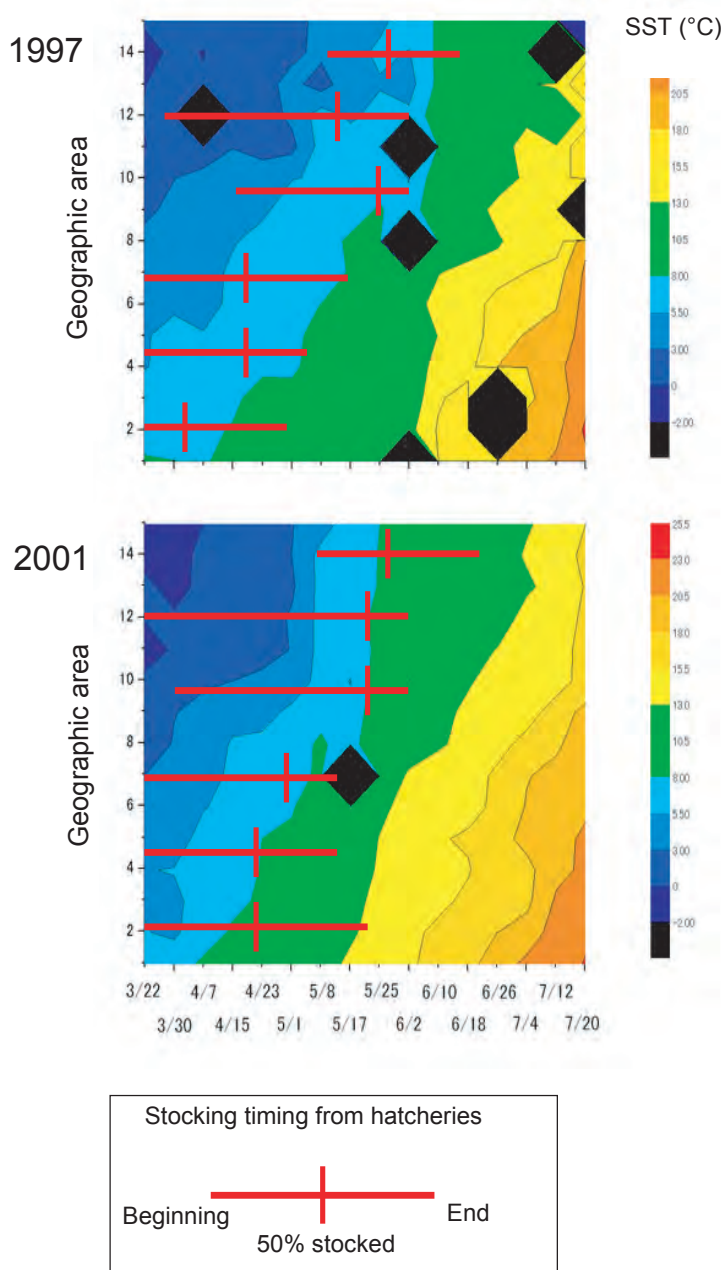


reaching the optimum range (8–13°C) and return rate was negatively significant ($R^2 = 0.46$, $P < 0.05$); i.e., the earlier the period of coastal SST first reaching the optimum range for chum salmon, the higher the return rate. This study suggests that the timing of optimum temperature range in coastal areas is an important factor affecting the survival of chum salmon stocked from hatcheries in the eastern region of the Okhotsk coast on Hokkaido, while other factors, e.g., fish size, stocking timing, and environmental conditions in the high seas, would also affect the return rate. This study also showed that a portion of hatchery-reared chum salmon was stocked too early when coastal SST was unfavorable, and reducing such ineffective stocking is important to conduct the hatchery programs efficiently.

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Fig. 2. Isoleths of coastal sea surface temperature of the Sea of Japan and Okhotsk Sea along the coasts of Hokkaido in 1997 and 2001. Green areas in the isopleths indicate the optimum temperature range for residence of juvenile chum salmon in the coastal waters.



Visual Characteristics of Three Species of Salmonids Stocked from Japanese Hatcheries

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Keywords: Chum salmon, pink salmon, masu salmon, spectral sensitivity, UV sensitivity, polarized light sense, biological clock

The optomotor reaction is defined as any movement by an animal that retains the image and direction of a visual target. In fishes, this reaction plays an important role in rheotaxis (Lyon 1904), migration (Jones 1968), and schooling behaviour (Shaw and Tucker 1965; Shaw and Sachs 1967). Consequently, improved knowledge of this reaction can help us to understand numerous forms of fish behaviour. Inoue and Kondo (1972, 1973) investigated the optomotor reaction of fishes in order to understand their reaction to fishing gears by using visual patterns such as stripes, net mesh, rope and fish as targets. Optomotor reactions have also been used to measure the pigment sensitivity of fishes (Northmore et al. 1981; Schaerer and Neumeyer 1996; Krauss and Neumeyer 2003; Neuhauss 2003). Cronly-Dillon and Muntz (1965) obtained photopic spectral sensitivity curves for the goldfish (*Carassius auratus*), by means of the optomotor reaction. The reaction has also been used to measure the spectral sensitivity of fishes under scotopic conditions (Hasegawa 1998). In those experiments, the spectral sensitivity curve of medaka (*Oryzias latipes*) and cobaltcap silverside (*Atherina tsurugae*) coincided well with the absorption spectrum of their rod visual pigments. Recently, the optomotor reaction of the red sea bream (*Pagrus major*) was measured to determine its spectral sensitivity in photopic conditions (Hasegawa 2005). This paper describes experiments that use the optomotor reaction to measure the spectral sensitivity and polarized light sensitivity of juveniles of three salmonid fish: chum salmon (*Oncorhynchus keta*), pink salmon (*O. gorbuscha*) and masu salmon (*O. masou*). These fish were treated according to the guidelines of the Japan Ethological Society for animal behaviour research. Juveniles are defined as being in the “swim-up” stage meaning they can feed spontaneously.

In addition, the possible role of the biological clock was evaluated by examining the periodicities in swimming depths for chum salmon returning to the coast for spawning. The polarized light sense and the biological clock relate to the function of the direction search of the salmon.

The equipment used to measure the optomotor response is essentially the same as that used in Hasegawa et al. (2001) and Hasegawa (2005). Suspended particles (i.e., kaolin in a concentration of 28.6 NTU) were added to the water of the measurement tank in an effort to scatter light rays making them visible in the transverse direction.

A halogen lamp was used as a light source and the light was divided into 12 equal parts using optical fibres. A convex lens was installed in the tip of each fibre. These lights were shone vertically through the water. The lights were installed in a rotating base that was able to turn clockwise and anticlockwise at various speeds. A cylindrical acrylic tank was filled with water containing a little kaolin and set on the rotating base. Monochromatic light of 400, 440, 480, 520, 560, 600 and 620 nm were obtained by the use of interference filters (Andover Corporation Optical Fiber) that were inserted in the mouths of the optical fibres. The light intensity was adjusted to be $2.0 \times 10^{-2} \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at each wavelength. In addition, sensitivity to polarized light was examined by measuring the optomotor reaction with the visual target that alternately arranged the polarized light filter as the penetration vibration side of light was orthogonal.

A fish was transferred into the experimental tank, and left to adapt for five minutes in the state where stimulus light (visual target) was irradiated. The visual target was then started in a clockwise direction and fish behaviour observed for five minutes. The time (T) taken for the trial fish to swim in the same direction as the visual target was considered to be the optomotor reaction rate. That is to say, the rate of optomotor reaction was calculated using the following formula, $(T \text{ min} / 5 \text{ min}) \times 100\%$ (Arimoto et al. 1979). The tangential velocity of the visual target was $\pi/2 \text{ rad}\cdot\text{sec}^{-1}$.

The optomotor reaction rate of chum salmon was highest at 520 nm, with no significant differences among reaction rates at 400 nm, 440 nm and 520 nm (Mann-Whitney U-test, $p > 0.05$). The optomotor reaction rate of pink and masu salmon was highest at 560 nm and in pink salmon it was significantly different from that at wavelengths shorter than 480 nm ($p < 0.01$). In masu salmon there were significant differences from the other wavelengths except for 400 nm ($p < 0.05$). In masu salmon a high reaction rate was observed at 400 nm, suggesting that these fish are sensitive to ultraviolet light (UV). The pectoral fins of masu salmon are UV reflective at 350 nm as indicated by photographs taken using an UV transmitting filter. Attenuation of reflectance was observed by

nearly 360 nm shorter than the shortest wavelength with visible light. In the sample used, several juvenile masu salmon were observed with damaged pectoral fins. This damage likely resulted from interference aggression among individuals (Kobayashi 1994). Abbott and Dill (1985) report high rates of nipping at the pectoral fin in juvenile steelhead trout (*O. mykiss*) which are also UV reflective in the pectoral fin region. Given that masu salmon and steelhead trout are closely related species (Phillips et al. 1992; Osinov and Lebedev 2000), nipping might also be highly concentrated at the pectoral fin. Sensitivity to UV may facilitate the use of the reflective pectoral fin patch as a cue or target for nipping.

Although the sensitivity curve of the closely related chum and pink salmon was similar, there is a small difference in the composition of visual pigment between the two species. The rhodopsin ratio of chum salmon is higher than that of pink salmon (Hasegawa et al. 2002). The difference of the λ max between both species may be a reflection of this phenomenon. Moreover, although these two species have violet/ultraviolet-sensitive opsin (Dann et al. 2004), the rate of optomotor reaction in the short wavelength region was low. However, Nicol (1989) has indicated that several kinds of photopic spectral sensitivity curves vary according to experimental conditions and so it will be necessary to re-examine these results using other action indices, in order to determine whether the results described here are valid.

The rates of optomotor reaction were compared when the optical penetration direction side of the polarized light filter was alternately put every 90 degrees and when the same side was alternately put. The rate of the former was better ($p < 0.01$). Therefore, it was suggested that masu salmon are sensitive to polarized light. The importance of polarized light sense was not demonstrated for chum salmon or pink salmon. It is necessary to examine other action indices for these species. However, a 24 h periodicity was confirmed by changes in the swimming depth of chum salmon. Salmon that have a biological clock and are sensitive to polarized light will be able to perceive the direction of movement of the sun and moon.

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Identification of an Olfactory Imprinting-Related Gene in Sockeye Salmon

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Keywords: Imprinting, olfactory system, olfactory epithelium, olfactory hypothesis, cDNA-RDA, sockeye salmon

Salmon accurately home to their natal river and spawning areas. Many behavioral and electrophysiological studies have addressed the important functions of olfactory system (olfactory epithelium, olfactory nerve and olfactory bulb) in salmon (Dittman and Quinn 1996; Shoji et al. 2000). Hasler and his co-workers proposed the olfactory hypothesis on salmon homing in 1950s.

In mammals, the olfactory memory is thought to be formed by the long-term potentiation (LTP) in synapse (Martin et al. 2000). LTP was also detected in the olfactory bulb of lacustrine sockeye salmon (*Oncorhynchus nerka*) at the smolt stage (Satou et al. 1996). Recently, odorant receptors have been isolated from Atlantic salmon (Wickens et al. 2001; Dukes et al. 2006). Dukes et al. (2004) also reported that odorant receptor gene expression changes during the parr-smolt transformation in salmon. However, the molecular basis of olfactory imprinting of salmon is poorly understood.

The cDNA representational difference analysis (cDNA-RDA) is a PCR based subtractive enrichment procedure. It has been adapted to enable the isolation of genes with an altered expression between various tissues or cells (Hubank and Schatz 1994). This technique offers several advantages over other approaches for assessing gene expression, including a low number of false positives. Thus, unwanted difference products can be competitively eliminated and genes producing rare transcripts, which may not be represented in the currently available database, are also detectable. In this study, we attempted to identify imprinting specific genes in the olfactory system of lacustrine sockeye salmon by using the cDNA-RDA method.

We used one and three-year-old lacustrine sockeye salmon reared at the Toya Lake Station, Field Science Center for Northern Biosphere, Hokkaido University. We sampled one-year-old (1⁺) smolts fish in the May 2002 and three-year-old (3⁺) fish in June 2002. The body color of smolts became silver, with fins that had intense black pigment. All the sub-adults sampled did not have smolt characteristics. Twenty fish were used from each age group. Fish were anesthetized with eugenol (4-allyl-2-methoxyphenol) and the olfactory epithelium, gill, liver, heart, head, kidney, spleen, muscle and brains were surgically isolated. The brain was cut into small regions consisting of olfactory bulb, telencephalon, hypothalamus, optic tectum, cerebellum and medulla oblongata.

