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## **TECHNICAL REPORT 6**

### **Workshop “BASIS-2004: Salmon and Marine Ecosystems in the Bering Sea and Adjacent Waters”**

**Edited by:** Tomonori Azumaya, Richard Beamish, Jack Helle,  
Sukyung Kang, Vladimir Karpenko, Chae Sung Lee,  
Katherine Myers, Toru Nagasawa, Olga Temnykh and  
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# **Workshop “*BASIS-2004: Salmon and Marine Ecosystems in the Bering Sea and Adjacent Waters*”**

***Sapporo, Hokkaido, Japan, October 30-31, 2004***

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## **Foreword**

The International Workshop “BASIS-2004: Salmon and Marine Ecosystems in the Bering Sea and Adjacent Waters” was held in Sapporo, Hokkaido, Japan, on October 30–31, 2004. 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 80 scientists, industry representatives, and fisheries officials attended the Workshop. There were 20 oral presentations including two keynote addresses, followed by a panel and summary session, and 27 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 The material presented in this Technical Report has not been peer reviewed, and does not necessarily reflect the views of the NPAFC or the Parties. Some work may be preliminary. The material has been edited for clarity and publication purposes only.



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## Opening Remarks

The Bering-Aleutian Salmon International Survey "BASIS" program, which is the key element of the 2001–2005 NPAFC Science Plan, was started in 2002. The goal of the BASIS is to understand the mechanisms underlying the effects of environmental variation and density-dependence on the salmon-carrying-capacity of the Bering Sea for sustainable conservation of salmon stocks in the North Pacific.

In 2002–2004, many scientific surveys were carried out in the Bering Sea under this program. The meaningful international cooperation was achieved by the member countries in joint surveys, exchange of samples and data, and analyses of research results. This program has been very successful so far. However, in order to accomplish the final goal of the BASIS, we need to evaluate the progress of the BASIS to date. The major objectives of this workshop are: to review the results of recent researches in the Bering Sea, and to discuss the new problems discovered by the BASIS research. The discussions will be used for planning future BASIS research and cruises. I believe that results of this workshop will provide us with the new knowledge about salmon and the Bering Sea.

I would like to extend my thanks to the persons who did the planning for the BASIS program and who have been doing investigation in the Bering Sea. I also appreciate the NPAFC Secretariat's efforts for preparing the workshop and this Technical Report.

Tomonori Azumaya  
*Chair of the Workshop Organizing Committee*





## **BASIS as a Model for International Scientific Collaboration: the Project is Greater than Just the Sum of its Parts**

**Fran Ulmer**

U.S. Representative to the North Pacific Anadromous Fish Commission 1994–2004  
1700 Angus Way, Juneau, Alaska 99801, USA



I am pleased to be able to join you here in Sapporo to listen to your presentations and learn from your research and analysis. I am honored to have the opportunity to offer some comments this morning about the importance of your work and its relationship to other cooperative efforts to expand our understanding of ocean life.

During the last century, many nations developed processes for managing natural resources, because they recognize that higher concentrations of humans and their demand for natural resources required some governmental regulation and protection. Those processes began simply and evolved into complex local, regional, national and international systems. Based on both public input and scientific information, decision-makers attempted to provide the necessary guidance to both utilize and protect the resources, some wisely and some poorly. Legal requirements and official mandates vary greatly. Some assure sustained yield harvests and attempt to achieve long-term sustainability; others guarantee specific levels of harvest to provide economic and social benefits.

The wide range of both goals and implementation strategies share one common characteristic: the need for information upon which to make decisions.

Demand for reliable information has increased interest in scientific research and data accumulation. However, obtaining the necessary financial support to conduct that research has been difficult. The rapid rate of change of both natural systems and human impacts upon them accelerates the need for more data and research, at the same time that governments are reducing budgets. Under these circumstances, it seems prudent to look for new funding sources and to evolve the most efficient ways to use the resources that are available.

All of these considerations make it even more appropriate to look beyond national borders to get the job done. Pooling of resources and sharing of time, talent and information all help to stretch capacity. Moreover, many of the questions about natural systems, particularly ocean systems, can only be answered with international collaboration. This is particularly true for research on anadromous fish in the North Pacific, where five countries contribute fish to the area, Japan, Russia, Korea, Canada and the United States.

The North Pacific Anadromous Fish Commission is an excellent example to the world of how nations can work together productively in the stewardship of their shared marine resources and ecosystems. For several years, scientist from these countries have worked together to share information and to jointly conduct research under BASIS, the Bering Aleutian Salmon International Survey.

BASIS is an NPAFC coordinated program of ecosystem research on salmon in the Bering Sea. The major goal of the program is to clarify how changes in ocean conditions affect the survival and growth of salmon. The BASIS Research Plan calls for synoptic research vessel operations across the entire Bering Sea 2002–2006 to collect information on oceanographic conditions, salmon and associated species. The results will help clarify the mechanisms of biological response to the conditions influenced by climate change (see Myers 2004).

BASIS is unique in its level of cooperation and productivity. It has an unusual foundation: a treaty signed in 1992 by the member nations enabling them to share data and resources for a common mission (the protection of anadromous fish).

However, its success lies in something else: mutual trust and respect among the participating scientists and the shared vision that no one country can accomplish this mission alone. Joint research cruises enable participation of scientists from several countries and facilitate the sharing of research technology, methodology and results. New genetic techniques, mass marking strategies, and the use of “smart” tags are being applied to study distribution of salmon stocks. Data storage tag (DST) recoveries in 2003 provide insight into salmon migration routes. Studies of salmon diets are casting new light into the early life history and survival of salmon.

This workshop in Sapporo provides a forum for the exchange of research results by scientists from Japan, Canada, Russia, Korea and the United States, and for additional standardization of sampling gear, data and analysis. I applaud the efforts of the workshop participants to continue the quest for greater understanding of this precious salmon resource and the ecosystems that support it and I thank you for your remarkable level of collaboration and cooperation.

Now more than ever, this approach of working together is needed.

Recent efforts to assess the status of the health of the oceans have produced reports that are alarming. According to the U.S. Commission on Ocean Policy and the Pew Ocean Commission, there is an emerging

consensus that our oceans are in crisis and reforms are essential. See [www.pewoceans.org/oceans](http://www.pewoceans.org/oceans) and [www.oceancommission.gov/documents](http://www.oceancommission.gov/documents)

Experts identify the four major challenges that threaten ocean health as overfishing, incidental by-catch, pollution, and habitat destruction. Both Commissions document these challenges and make compelling arguments for addressing them.

I would add one more challenge: the lack of information and understanding of the complex bio systems of our seas and oceans. Over 90% of the globe's oceans remain unexplored below the surface, and only a small amount of public and private research funding supports these efforts.

Will this change? Many experts think that the time is right for a huge change in the amount of attention paid to oceans. According to Roger Rufe, President of the Ocean Conservancy, "This is a seminal moment."

The United States Council on Environmental Quality's Director James Connaughton said: "Restoration, wise use and conservation of the oceans has come to the forefront of environmental priorities, not just for the nation but for the world. There's a massive bipartisan and regional consensus toward embarking on a new generation of progress." (The Washington Post, 10/09/04)

The Pew Ocean Commission recommends doubling the funding for basic ocean science and research, and developing a comprehensive ocean research and monitoring strategy.

The U.S. Commission on Ocean Policy's Final Report "An Ocean Blueprint for the 21<sup>st</sup> Century" recommends an eco-system based management approach, a new coordinated ocean policy framework and "cutting edge ocean data and science translated into high quality information for managers". The Commission also recommends doubling the nation's investment in ocean research and launching a new era of ocean exploration.

Whether the United States follows through on these recommendations and what level of support it contributes to the effort remains to be seen. Whether other nations move ocean research higher on the agenda also is unclear.

But to make progress, it is not up to just the heads of state or the directors of research organizations. It is also up to those of us who have had some experience with successful collaborative efforts, like BASIS; we must make every effort to inform others of what is possible and why it is needed.

BASIS has already produced positive results, both useful information and positive peer relationships. It offers an excellent example to other organizations and regions of how to undertake complex international research in the most meaningful and efficient way. All of the countries contribute resources (vessels, researchers, transportation support, analysis or supplies) and all of the countries have access to the accumulated information, which they can use, for additional analysis, interpretation and publication. Representatives from all of the countries participated in designing the research plan that guides the BASIS effort and all are welcome to share their results and ideas at annual meetings and workshops.

I would like to encourage you all to do continue the sharing process after this workshop and beyond Sapporo, as well. Policy makers, regulators, fishermen, community leaders, university faculty, foundation and grant giving organizations and media representatives must be educated about BASIS. They need to know about the progress underway at NPAFC to provide a new paradigm for international science and information sharing. I for one, plan to do so whenever the opportunity presents itself. One of those opportunities will be in Anchorage, Alaska next April at the 2005 State of the Salmon Conference. The sponsors hope to forge new alliances across the North Pacific to create a common baseline of knowledge regarding best practices in salmon management.

Many people see the need for common efforts, but few organizations have laid the groundwork as successfully as you all have in actually achieving them. It will be easier to develop the necessary financial support to see your work continue and grow if more potential funders come to understand what you have already accomplished and the opportunity that this model provides. I hope that before leaving tomorrow, you will recommit yourselves to sharing the results, the experiences and the vision of BASIS back home, wherever that might be.

In closing, I want to thank NPAFC for inviting me to participate, and to thank each and every one of you for the contribution that you are making to our improved understanding of the oceans and our world.

## REFERENCES

Myers, K.W. 2004. BASIS Research Results in 2003. N. Pac. Anadr. Fish Comm. Newsletter 16: 4-5.

# North Pacific Ocean Carrying Capacity—Is it Really too Low for Highly Abundant Salmon Stocks? Myths and Reality

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**Keywords:** Carrying capacity, salmon, growth, trophic structure

Carrying capacity is the ability of an environmental system to sustain reproduction and normal function of a given number of organisms. As for salmon-related issues concerning carrying capacity of the Subarctic Pacific and the Far Eastern seas, special attention is usually given to the amount of food available for salmon during their marine forage stage implying direct and indirect influence of prey-related factor. In this respect, much attention is given to competitive relationships between chum and pink salmon. This problem was first outlined by Japanese and American scientists (Ishida et al. 1993; Ogura and Ito 1994; Welch and Morris 1994; Bigler et al. 1996; Azumaya and Ishida 2000), and later was considered by Russian researchers (Volobuev 2000; Volobuev and Volobuev 2000; Gritzenko et al. 2001; Klovach 2003).

We believe that some of conclusions from these studies suggested too dramatic a course of events and hardly reflected the real pattern. The following statements seem groundless:

- the North Pacific carrying capacity has been surpassed for salmon stocks, and they are thought to experience degradation along with enhancement of hatchery chum stocks;
- extremely high abundance of chum has led to drastic rearrangements in the trophic structure of the North Pacific pelagic communities;
- pink salmon forces out and even suppresses chum salmon in most areas of their shared habitat. One of the exclusive statements is that these species exemplify the Gause principle of competitive elimination;
- chum salmon was forced to make an adaptive shift towards low-calorie prey (gelatinous species), which resulted in weakening of its skeletal musculature and in other pathologic body changes;
- salmon prey availability may be extremely low, especially in winter.

Large-scale comprehensive investigations conducted by TINRO-Centre made it possible to collect an expanded amount of data on these and related issues of salmon marine ecology, and in most cases these observations resulted in a different point of view on the above mentioned statements.

1. The greater part of the marine life of salmon is spent in deep-water regions, and this is shown by data on salmon species distribution in the Far Eastern seas and northwestern Pacific. Nektonic species density in deep-water regions is lower than in shelf areas, and is especially low in the upper epipelagic zone where most salmon stocks are distributed. The plankton to nekton biomass ratio exceeds several tens and even hundreds in the offshore epipelagic zone, while on the shelf it is usually significant lower. These observations imply that the density factor and intensiveness of competition for food should decrease oceanward. During the course of their ecological history, Pacific salmon species were successfully incorporated into the upper epipelagic zones of the vast pelagic biotopes distributed over deep-water regions of the seas and oceans. These areas contained plentiful food resources, and were weakly occupied by nekton.

2. However, during each season salmon occupy just a part of the potential distribution area. Thus, food competition may occur due to high abundance of salmon under condition of low plankton concentrations. This may affect their growth rate.

Inverse relationships between weight and total abundance of pink salmon were observed for both even- and odd-year generations during their summer migrations to the coast in the Okhotsk Sea (Table 1). On another hand, there is no definitive dependence of weight and abundance in odd and even generations of pink salmon from western Bering Sea stocks (Fig. 1). The average body sizes of more abundant odd-year generations pink salmon were larger than those of even-year generations for all Japanese stocks (Table 2). There is no definitive dependence of size and feeding rate upon macroplankton concentration for the Okhotsk Sea pink salmon stocks (Table 1) and the Bering Sea pink salmon stocks. These results may be indicative of much more complicated relationships between salmon sizes and the forage base.

The density dependence of stocks is a well-documented process, and it may impact salmon during their marine and oceanic forage period. However, variability in the size and growth rate of fish does not necessarily reflect the influence of a density factor, because these characters are not always dependent upon fish abundance and the abundance, quality, and availability of prey. Temperature and other hydrological factors, as well as heredity, may

influence the metabolic processes of fish, including growth rate. The known genetic components of growth and their impacts are clearest in highly structured stocks. All the above mentioned observations suggest that not all of the factors responsible for the observed changes in the size structure of pink salmon stocks are known at present time.

3. Pink and chum salmon are key species for understanding salmon biology and dynamics of abundance. As mentioned above, some authors even suggested that these two species might exemplify a principle of competitive elimination (Volobuev and Volobuev 2000). From our point of view, these conclusions are groundless. The results of most Russian investigations conducted in Asian waters since the 1980s have suggested that chum and pink salmon are somewhat different in terms of trophic relationships (Volkov 1996; Naidenko 2002, 2003; Naidenko and Kuznetsova 2002; Kuznetsova 2004; Temnykh et al. 2004).