In the forward subtraction experiment, the double strand cDNA of the olfactory bulb from 1⁺ fish was used as a tester, and in reverse subtraction, the tester consisted of 3⁺ fish. The cDNA-RDA technique was performed according to the protocol of Niwa et al. (1997). A forward subtractive (1⁺) cDNA library was constructed after three cycles of subtractive enrichment. Approximately 1000 white colonies from the forward subtraction library were

randomly picked up and differential screening was performed using forward and reverse subtraction product probes. As a result, we obtained a clone that showed a positive reaction in the forward subtraction probe from differential screening. Semi-quantitative RT-PCR was used to find a difference in the expression levels of mRNA between the olfactory bulb of 1⁺ and 3⁺ fish. The clone was expressed only in the olfactory bulb of 1⁺ fish (Fig. 1). We named this partial clone “Sockeye salmon Olfactory system Imprinting related Gene” (SOIG). Expression of SOIG mRNA in the brain and body tissues from 1⁺ lacustrine sockeye salmon was analyzed by northern blotting. A strongly hybridized signal corresponding to about 1.7 kb was only detected in the olfactory epithelium (Fig. 2). No signal was detected by northern blot analysis in six

Fig. 1. Results of 3% agarose gel electrophoresis of semi-quantitative RT-PCR product. Specific product for clone and β -actin mRNAs were amplified from aliquots of the same mRNAs of the olfactory bulb of one-year-old (1⁺) and three-year-old (3⁺) fish.

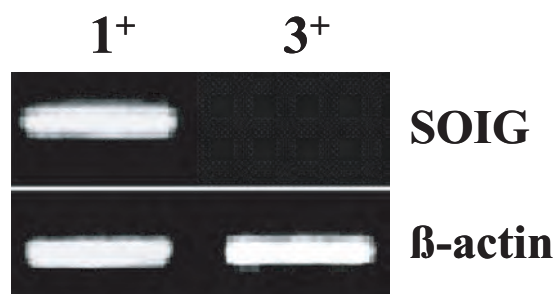


Fig. 2. Northern blot analysis of 1⁺ lacustrine sockeye salmon SOIG mRNA in the body tissues. Total RNA (10 µg) isolated from body tissues was blotted to nylon membrane. The position of SOIG transcripts is indicated by arrow. The relative positions of 28S and 18S ribosomal RNA are indicated.

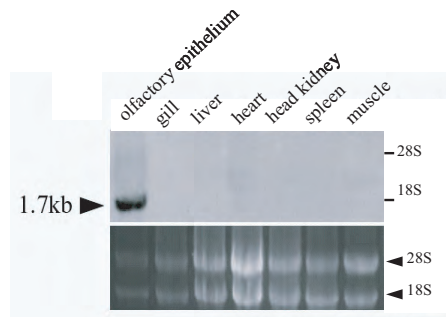


Fig. 3. Expression of SOIG mRNA demonstrated by *in situ* hybridization in the olfactory epithelium of lacustrine sockeye salmon. (A) Adjacent sections were stained with Carazzi's hematoxylin and eosin counter-stain. (B) Section hybridized with antisense probes. (C) Section hybridized with sense probes as a negative control. Olfactory receptor cell and basal cell are indicated a and b. Scale bar = 50 µm.

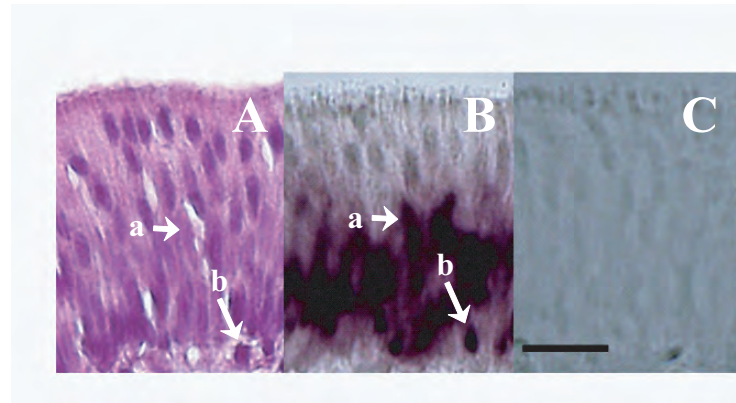


Fig. 4. Comparison of SOIG amino acid sequence with monkey and bovine uPAR. Red characters indicate cysteine residues. Black characters indicate residue that are conserved throughout all sequences. Grey characters indicate residues that are the same for 2/3 sequences. Dotted underlines denote CCXXXXCN motif. Sequence alignments and analysis were done with ClustalW.

Monkey	MGHPILLPLLLLLLHTGVPASWGLRCMCNGHGNCRVEECALGQNLCRTTSVRHWEEGEEVEMVEKSC TH SEKTNRTMSFRTGVRITTLT	90
bovine	MGQPLLLL---LLVYTYIPGSWGLRC ^{LQ} CENTTSC ^{SV} EECTPGQDLCRTTVLSVWEGGNEMNVVRKGC TH PDKTNRSMSYRAADQIITLS	87
SOIG	MKHTIILL-----LACMLL-----CIAVSCSAALQ-----	25
Monkey	EAVCG ^{LD} ICNQDSSGPAVTFPFSRFLC ^{IS} CG-----SSDMS ^{CE} RGRHQSLQCTSPKEQ-----CLDMVTHRTSEA	156
bovine	ETVCRSDLCNKPNPGRDATVSRNRYLEC ^{AS} CS-----STDLS ^{CE} RGWDQTMQCLKSRDQ-----CVDVITHRSLKE	153
SOIG	-----CFTCKDLADTHCLEQTLETCS ^{DG} QVCS ^{TN} SSSSLSRVVNDGRGRIHFSIWDVDIDIRWGKDR	88
Monkey	EEG-----RPKDDHHIRGCGHLP ^{CG} PGIAGFHS ^{ED} TFHFLK---CCNTTKCN ^{GG} PILSLANLPKNGHRC ^{YS} CQGNSTHGCSS ^{EN} TVLTD	237
bovine	N-----PGDERHIRGCGILPGCPGPTGFHNNHTF ^{HL} RLR---CCNTTKCN ^{AG} SVLELQNLPPNGLQC ^{YS} CEGNGAHRCSSE ^{ET} FLID	231
SOIG	TATPNVVSNSINERIVKGC ^{MD} DHFCQSSPKMSLNIGF ^{HQ} TSSCC ^{NS} SGCNSD---TFSDDPHNGLECFSC ^{TD} PEDEVCN---QAVT	171
Monkey	CRGPMNQ ^{LE} ATGIYEPLSESYMVRGCATSSMCQH ^{DH} VSDAFMSHIDVAC ^{CT} TENDCN ^{PA} EDIQHRSEAA ^{PQ} PGFAHLSLTITGLMTAR	327
bovine	CRGPMNQ ^{LE} ATGTGLRNPSTYTI ^{RG} CAAPSWCQSLHVAEAFDLTHVNVSC ^{CT} TSGSCN ^{HP} ARDQPGKGGAPKTS ^{PA} HLSFFVSLLLTTL	321
SOIG	CQG ^{VQ} DHCLNDT-VTASNGRSVTLRG ^{CV} SRSMCGSGSG-----SVSC ^{CE} GSLCNR-----NRAMNSAQPVALT ^{VL} TLLVGITTTTL	246
Monkey	LWGGTLLWT	336
bovine	LWGATLLCT	330
SOIG	LQSVDQ---	252

regions of brain (data not shown). To determine the distribution of SOIG mRNA expression in the olfactory system (olfactory epithelium and olfactory bulb), we performed *in situ* hybridization using DIG-labelled RNA probes. The signals for SOIG were observed mainly in the olfactory receptor cells and basal cells in the olfactory epithelium of 1⁺ lacustrine sockeye salmon (Fig. 3). We did not obtain the signal for SOIG mRNA by *in situ* hybridization in the olfactory bulb (data not shown). To isolate full length SOIG cDNA, we constructed a cDNA library from 1⁺ lacustrine sockeye salmon olfactory epithelium. SOIG cDNA was 1700 bp in length, having an open reading frame of 759 bp encoding 252 amino acids. Database searches showed that the SOIG amino acid from 102 to 220 share amino acid sequence similarity with urokinase plasminogen activator receptor (Fig. 4). Overall, SOIG shares 28.2 and 30.3% similarity, respectively, with the amino acid sequence of urokinase plasminogen activator receptor from bovine (Kraetzschmar *et al.* 1993) and monkey (Engelholm and Behrendt 2001).

The urokinase plasminogen activator receptor (uPAR) is one of the members of uPAR/Ly-6/CD59/snake toxin-receptor (Ly-6) superfamily. The detailed biological function of the superfamily members is not known, except for uPAR, which has an important role in proteolysis of extracellular matrix proteins (Tarui *et al.* 2001). Ly-6 superfamily has a unique structure showing conserved 8–10 cysteine residues with a characteristic spacing pattern and shares the consensus sequence motif CCXXXXCN at the carboxy-terminal end (Palfree 1996). SOIG contains the CCXXXXCN motif (Fig. 4; positions 134–141 and 212–219), indicating that SOIG may belong to Ly-6 superfamily.

The present study demonstrated that a strongly hybridized SOIG mRNA signal in the olfactory epithelium

was detected by northern blot analysis. SOIG mRNA was also expressed in the olfactory receptor cells. No SOIG mRNA signal was detected in other tissues or organs. These results suggest that SOIG may play important role on the imprinting function in the lacustrine sockeye salmon.

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Physiological Study on Imprinting and Homing Related Olfactory Functions in Salmon

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Keywords: Amino acids, imprinting, odorants, home stream, homing migration, salmon

As for the upstream homing migration of salmon from the coastal sea to the home stream, the olfactory hypothesis proposed by Hasler and Wisby (1951) has been discussed with many behavioral and electrophysiological studies (Hasler and Scholz 1983; Ueda 1985; Stabell 1992; Dittman et al. 1996; Ueda and Shoji 2002). However, these odor substances of home stream are still unknown. From our recent electrophysiological experiments, we proposed that amino acids dissolved in the home stream water were possible home stream odor substances for salmon (Shoji et al. 2000). Additionally, we carried out behavior experiments to test whether amino acid mixtures have attractive effects on male chum salmon (*Oncorhynchus keta*) and lacustrine sockeye salmon (*O. nerka*) of both sexes upstream selective movement or not by means of the two-choice test tank. Of 44 male chum salmon tested, 28 fish were found in one of the choice arms and 24 (86%) of these fish were in the arm running their artificial home stream water containing the amino acid mixture of their home stream (Shoji et al. 2003). In sockeye salmon, of 151 fish tested, 61 fish showed upstream movement to one of the choice arms and 47 (76%) of these fish were found in the arm running the artificial home stream water containing amino acid mixture of their home stream. From these results of electrophysiological experiments and behavior experiments, we proposed that amino acids dissolved in the home stream water were possible home river substances for salmon.

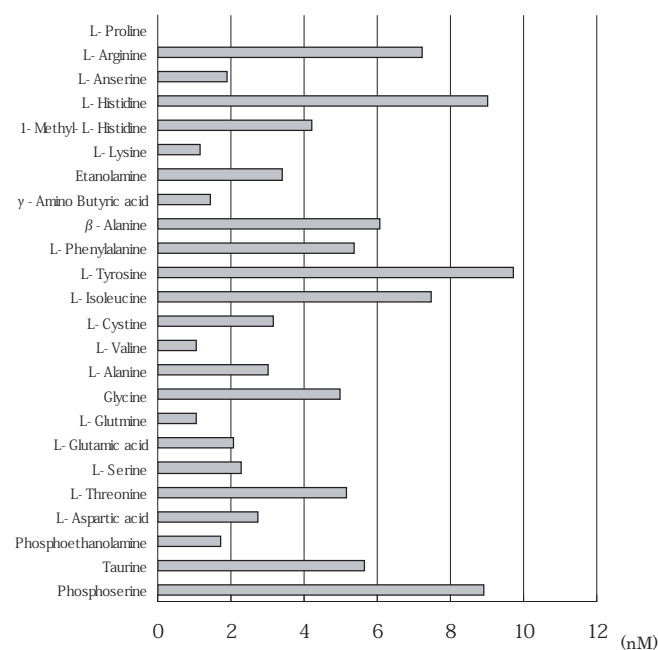
Juvenile salmon are considered to be imprinted by site-specific odors associated with their home stream and adult salmon utilize these “odor” memories for homing. This imprinting phenomenon was demonstrated on juvenile coho salmon (*O. kisutch*) by imprinting them with the artificial odorants β -phenylethyl alcohol (PEA) or morpholine (Cooper et al. 1976; Scholz et al. 1976; Dittman et al. 1996). Additionally, Nevitt et al. (1994) showed that olfactory receptor cells of coho salmon that had been imprinted with PEA have a higher sensitivity to PEA than that of

non-imprinted fish. We have a test of whether lacustrine sockeye salmon can be imprinted by one amino acid that is absent in natural home stream water.

In the experiment, one-year-old lacustrine sockeye salmon cultured in the pond of the Toya Lake Station were used. The pond water flows into the lake through a small stream. Hence, this stream is the home stream for the salmon. We analyzed the compositions of amino acids in water from Toya Lake Station stream water (Shoji et al. 2000). Water from Toya Lake Station stream contains various species of amino acids, but does not contain L-Proline (Pro) (Fig. 1), thus we tested whether lacustrine sockeye salmon might be able to be imprinted by Pro.

Imprinting procedure was carried out according to Nevitt et al. (Nevitt et al. 1994). One-year-old sockeye salmon hatched and reared at the Toya Lake Station were used in the experiments from March to July. Fish were divided into experimental and control groups. Fish in the experimental group was imprinted for two weeks by adding Pro to the water intake at

Fig.1. The concentration of amino acids and related substances in the Toya Lake Station river water. The line of the graph shows the concentration (nM) of each amino acid.



concentrations of 10^{-6} nM from March to July. Control fish were never exposed to Pro. Experimental (Pro-exposed) and control groups (Pro-naïve) were marked and transferred to a common outdoor fresh water rearing Toya Lake Station. To test whether salmon can be imprinted by Pro, electro-olfactogram (EOG) response to the experimental water was measured. We compared sensitivity to Pro of imprinted fish with non-imprinted control fish. EOG were obtained by using an experimental technique according to Evans and Hara (1985). Odor-evoked EOGs were recorded by using a pair of glass microelectrodes filled with 2% agar-saline and bridged to Ag-AgCl electrodes by 3-M KCl. The recording electrode was placed along the midline of the rosette at the base of the large, posteriormost lamella with the aid of a stereomicroscope mounted on a boom stand. A reference electrode was placed in the skin above the rosette. A separate ground was placed in the muscle near the tail. The differential signal was amplified ($500\times$) and filtered (100-Hz low-pass) with an amplifier (MOD. 3000, A-M Systems, Inc, Carlsberg, WA, USA). The signal was then integrated by an electrical integrator.

From March to June, the responses of Pro imprinted fish to the experimental water were greater than that of non-imprinted fish. In July, however, the responses to experimental water is smaller than other months. There is no significant difference in the average values of relative magnitudes of responses to experimental water in the Pro imprinted groups. There is no significant difference in the average values of relative magnitudes of responses to experimental water in the Pro imprinted groups. These results suggest that sockeye salmon may be imprinted by one amino acid (Pro), and may be imprinted not only during parr-smolt transformation but also either before or after parr-smolt transformation.

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A Comparison of Secondary Sexual Characters and Age Composition of Wild and Hatchery Chum Salmon (*Oncorhynchus keta*) in the Yurappu River, Southern Hokkaido in Japan

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Keywords: Yurappu River, chum salmon, wild population, hatchery population, secondary sexual character, age composition

Hatchery salmon may develop their secondary sexual characters less significantly than wild fish because of no opportunity of breeding competition (Fleming and Gross 1989). In the Yurappu River, southern Hokkaido, chum salmon (*Oncorhynchus keta*) originated from hatchery spawn at the upper reaches (designated as hatchery salmon), whereas possible wild chum salmon spawn at the lower reaches. We compared their secondary sexual characters and age composition among both populations during the fall and winter of 2005.

Adult chum salmon were collected at the upper and lower reaches of the Yurappu River (Fig. 1), measured for fork (FL), head (HL) and upper jaw lengths (UJL), and recorded by a digital camera. The digital images were analyzed by a simple digitizer software, and measured for mid-eye to hypural flexure length (MEH), head length (HL), upper jaw length (UJL), kype length (KYPE), body depth (BD), dorsal fin base length (DB), anal fin base length (AB), adipose fin length (AFL), and caudal peduncle depth (CPD). In addition, scales were collected from each fish for the age determination.

Wild and hatchery chum salmon did not show significant difference in their temporal and spatial age composition, although wild salmon was slightly older than hatchery fish (χ^2 -test, NS; Fig. 2). Wild salmon had significantly larger body size than hatchery salmon (t -test, $P < 0.01$; Fig. 3a), although age-6 male and age-4 and

Fig. 1. Locations for collecting adult chum salmon in the Yurappu River system.

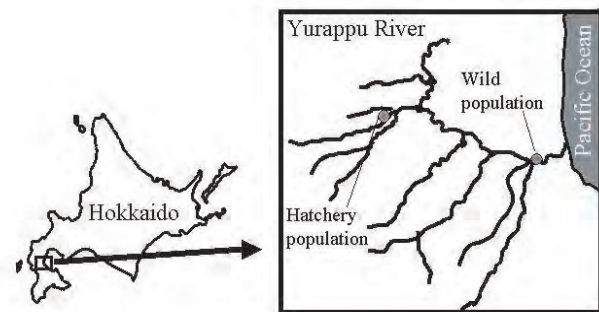


Fig. 2. Temporal-spatial variation of age composition of hatchery (a) and wild (b) chum salmon in the Yurappu River.

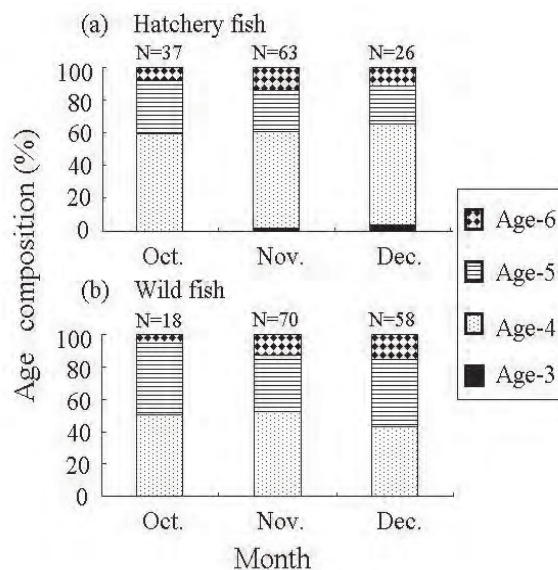


Fig. 3. Frequency distribution in fork length of male (a) and female (b) chum salmon in the Yurappu River. Open bar, wild fish; shaded bar, hatchery fish (t -test: * $P < 0.05$, ** $P < 0.01$).

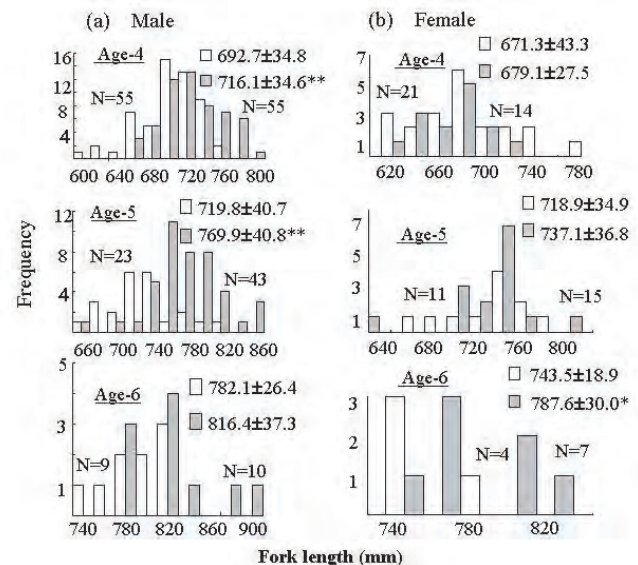
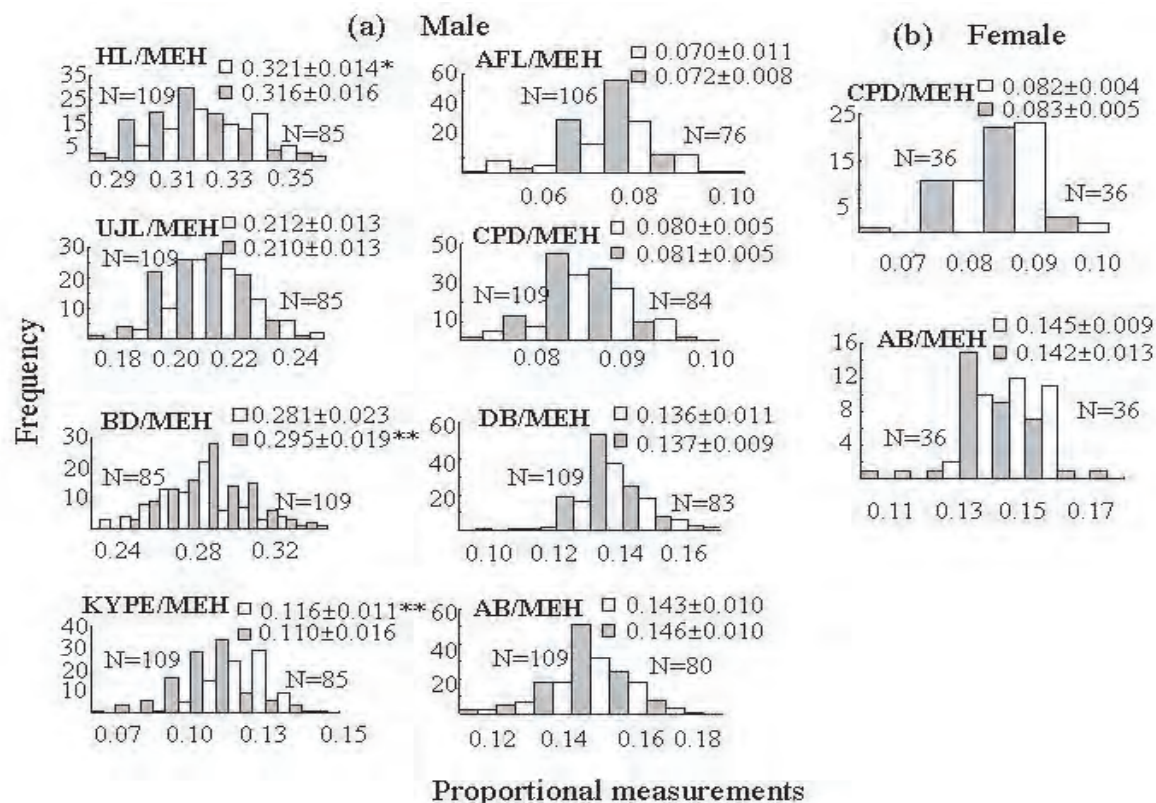


Fig. 4. Frequency distribution in proportional measurements concerning the secondary sexual characters of male (a) and female (b) chum salmon. Open bar, wild fish; shaded bar, hatchery fish (*t*-test: * $P < 0.05$, ** $P < 0.01$).



-5 female salmon did not show significant differences between both populations (U-test, NS; Fig. 3b). In the proportional measurements concerning the secondary sexual characters, wild male had significantly higher BD, smaller HL and KYPE than hatchery salmon (*t*-test, $P < 0.05$; Fig. 4a), and wild salmon had smaller UJL than hatchery male despite no significance (*t*-test, NS; Fig. 4a). Other characters (such as AFL, DB, AB and CPD) of male salmon had no differences between both populations (*t*-test, NS; Fig. 4a). Secondary sexual characters of adult females had no difference between both populations (*t*-test, NS; Fig. 4b).

Sockeye salmon developed the secondary sexual characters as a result of the breeding trade-off between mortality risk and reproductive success (Quinn et al. 2001). Difficulties with the migration to spawning ground and intensity of breeding competition affected the morphology of adult female salmon (Fleming and Gross 1989). Male sockeye salmon which had larger body size and larger dorsal humps obtained higher status for breeding competition in the spawning grounds than other males (Quinn and Foote 1994). In this study, wild male chum salmon spawning at the lower reaches had higher BD, and smaller HL, KYPE and UJL than hatchery salmon spawning at the upper reaches. This morphological difference salmon may response the opportunity of breeding competition and the migration distance to each spawning ground.