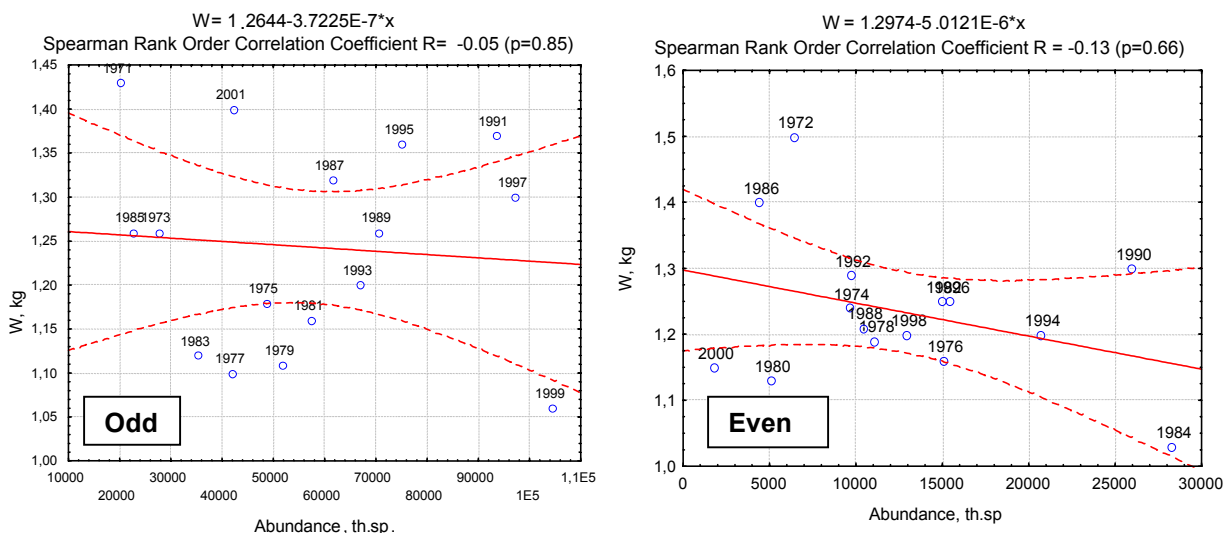
**Table 1.** Correlation matrix for relationships between parameters indicating the abundance and size of pink salmon from the Okhotsk Sea stocks, feeding intensity, and concentration of prey organisms in 1991–2003. 1 – pink salmon biomass,  $10^3$  t; 2 – average pink salmon weight in the Okhotsk Sea, kg; 3 – average pink salmon weight in Kuril oceanic waters, kg; 4 – feeding intensity of pink salmon in the Okhotsk Sea, 0/000; 5 – feeding intensity of pink salmon in Kuril waters, 0/000; 6 – macroplankton biomass in the southern Okhotsk Sea,  $t/km^2$ ; 7 – biomass of euphausiids, hyperiids and pteropods,  $t/km^2$ ; 8 – biomass of small nekton (fishes, squids),  $t/km^2$ . Statistically significant correlation coefficients are marked by bold font.

	1	2	3	4	5	6	7	8
1	1	<b>-0.66</b>	<b>-0.64</b>	0.19	-0.22	-0.35	-0.12	-0.01
2	<b>-0.66</b>	1	0.62	-0.17	0.23	-0.23	-0.44	0.45
3	<b>-0.64</b>	0.62	1	0.30	0.36	-0.19	-0.31	0.19
4	0.19	-0.17	0.30	1	-0.24	-0.05	-0.04	-0.13
5	-0.22	0.23	0.36	-0.24	1	-0.19	-0.28	0.23
6	-0.35	-0.23	-0.19	0.05	-0.19	1	<b>0.81</b>	-0.33
7	-0.12	0.44	-0.31	-0.04	-0.28	<b>0.81</b>	1	-0.37
8	-0.01	0.45	0.19	-0.13	0.23	-0.33	-0.37	1

**Table 2.** Average catches ( $10^3$  t) and weight (kg) of pink salmon from Japan sea stocks in 1971–2002.

Stocks	Odd- year generations		Even- year generations	
	Average catches	Average weight	Average catches	Average weight
Amur	1.2	1.32	1.96	1.17
Western Sakhalin	4.4	1.37	1.68	1.08
Primorye	2.1	1.66	1.88	1.27
Average total catches	7.7		5.52	

**Fig. 1.** Relationship between body weight and total abundance of pink salmon in the eastern Kamchatka region. th.sp. = thousands of fish

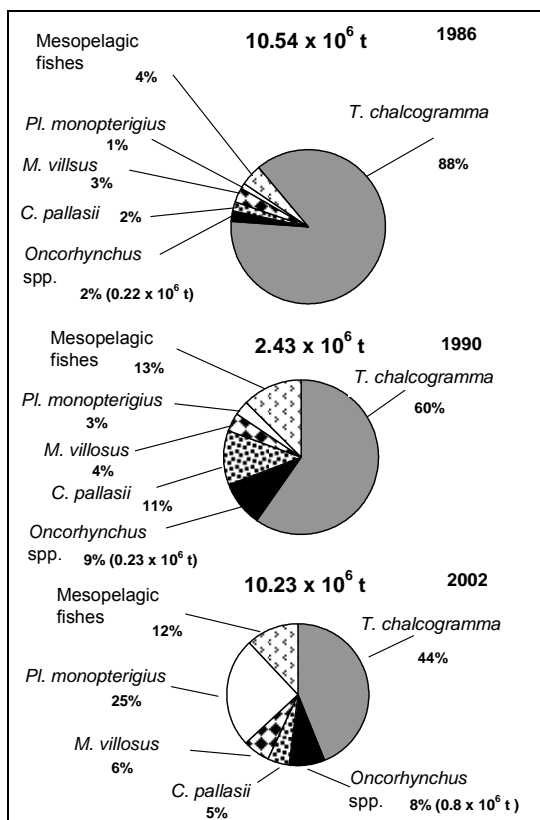


In the case of chum salmon, special attention should be paid to the gelatinous groups of prey. According to some researchers (Gritzenko et al. 2001; Klovach 2003), the feeding of chum salmon on gelatinous prey reflected an induced adaptation that resulted from food deficiency due to high abundance of chum and other salmon species, as well as competition with pink salmon. These groups of gelatinous prey may account for up to 30–50% or more of the total fish ration. However, a high occurrence of gelatinous animals was especially characteristic of mature fish distributed closer to the coast (Naidenko and Kuznetsova 2002; Starovoitov 2003; Temnykh et al. 2004). This indicates to us that these planktonic prey organisms may be important for fish physiology.

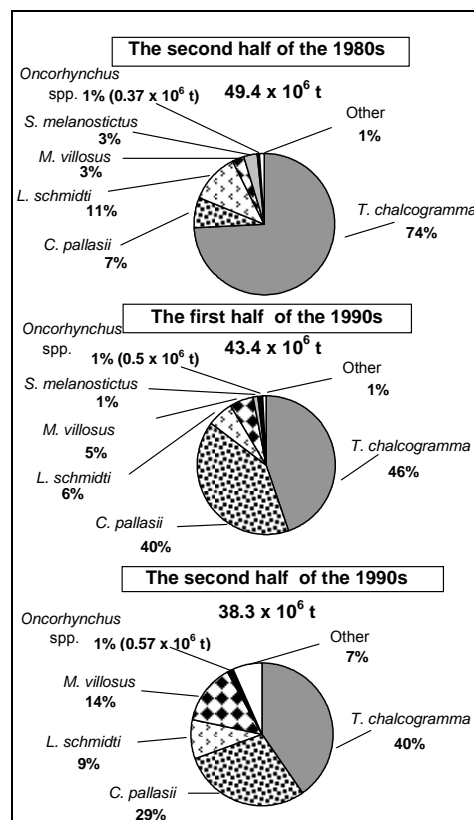
4. In order to test conclusions about salmon overpopulation in the North Pacific and rearrangement of energetic pathways in ecosystems related to high abundance of hatchery chum, it is necessary to analyze the trophic structure of nektonic communities in general and to estimate forage resources of the pelagic zone. In this respect, the point should be stressed that the scale of salmon aquaculture and the amount of food consumed by salmon species in general are much lower than the capacity of pelagic ecosystems and even separate trophic levels and their components. We have already noted (Shuntov et al. 1993; Shuntov 2001; Dulepova 2002) that the biomass and production of zooplankton and especially macroplankton are frequently underestimated by several times in modern-day publications. Salmon input into the trophic structure of pelagic communities is generally low, and an additional several hundred thousand tons of artificially reared salmon cannot significantly change this trophic structure.

Long-term dynamics in the amount of plankton consumed by nekton in the western Bering and Okhotsk seas may serve as examples. In the Bering Sea, the total absolute amount of food consumed by salmon increased only slightly from 1986 to 1990 (Fig. 2). However, the share of prey consumed by salmon in the total amount of prey consumed by all nektonic species increased from 2% in 1986 to 9% in 1990. This level has remained stable, accounting for 8% of prey consumed by all nektonic species in 2002, though the absolute amount of prey consumed by salmon was approximately three times higher than in 1990. In the Okhotsk Sea, the amount of food consumed by salmon increased during the 1990s, and was especially high by the late 1990s due to the rise in salmon abundance, primarily pink salmon and to a lesser extent chum salmon (Fig. 3). The share of food consumed by salmon persisted at a low level of approximately 1%, though the absolute numbers increased two times (from 0.7% to 1.5%; Temnykh et al. 2004). Though the amount of plankton consumed by nektonic animals is very high, it presumably does not exceed 10% of all the plankton production (Shuntov et al. 1993).

**Fig. 2.** Consumption (%) of zooplankton by abundant fish species in the epipelagic zone of the western Bering Sea during autumn (Temnykh et al. 2004).



**Fig. 3.** Consumption (%) of zooplankton by abundant fish species in the epipelagic zone of the Okhotsk Sea during summer (Temnykh et al. 2004).



All these data suggest that though salmon species consume a large amount of food, especially during periods of high abundance, their role in trophic chains is far from being highly important. Even two- or three-fold variations in Pacific salmon abundance will hardly lead to significant changes in the trophic structure of nektonic communities. It is worth mentioning here that many highly important nektonic fluctuating species (pollock, sardine, herring, anchovy, mackerel, squids, etc.) regularly experience sharp variations in abundance, sometimes of one or two orders of magnitude, and their distributional ranges are smaller than those of salmon. At the same time, in spite of high variability of the species abundance and community structure (including trophic structure) there is no real base for considering these as critical or crisis events.

5. A number of observations also support the idea that salmon stocks are below the North Pacific carrying capacity, and that salmon do not overpopulate epipelagic ecosystems. These are as follows:

- (a) A record number of salmon was estimated for the Russian sector of the Bering Sea in 2002–2003 ( $465\text{--}936 \times 10^3$  t). However, daily rations of salmon were maintained at the level observed in previous years (Efimkin in press).
- (b) The most abundant salmon species (pink, chum, and sockeye) are known for highly expressed prey selectivity, especially during periods when their numbers are high. In particular, they prefer hyperiids and pteropods, which are subdominant groups in plankton communities.
- (c) All salmon species can feed during any time of the day, though they prefer feeding in daytime and evening hours. If necessary, they may replenish their ration at night when concentrations of macroplankton and small nekton become notably higher in the upper water layers.
- (d) Small-sized nektonic species (fishes, squids) are important prey items for salmon. Feeding upon these animals, salmon leave valuable quantities of small- and medium-sized plankton from being consumed, adding to the total zooplankton biomass.
- (e) An increase in the abundance of any marine species is accompanied by expansion of their distributional ranges. Such a trend has been particularly observed in the late 20th century when an increase in abundance of chum from Japanese hatcheries resulted in extension of its marine range (Ogura and Ito 1994). The idea that salmon species do not overpopulate the North Pacific is also supported by their low occurrence in some areas.

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## Which Salmon are using the Bering Sea as their Feeding Area? (Japanese National Overview of BASIS Research)

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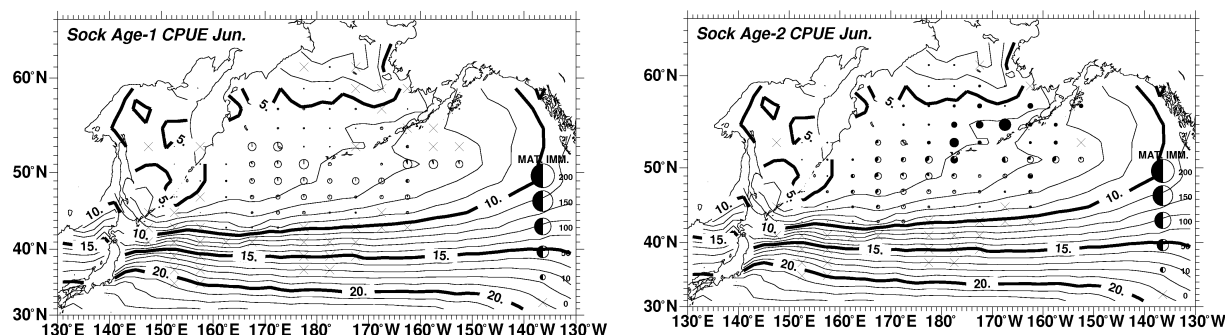
Keywords: Bering Sea, distribution, chum salmon, sockeye salmon, pink salmon

Japanese high-seas salmon research in the North Pacific Ocean was initiated in 1952. Research gill-nets have been the standard gear used for the high-seas salmon studies (Takagi 1975). June to August was the most common time for these surveys (Ishida and Ogura 1992). Japanese research activity under BASIS began in 2002, and this research uses surface trawls to cover the high-seas waters of the central Bering Sea.

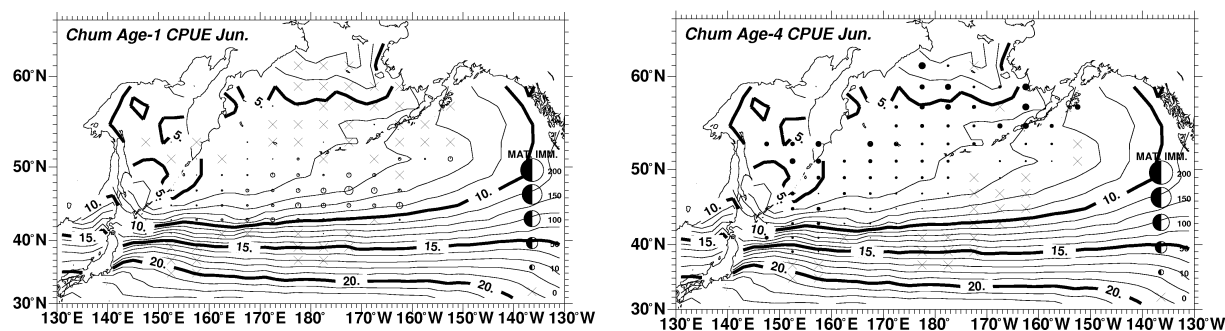
We expect the data from BASIS will result in new and extensive knowledge on the biology of salmon in the Bering Sea ecosystem. However, because the BASIS data is in the initial phase of collection and analysis, we will provide a retrospective analysis of the drift-net data from 1972–2000 for comparison with the newer surface trawl data. Of special interest is the comparison of distribution of species by age.

Mean catch-per-unit-effort (CPUE) of juvenile or immature sockeye salmon was relatively low in the Bering Sea in June; while, maturing sockeye were common and relatively abundant in June near Bristol Bay (Fig.1). Chum salmon of age 0.1 were rare in the Bering Sea in June. Older chum salmon (age 0.4) were usually more abundant in the northern Bering Sea, even in June (Fig. 2). Apparently, older chum salmon enter the cool Bering Sea earlier than younger chum. Maturing pink salmon were more abundant in the western part of the North Pacific than in the

**Fig. 1.** Mean CPUE distribution (research gillnet) of sockeye salmon calculated by age group, by month ( $2^{\circ} \times 5^{\circ}$  mesh, average from 1972 to 2002) in the Bering Sea and adjacent waters. Left shows for age X.1 age sockeye salmon. Right shows X.2 age sockeye salmon in June.