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Trends of Hormonal Levels in the Brain, Pituitary and Serum of Chum Salmon during Homing Migration

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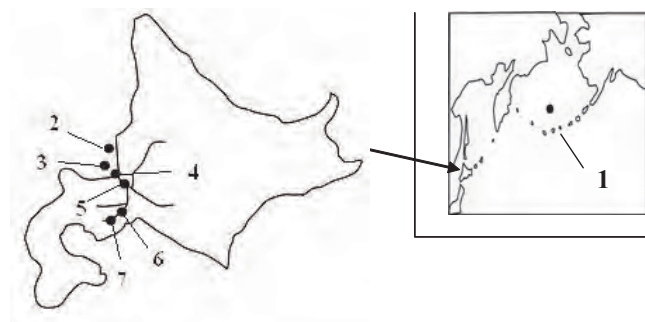
Keywords: Chum salmon, homing migration, steroids, sGnRH, GTHs

In salmonids, at a particular stage of ocean growth, certain endocrinological changes cause the fish to shift from feeding migration to spawning migration. Previous reports indicate that this shift has been thought to coincide with the onset of gonadal maturation which in turn is regulated by brain-pituitary-gonadal axis (Urano et al. 1999). The hypothalamic decapeptide, gonadotropin-releasing hormone (GnRH) is secreted from axon terminals of GnRH neurons and carried to pituitary where it stimulates the release of gonadotropins (GTHs) from gonadotrophs into the blood stream (King and Millar 1992). GTHs control gametogenesis and production of gonadal steroid hormones (Nagahama 1994).

GnRH released from different regions of brain is considered to have functions not only as a hypophysiotropic hormone that controls reproductive functions but also as a neuromodulator that controls arousal states of various nervous actions in the animal (Oka 1997; Ishizaki et al. 2004). Kudo et al. (1996) investigated the changes in the levels of sGnRH mRNA in chum salmon (*Oncorhynchus keta*) during their migration and reported that a strong signals of sGnRH mRNA in olfactory bulb (OB) and the olfactory nerve were seen at the coastal sea, but these signals were not observed at the spawning ground. This could indicate that GnRH secreted in each brain region may have specific functions during upstream migration in salmonids. There are several reports which investigated changes in the levels of serum steroid hormones during spawning migration in salmonids (Ueda and Yamauchi 1995). However, very little is known about the changes in GnRH and GTHs, and their relationship with steroid hormone levels during homing migration. And, it would be very important to accumulate data on endocrinological changes during the spawning migration of chum salmon. Thus, in this study changes in salmon GnRH (sGnRH) in each brain region were examined for three years. Besides, other reproductive related hormones such as luteinizing hormone (LH) and follicle-stimulating hormone (FSH) in the pituitary, and steroids in serum were also measured.

Chum salmon were sampled in the Bering Sea from late-June to mid-July 2003, 2004 and 2005 during the cruise of RV *Wakatake-maru*. Besides, fish were caught at four to six points along their homing route from Ishikari Bay to their spawning ground in the Chitose River in Hokkaido from late-September to early-October of 2003,

Fig. 1. Locations of sampling points. 1, the Bering Sea; 2, offshore of Ishikari Bay; 3, coastal sea; 4, estuary; 5, branch point of the Chitose River; 6, pre-spawning ground; 7, spawning ground.



2004 and 2005 for three years (Fig. 1). Blood samples were collected from caudal vasculature, temporarily kept on ice, centrifuged to obtain serum. Upon decapitation, brain and pituitary were removed, where brain was divided into three regions; olfactory bulb (OB), telencephalon (TE) and hypothalamus (HYP) and immediately frozen at -80°C until assayed. Steroids (estradiol 17- β (E2), 11-ketotestosterone (11-KT) and testosterone (T) and 17 α , 20 β -dihydroxy-4-pregnen-3-one (DHP)) from serum, sGnRH from OB, TE, HYP and pituitary; and GTHs from pituitary were measured by time-resolved fluoroimmunoassays (Yamada et al. 1997).

Fig. 2. Changes in serum levels of steroid hormones in chum salmon during homing migration from 2003 to 2005. Each value represents the mean \pm standard error.

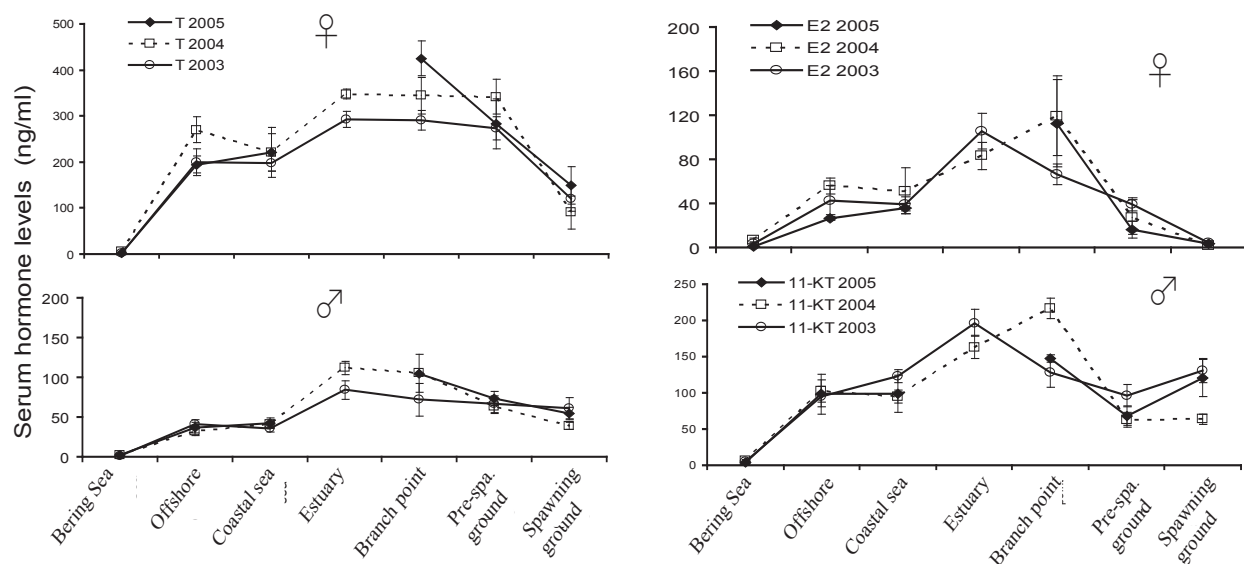
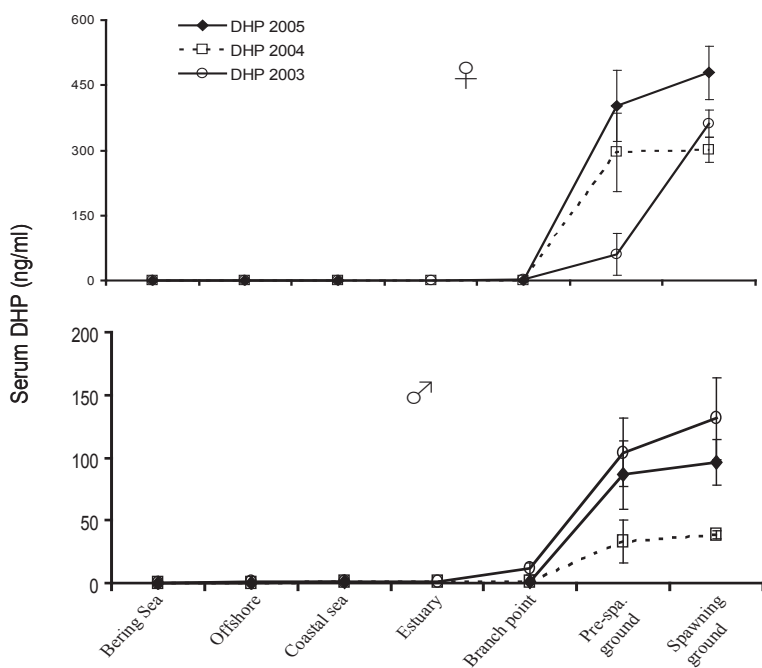


Fig. 3. Changes in serum levels of DHP in chum salmon during homing migration from 2003 to 2005. Each value represents the mean \pm standard error.



In both sexes of the three years examined, serum levels of T and E2 were increased significantly at estuary and/or branch point of the Ishikari River from the Chitose River during the homing migration (Fig. 2). In males, serum 11-KT levels were elevated in the same manner as T (Fig. 2), whereas in females they showed an increasing tendency at the spawning ground (data not shown). On the other hand, serum DHP levels of both sexes of three years showed a surge increase in the pre- and spawning ground (Fig. 3). These results are quite similar to those of previous reports (Onuma et al. 2003).

Increased levels of sGnRH in the OB, TE and HYP were observed at offshore in 2004 and 2005, but sGnRH levels at the Bering Sea were similar to those at offshore of Ishikari Bay in 2003, indicating the involvement of BPG axis prior to the onset of spawning migration. Salmon GnRH levels in OB, TE and HYP showed peak values

either at estuary or branch point but the absolute values varied from year to year. In all years examined, LH levels in pituitary increased at the coastal and midway of the homing migration, whereas FSH levels increased at the coastal and showed a decreasing tendency at the spawning ground. Salmon GnRH levels in the pituitary showed similar pattern of changes with LH. There were year-to-year differences in the absolute amounts of serum steroids, brain sGnRH and pituitary GTHs though the general trend of hormonal changes was similar in the years examined. Further comparative approaches will be applied to investigate whether the oceanographic environment influenced the physiological data obtained in this study.

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Role of Non Governmental Organizations (NGOs) in Mitigating Threats to Salmon and Their Marine Environment

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Keywords: Pacific salmon, conservation, marine ecosystem, monitoring, threats, Kamchatka

The Kamchatka Peninsula and Sakhalin Island harbour one third of the world's Pacific salmon. The level of intra-specific diversity of the Far Eastern salmon species is unlike anywhere else in the world. As salmon biodiversity in many regions is being lost, partially due to global warming in the north-eastern Pacific, and also due to other reasons (construction of dams, deforestation of river basins, poaching, salmon farming and associated diseases, etc.), freshwater and marine habitats of salmon in the Far East become increasingly important to preserve. At the same time the well-being of salmon and their marine environment in the Russian Far East is threatened by various factors including on-going oil and gas drilling development, inefficient management of salmon stocks, and illegal fishing and trade. Therefore the following salmon biodiversity conservation efforts are urgent: switching to and improving practices of sustainable fishery management, development of adaptive management, monitoring of salmon stocks, assessments of threats, pollution prevention, and research on salmon migrations and life history. Examples of ways that non-governmental organizations (NGOs) could participate in and promote the conservation and wise use of Pacific salmon in Russia include improvement of interagency communication to protect and manage salmon, creation of special marine protective fishery zones in areas important for salmon growth and survival, and independent environmental assessment of mineral resources development projects. In 2006 a new three-year project of the World Wide Fund for Nature (WWF) named "Conservation of Kamchatka Wild Salmon in Their Marine Environment" began that is aimed at accomplishing some of those things by establishing a dialogue and facilitating cooperation between government groups, the scientific community, NGOs, and fishermen. The WWF invites experts on salmon ecology to join this undertaking to provide the scientific basis behind efforts to change government policies and industry practices to help protect and maintain the diverse and healthy salmon populations in Russia's Far East.

Congruence of Population Genetic Profiles Obtained from Mitochondrial and Microsatellite DNA Analyses in the Pacific Rim Chum Salmon Populations

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Keywords: Chum salmon, mitochondrial DNA, microsatellite DNA, genetic variation, genetic structure

Chum salmon have received considerable attention due to their high commercial importance and wide geographic distribution in the Pacific Rim (Quinn 2005). Stock identification of chum salmon in mixed aggregations in high seas is therefore a fundamental international issue. Genetic stock identification using polymorphic mitochondrial and nuclear DNA markers could become a competent method with high resolution power and technical ease compared with the conventional allozyme analysis.

In this study, we performed nucleotide sequence analysis of the mitochondrial (mt) DNA using 96 populations recruiting 20 additional populations from North America to previously analyzed 76 populations (Yoon et al. 2004), to improve estimation of the genetic diversity and population structure in the Pacific Rim chum salmon. In addition,

Fig. 1. Distribution of the three mtDNA lineages (A, B, and C) of chum salmon in Japan/Korea (JK), Russia (RU), and North America (NA) along the Pacific Rim. Dots indicate geographical position of sampling site.