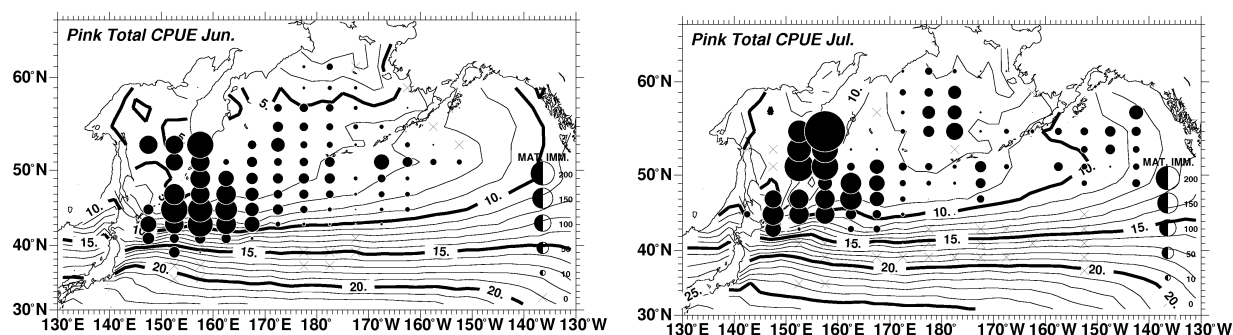


**Fig. 2.** Mean CPUE distribution (research gillnet) of chum salmon calculated by age group, by month ( $2^{\circ} \times 5^{\circ}$  mesh, average from 1972 to 2002) in the Bering Sea and adjacent waters. Left shows for age 0.1 chum salmon, right shows 0.4 age chum salmon.

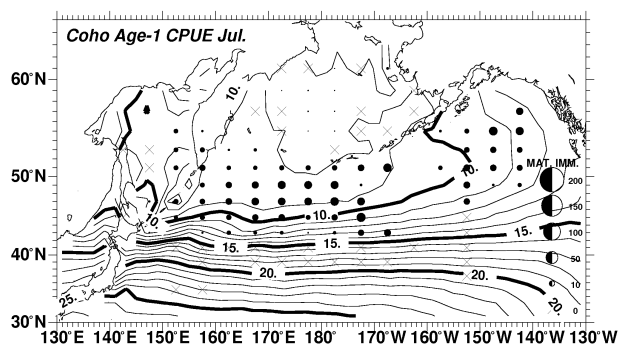


Bering Sea (Fig. 3). Although maturing pink salmon of eastern Kamchatka and western Alaska stocks appear in the Bering Sea in June, they must return to their natal rivers by August. Coho salmon were relatively rare in the Bering Sea in each month, but abundant in the northern North Pacific Ocean (Fig.4). It seems that the Bering Sea is not an important feeding area for most stocks of coho salmon. Although a few chinook salmon were captured during the surveys, they occurred widely in the Bering Sea and northern North Pacific from June to August (Fig. 5). Although many maturing pink salmon feed in the Bering Sea, their feeding period is shorter than other Pacific salmon which have longer ocean life. Thus, it appears that the Bering Sea is an especially important feeding area for salmon which have long ocean life periods (e.g. chum, sockeye and chinook).

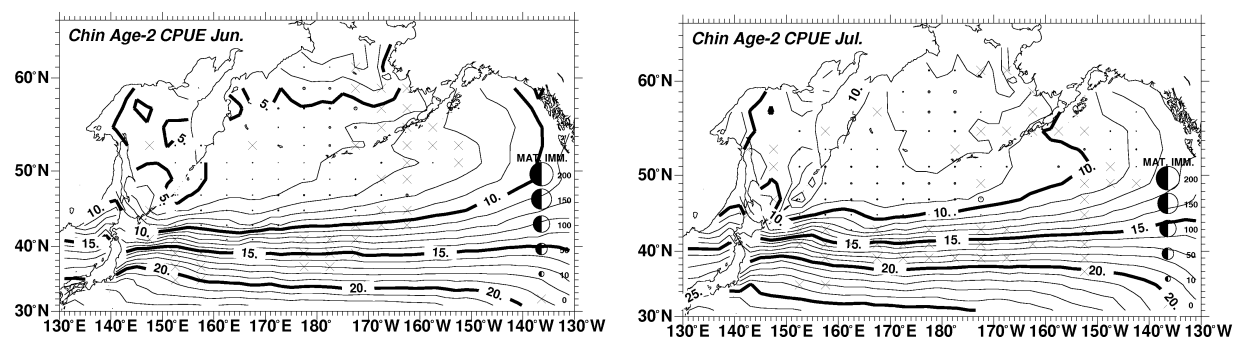
**Fig. 3.** Mean CPUE distribution (research gillnet) of pink salmon calculated by age group, by month in the Bering Sea and adjacent waters in June (left) and July (right).



**Fig. 4.** Mean CPUE distribution (research gillnet) of coho salmon in the Bering Sea and adjacent waters in July.



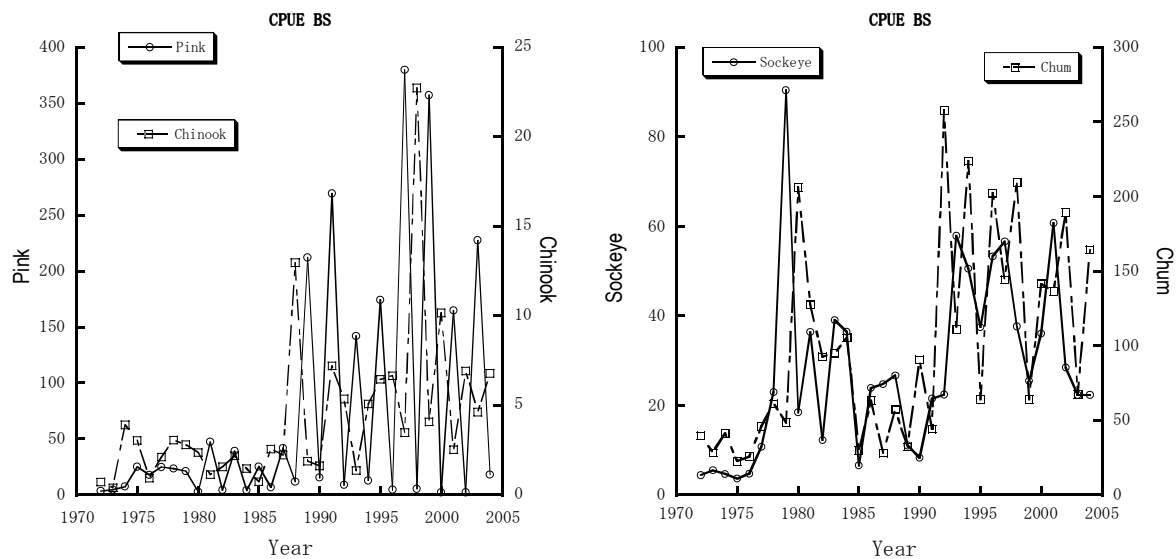
**Fig. 5.** Mean CPUE distribution (research gillnet) of X.2 age chinook salmon calculated by month ( $2^\circ \times 5^\circ$  mesh, average from 1972 to 2002) in the Bering Sea and adjacent waters in June and July.



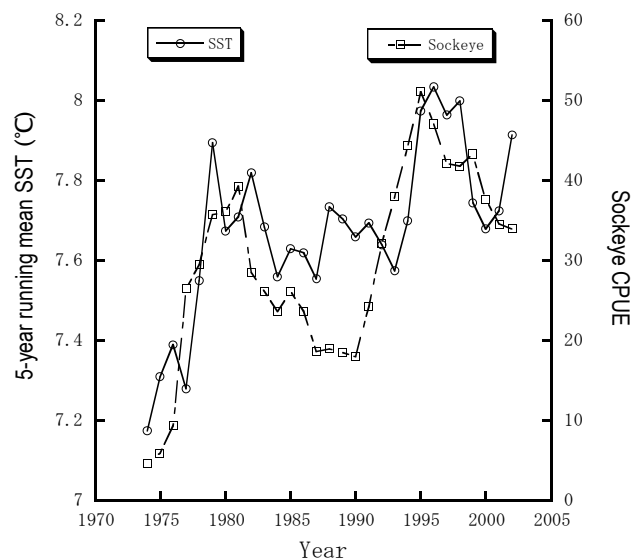
Two distinct patterns are apparent in CPUE of salmon (Fig. 6). The CPUE of pink and chinook salmon increased after 1988 and has remained at this level to present. Whereas, the CPUE of sockeye and chum salmon was low prior to 1977, peaked in 1980, declined until 1989, and then increased until the present. The CPUE trends of sockeye and chum salmon seem to coincide with fluctuations in Bering Sea, sea surface temperature (SST) where higher densities of sockeye and chum salmon in the Bering Sea occur during warm periods and lower densities occur during cool periods (Fig. 7).

We have concentrated our research on distribution and biology of pacific salmon during the season from late spring to late summer. We definitely need to add winter and early spring surveys to the BASIS program.

**Fig. 6.** Time series of mean CPUE (research gillnet) of four Pacific salmon species in the Bering Sea.



**Fig. 7.** Time series of five year running mean SST and sockeye salmon CPUE in the Bering Sea.



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## Russian National Overview of BASIS Research

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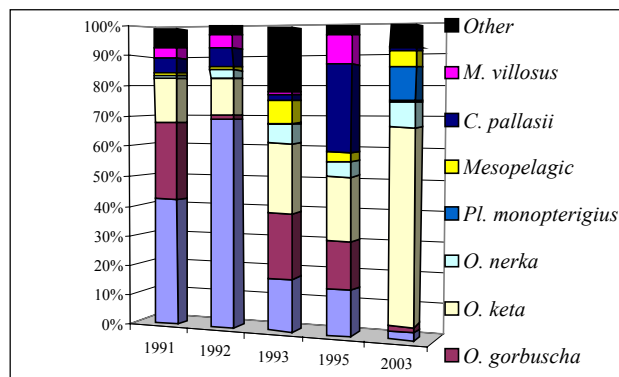


**Keywords:** Nekton community, salmon, biomass, distribution

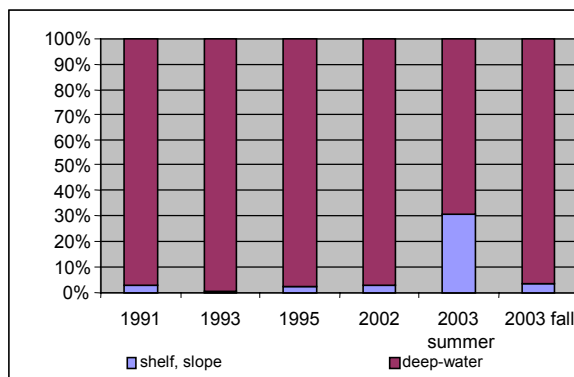
BASIS research by the R/V *TINRO* was conducted in the fall of 2002 (86 sampling stations) and summer and fall of 2003 (176 sampling stations) in the western Bering Sea and adjacent Pacific waters. Each sampling station included a trawl tow, as well as, hydrobiological and hydrological stations, which were carried out in accordance with standard methods of TINRO-Centre (Temnykh et al., 2004). The results of Russian research within BASIS program (2002 and 2003) are as follows:

1. In 2002 and 2003 the tendency of hydrological processes in the western Bering Sea followed a warm year type. Intensification of water exchange between the Bering Sea and Pacific Ocean was accompanied with the rise of SST and the increase of its discharge through the Kamchatsky Strait (Khen and Basyuk 2005).
2. During the last two years, a marked decrease in plankton biomass through the reduction of copepods abundance was noted for Aleutian and Commander basins within the Russian EEZ. On the other hand, relative abundance of euphausiids has increased (Volkov et al. 2005).
3. Total nekton biomass in the western Bering Sea was estimated as 1.7–2.8 million tons in fall of 2002–2003 and 1.3 million tons in summer of 2003. In the summer of 2003 the biomass of Pacific salmon exceeded 939 thousand tons. During summer-autumn period early 2000-ies a significant increase of Pacific salmon share in total fish biomass in upper epipelagic layer took place (Fig. 1). The biomass of salmon distributed in shelf zone was 10–100 times lower than their abundance in the deeper-water within the Bering Sea basin (Fig. 2) (Temnykh, 2004). According to the diel study at different water strata the major concentrations of salmon are located in the upper 30 m.
4. Comparative analysis of spatio-temporal variability of Pacific salmon's biological characteristics suggests species-specific and age-specific adaptive strategy, which is aimed at the lessening of density-dependent interactions and maximum utilization of available feeding grounds (Sviridov et al. 2004a).
5. Asian stocks of immature age .1 and .2 sockeye salmon dominate within the southwestern Bering Sea and the adjacent waters of the northwest Pacific Ocean in September–October (Bugayev 2003, 2004a, 2004b). There were differences in the interspecies structure in the catches for different age groups that reflects divergence in distribution range among different age regional groupings of salmon during their marine growing period.
6. The rates of different types of traumatization and infestation occurrence are species- and age-specific and are subject to significant spatio-temporal variability (Sviridov et al. 2004b).

**Fig. 1.** Interannual dynamics of fish communities composition (% of total biomass) in the upper epipelagic layer in the southwestern Bering Sea (within Russian EEZ) in summer 1991–2003.



**Fig. 2.** Ratio (%) of Pacific salmon biomass in shelf and deep-water regions of the western Bering Sea.



7. Analyses of long-term datasets on salmon food habits in the western Bering Sea suggests that the composition and amount of Pacific salmon ration in 2000s is not significantly different between the 1980s to mid-1990s period (Temnykh 2004; Temnykh et al. 2004; Shuntov and Temnykh 2005; Volkov et al. 2005). In addition, conclusions on considerable food competition between two most abundant Pacific salmon species (chum and pink salmon) are not supported by our data (Dulepova 1998; Dulepova and Dulepov in press; Efimkin et al. 2004; Temnykh, et al. 2004; Shuntov and Temnykh 2005).

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## National Overview of BASIS Research for the United States

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**Keywords:** Salmon, ecosystem, genetics, oceanography, climate

Small-scale studies on early marine life history of juvenile sockeye salmon (*Oncorhynchus nerka*) in Bristol Bay in the southeastern Bering Sea were done during 1966–1972 (Straty 1974; Straty and Jaenicke 1980). Current salmon research by the United States in the Bering Sea began in 1999 with emphasis on monitoring the effects of ocean conditions on growth, migration, and distribution of juvenile sockeye salmon in Bristol Bay (Farley et al. 1999). Since then, the U.S. program has expanded to include most of the continental shelf in the eastern Bering Sea and includes comprehensive ecosystem information on other species of salmon, forage fish, other nekton, plankton, and oceanographic conditions. Research on immature and adult salmon in the Bering Sea has been accomplished largely through retrospective studies and cooperative high seas research programs with other North Pacific Anadromous Fish Commission (NPAFC) parties.

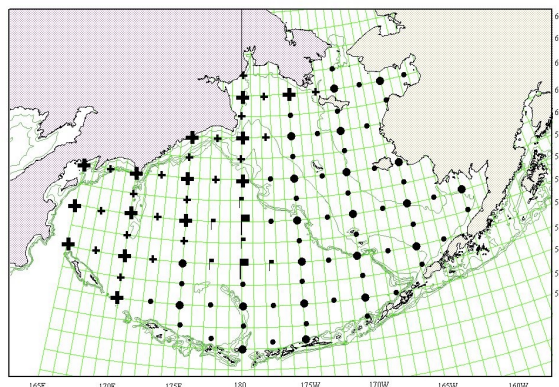
Concerns about declines in salmon abundance on both the Asian and North American sides of the Bering Sea resulted in the NPAFC developing a BASIS research plan in 2001. This plan called for seasonal synoptic surveys of salmon abundance and distribution throughout the Bering Sea (Fig. 1). Russian scientists would survey the western Bering Sea, Japanese scientists would survey the central Bering Sea, and U.S. scientists would survey the eastern portion. In addition to salmon surveys, observations would be made on forage fish, plankton, and oceanographic conditions. Synoptic surveys began in 2002 and continued in 2003 and 2004.

Large trawls towed at the surface were used to capture salmon and associated marine species. Each country had developed trawls to fish from their own vessels in previous marine salmon research. In 2002, the Russian vessel RV *TINRO*, the Japanese vessel RV *Kaiyo maru*, and the U.S. vessel FV *Northwest Explorer* rendezvoused near Attu Island in the western Aleutian Islands and the three vessels made side-by-side tows to compare the catches by the three different vessels and trawls. In addition to the FV *Northwest Explorer*, the United States also used the FV *Sea Storm* for surveys in the eastern Bering Sea in 2002. Due to budget cuts, the United States used only the FV *Sea Storm* for surveys in 2003 and 2004.

One U.S. scientist participated in cruises on the *TINRO* in 2002 and one U.S. scientist was on the *Kaiyo maru* in 2002. Three U.S. scientists participated on the *Kaiyo maru* cruise in 2003 and one U.S. scientist was aboard the *Kaiyo maru* in 2004. One Russian scientist participated in the *Northwest Explorer* cruise in 2002. Two Russian scientists participated in cruises of the *Sea Storm* in 2003 and in 2004. A Canadian scientist was aboard the *Sea Storm* in 2002 and 2003.

United States research activities in the BASIS plan were designed to address four major issues or questions: 1) what are the seasonal stock-specific migration patterns of salmon inhabiting the Bering Sea, particularly those stocks exhibiting recent declines in production, and what is their relation in the Bering Sea ecosystem, 2) what are the key biological, climatic, and oceanographic factors affecting long-term changes in Bering Sea food production and salmon growth rates, 3) what are the similarities (or dissimilarities) in production or survival trends among salmon populations originating in rivers around the Bering Sea Rim, and 4) is there a limit (carrying capacity) to the amount of salmon that can be produced in the Bering Sea, and what is the effect of hatchery salmon on Bering Sea food supplies?

**Fig. 1.** Sampling locations for BASIS. Symbols indicate stations in Russian (plus sign), international (flag), and U.S. (closed circle) waters.



Genetic stock identification is an integral part of research on all of the issues above. For more than a decade, the United States, Russia, and Japan collaborated to produce a common allozyme data base (Kondzela et al. 2002) that provides substantial insight into the migration of chum salmon in the Bering Sea (Urawa et al. 2004). New DNA techniques are enhancing our ability to identify salmon stocks anywhere in the Bering Sea (Seeb et al. 2005; Habicht et al. 2005; Fig. 2).

When BASIS was being planned in 2001, scientists were primarily concerned about the declining numbers of salmon returning to Russia, Japan, and western Alaska. Similar declines in all three countries suggested the source of the problem was in the marine environment and not in the rivers. Now, because of the very obvious changes in the ocean and atmosphere in the Bering Sea, BASIS is evolving into a major international ecosystem and climate-change research program.

A highly visible change in the eastern Bering Sea has been coccolithophore blooms. These blooms were first noticed in 1997 by ships at sea and were clearly visible from satellite photos. These blooms were present in 1997–2000, mostly absent in 2001–02, and scattered in 2003–04. When possible, juvenile salmon appeared to avoid these blooms.

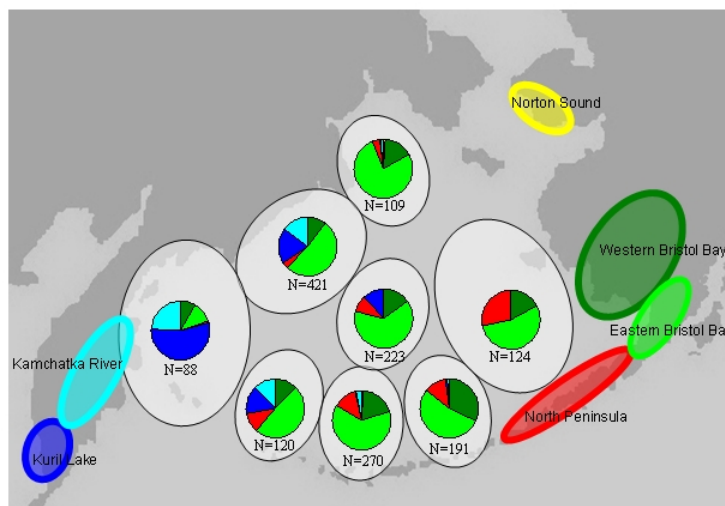
Sea surface temperatures, as reported by Japan, Russia, and the United States at this workshop have been warmer during the past several years. Sea temperature data from a NOAA mooring in the southeastern Bering Sea shows temperatures at depth have warmed too. Depth-averaged temperatures were consistently warmer during mid-July through mid-September for 2001–2003 when compared to the same months for 1995–1997 (Overland and Stabeno 2004).

Air temperatures at St. Paul Island in the eastern Bering Sea have been warmer in the past four years; however, the warming pattern actually started in the mid-1970s (Overland and Stabeno 2004). Along with warming sea and air temperatures, sea ice concentration in the eastern Bering Sea has also decreased. Feeding areas of walrus and grey whales have moved northward with the receding sea ice (Kelly 2001; Moore et al. 2003).

The warming trend has also affected the land. In northern Alaska, permafrost has been melting, causing a change in vegetation types (Jorgenson et al. 2001) and subjecting villages in coastal areas to erosion (see Time Magazine, October 4, 2004, pp. 68–70).

Clearly, the Bering Sea ecosystem is in the midst of a major climate change. Whether the changes are part of natural cycles in climate or are “global warming” caused by anthropogenic causes may be arguable. Regardless of the causes, the changes to natural resources in the Bering Sea are already large and the implications for the future are unknown. The research done under the BASIS program has already significantly added to our knowledge of the Bering Sea. Expanding our observations to encompass more data that can be used to evaluate climate change is an obvious goal. The original BASIS plan called for field observation during 2002–2006. The success of BASIS at a time of major ecological change suggests that BASIS should be extended beyond 2006.

**Fig. 2.** Stock proportions of immature sockeye salmon sampled from throughout the Bering Sea during August of 2002 and 2003 ( $N$  = sample size). Baseline stocks were pooled into six reporting groups and are symbolized with colored ovals. Pale ovals under the pies represent the general area where stock mixtures were captured and pie colors correspond to reporting group colors.





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# Distributions of Oceanographic Variables, Juvenile Sockeye Salmon and Age-0 Walleye Pollock in the Southeastern Bering Sea during Fall 2000–2003

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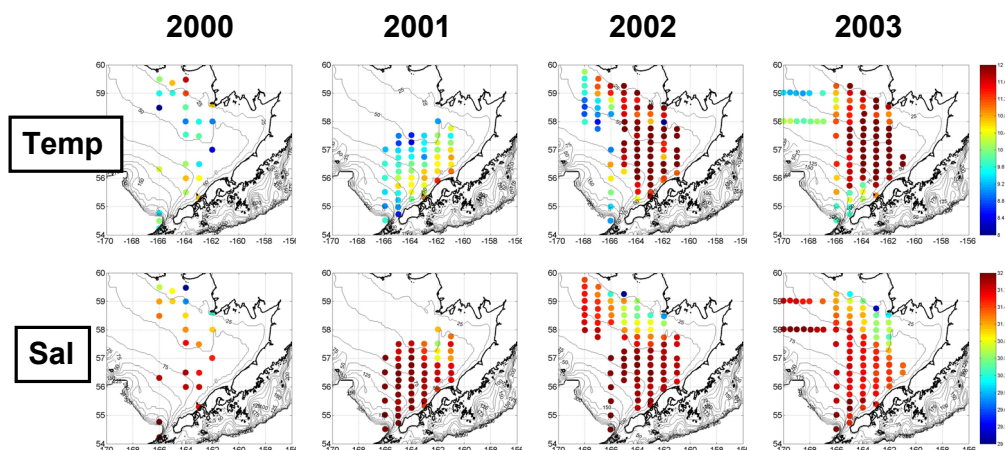
**Keywords:** Juvenile sockeye salmon, age-0 walleye Pollock, oceanography, Bering Sea

We conducted surveys in Bristol Bay on the southeastern Bering Sea shelf during late August to mid-September 2000–2003, as part of the Bering-Aleutian Salmon International Survey (BASIS). Our main objective was to compare biological and physical oceanographic characteristics to the distributions of juvenile sockeye salmon (*Oncorhynchus nerka*) and age-0 walleye pollock (*Theragra chalcogramma*) during fall in the southeastern Bering Sea. We characterize the horizontal and vertical structure of oceanographic variables for 2000 to 2003, and then describe how spatial and temporal variations in oceanographic characteristics relate to juvenile sockeye salmon and age-0 walleye pollock distributions. This characterization of marine habitat provides important information for understanding relationships among climate, oceanography, lower trophic levels, and forage fish (including juvenile salmon and pollock).

Stations were generally spaced 15–30 km apart in Bristol Bay, although spatial coverage varied by year. Surface fish trawls were conducted with a rope trawl (Cantrawl models 400 and 300, ~15 m deep by 55 m wide) towed for 30 minutes at 3.5–5 knots. Abundance, weight, and length were recorded for salmon and associated species. Vertical profiles of temperature, salinity, and chlorophyll a (chl a) fluorescence were conducted to within 10 m of the bottom using a Sea-Bird 19 or Sea-Bird 25 CTD (Conductivity-Temperature-Depth) profiler. During 2003, we also collected discrete samples at select depths for chl a, nutrients, and phytoplankton species. Chl a samples were filtered onto GF/F filters, stored frozen, extracted in 90% acetone, and analyzed with a Turner Model TD-700 fluorometer (Parsons et al. 1984). Nutrients were stored frozen and analyzed with a Technicon Auto Analyzer following standard colorimetry protocols (UNESCO 1994). Phytoplankton species were preserved in buffered formalin and taxa greater than 5–10  $\mu\text{m}$  in diameter were quantified using the inverted microscope technique (Lund et al. 1958).

Surface (5 m) temperature and salinity values indicated that 2002 and 2003 had higher sea surface temperatures than 2000 and 2001 (Fig. 1). Surface salinities were lower in 2003 than in 2000–2002 (Fig. 1). In 2003, surface chl a values were high in southern Bristol Bay and along the longitude 166° W transect, although distributions were patchy (Fig. 2). Dissolved Inorganic Nitrogen (DIN) concentrations were high ( $> 5 \mu\text{M}$ ) below the pycnocline throughout Bristol Bay and near the surface in southern Bristol Bay (Fig. 2). Upwelling of water through Unimak Pass (Stabeno et al. 2002) likely introduced this nutrient-rich water into southern Bristol Bay and subsequently fueled production in this area.

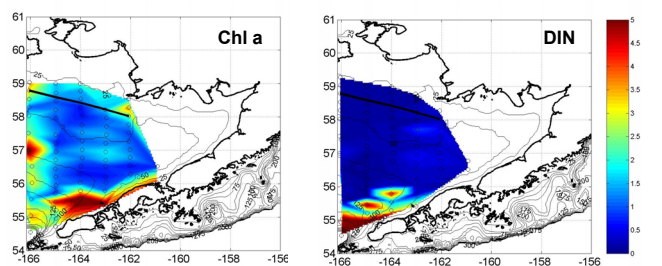
**Fig. 1.** Surface (5 m) temperature ( $^{\circ}\text{C}$ ) and salinity from CTD data for late August to mid-September for 2000–2003 in the southeastern Bering Sea.



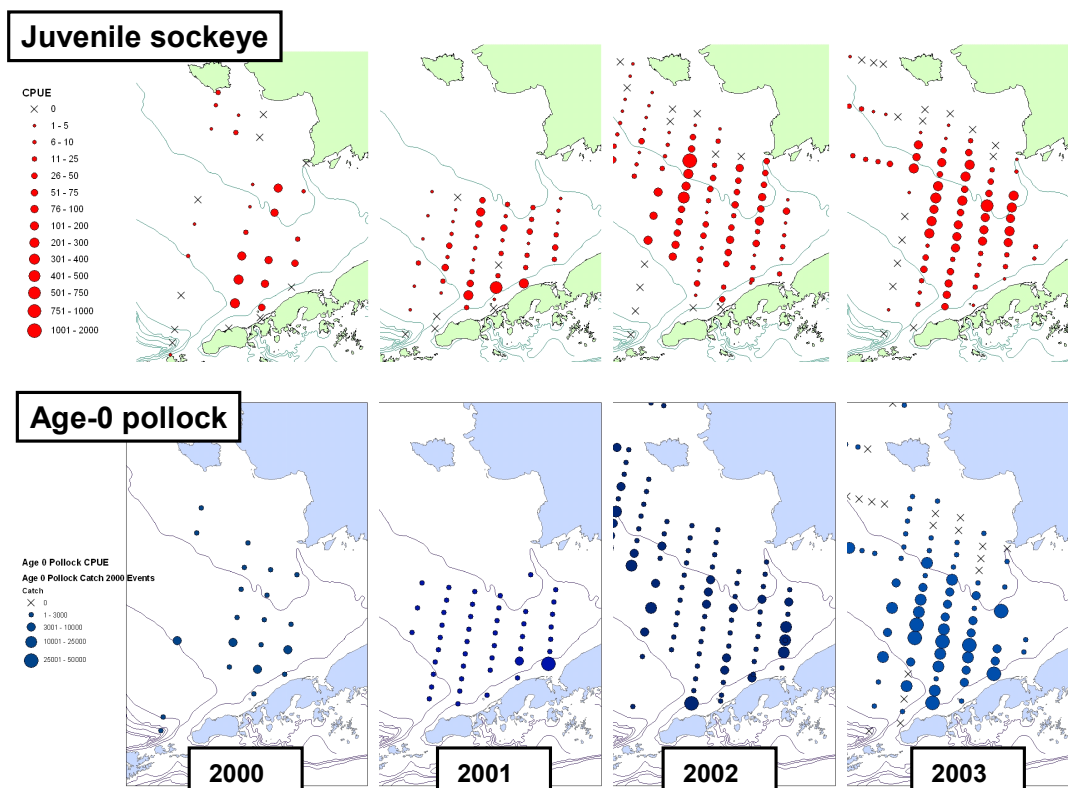
An evaluation of vertical sections of CTD data along the longitude 164°W transect indicated that temperatures below the pycnocline and near the surface were cooler in 2000 and 2001 than in 2002 and 2003, in agreement with data from the M2 mooring at 56.8°N, 164°W (Overland and Stabeno 2004). During all years, we observed relatively high surface chl a fluorescence near the 50-m isobath, the approximate vicinity of the Inner Front separating the well mixed coastal waters from the stratified Middle Domain (Schumacher and Stabeno 1998). The Inner Front region can be an area of prolonged primary production (Kachel *et al.* 2002), which in turn stimulates production at higher trophic levels. In 2003, relatively high subsurface chl a fluorescence values were observed at the base of the pycnocline in the Middle Domain, whereas high surface values were seen near the southern end of the transect in the area with high surface DIN (Fig. 2). Examination of the phytoplankton taxa indicated that the subsurface blooms were predominantly dinoflagellates, with diatoms seen closer to the northern coast and in the surface waters at the southern end of the longitude 164°W transect.