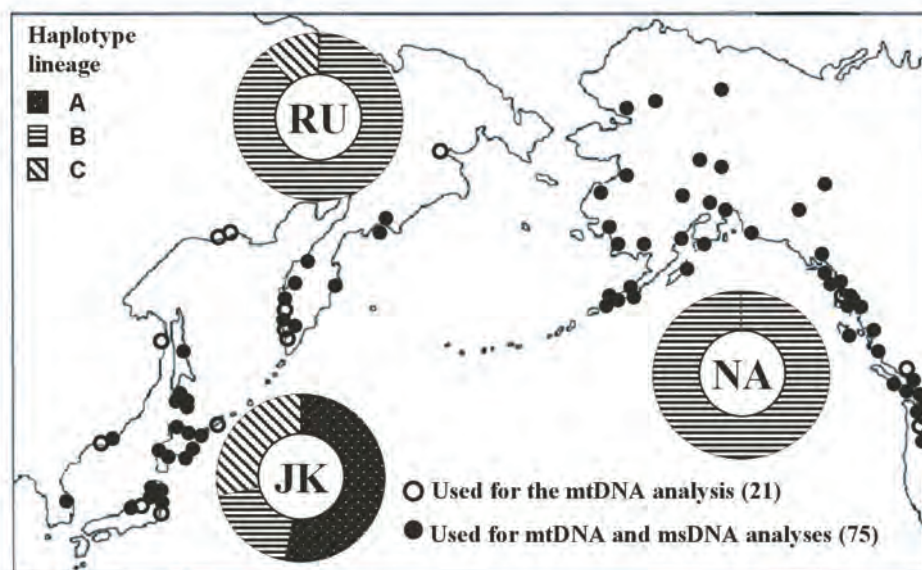


Table 1. Results of the hierarchical analysis of molecular variance based on mtDNA and msDNA for chum salmon. The percentage of variance (%), probability estimated from permutation (P), and the F-statistic (Φ) are given at hierarchical level (Excoffier et al. 1992). Indicated data are depicted from four different analyses.

Variance component	mtDNA			msDNA		
	%	P	Φ	%	P	Φ
Analysis I						
Among regional groups (Japan, Russia and North America)	68.7	$P < 0.001$	0.68	5.1	$P < 0.001$	0.05
Analysis II						
Among regional groups in Japan	7.8	$P < 0.001$	0.09	0.6	$P < 0.01$	0.01
Analysis III						
Among regional groups in Russia	29.0	$P < 0.001$	0.31	4.3	$P < 0.001$	0.04
Analysis IV						
Among regional groups in North America	2.1	$P < 0.001$	0.02	5.3	$P < 0.001$	0.05

nuclear microsatellite (ms) DNA analysis was performed with four polymorphic loci (OKM4, OKM5, OKM7 and OKM8) (Abe et al. 2002) using more than 3,000 individuals from 75 of the above 96 populations, including those of Japan and Korea (15), Russia (15) and North America (45), to compare the genetic features obtained from the mtDNA analysis (Fig. 1).

Estimation of the 481 bp sequence in the 5' variable portion of chum salmon mtDNA control region disclosed 22 variable sites in 4,243 individuals from 96 populations examined, which defined a total of 32 haplotypes of three clades (A, B, C) including the previously defined 30 haplotypes (Sato et al. 2004) and newly identified two haplotypes of clade B from the 20 additional North American populations. Pairwise net nucleotide divergence among the three lineages ranged from 0.0019 (between clade A and B) to 0.0053 (between clade C and B), indicating a shallow haplotype genealogy. The occurrence of haplotypes was in keeping with our previous observations (Sato et al. 2004) and further advocated a geographic association of haplotypes, in that clade A and C haplotypes characterized Asian and Russian populations and clade B haplotypes distinguished North American populations (Fig. 1).

Haplotype diversity was highest in the populations of Japan (0.607 ± 0.001), followed by those of Russia (0.359 ± 0.001) and North America (0.174 ± 0.001), whereas nucleotide diversity was nearly similar in Japanese (0.0021) and Russian populations (0.0017), but lower in North American populations (0.0005). These findings suggest a greater genetic variation in the populations of Japan than those of Russia and North America.

F_{ST} estimates were significantly greater between Japan and North America (0.667 to 0.905) than between Japan and Russia (0.013 to 0.883) or between Russia and North America (0.000–0.867). The analysis of molecular variance (AMOVA; Excoffier et al. 1992) revealed very strong geographic structuring among Japan, Russia and North America (68.7% of the total variance, $p < 0.001$) and a substantial geographic structuring among local populations within regions (Table 1).

Nearly identical population genetic profiles were obtained from msDNA analysis. The number of alleles per

locus was highest at the OKM8 locus (29) in the Japanese populations, and lowest at the OKM7 (13) in the North American populations. The expected heterozygosity of Japanese population (0.702) was higher than Russian (0.498) and North American populations (0.438) (Fig. 2). This supports the findings obtained from mtDNA analysis, in that genetic variation is greater in the populations of Japan than those of Russia and North America. Even though msDNA analysis suggested the low level of genetic differentiation among regional groups in Japan and Russia ($p < 0.01$), substantial structuring among Japan, Russia and North America ($p < 0.001$) and among local groups within regions ($p < 0.001$ to $p < 0.01$) was inferred from AMOVA (Table 1).

In addition, msDNA analysis revealed

Fig. 2. Observed and expected heterozygosity at four msDNA loci in 75 chum salmon populations.

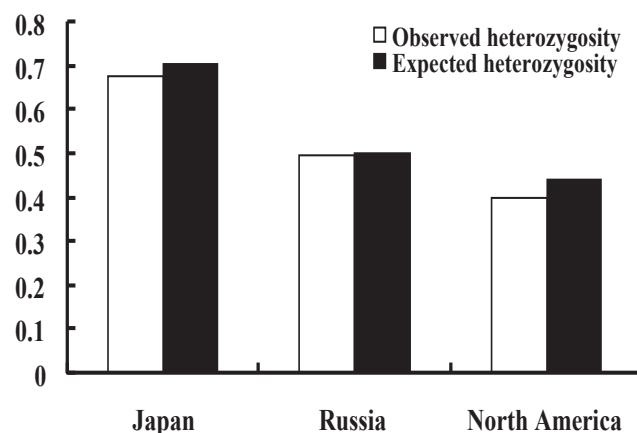
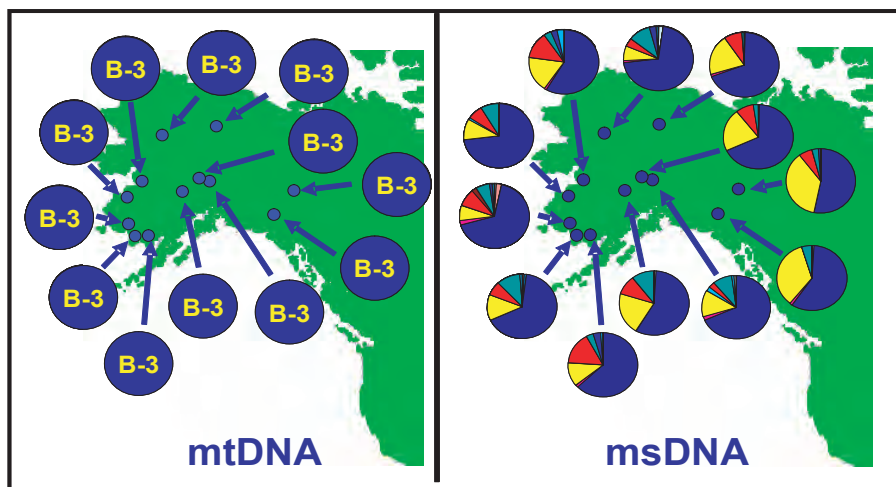


Fig. 3. Direct comparison of allelic frequency at the OKM 5 msDNA locus and mtDNA haplotype frequency among Alaskan populations. Populations with single mtDNA haplotype have a number of msDNA alleles at the examined locus, showing a total of 14 alleles with the observed (0.517) and expected heterozygosity (0.534).



distinct genetic structure in populations with single or a few mtDNA haplotypes of clade B lineage in North America (Fig. 3).

The observed congruence of population genetic profiles obtained from mtDNA and msDNA analyses suggests that a battery of these two DNA markers will become useful for better genetic stock identification of chum salmon in high seas.

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Energy Consumption and Expenditure of Juvenile Salmon during Post-Catadromous Feeding Migrations in the Okhotsk Sea

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Keywords: Juvenile salmon, energy consumption, feeding migration, Okhotsk Sea

External environment influences on rapidity of all vital processes changing intensity of metabolism. Dynamics of feeding conditions can be analyzed by balancing the elements of metabolism in a particular data series. Classical equation of “standard” metabolism (Equation 1) is not suitable for this comparison. Values of “standard” metabolism were tested on fish at the state of minimum activity (nearly motionless state) in the laboratory: $Q_{st} = (a/q)W^k$ (equation 1), where Q_{st} , consumed oxygen, ml/sample an hour; a , speed of oxygen consumption ml/hour by fish with a weight of 1g (for salmon = 0.498 ml/hour); q , temperature correction to adjust metabolism indexes to real temperature according to Krog’s normal curve; W , weight of fish, g; k , coefficient, for salmon = 0.76 (Winberg 1956). Thus, it is necessary to operate values of metabolism for fish in natural conditions.

The main aim of this work was to determine real level of metabolism and its elements in natural habitat conditions of fish. One of the research tasks is calculation of transient coefficient from standard to active metabolism (coefficient “Winberg-2”) (Mann 1965; Shulman and Urdenko 1989): $k_{v2} = Q/Q_{st} = A/a$ (Equation 2), where Q , consumed oxygen, ml/sample. an hour in conditions of natural activity, A , speed of oxygen consumption ml/hour by fish with a weight of 1g in conditions of natural activity.

Contents of 1500 stomachs were taken for quantitative and qualitative analysis of feeding, 3,342 fish samples were weighted to calculate daily increments, 238 fish samples were taken for calculating calorie content.

Calculations of fish increments: Growth diagrams were built to obtain values of daily increments (coefficient of “x”) of regression line $y = ax + e$ (Equation 3).

Calculations of daily rations: Calculations of daily rations were based on stomach contents of fish caught at daily stations (series of trawling were done every 2–3 hours during the day at one area “point”). An example of daily ration calculation of is given in Table 1.

The column I—remainder (index of fullness) includes food mass in stomachs in grams per sample. Calculation of average speed of food digestion from a stomach (v) in g/hour/sample is based on food intensity drops (Romanova 1958; Kogan 1963; Yerokhin and Shershneva 2000).

Weight of educed food (g/samples) for each sampling from daily series is calculated according to the formula $ef = v\Delta T_i$ (Equation 4), and weight of consumed food is calculated as $cf_i = ef_i + I_i - I_{(i-1)}$ (Equation 5).

Table 1. Dynamics of feeding and daily ration of juvenile pink salmon based on the data of daily station in the south-western waters of Kamchatka on October 2–3, 1997.

Interval between stations in a series, hr:min	ΔT —Interval between stations, hour	Average food weight per sample, g		
		cf —consumed	ef —educed	I —remainder
00:35–3:35	2.50	0.327	0.893	0.340
3:35–5:55	2.84	0.822	1.014	0.148
5:55–6:25	0.50	0.084	0.179	0.053
6:25–9:30	3.08	1.326	1.100	0.279
9:30–12:55	3.42	1.450	1.221	0.508
12:55–16:15	3.33	1.376	1.189	0.695
16:15–19:25	3.17	2.073	1.132	1.636
19:25–20:45	1.33	0	0.567	1.069
20:45–00:35	3.83	1.204	1.367	0.906
Σ = daily ration:		8.660	8.660	

Table 2. Balance of energy metabolism of juvenile pink salmon in the Okhotsk Sea.