Juvenile sockeye salmon were more abundant and distributed further south in 2002 and 2003 compared to 2000 and 2001 (Fig. 3). The higher abundances may be associated with the higher surface temperatures during the latter two years (Figs. 1, 3). Age-0 walleye pollock, a primary prey of juvenile sockeye salmon, were also more abundant during our surveys in 2002 and 2003 than in 2000 and 2001 (Fig. 3). Subsets of the juvenile sockeye salmon and age-0 walleye pollock distributions along the longitude 164°W transect were located in the cooler water advected into Bristol Bay from Unimak Pass (Figs. 1, 3). Because this water contained different phytoplankton species, it is possible that the forage fish in this area were influenced by different food web dynamics than assemblages found farther north in Bristol Bay.

**Fig. 2.** Surface (5 m) chlorophyll a ( $\mu\text{g L}^{-1}$ ) and dissolved inorganic nitrogen (DIN,  $\mu\text{M-N}$ ) determined from discrete samples analyses for 2003. Stations indicated by open circles. Solid black line is the approximate location of the inshore edge of the Inner Front.



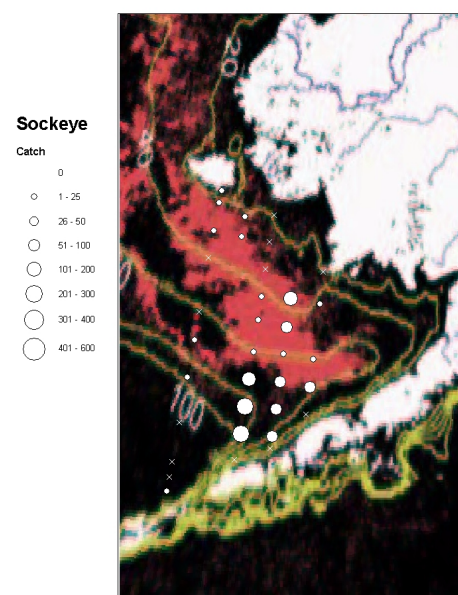
**Fig. 3.** Juvenile sockeye salmon and age-0 walleye pollock distributions (catch for 30-min trawl) for 2000–2003.



Extensive blooms of coccolithophores (calcareous phytoplankton that scatter light and give the water a chalky, aquamarine appearance) were observed in the Bering Sea during 1997–2001 (Iida et al. 2002). A comparison of the juvenile sockeye salmon and coccolithophore distributions for 2000 indicated that the juvenile sockeye salmon were generally distributed outside of the bloom area, farther south than typically observed (Fig. 4). Coccolithophore blooms could negatively influence juvenile salmon by obscuring visibility for effective capture of prey or may promote a less productive food web since coccolithophores can be a less desirable prey for lower trophic level organisms such as microzooplankton (Olson and Strom, 2002). As compared to earlier years (Iida et al. 2002), we observed a much less extensive coccolithophore bloom during our survey in 2003 and did not observe a bloom in 2002.

In conclusion, the higher temperatures and lack of extensive coccolithophores blooms may have contributed to higher juvenile sockeye salmon survival during 2002 and 2003. Subsets of age-0 walleye pollock and juvenile sockeye salmon were seen in the cooler, nutrient-rich water advected through Unimak Pass. Different phytoplankton taxa and vertical distributions were seen in this nutrient-rich water than in the two layer system farther north, suggesting food web components and interactions varied between the Middle Domain and the southern Bristol Bay waters.

**Fig. 4.** SeaWiFS coccolithophore mask composite image (Iida et al. 2002) overlain with juvenile sockeye salmon catches for 2000. Grey indicates coccolithophore distribution.



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# Thermohaline Structures in the Bering Sea Basin in Summer and Autumn

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**Keywords:** Thermohaline structure, Aleutian Basin, temperature minimum, geostrophic velocity

The Bering Sea is one of the marginal seas of the North Pacific and thought to be a main habitat of chum salmon produced in Japan (Urawa 2000). The oceanographic structures in the Bering Sea, therefore, would influence salmoid migrations and distributions. The flow structures and magnitudes in the basin also probably influence on salmon distributions and migrations (Thomson et al. 1992). The Bering Sea has a cyclonic circulation pattern (Favorite et al. 1976). Roden (1995) reported that the Bering Sea basin in summer is composed of a thin mixed layer, a temperature minimum layer, and a temperature maximum layer. Miura et al. (2002) showed that dichothermal water is formed in winter in the mixed layer in the Bering Sea, because the properties of the dichothermal water in the warming season are almost the same as those in the winter mixed layer. Most of these studies, however, have been derived from observations conducted along one transect line or a composite data. There have been few comprehensive hydrographical observations conducted over large areas, simultaneously in the Western Aleutian Basin. The purpose of this report is to estimate the thermohaline and flow structures in the Aleutian Basin, which influence salmon migrations and distributions.

From 2002 to 2004, hydrographic observations were conducted in the Aleutian Basin and around the Aleutian Islands on board the R/V *Kaiyo maru*. These observations were conducted in late June to mid July (summer), and late August to mid September (autumn), respectively. Vertical profiles of temperature and salinity were obtained with a CTD at each observational point. Surface temperature and salinity were measured by EPCS (Electronic Plankton Counting and Sizing System) in every one minute during the cruise.

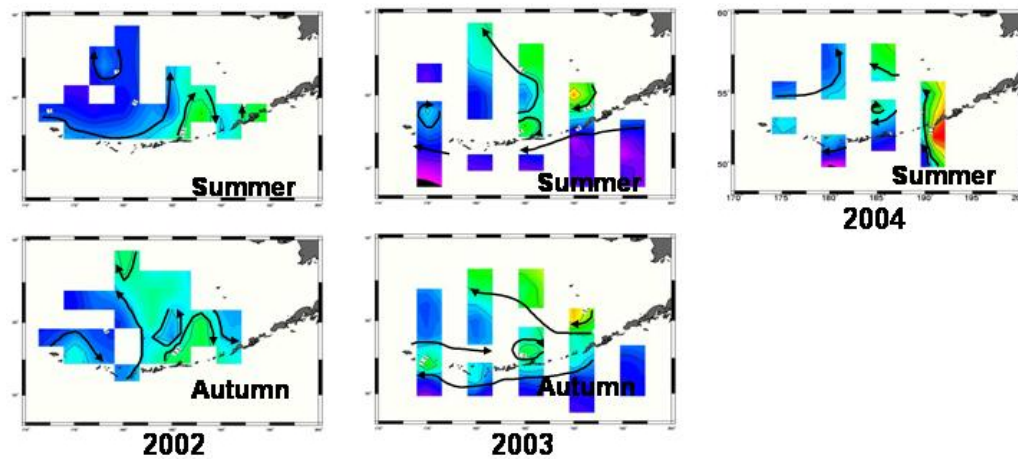
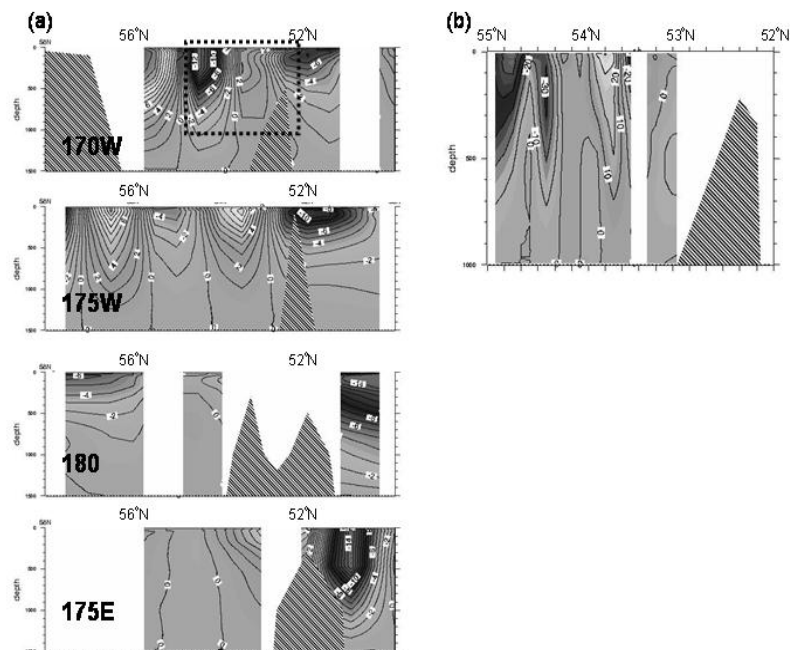
In generally, surface temperature in the eastern part was higher than in the western in all observational periods. In the summer of 2002, surface temperature was lower in all areas than in the other years. The higher temperature in the eastern part would be caused by the Pacific Water inflows through the eastern Aleutian Passes. Around the Aleutian Passes, water temperature was significantly lower than in the Bering Sea and Pacific water. This is probably caused by the vertical mixing in the passes. Unlike the temperature distribution, in the salinity in the east was generally lower than in the western basin. In particularly, the eastern continental shelf was characterized by salinity which was less than 32.0 psu. In summer of 2002, however, salinity was about 0.5 higher in the eastern shelf than the other years. A pronounced salinity front was formed along a continental shelf edge and the front was almost stationary during the course of the observational periods. While the annual salinity variation is smaller in the western basin, there was a larger variability in the coastal region. The internal variability of salinity distribution may be associated with an increased ice cover during previous winter.

In the basin, a thin mixed layer about 20–30 m thick was present in summer and autumn. In the strait areas, however, it increased to the equivalent of the deep layer. Below the mixed layer, a temperature minimum was evident around 100–150 m depth in the western basin and not obvious in the eastern basin. The temperature minimum was increasingly lower in 2002. The minimum temperature, however, increased and the density at this layer was reduced in the last two years. This minimum structure formed as a result of winter cooling, probably because the previous two winters were moderate and convection was weak.

Dynamic topographies were referred to 1,000 db were calculated to clarify a circulation pattern in the basin (Fig. 1). In the center of the Aleutian Basin, lower values were recognized, compared with the coastal regions and the Aleutian Passes. General circulations over the Aleutian Basin were characterized by a cyclonic loop with some meanders. There were, however, always some eddy-like features in the basin, and the flow patterns were variable with years.

Figure 2a is a result of geostrophic velocity referred to 1,500 db at each observational transect in autumn of 2003. South of the Aleutian Islands, baroclinic structures of the Alaskan stream were well developed to deep layers. In contrast, the velocities were smaller in the Aleutian Basin except for eddy-like structures in the eastern side. To estimate the Aleutian North slope current accurately, expendable CTD observations were conducted at every 10 nautical miles in the rectangular region shown in Fig. 2a. As a result, very finite and complicated flow structures were evident, faster velocities (> 30 cm/s) were observed and those widths were less than about 20 km just north of the Aleutian Islands (Fig. 2b).



**Fig. 1.** Dynamic topography at the surface referred to 1,000db around the Aleutian Basin during the course of observational periods**Fig. 2.** Vertical cross-sections of geostrophic velocity (cm/s) referred to 1500db in autumn of 2003(a), and a vertical cross-section of geostrophic velocities (cm/s) referred to 1000 db along 170°W near the eastern Aleutian passes (b), which is associated with a dot's region of Fig.2a.

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# Oceanographic Condition of the Bering Sea in BASIS

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Keywords: Bering Sea, Kamchatka Current, Bering Slope Current, Positive anomalies, seasonal pycnocline

Several interdecadal changes have taken place in atmosphere and hydrosphere of the northern Pacific in the past three decades. The most important change was in late 1970s (Minobe 1997). It is known as “climate shift”. Some scientist (Krovnin et al. 2001; Minobe 2002) considered that the cooling in 1998 was a “climate shift”.

From 2002 both air temperature in spring and sea surface temperature in summer changed to warming in the Bering Sea again and 2003 was one of the warmest since 1950. Thus the start of BASIS coincided with a warming in the Bering Sea.

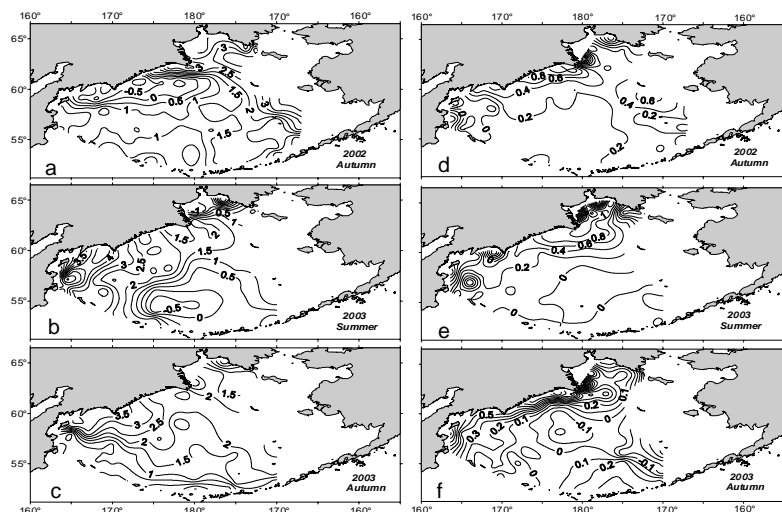
Intensification a water exchange between the Pacific and Bering Sea occurred during the last five years.

From 1999 to 2003, the transport of the Kamchatka Current grew from 3.37 to 6.05 Sv in summer, and from 3.67 to 9.01 Sv in autumn. During BASIS years, the Kamchatka Current has increased approximately 15%.

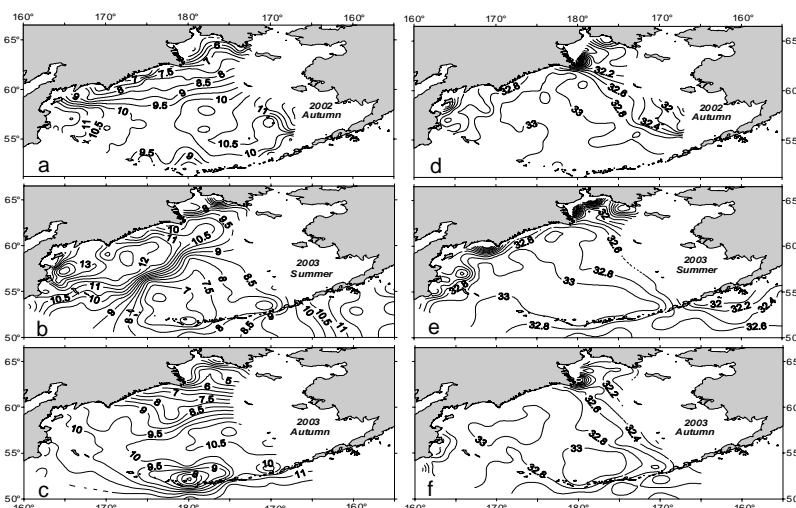
The analyzed oceanographic data were obtained by two research vessels: the Russian R/V *TINRO* in Russian Economic Zone and the Japanese R/V *Kaiyo maru* in the southeastern. The surveys were conducted in autumn 2002, summer and autumn 2003. Dynamic topography and spatial distributions of temperature, salinity and there anomalies were investigated virtually throughout the whole Bering Sea, excluding the costal region of Alaska.

In first years of BASIS the warmest areas on the sea surface were found in the western and in the eastern parts of the Bering Sea (Fig. 1a, b, c). Surface layer in these areas was shallow: to 10 m in summer and to 20 m in autumn. The stability was high because of low salinity (< 32.5 psu) at the surface (Fig. 1d, e, f). In the Deep Basin, the surface salinity was higher (32.8–33.0 psu), and the upper layer was deepened beneath 20 m in summer and beneath 30 m in autumn.

**Fig. 2.** Anomalies of surface temperature (a, b, c) and salinity (d, e, f) in the Bering Sea.



**Fig. 1.** Surface Temperature (a, b, c) and salinity (d, e, f) in the Bering Sea.



the surface salinity was higher (32.8–33.0 psu), and the upper layer was deepened beneath 20 m in summer and beneath 30 m in autumn.

Positive anomalies of temperature dominated at the sea surface (Fig. 2a, b, c). The highest values of the positive anomalies (2.0–2.5°C) were found in the east of the Sea and in the Gulf of Anadyr in autumn 2002. In 2003, the region of the highest anomalies (3.5–4.5°C) shifted to the opposite side of the sea—to the Kamchatka Basin. The anomalies lowered in autumn to 2.5–3.5°C. In the eastern part of the sea the anomalies did not exceed 1–2°C.

The high positive salinity anomalies (> 0.5 psu) in the Gulf of Anadyr and the eastern part of the Sea

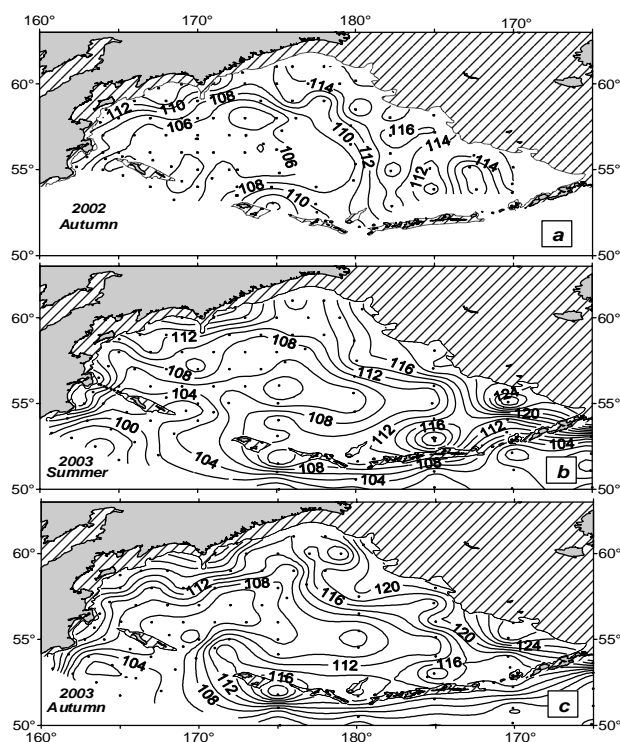
in 2002 (Fig. 2d) were probably related with the small input of the fresh water. The salinity in the western part of the Sea was about average.

In the next year the distribution of salinity anomalies changed (Fig. 2e, f). In the east, salinity was noticeable lower the average, especially in autumn. The differences of salinity between 2003 and 2002 corresponded to the differences in river runoff affecting the region. In 2003 the freshwater influence extends over the continental shelf, its trace could be seen even in the Aleutian basin. In contrast to the east and west, positive salinity anomalies were observed along Korjak coast in both BASIS years. In general, geostrophic circulation in the BASIS years corresponded to the well known pattern of currents in the Bering Sea (Arsenev 1967; Stabeno and Reed 1994). Cyclonic circulation dominated in the Deep Basin, with the Bering Slope Current (BSC) and Kamchatka Current along the continental slope. An extraordinary situation occurred in the southeastern side of the Deep Basin in 2002 (Fig. 3a). Firstly BSC was not expressed along the eastern shelf break, but there were five anticyclonic and two cyclonic eddies in this area. Secondly, strong current was observed from the Amchitka Pass, it flowed northward as the eastern boundary of the Bering Sea cyclonic gyre, like BSC has been in another years. We inferred that BSC shifted westward as far as Bowers. In 2003, the BSC flowed northwestward along the eastern continental slope as usual (Fig. 3b, c).

Beneath the seasonal pycnocline which was found at the depth 5–25 m in summer (Fig. 4b) and 20–45 m in autumn (Fig. 4a, c), the temperature and salinity anomalies had other distribution than at the sea surface. The negative temperature anomalies were observed at the depth 50 m in the Deep Basin. The lowest negative anomalies ( $-0.5$ ;  $-1.0^{\circ}\text{C}$ ) were observed at the cyclonic eddies. High positive anomalies ( $1.0$ – $2.5^{\circ}\text{C}$ ) could be seen in the north around Navarin Cape. The salinity anomalies at 100 m reflected an autumn intensification of the Pacific water inflow through the central Aleutian passes. High positive anomalies ( $0.1$ – $0.2$  psu) were observed at the northern side of the Aleutian Islands in autumn of 2002 and 2003. In the central part of the Deep Basin, the salinity was about average both in summer and in autumn.

The beginning of BASIS investigations (2002–2003) coincided with warming and intensification of water exchange between the Pacific and the Bering Sea. During two BASIS years the warmest areas on the sea surface were found in the west and in the east of the Sea. Positive anomalies of temperature and salinity were dominated at the sea surface in 2002 and 2003. In autumn 2002, the highest positive salinity anomalies were observed in the eastern part of the Sea and in its western part in autumn 2003. In 2002, the Bering Slope Current was not expressed the eastern shelf breaks it shifted westward as far as Bowers Ridge. Beneath the seasonal pycnocline negative temperature anomalies were observed in the Deep Basin and high positive salinity anomalies at the northern side of the Aleutian Islands in autumn of 2002 and 2003.

**Fig. 3.** Dynamic topography of the surface of the Bering Sea basin relative 1000 db.



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## Salmon Food Habits Studies in the Bering Sea, 1960 to Present

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Keywords: Salmon food habits, diet overlap, daily ration, bioenergetics

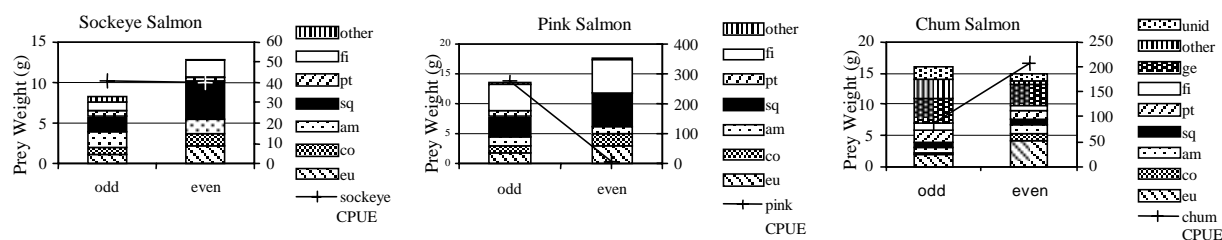
Salmon food habits studies are important to BASIS research because they help identify salmon density-dependent effects on growth and survival and can be used for food web models (NPAFC 2001). Since the 1960s these studies have been conducted in the western (e.g., Ito 1964; Andrievskaya 1966; Machidori 1968; Karpenko 1982a; Karpenko and Maksimenkov 1988; Chuchukalo et al. 1995; Klovach et al. 1996; Koval and Karpenko 1998; Bugaev and Shaporev 2002; Karpenko 2003; Smorodin et al. 2004), eastern (e.g., Nishiyama 1974; Straty 1974; Carlson et al. 1998; Murphy et al. 2003; Davis et al. 2004; Farley et al. 2004), and central (e.g., Kanno and Hamai 1972; Azuma 1992; Davis et al. 2000; Myers et al. 2004) Bering Sea. In this abstract, we review information on Bering Sea salmon food habits useful to BASIS researchers investigating salmon prey, diet overlap, ration, and bioenergetics.

Salmon distribution during their ocean migration has been linked to prey availability (Nishiyama 1974; Straty 1974; Carlson 1976; Karpenko 1979, 1983; Karpenko and Piskunova 1984; Sobolevskiy et al. 1994; Farley et al. 2004; Klovach and Gruzevich 2004). Review of 40 Bering Sea salmon food habits studies showed the major prey common to all species of salmon include euphausiids (*Thysanoessa*), hyperiid amphipods (*Themisto*), pteropods (*Limacina*), and juvenile squids (*Gonatopsis*, *Gonatus*, and *Berryteuthis*). Important fish prey include *Stenobranchius leucopsarus* and juvenile greenlings (*Pleurogrammus*) in basin habitats, and juvenile walleye pollock (*Theragra chalcogramma*), capelin (*Mallotus villosus*), and sand lance (*Ammodytes*) in shelf habitats. Future studies should focus on distribution and abundance of these major prey because this will improve our assessment of diet overlap and feeding competition.

In response to the biennial cycle of pink salmon abundance in the Bering Sea, density-dependent shifts in prey composition have been observed in the food habits of pink, chum, and sockeye salmon (Ito 1964; Andrievskaya 1966; Tadokoro et al. 1996; Karpenko et al. 1998; Davis 2003). During even-numbered years (low abundance of maturing pink salmon), total stomach content weight and proportions of euphausiids, copepods, fish, and squid increase in sockeye and pink salmon, and the proportion of euphausiids and other crustaceans increase in chum salmon stomach contents (Fig. 1).

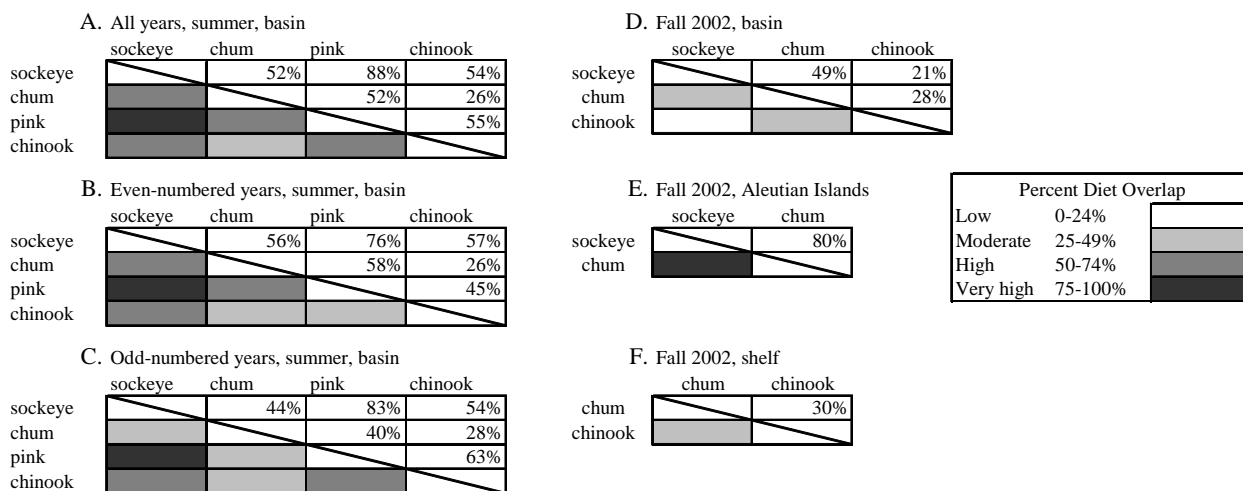
Salmon diet overlaps (percent similarity index) were calculated for sockeye, chum, pink, and chinook salmon collected in the basin during the summer cruises (1991–2003) of the *Wakatake maru* (Fig. 2). Results showed a very high (> 75%) diet overlap between sockeye and pink salmon in odd- and even- numbered years. In odd-numbered years, however, diet overlaps between chum and sockeye, and chum and pink salmon were reduced. Comparing summer to fall overlaps using data collected onboard the *Northwest Explorer* in 2002 (Davis et al. 2004), indicated seasonal reduction in diet similarity between sockeye and chum salmon, and sockeye and chinook salmon (Fig. 2). In fall, overlap between sockeye and chum salmon in the Aleutian Islands was very high (> 75%), while overlap between chum and chinook salmon was moderate (28–30%) in the basin and the eastern shelf.

**Fig. 1.** Mean weight (g) of each prey category observed in the stomach contents of sockeye, pink, and chum salmon and mean CPUE (number of fish/50-m tan of research gillnet) observed during odd- and even-numbered years in the central Bering Sea in July, 1991–2000. eu = euphausiids, co = copepods, am = amphipods, sq = squid, pt = pteropods, fi = fish, ge = gelatinous zooplankton, unid = unidentified.

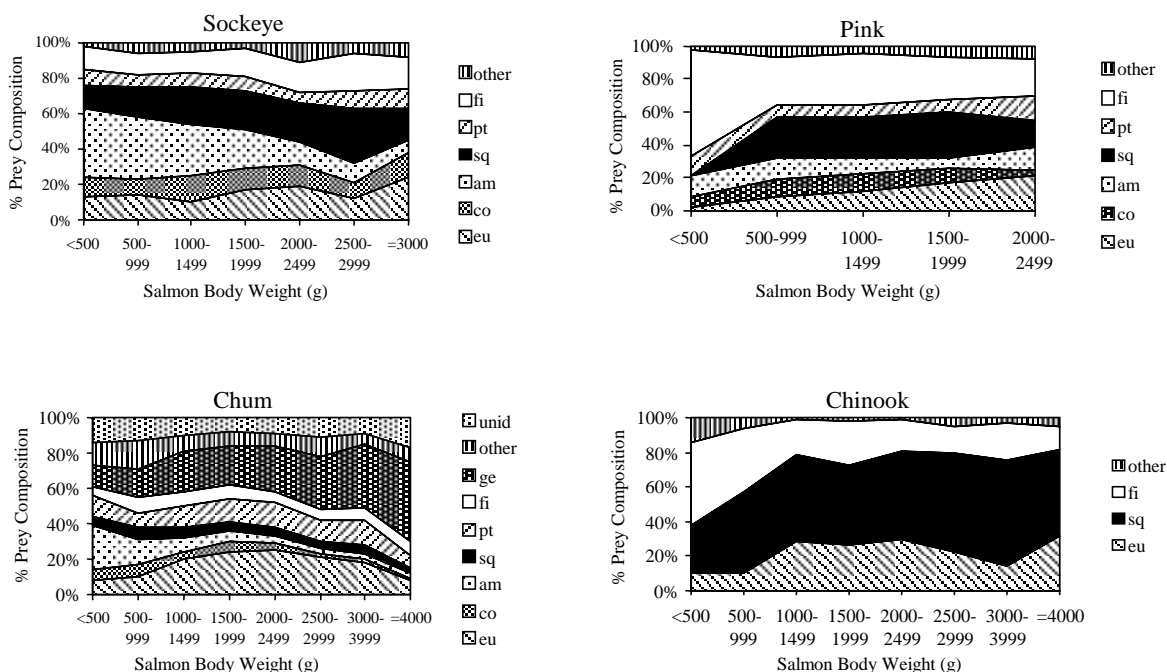


Bering Sea food habits studies have shown that prey composition shifts with salmon body size (Dell 1963; Andrievskaya 1968; Davis 2003; Dulepova and Dulepov 2003; Temnykh *et al.* 2003). In the basin, smaller sockeye and chum salmon contain a higher proportion of hyperiid amphipods than larger salmon (Fig. 3; Davis 2003). The proportion of squid in sockeye salmon increased with salmon body size, and the proportion of gelatinous zooplankton increased in chum salmon larger than 2500 g. Maturing chum salmon may consume more gelatinous zooplankton because it is easily digestible and widens their feeding niche (Dulepova and Dulepov 2003).