Year	Period and location	Temperature of water layer (C°)	Caloric content of food (kcal/g of wet weight)	Caloric content of fish (kcal/g of wet weight)	Total caloric content (kcal)	Total caloric content of daily ration (kcal)		Real expenditure for metabolism								k _{v2}	Number of fish
								total		body growth		K ₂		active metabolism			
						kcal	%	kcal	%	kcal	%		kcal	%			
1986	September, 14–19 52°–54°N; 150°30–152°30'E	12	1.214	1.439	180.062	14.313	7.95	11.450	6.36	5.776	3.21	50.44	5.674	3.15	5.40	40	
1991	September, 20–25 South-west	11	1.204	1.103	143.589	12.943	9.01	10.354	7.21	5.140	3.58	49.64	5.214	3.63	5.30	72	
1999	September, 11–19 52°–53°N; 148°–150°E	13	1.184	1.202	79.920	10.517	13.16	8.414	10.53	4.532	5.67	53.86	3.882	4.86	5.30	102	
1999	September, 24–30 56°–57°N; 153°–156°E	11	1.075	1.225	100.217	9.405	9.38	7.524	7.51	3.598	3.59	47.82	3.926	3.92	5.70	94	
Average data for September (intensive feeding):		11.8	1.169	1.242			9.88		7.90		4.01	50.44		3.89	5.43	308	
2001	September, 27–28 53°N–155°30'E	9	1.281	1.072	87.315	6.620	7.58	5.296	6.07	1.738	1.99	32.81	3.559	4.08	6.60	51	
1997	October, 2 52°N; 155°E	9	1.054	1.159	118.366	9.128	7.71	7.302	6.17	2.277	1.92	31.19	5.025	4.25	7.80	80	
Average data at the end of September and beginning of October (feeding, beginning migration):		9.0	1.168	1.116			7.65		6.12		1.96	32.00		4.16	7.20	131	
1982	October, 2–8 53°N; 154°30'E	8	0.898	1.030	77.044	4.548	5.90	3.639	4.72	0.917	1.19	25.19	2.722	3.53	6.10	62	
1991	October, 2–5 North-west	8	0.984	0.916	96.052	6.907	7.19	5.525	5.75	1.469	1.53	26.59	4.056	4.22	7.10	50	
1991	October, 11 54°N; 152°E	9	0.968	0.916	127.168	10.396	8.18	8.317	6.54	2.099	1.65	25.23	6.219	4.89	7.70	60	
Average data for October (active migration):		8.3	0.950	0.954			7.09		5.67		1.46	25.67		4.22	6.97	172	

Table 3. Balance of energy metabolism of juvenile chum salmon in the Okhotsk Sea.

Year	Period and location	Temperature of water layer (C°)	Caloric content of food (kcal/g of wet weight)	Caloric content of fish (kcal/g of wet weight)	Total caloric content (kcal)	Total caloric content of daily ration (kcal)		Real expenditure for metabolism								k _{v2}	Number of fish
								total		body growth		K ₂	active metabolism				
						kcal	%	kcal	%	kcal	%		kcal	%			
1999	September, 12–19 52–53°N; 148°–150°E	13	1.028	1.228	102.77	9.181	8.93	7.345	7.15	3.663	3.56	49.9	3.682	3.58	4.3	69	
1999	September, 14–16 52–53°N; 154–156°E	11.5	1.126	1.203	96.76	10.188	10.53	8.150	8.42	3.473	3.59	42.6	4.677	4.83	6.4	73	
1991	September, 20–25 South-west	11	1.144	1.078	154.05	12.039	7.82	9.632	6.25	5.004	3.25	52.0	4.627	3.00	4.5	69	
Average data for September (intensive feeding):		11.8	1.099	1.170			9.09		7.27		3.47	48.1		3.81	5.07	211	
1999	September, 25–30 56–57°N; 153–155°E	10.2	0.703	1.219	122.46	5.946	4.86	4.757	3.88	1.445	1.18	30.4	3.312	2.70	4.5	73	
2001	September, 27–28 53°N; 155°30'E	9.2	1.266	1.122	99.51	7.866	7.90	6.293	6.32	2.765	2.78	43.9	3.528	3.55	6.1	82	
Average data at the end of September (feeding, beginning migration):		9.7	0.985	1.171			6.38		5.10		1.98	37.2		3.12	5.30	155	
1991	October, 11 54°N; 152°E	9	0.769	1.033	152.93	9,052	5.92	7,242	4.74	2.922	1.91	40.4	4.319	2.82	5.1	56	

Daily sum of consumed (educed) food is equal to daily ration. Calculation of caloric content of food consumed by salmon is based on the data (Shershneva and Koval 2004).

Calculation of energy expenditures: Value of expenditures on real metabolism was determined using the equations of balanced equality: $R = 0.8r - \Delta W$ (Equation 6), where R , expenditures on real metabolism, kcal/sample per day; r , daily ration, kcal; ΔW , daily weight increment, kcal (Ivlev 1939). Daily expenditures on standard metabolism were calculated using Equations 1, 7, and 8: in g/sample per day: $R = 24 \cdot 4.86 \cdot 10^{-3} Q_{st} C^{-1}$ (Equation 7), kcal/sample per day; $R = 24 \cdot 4.86 \cdot 10^{-3} Q_{st}$ (Equation 8), where 4.86, oxy calorie coefficient, cal./ml; C , total

calorie content of fish body, kcal/g of wet weight (Winberg 1956; Anon 1986). Coefficients of physiologically useful part of food for growth were calculated as $K_2 = 100 \Delta W / 0.8 r$ (Equation 9) (Ivlev 1939).

Juvenile salmon metabolism in conditions of active mode of life in marine habitat is 4.3–7.8 times higher than standard one (coefficient values “Winberg-2”) (Tables 2, 5). Maximum values of total calorie content, level of total metabolism, increment expenditures, and maximum daily rations of juvenile salmon during August–October were observed at maximum thermal saturation of the upper water layer (11–13°C) in September. Among all the species pink and coho are the most active ones. In some cases their metabolism level at this period is 10.5 and 9.7% (on the average 7.9 and 7.7%), respectively, consumption of total organism energy is 12.1 and 13.2% (on the average, 9.9 and 9.6%) (Table 2, 5). Sockeye is the least active species (Table 4). Chum is closer to the first group (Table 3). Expenditures on fish growth are determined according to intensity of total metabolism and consumption. In September the average level of expenditures for pink, coho and chum is 4.0, 3.9 and 3.5% of total organism energy, respectively, that is much higher than for sockeye (2.1%).

Total metabolism intensity regularly reduces with drop of water temperature in October. Intensity of energy expenditures on growth is nearly equal for all the species by this period (1.6–1.9% of total energy balance). However, rate of decrease of particular elements of metabolism are synchronous only for sockeye (in October elements of total, active metabolism and metabolism associated with muscular activity are 1.2 times lower than in September). Expenditures on growth reduce rapidly for chum and coho: 1.9 times for chum (total—1.5 times, active—1.3 times), 2.1 times for coho (total—1.6, active—1.3 times). Dynamics of metabolism of juvenile pink salmon differs from all the species. Having more gradual decline of total metabolism—1.3 times, the level of metabolism associated with muscular activity decreases rapidly—2.7 times (from 4.1% in September to 1.5% in October), but the level of active metabolism increases (from 3.9% to 4.2%). Consequently, pink has the highest level of food consumption among four species. A sharp drop of metabolism associated with muscular activity for pink at the end of feeding migration in Kamchatka waters indicates an important role of the factors making juvenile intensify active expenditures. One of these is the density factor. By October pink, like chum, migrating from the north in the Sea of Okhotsk flows into aggregations in the south 55–56° N, noticeably increasing their density. Consuming secondary food objects, juvenile has more diversified food composition. It is sustained by declining caloric content of rations (Table 2). Deficit of energy consumed with food increases its payment. Thus, searching

Table 4. Balance of energy metabolism of juvenile sockeye salmon in the Okhotsk Sea.

Year	Period and location	Temperature of water layer (°C)	Caloric content of food (kcal/g of wet weight)	Caloric content of fish (kcal/g of wet weight)	Total caloric content (kcal)	Total caloric content of daily ration (kcal)		Real expenditure for metabolism								k_{V_2}	Number of fish
								total		body growth		K_2	active metabolism				
						kcal	%	kcal	%	kcal	%		kcal	%			
						1999	September, 21–30 56°–57°N; 153°–156°E	10.8	0.989	1.167	144.957	9.536	6.58	7.629	5.26		
2001	September, 27–28 53°N–155°30'E	9	1.243	1.143	149.952	11.577	7.72	9.262	6.18	3.453	2.30	37.3	5.809	3.87	7.5	78	
Average data for September (intensive feeding):		9.9	1.116	1.155		7.150		5.720		2.076		36.2	3.643		6.45	176	
1997	October, 2 52°N; 155°E	9	1.226	1.234	179.304	10.791	6.02	8.633	4.81	3.150	1.76	36.5	5.483	3.06	6.5	58	

Table 5. Balance of energy metabolism of juvenile coho salmon in the Okhotsk Sea.

Year	Period and location		Temperature of water layer (C°)	Caloric value of food (kcal/g of wet weight)	Caloric value of fish (kcal/g of wet weight)	Aggregate caloric capacity of fish (kcal)	Aggregate caloric capacity of daily ration (kcal)		Real expenditure for metabolism								k _{v2}	Number of fish
									aggregate		body growth		K ₂	active metabolism				
							kcal	%	kcal	%	kcal	%		kcal	%			
1986	28.8–4.9	52°–54°30 N	12.6	0.988	1.271	372.36	31.098	8.35	24.879	6.68	11.431	3.07	45.95	13.447	3.61	6.3	70	
1999	September, 14–21	52°–55°N; 154°–156°E	11.2	1.110	1.148	226.88	27.439	12.09	21.951	9.68	11.457	5.05	52.19	10.494	4.63	7.6	62	
2001	September, 27–28	53°N, 155°30 E	9	1.118	1.130	298.13	24.777	8.31	19.822	6.65	10.494	3.52	52.94	9.327	3.13	7.1	47	
Average data for September (intensive feeding):			10.9	1.07	1.18		9.59		7.67		3.88		50.36	3.79		7.00	179	
1997	October, 2	52°N; 155°E	9	1.015	1.216	347.12	20.843	6.00	16.674	4.80	6.526	1.88	39.14	10.148	2.92	7.3	44	

and catching activities are intensified. Increase of motional activity leads to the growth of active expenditures in the balance of energy distribution. But the energy of obtained food is insufficient for growing motional expenditures and for preservation of previous level of somatic growth.

However, in October only the northern part of total aggregation is observed in the waters of Kamchatka, as it inhabits cooling southern part of the Sea of Okhotsk more slowly (Shuntov 1989, 1994). Consequently, it is reasonable to submit that this situation can indicate decrease of food sufficiency, but it does not characterize production characteristics of the whole complex of stocks of the given period. Apparently, for dominant majority of pink and chum fingerlings, feeding in the waters of Kamchatka in September, temperature and feeding conditions are satisfactory with movement to the southern areas. And possibly, high rates of metabolism associated with muscular activity can occur in October.

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Estimation of Pink and Sockeye Salmon Adult Returns to Western Kamchatka Based on the Data of Juvenile Salmon Trawl Catches in the Okhotsk Sea

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Keywords: Pink salmon, sockeye salmon, adult return, forecast

The data of trawl catches obtained by KamchatNIRO in 1982–2003 was used to forecast adult returns of pink and sockeye salmon in western Kamchatka. Methods of forecast for each species were demonstrated. Forecast effectiveness was analyzed. In the forecast of highly abundant returns of western Kamchatka pink salmon (over 25 million samples) deviations from the actual number did not exceed +25% in 75% of cases. In the forecast of sockeye salmon returns the accuracy was in 65% of cases.

The method of estimation of pink adult returns was based on the data of juvenile trawl catches by KamchatNIRO in the Okhotsk Sea, and it was applied successfully in the Bering Sea in 1986–1991 (Karpenko et al. 1998; Erokhin 2002; Erokhin 2006). In 2005 the analogous method was applied for estimation of adult returns of sockeye salmon in Kurilskoye Lake (the largest sockeye stock in Asia) in 2006. The basis for using similar methods to forecast sockeye and pink salmon was the following: 1) spawning stocks of Kamchatka juvenile of both species were completely covered by trawl surveys during their maximum distribution in the western part of the Okhotsk Sea; 2) size similarity of sockeye and pink juveniles in their aggregations in the sea gave an opportunity to use the integrated coefficient of catch capacity for fishing gear for both species (Erokhin 1998, 2002); 3) juvenile sockeye salmon along the western coast of Kamchatka were primarily from Kurilskoye Lake (Bugayev 1995); and 4) biostatistics and statistics of sockeye returns to Kurilskoye Lake were the fullest.

The work was based on the data of trawl surveys conducted by KamchatNIRO in September and October, 1981–2005 in the Okhotsk Sea on board of middle-tonnage vessels. Since 1985 catches were conducted by the special pelagic rope trawl 54.4/192 m with a vertical opening of 25–30 m and with a horizon opening of about 40 m (Anon. 1997; Kim et al. 2005). Early catches by other types of trawls were recounted by the trawl 54.4/192 m, working in standard regime. The coefficient of trawl catch capacity ($k = 0.6$) was used to calculate juvenile abundance (Erokhin 2002, 2006). Absolute juvenile abundance (N_a) was calculated by the area method according to the formula: $N_a = ns / vdtk$, where n , average catch per trawling (samples); s , area of surveyed territory (km^2); v , trawling speed (km/hour); d , horizon opening of trawl mouth (km); t , trawling time (hr).

Expected number of pink salmon spawners was estimated by the equation: $N = aN_a^2 + bN_a + c$, where N , forecasted abundance of spawners in million; a , b , c , empirical coefficients. The results of estimation of pink adult returns of western Kamchatka were given in Table 1. Deviation from the actual number did not exceed $\pm 25\%$ in 75% of cases.

Returns of sockeye salmon were estimated simultaneously with pink salmon in the sea; consequently, there was an opportunity to check accuracy of calculations of estimated sockeye salmon juvenile abundance and to correct it

Table 1. Abundance of calculated juvenile pink salmon in the Okhotsk Sea and return of adult pink salmon to the rivers of western Kamchatka (millions of fish). The majority of estimated juveniles was immigrants.

Year	forecast (N)	actual return (N_F)	Repetition factor related to forecast (N_F / N)	Forecast deviation from fact (%) ($N - N_F$) / N_F
1981	39.5	37.3	0.94	+5.9
1982	160.7	141.1	0.88	+13.9
1985	32.9	26.0	0.79	+26.7
1995	84.9	79.6	0.94	+6.7
1997	151.2	126.6	0.84	+19.4
1999	85.0	87.0	1.02	-2.3
2001	57.0	82.7	1.45	-31.1
2003	108.5	103.5	0.95	+4.9

promptly based on next years pink salmon returns. The index of repetition factor of actual pink salmon was used as a correcting coefficient for estimated sockeye.

Applying correcting coefficients for particular years, it was possible to correct estimated indexes of sockeye salmon juvenile abundance of the western coast of Kamchatka for the same years (Table 1). On the basis of correlation of the main and secondary stocks (9:1), abundance of the Kurilskaya juvenile stock was determined out of the total sockeye salmon juvenile abundance, estimated in the sea (Erokhin 2006). Respectively, abundance of the Kurilskaya juvenile stock (N'_a , million fish), presented in Table 2 was multiplication of constant coefficient 0.9 (a portion in the total feeding stock), varying in the years of correcting coefficient and total estimated abundance in the sea: $N'_a = 0.9 k' N_a$.

The main age groups of 14 groups returning to Kurilskoye Lake were 2.2, 2.3, 3.2, and 3.3 (Bugaev 1995). Estimations of average portions in return at the age were presented by three age combinations 2.2–3.2; 2.3–3.3, 2.2–3.2–2.3, and 3.3. Over two last decades in spawning stocks of Kurilskaya sockeye the total portion of fish at the age of 2.2 and 3.2 increased from 21% (in 1984–1985) to 30% (1986–2000) and decreased to 22% in 2001–2004. At the same periods the total portion of fish at the age of 2.3 and 3.3 was 77, 64 and 69%, and the total portion of all four age groups was 98, 94 and 91%, respectively.

Table 2. Forecast of return of separate age groups of western Kamchatka sockeye salmon based on the data of juvenile trawl catches.

Estimated juvenile abundance (N'_a) in million fish			Forecasted abundance of return ($k_{sp} N'_a$) in million fish					
Year of estimation	2+	3+	Year of return	2.2	3.2	Year of return	2.3	3.3
1982	5.93	0.88	1984	0.83	0.26	1985	2.19	0.26
1985	3.42	0.38	1987	0.48	0.11	1988	1.26	0.11
1986	8.12	0.39	1988	1.14	0.11	1989	3.00	0.11
1987	13.26	0.56	1989	1.86	0.16	1990	4.91	0.16
1989	16.54	0.74	1991	2.32	0.21	1992	6.12	0.21
1990	17.56	2.00	1992	2.46	0.58	1993	6.50	0.58
1991	7.24	0.95	1993	1.01	0.27	1994	2.68	0.27
1997	9.35	2.95	1999	1.31	0.85	2000	3.46	0.85
1999	13.61	0.19	2001	1.91	0.06	2002	5.04	0.06
2001	10.35	1.51	2003	1.45	0.44	2004	3.83	0.44
2002	9.49	1.05	2004	1.33	0.30	2005	3.51	0.30
2003	25.09	2.01	2005	3.51	0.58	2006	9.28	0.58
Average coefficient of specific return (k_{sp})				0.14	0.29		0.37	0.29

Table 3. Retrospective and perspective forecast (2006) of return of Kurilskoye Lake sockeye salmon based on the data of trawl catches.

Year of return	1984	1985	1987	1988	1989	1990	1991	1992	1993	1994	1999	2000	2001	2002	2003	2004	2005	2006
Forecasted age groups	2.2 3.2	2.3 3.3	2.2 3.2	2.2 2.3 3.2 3.3	2.2 2.3 3.2 3.3	2.3 3.3	2.2 3.2	2.2 2.3 3.2 3.3	2.2 2.3 3.2 3.3	2.3 3.3	2.2 3.2	2.3 3.3	2.2 3.2	2.3 3.3	2.2 3.2	2.2 3.3	2.2 3.3	2.3 3.3
Average of total portion of given age groups in return (%)	21	77	30	94	94	64	30	94	94	64	30	64	22	69	22	91	91	69
Forecast of total return of age groups (million fish)	1.086	2.45	0.59	2.62	5.14	5.07	2.53	9.37	8.37	2.95	2.16	4.31	1.96	5.09	1.89	5.90	7.91	9.87
Forecast of whole stock return (million fish)	5.17	3.18	1.96	2.79	5.47	7.92	8.43	9.97	8.90	4.62	7.21	6.74	8.92	7.38	8.58	6.48	8.69	14.30
Deviation of forecast From fact, %	+24	-46	-65	-25	+10	-25	+21	+52	+46	-13	+45	+7	+11	-30	+14	-3	-2	-

Based on the data of abundance of juvenile age groups in the sea and statistics on adult return and abundance of return actual abundance indexes (N_{sp}) and return coefficients of sockeye age groups ($k_{sp} = N_{sp} / N'_a$) were determined. Averaging the data, return coefficients for main age groups for many years were obtained (Table 2). Theoretical indexes of adult returns according to the age were obtained by multiplication of coefficients and abundance of juvenile age groups ($k_{sp} N'_a$).

Total abundance of return of forecasted age groups was multiplied by the coefficient of their portion in the spawning run. Thus, theoretical indexes of the whole stock were obtained (Table 3). Owing to intervals between trawl surveys, expected return of sockeye of kurilskoye stock based on four main age groups of spawners was calculated only for six years (1988, 1989, 1992, 1993, 2004, and 2005). For the other years calculations were based on two age groups in combinations 2.2–3.2 and 2.3–3.3.

In retrospect, estimated deviations of forecasted indexes from actual ones varied from -65 to $\pm 52\%$, and for 11 out of 17 years they did not exceed the limits of 25% range. Spawning sockeye salmon returns estimated on the basis of trawl catch data of late years showed the least range of index fluctuations. Synchronism in fluctuations of calculated and actual indexes of return was more apparent during this period except failure in 2002 (Table 3).

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Video Analysis of the Schooling Behavior of Juvenile Chum Salmon under Light and Dark Conditions Using a Mathematical Model

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Keywords: Schooling behavior, mathematical model, vision, lateral line, juvenile chum salmon

Many fish form schools, which provide several advantages such as protection from predators and improving prey search efficiency (Pitcher and Parrish 1993). Chum salmon (*Oncorhynchus keta*) form small schools when they enter saltwater (Salo 1991). In most cases, the predominant sensory systems used for forming and maintaining schools are vision and the lateral line (Partridge and Pitcher 1980). The object of this study was to investigate the role of vision and the lateral line in the schooling behavior of juvenile chum salmon under different light conditions.

Juvenile chum salmon were collected by a set net in Hakodate Bay (southern Hokkaido, Japan) during June 2005 and held in a circular tank (12,000 liter, diameter 4 m, water depth 1 m) for 3–7 days. Fish of similar size (72.2 ± 6.1 mm body length) were selected for the experiments. An experimental group of fish was placed in seawater containing 0.5 g l^{-1} streptomycin sulphate for 3 hours to deactivate the lateral line system (Blaxter and Fuiman 1989). Experiments were carried out under uniform light intensity. A cylindrical tank (diameter 1.8 m) was used for the experiments. The water column was shallow (10 cm deep) to minimize the vertical movement of fish. The water temperature in the experimental tank was 10°C . The swimming behaviors of the experimental group and a control group (not exposed to streptomycin sulphate) were observed under both light (80 lx) and dark (< 0.01 lx) conditions. The school size examined for each group was 15 individuals randomly sampled from the stock tank.

The two-dimensional motion of individuals during three minute observation periods was digitized and processed, and a fish behavior model (Sannomiya and Matuda 1987; Sannomiya et al. 1993) based on Newton's second law of motion was used to quantify the forces dominating the swimming behavior. In this model, the motions of N_f fish in a school are described by

$$\dot{\mathbf{x}}_i = \mathbf{v}_i \quad (1)$$

$$\begin{aligned} m\dot{\mathbf{v}}_i &= \mathbf{F}_{i1} + \mathbf{F}_{i2} + \mathbf{F}_{i3} + \mathbf{F}_{i4} \\ &= a_i \mathbf{f}_{i1} + k_{wi} \mathbf{f}_{i2} + k_{bi} \mathbf{f}_{i3} + k_{ci} \mathbf{f}_{i4} \end{aligned} \quad (2)$$

where $\dot{\mathbf{x}}_i$ and $\dot{\mathbf{v}}_i$ are the velocity and acceleration vectors, respectively, of individual i ($i = 1, 2, \dots, N_f$), m is the mean mass of individuals, and \mathbf{F}_i is the resultant of four forces that cause the motion of individual i (\mathbf{F}_{i1} , a propulsive force; \mathbf{F}_{i2} , a resultant force of repulsion and attraction from tank wall; \mathbf{F}_{i3} , an interactive force to keep a proper distance between neighbor fishes; and \mathbf{F}_{i4} , a schooling force to make the velocity of each fish uniform).

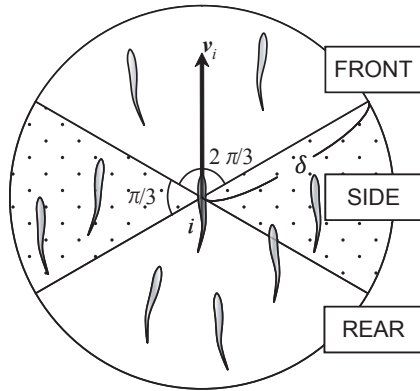
To evaluate the magnitude of each schooling force that is affected by neighbors in three separated areas (Fig. 1), partial schooling forces in front, side, and rear areas, \mathbf{F}_{i4}^F , \mathbf{F}_{i4}^S , and \mathbf{F}_{i4}^R were defined as

$$\begin{aligned} \mathbf{F}_{i4} &= \mathbf{F}_{i4}^F + \mathbf{F}_{i4}^S + \mathbf{F}_{i4}^R \\ &= k_{ci}^F \mathbf{f}_{i4}^F + k_{ci}^S \mathbf{f}_{i4}^S + k_{ci}^R \mathbf{f}_{i4}^R \end{aligned} \quad (3)$$

The magnitude of each force can be compared by estimating the coefficients a_i , k_{wi} , k_{bi} , and k_{ci} from Equation (2). The least squares method was then applied to the linear equations derived observed data in each time step, and the unknown parameters were estimated for an individual in each experimental condition. The parameters in each case were calculated by substituting time-series coordinates for an individual as described as in a previous paper (Suzuki et al. 2003).