**Fig. 2.** Percent diet overlap of sockeye, chum, pink, and chinook salmon collected in the Bering Sea Basin, Aleutian Islands, and eastern Bering Sea shelf. Panel A = diet overlap in the basin for all years, summer 1991-2003; Panel B = even-numbered years, basin, summer 1992-2002; Panel C = odd-numbered years, basin, summer 1991-2003; Panel D = fall, 2002, basin; Panel E = fall, 2002, Aleutian Islands; Panel F = fall, 2002, eastern Bering Sea shelf.



**Fig. 3.** Percent composition (by weight) of major prey categories collected from sockeye, chum, pink, and chinook salmon stomach contents for size groups of fish caught in the central Bering Sea basin in July, 1991-2000. Size class < 500 g represents the smallest size group for ocean age-1 fish. eu = euphausiids, co = copepods, am = amphipods, sq = squid, pt = pteropods, fi = fish, ge = gelatinous zooplankton, and unid = unidentified.



Daily ration estimates should be age- or size-specific, rather than generalized to life history stage because consumption rates shift as the fish grows (Davis *et al.* 1998). Such estimates will lend more realism to Bering Sea trophic models. Until recently, most consumption estimates for salmon were for fish described only by maturity stage. In addition, reporting ration as a percentage of body weight and energy per gram body weight would improve assessment of salmon diet quality.

Using bomb calorimetry, caloric value of some salmon prey organisms have been determined (Davis 2003). Gelatinous zooplankton (salps, ctenophores) had the lowest caloric value (< 100 cal/g wet weight, ww). Pteropods, hyperiid amphipods, smaller euphausiids, and juvenile squid (< 2 cm mantle length) had values ranging from 500–1000 cal/g ww. Caloric values of juvenile fishes, small Atka mackerel (*Pleurogrammus monopterygius*), larger euphausiids, and medium-sized squids (approximately 4 cm ML) ranged from approximately 1000 to 1500 cal/g ww, and 1500 to 2000 cal/g ww was measured from larger squid (8–9 cm ML). High values (> 2000 cal/g ww) were found in deep sea smelt (*Leuroglossus schmidtii*) and *S. leucopsarus*.

Bering Sea salmon daily rations have been estimated from gut fullness and bioenergetics models (Nishiyama 1974; Karpenko 1982b; Karpenko and Nikolaeva 1989; Shuntov *et al.* 1993; Chuchukalo *et al.* 1995; Radchenko and Chigirinsky 1995; Volkov *et al.* 1995; Sobolevskiy and Senchenko 1996; Davis *et al.* 1998; Glebov 1998; Walker *et al.* 2000; Temnykh *et al.* 2003; Radchenko and Mathisen 2004). Gut fullness can be corrected for digestion rate, which is affected by prey composition, prey size, meal size, and water temperature (Windell 1978; Ney 1990). However, this method requires frequent sampling (approximately every 3 hrs) and assumes stomach contents measure food consumed. Because gut evacuation and feeding occur simultaneously, stomach contents at the end of the feeding period can underestimate the amount consumed (Elliott and Persson 1978). The bioenergetics approach uses a balanced energy budget. The Winberg bioenergetics model assumes waste and food processing costs are fixed proportions of consumption, and active metabolism is a multiple of standard metabolism (Ney 1990). The Wisconsin bioenergetics model estimates consumption as a proportion of maximum consumption of a fish at any weight or temperature and could provide relative consumption or growth estimates under differing conditions of temperature and prey availability (Ney 1990). Future bioenergetics models can simulate growth potential based on temperature predictions from Bering Sea climate models and improve our assessment of potential effects of climate change on salmon food habits and growth.

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## Feeding Habits and Distribution of *Stenobranchius leucopsarus* (Myctophidae) in the Central Bering Sea during Late Summer

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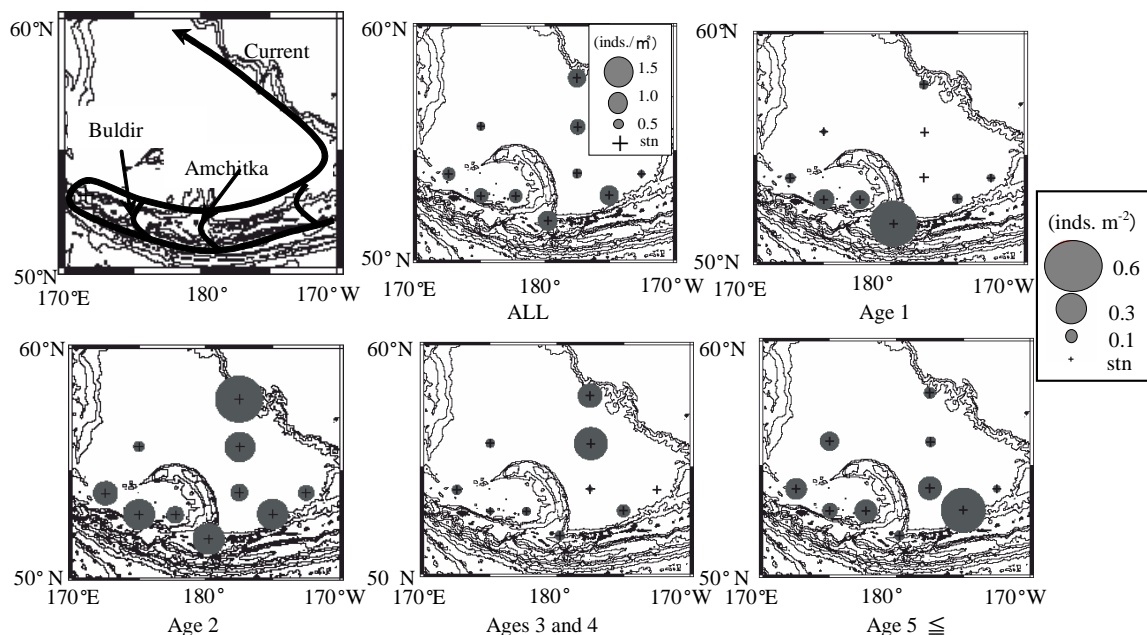
Keywords: *Stenobranchius leucopsarus*, feeding habits, competitor, Bering Sea

*Stenobranchius leucopsarus* is one of the most abundant fish species in the Bering Sea and play an important role in transporting organic matter from the productive epipelagic zone to the deep sea (Longhurst and Harrison, 1988). Besides being an important prey for higher trophic levels, *S. leucopsarus* is also a potential competitor for zooplanktivorous salmon, which utilize the Bering Sea as a nursery area during summer. In the present study, we examined the distribution, density and feeding habits of *S. leucopsarus* in the central Bering Sea during late summer.

We collected micronekton at 10 stations in the central Bering Sea using an RMT net on board the R/V *Kaiyo maru* during September 3–18, 2002. Oceanographic data were collected at 27 stations in the central Bering Sea using a CTD instrument. We towed the midwater trawl obliquely from 500 m depth to the surface one hour after sunset at each station. We then measured and weighed each *S. leucopsarus* collected, and removed the stomachs from up to 20 individuals at each station. The age of individuals was presumed from their standard length accordingly based on the length-age relationship described in Nishimura *et al.* (1999).

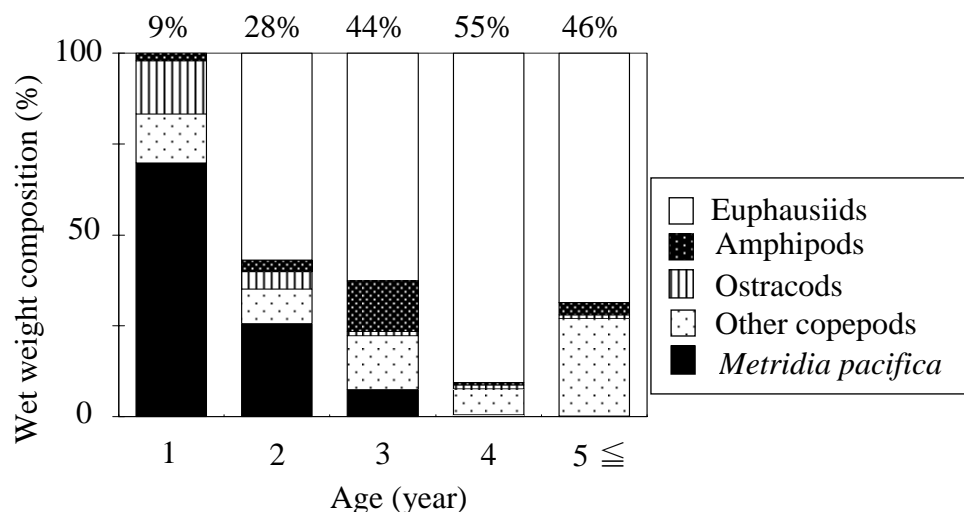
*S. leucopsarus* was the most abundant micronekton collected (mean abundance: 0.8 inds. m<sup>-2</sup>; mean biomass: 2.0 wwt g m<sup>-2</sup>). Although no clear patterns were found in the overall distribution, distribution patterns of *S. leucopsarus* differed by age (Fig. 1). Age-1 fish were abundant inshore near Amchitka Pass and Buldir Pass whereas age-2 fish were abundant both near the Aleutian Islands and in offshore waters. Age-3 and Age-4 fishes were both most abundant offshore, and fishes Age-5 and above were most abundant near the Aleutian Islands. These changes in the distribution with age suggest the early stages moved northward from near the Aleutian Islands in the counterclockwise current flow. The older stages were abundant near the islands, suggesting a possible southward return migration.

Fig. 1. Schematic of water current in study area and horizontal distribution of *Stenobranchius leucopsarus* at different ages.



Age-1 fish fed mainly on *Metridia pacifica*, however predation on this copepod decreased with increasing age (Fig. 2). Older ages fed increasingly on euphausiids. Small *S. leucopsarus* fed heavily on *Metridia* spp, suggesting there is little diet overlap with salmon. However, as *S. leucopsarus* grew, it began to prey heavily on euphausiids, which are also preyed upon by salmon. This suggests that *S. leucopsarus* becomes a potential competitor with salmon as it grows, especially with sockeye salmon, which prey heavily on euphausiids (Radchenko and Mathisen, 2004). More research is needed to better understand the role of *S. leucopsarus* in the Bering Sea ecosystem, especially regarding its role as a potential competitor with salmon.

**Fig. 2.** Diet of *Stenobrachius leucopsarus* expressed as wet weight composition for different age. Each number above columns was empty stomachs percentage.



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## Spatial Comparison of the Feeding Ecology of Sockeye (*Oncorhynchus nerka*) and Pink Salmon (*O. gorbuscha*) in the Ocean during the Summer of 2003

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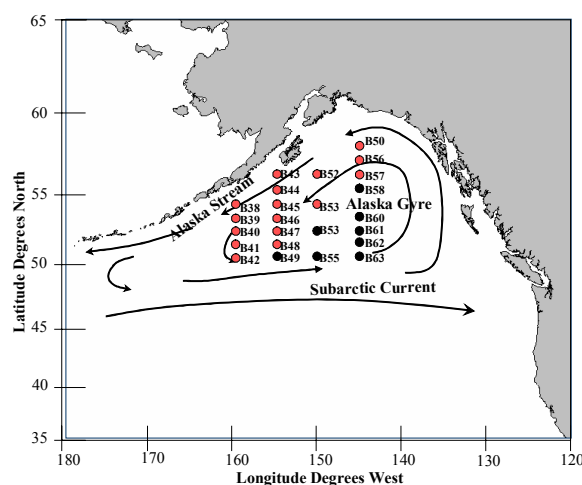


**Keywords:** Pink salmon, sockeye salmon, feeding ecology, spatial overlap

Research on the feeding ecology of Pacific salmon has been carried out in the North Pacific Ocean and adjacent seas since the late 1950s (e.g., Ito 1964; LeBrasseur 1966; Shimazaki and Mishima 1969; Percy et al. 1988, 1999; Aydin et al. 2000; Kaeriyama et al. 2000, 2004; Radchenko and Mathisen 2004). These studies have shown that salmon are extremely adaptable to changes in the ocean environment and their forage base, and prey on a wide diversity of organisms. In summer 2003, the Japan BASIS study area was expanded to adjacent North Pacific waters in order to investigate potential changes in the distribution and feeding ecology of salmon during a year of high abundance of Asian pink salmon (*Oncorhynchus gorbuscha*). In this paper we investigate spatial differences in the feeding ecology of immature sockeye (*O. nerka*) and maturing pink salmon in the western Gulf of Alaska (145–160°W, 50–58°N), examine the effects of oceanographic environment and biological interactions on salmon feeding behavior, and evaluate our methods and results with respect to future BASIS research.

Salmon samples were collected aboard R/V *Kaiyo maru* during daytime (1-hr) tows of a surface trawl at 16 stations in the western Gulf of Alaska (145–160°W, 50–58°N) from 2 August to 14 August 2003. A conductivity, temperature, and depth sensor (CTD) was used at 24 stations in the same area for measuring water temperature and salinity (Fig. 1). The relative abundance or catch per unit effort (CPUE) of each species at each station was calculated as the number of individuals caught per 1-hr tow of the trawl. The whole body mass (BW, g), gonad somatic mass (GSW, g), and fork length (FL, mm) of salmon were measured. Stomachs were collected from up to 10 fish of each salmon species at each trawl station, and preserved in a 10% Formalin-seawater solution. Stomach contents were classified to 12 taxa (Kaeriyama et al. 2000) to the lowest identifiable taxon using a dissecting microscope, and counted and weighed by species. A gonad somatic index (GSI;  $GSW / BW \times 100$ ) was used to evaluate the maturity stage. Stomach contents were analyzed in terms of a stomach index (SCI;  $\text{prey weight} \times 100 / BW$ ), as well as a modified index of relative importance (IRI) method (Pinkas et al. 1971; Kaeriyama et al. 2000). The Shannon-Wiener index ( $H'$ ; Colwell and Futuyma 1971) was used to measure prey diversity. A simplified Morishita's index ( $C_H$ ; Horn 1966) was used to estimate diversity and similarity of food niche between species by their prey composition. The average linkage clustering method (Krebs 1998) was used to estimate food similarity among sampling stations by prey composition. Student's and Welch's t-tests, and a nonparametric Mann-Whitney

**Fig. 1.** Locations for collections of Pacific salmon (red circles) and CTD-data (red and black circles) in the Gulf of Alaska in August 2003.