The mean values a^* , k_w^* , k_b^* , and k_c^* of the normalized parameters of a_i , k_{wi} , k_{bi} , and k_{ci} were calculated to compare the predominance of each force on the swimming behavior under each experimental condition (Fig. 2). The propulsive force magnitude a^* in all experimental conditions, and the schooling force magnitude k_c^* in both

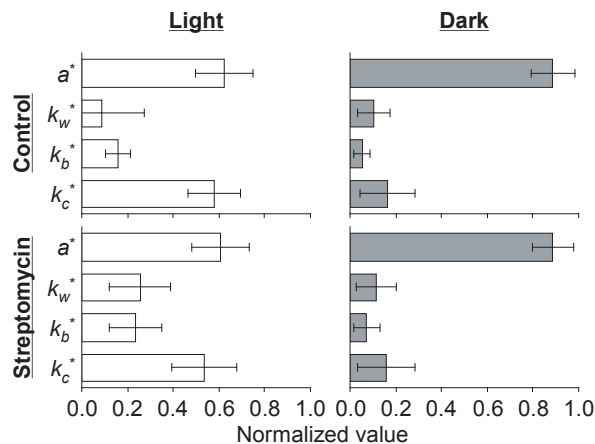
Fig. 1. The three separated areas for evaluating directivity of the schooling force. δ : an influence range for the schooling force.



stronger directivity when using the lateral line than when using vision.

Juvenile chum salmon probably form schools using both vision and lateral line under light condition, and yet they may be more dependent on vision for schooling. Low light condition influences the synchronization of individuals in the school, thus it may reduce their ability to avoid predators, and fishing and sampling gears.

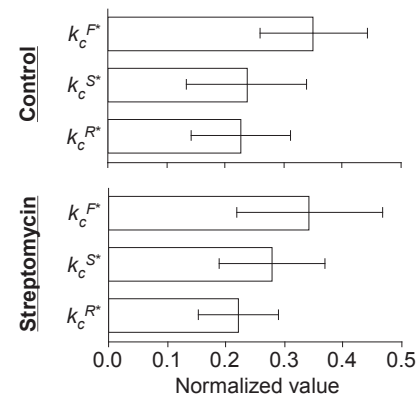
Fig. 2. Normalized values of each force in the model.



groups under light condition were large. Thus, both F_{i1} and F_{i4} dominated the swimming behaviors under light condition, and only F_{i1} dominated the swimming behavior under dark condition. In all experimental conditions k_w^* and k_b^* were relatively small, thus F_{i2} and F_{i3} did not strongly affect the swimming behavior. These results suggest that the crucial function for schooling of juvenile chum salmon is not so much the interactive force as the schooling force, and that they depend on vision to form schools.

The mean values k_c^{F*} , k_c^{S*} , and k_c^{R*} of the normalized parameters of k_{ci}^F , k_{ci}^S , and k_{ci}^R were calculated to compare the predominance to the fish behavior under each experimental condition. Figure 3 shows the results from only the light condition because the schooling force did not strongly affect the swimming behavior in the dark condition. For the control group, k_c^{F*} was significantly larger than k_c^{S*} and k_c^{R*} ($P < 0.05$, Scheffe's test). For the experimental group, k_c^{F*} and k_c^{S*} did not significantly differ. These results suggest that there is

Fig. 3. Normalized values of partial schooling forces in three separate areas.



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Workshop Review

In 2000 the North Pacific Anadromous Fish Commission (NPAFC) adopted a five-year (2001-2005) science plan that focused cooperative research efforts on major gaps in our understanding of the marine life history of salmon with respect to marine ecosystem processes that affect the abundance and biomass of anadromous stocks. The science plan emphasized in three areas: 1) Bering Sea salmon research, 2) juvenile salmon research in eastern and western North Pacific waters, and 3) winter salmon research. In order to increase our understanding of determination of population sizes and our ability to forecast stock sizes, the science plan addressed juvenile salmon research on seasonal distribution and migration, population size and survival estimates, trophic linkages and growth changes, and primary production and salmon food resources. A purpose of the present workshop was to review juvenile salmon research during 2001-2005 for developing new research strategies.

At the Session 1, "National Overviews" were presented by representative scientists. In Canada, juvenile salmon studies are focused in the Strait of Georgia and off the west coast to examine the relationship between climate and marine survival trends, bioenergetics, coastal migration, and food web dynamics. Korean study has focused on early growth and mortality of juvenile chum salmon in rivers. Russia has a long-term monitoring program by trawl surveys in the Okhotsk Sea, northwestern Japan Sea and western Bering Sea to examine the distribution, abundance and feeding habit of juvenile salmon, quantitative abundance of prey organisms, and ocean carrying capacity. Juvenile salmon research in the United States occurs in the wide coastal areas of Alaska, Washington, Oregon, and California to understand how the marine environment influences the migration, distribution, growth and survival of juvenile salmon during their early marine experience. Japanese marine research for juvenile salmon has been conducted in the coastal waters and the Okhotsk Sea to examine their distribution and survival using otolith and genetic marks.

At the Session 2, "Seasonal Distribution and Migration of Juvenile Salmon" was highlighted. In the west coast of North America, a permanent continental-scale tracking array has been developed for acoustically tagged juvenile salmon. This new system demonstrated striking differences in marine migration pathways and survival even between different populations of species, as well as between species. Juvenile salmon research along the eastern Bering Sea shelf also showed that the distribution of juvenile salmon varied among species. Juvenile coho, chinook and chum salmon were distributed near shore in significantly less saline water than the surrounding habitat. Juvenile pink salmon were distributed offshore during even years, but they inhabited also near shore during odd years maybe because of dominance of the even year adult pink salmon returning to western Alaska. Several papers have emphasized that the Okhotsk Sea and western Bering Sea are major habitat for Asian juvenile salmon during summer and fall. In the Aniva Bay of southern Sakhalin, juvenile pink salmon dwelled in coastal zone for 0.8-2.5 months, and their off-shore migration occurred simultaneously, possibly related with sea surface temperature (SST) increase. Japanese surveys in the coastal water of the Okhotsk Sea also indicated that the distribution of juvenile chum salmon was affected by SST. In the Okhotsk Sea and western Bering Sea, the distribution and migration of juvenile chum salmon were influenced by the abundance of large zooplankton, which were the major component of their diet. When water temperature decreased in late fall, Asian juvenile chum salmon left their foraging habitats for the western North Pacific. In winter they were distributed in a narrow range of lower temperature: the estimated temperature at the center of salmon distribution was 4.7°C in the western North Pacific, and 6.1°C in the eastern North Pacific. Chum salmon inhabited cooler waters, maybe because the abundance of prey zooplankton increased with decreasing water temperature in the western North Pacific.

The topic of Session 3 was "Trophic Linkages, Feeding and Growth of Juvenile Salmon". Juvenile pollock, sand lance, and capelin were dominant in the diets of juvenile salmon in the eastern Bering Sea shelf and northern Okhotsk Sea. Consumption demand on prey resources by juvenile pink salmon in the coastal Gulf of Alaska varied spatially across oceanic habitats, and the growth potential metric holds promise in its ability to explain variability in the marine survival of pink salmon. In the Okhotsk Sea coast of Hokkaido, cool ocean conditions might affect the growth and survival of juvenile chum salmon. Russian scientists assessed seasonal amounts of food consumed by juvenile salmon in the western Bering Sea during the fall. Juvenile salmon utilized 112-154 thousand tons of different zooplankton and nektons, while other major fish species have consumed 6.4-8.9 million tons of food animals.

The Session 4 dealt with "Climate Changes and Ocean Ecosystem". Climate variability, fishing, carrying capacity, and nutrients are important forces driving the growth and survival during the early life stages of salmon

in the ocean. The stable isotope analysis indicated significant inter-annual variability in diet overlaps and trophic interactions among salmon species, and trophic shifts within each of the species as a function of body size. It would be fundamentally important to develop comparative food web modeling of salmon in Eastern versus Western Bering Sea, because there are major diet differences. In the Okhotsk Sea, the growth of juvenile chum salmon increased in the 1990s, in association with increase in the SST during summer and fall, and decrease in the sea ice concentration. Thus their survival and growth in the Okhotsk Sea may be affected by climate changes such as the global warming.

“Population Size and Survival Estimates of Juvenile Salmon” was adopted at the Session 5. Marine survival of salmon is related to size and growth rate during juvenile and subsequent life stages. Juvenile pink salmon in Prince William Sound and the coastal Gulf of Alaska exhibited a 3-fold difference in marine survival during 2001–2004. High survival was associated with broader spatial distribution, greater feeding rates, faster growth and larger size during the first summer of ocean feeding. Significant size selective mortality occurred after the summer growing season. An opposite phenomenon was observed by Japanese scientists. In the coast of Nemuro Strait, eastern Hokkaido, 2000 brood year chum salmon juveniles had much higher growth rates than other brood years due to high prey production, but their adult return was the least abundant. Winter is generally considered to be a critical period in the early life of salmon. Size-selective mortality was apparent for juvenile chinook salmon in southeast Alaska. Size-selective mortality may regulate the dynamics of salmon at northern latitudes, but not at southern latitudes. Larger salmon utilized a larger fraction of their energy reserves over winter than smaller salmon.

At the final panel session, four questions were raised: 1) Why juvenile salmon inhabit in the continental shelf of the Bering Sea and Gulf of Alaska or the open water of the Okhotsk Sea during summer/fall? 2) Where, When, and How does mortality occur on juvenile salmon in the oceans? 3) What causes the fluctuations in marine survivals of juvenile salmon? 4) Future juvenile salmon research? In at least some species of anadromous stocks (e.g. pink and chum salmon), variation in adult returns may depend more on marine survival than on reproductive efficiency during the freshwater period. A common hypothesis is that the initial period of after migration to sea is the most critical phase with respect to ocean survival of anadromous stocks. Many papers have suggested considerable interannual variation in abundance, growth, and survival rates of juvenile salmon in the ocean. These variations may be related to climate-induced changes in habitat environments that operate at regional and local scales. To a greater or lesser extent, these processes are monitored annually in marine survey areas along the coasts of Asia and North America. A better understanding of these processes is needed for conservation and management of anadromous stocks. Future cooperative research may focus on 1) seasonal distribution and migration route/timing of juvenile salmon; 2) hydrological characteristics, primary production, and prey resources in the habitats; 3) trophic linkages, growth rates and predation rates of juvenile salmon; and 4) population size, survival rate and survival mechanism of juvenile salmon.

Shigehiko Urawa
Chair of the Workshop Organizing Committee

List of Participants

<i>Canada:</i>	Beamish, Richard Kristianson, Gerry Mazumder, Asit Trudel, Marc	<i>Korea</i>	Kang, Sukyung Lee, Chae Sung Park, Jung Youn
<i>Japan</i>	Abe, Syuiti Awakura, Teruhiko Azumaya, Tomonori Ban, Masatoshi Fujiwara, Makoto Fukuwaka, Masa-aki Hasegawa, Eiichi Hino, Hiroshi Ikeda, Masashi Imai, Naotaka Ito, Fumio Izawa, Toshiki Kaeriyama, Masahide Kaga, Toshiki Kaneko, Tomomi Katsuyama, Kiyoshi Kudo, Hideaki Kuribayashi, Takanori Mingist, Minwelet Mio, Ikue Miyashita, Kazushi Miyakoshi, Yasuyuki Nagasawa, Toru Nagata, Mitsuhiro Nakayama, Hirofumi Nomura, Tetsuichi Ohkuma, Kazumasa Sagawa, Yosuke Saito, Toshihiko Sasaki, Ritsuko Sasaki, Yoshitaka Sato, Shunpei Sawada, Mayumi Seki, Jiro Shimizu, Munetaka Shimizu, Ikutaro Shimizu, Yuichi Sugiwaka, Keiichi Suzuki, Katsuya Suzuki, Toshiya Takahashi, Masaya Teruhiko, Awakura Toda, Shuichi Ueda, Hiroshi Urawa, Shigehiko Yamamoto, Yuzo Yoon, Moongeun Yoshimitsu, Shunji	<i>Russia</i>	Karpenko, Vladimir Koval, Maxim Naydenkko, Svetlana Nazarov, Victor Radchenko, Vladimir Sharov, Petr Starovoytov, Alexander Sviridov, Vladimir Temnykh, Olga Volobuev, Vladimir
		<i>United States</i>	Beauchamp, David Caouette, Brian Farley, Ed Helle, Jack Low, Loh-Lee Rand, Peter Seeb, Jim Young, Sewall
		<i>NPAFC Secretariat</i>	Fedorenko, Vladimir Morris, Wakako Uoya, Toshinori