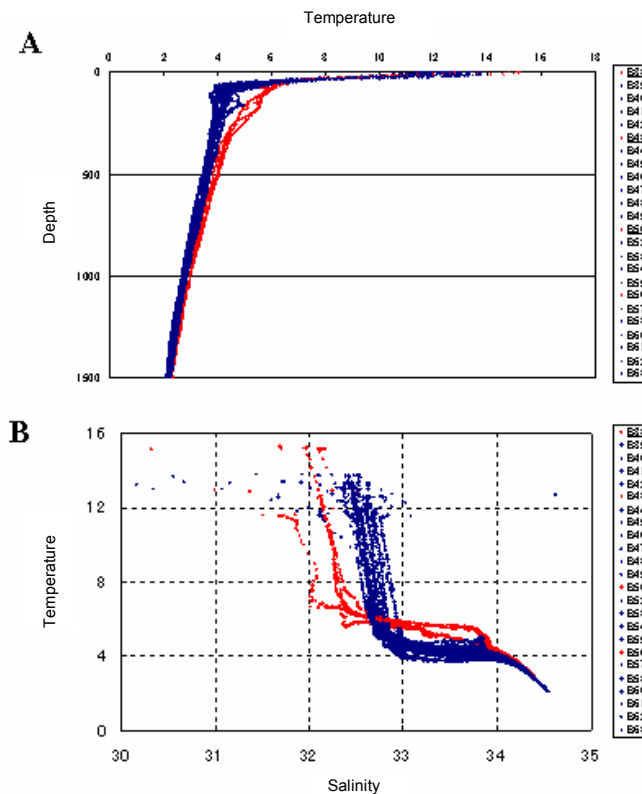
test were used to compare biological characters of sockeye and pink salmon. Significance in all tests was accepted at the  $P = 0.05$  level.

In August 2003, stations in the Alaska Stream (B38, B43, B50, and B56) had warmer water temperatures than stations farther offshore in the Alaska Gyre (Fig. 2). Sockeye salmon were distributed in more southern areas ( $51\text{--}53^\circ\text{N}$ ,  $155\text{--}160^\circ\text{W}$ ) than pink salmon ( $54\text{--}56^\circ\text{N}$ ,  $155\text{--}160^\circ\text{W}$ ). The CPUE of sockeye salmon ( $8.79 \pm 10.34$  fish) was higher than that of pink salmon ( $5.52 \pm 10.18$  fish), although the difference was not significant (Mann-Whitney test;  $P = 0.93$ ). Pink salmon were significantly larger (FL  $514 \pm 34$  mm, BW  $1,666 \pm 289$  g) than sockeye salmon (FL  $425 \pm 65$  mm, BW  $905 \pm 462$  g; Welch's t-test;  $P < 0.001$ ). The GSI of female pink salmon ( $8.05 \pm 2.25$ ) was significantly higher than that of female sockeye salmon ( $0.53 \pm 0.56$ ; Student's t-test;  $P < 0.001$ ). Most of female pink salmon were fully mature. Pink salmon distributed in coastal waters (Alaskan Stream) were at the maturing stage during their homing migration, whereas sockeye salmon distributed on the high seas (Alaska Gyre) were at the immature stage.

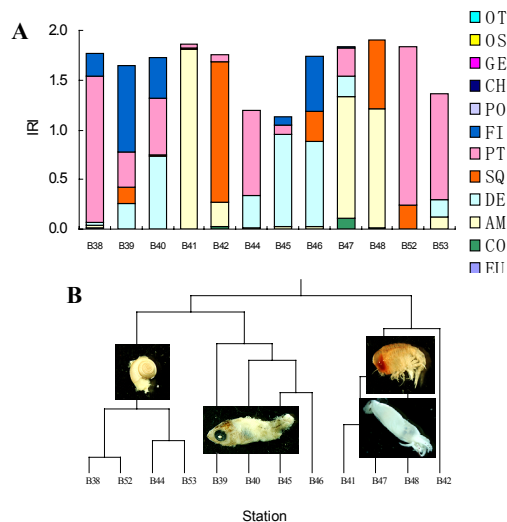
Sockeye salmon ( $0.80 \pm 1.08$ ,  $n = 94$ ) had a higher SCI than pink salmon ( $0.48 \pm 0.50$ ,  $n = 35$ ), although the difference was not significant (Mann-Whitney test;  $P = 0.98$ ). The offshore sockeye salmon had a higher SCI than coastal fish. Immature sockeye and maturing pink salmon consumed diverse prey, e.g., fishes, squids, amphipods, decapods, and pteropods (Figs. 3 and 4). At low CPUEs of both species, sockeye salmon fed on prey that were larger (fishes and squids) and had higher energy content than at high CPUEs. The cluster analysis results showed that sockeye salmon fed dominantly on pteropods in coastal waters, decapods in middle waters, and hyperiid amphipods and squids in offshore waters (Fig. 3), despite unclear results for pink salmon (Fig. 4). Sockeye salmon had a more diverse food niche ( $0.744 \pm 0.306$ ) than pink salmon ( $0.417 \pm 0.384$ ; Student's t-test;  $P = 0.02$ ). These differences in feeding ecology of pink and sockeye salmon may be caused by differences in their sexual maturity. The diets of sockeye and pink salmon did not shift from small to large prey with increase in body size (Fig. 5). The feeding niche overlap of sockeye and pink salmon was high ( $C_H > 0.6$ ), and both species fed on the same dominant prey (i.e., pteropods and decapods), when their distribution was sympatric (Fig. 6).

In conclusion, our results suggest that sockeye and pink salmon are omnivorous and opportunistic feeders, feeding on available and abundant prey species according to intra- and inter-specific competition, food composition, and oceanic environment. However, the sampling period (2–14 August) of our study was too late in the year to investigate the major period of overlap (winter-spring) in the distribution of sockeye salmon and Asian pink salmon in the Gulf of Alaska. More importantly, data from plankton sampling aboard the *Kaiyo maru* in August 2003 were not available at the time of our analysis. For future BASIS research, we recommend seasonal basin-scale process studies to investigate the effects of climate-induced changes in feeding conditions (especially prey composition and availability) and density-dependent interactions among species, size, age, and maturity groups, and stocks of salmon that migrate between the Bering Sea and Gulf of Alaska.

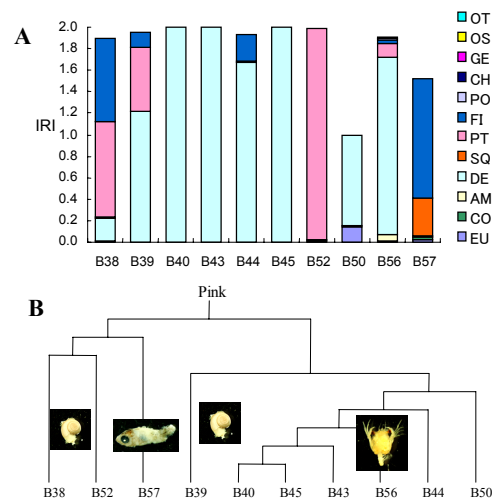
**Fig. 2.** Vertical profile of temperature (A) and relationship between salinity and temperature (B) in the Gulf of Alaska. Red dots: Sts. B38, B43, B50, and B56; Blue dots: other stations.



**Fig. 3.** IRI (A) and result of the cluster analysis (B) on stomach contents of sockeye salmon in the Gulf of Alaska in August 2003 (n: number of samples. EU: euphausiids, CO: copepods, AM: amphipods, DE: decapods, SQ: squids, PT: pteropods, FI: fish, PO: polychaetes, CH: chaetognaths, GE: gelatinous zooplankton, OS: ostracods, OT: other species).

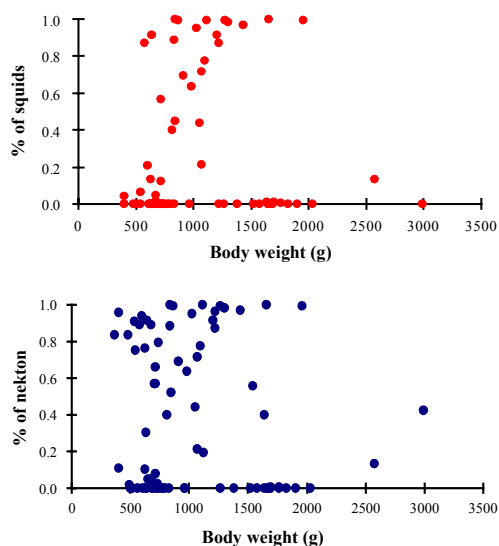


**Fig. 4.** IRI (A) and result of the cluster analysis (B) on stomach contents of pink salmon in the Gulf of Alaska in August 2003 (n: number of samples. EU: euphausiids, CO: copepods, AM: amphipods, DE: decapods, SQ: squids, PT: pteropods, FI: fish, PO: polychaetes, CH: chaetognaths, GE: gelatinous zooplankton, OS: ostracods, OT: other species).

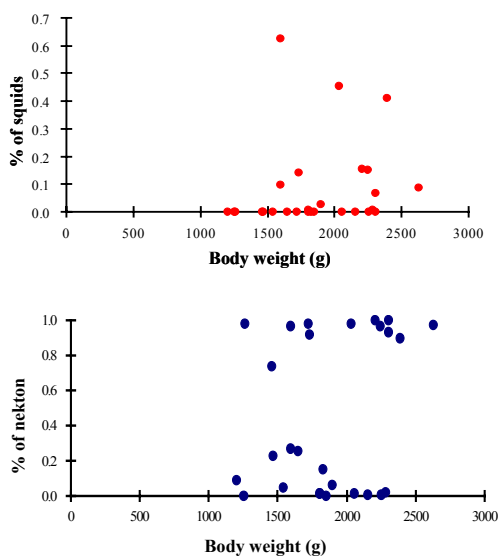


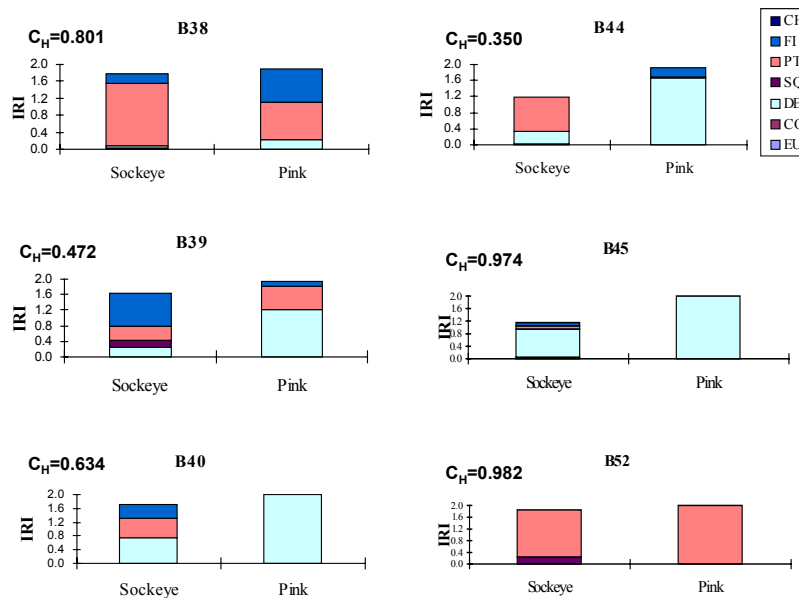
**Fig. 5.** Changes in rates of squid and nekton (squid and fish) occupied in the stomach of sockeye and pink salmon in the Gulf of Alaska in summer 2003.

#### Sockeye salmon



#### Pink salmon



**Fig. 6.** Diversity and overlap of feeding niche between sockeye and pink salmon in the Gulf of Alaska in summer of 2003.

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## Hydrobiological Investigations by the TINRO-Centre under the BASIS-2003 Program: Zooplankton and Pacific Salmon Feeding

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Keywords: Zooplankton, salmon, feeding

In September and October of 2003, the researchers of TINRO Centre undertook three complex expeditions to the Bering Sea (Fig. 1) during which they collected plankton using a Juday net. These samples were later processed according to the standard methods developed and practiced at TINRO (Volkov et al. in press).

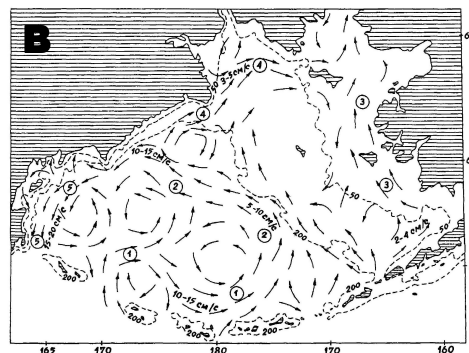
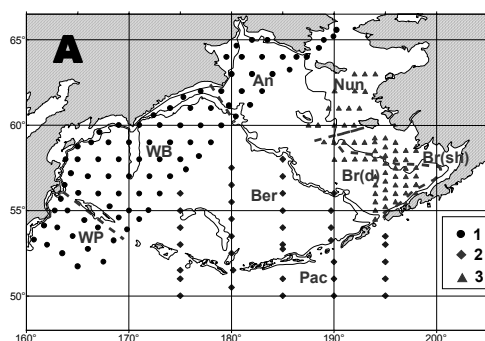
Small-fraction zooplankton (< 1.2 mm) were the most abundant in number and biomass in the shallow waters of the North-East Bering Sea (Table 1). The middle-size zooplankton fraction (1.2–3.3 mm) had the least biomass of the three fractions. As such, the middle size zooplankton biomass was within 15–95 mg/m<sup>3</sup> (4.5%–20% of the total). Only in the Bristol Bay shallow waters was this fraction found higher than the large fraction. The large-fraction zooplankton dominated throughout the year in most of the Far Eastern seas and in the adjacent Pacific oceanic waters which serve as feeding areas for numerous commercial species. As the abundance of this large fraction mainly determines the feeding base for commercial fishes, special attention has been given to the analysis of this part of the plankton.

During the period of the research, the highest biomass of large-size zooplankton occurred in the areas where the volumes of small-size fractions were lowest, and vice versa, i.e. (Fig. 2). The small-size zooplankton dominated in the total volumes caught in all the three eastern zones of the Bering Sea. Large-size zooplankton fraction biomass was the lowest especially in the Bristol Bay shallow waters where it was represented by only 9% of zooplankton total biomass. As for the other areas, with the exception of the Anadyr Bay, large-size zooplankton fraction biomass was considerably higher and its share was as much as 78%–85%.

As for the large-fraction zooplankton biomass parameters, copepods and chaetognaths dominated over the major part of the Bering Sea, while in the Okhotsk Sea, euphausiids dominated followed by chaetognaths and copepods, both represented in equal amounts. The leading 10 species caught in all areas made up over 90%, and the first three species represented 55% (from 55% to 79%). As for the shallow eastern areas, small-fraction species dominated, while in the rest areas, there outnumbered large-fraction zooplankton.

Data on salmon feeding (mainly chum and sockeye) and their food abundance were collected during the expedition of the fall season of 2003, which was undertaken on three research ships and covered the major part of the Bering Sea (Efimkin et al. in press). In deep waters of the Bering Sea (Western and Central parts), the large-fraction zooplankton was the major food for salmon (70%–100%), while nekton represents only 0%–30%. It is important to note that chum salmon had a preference in pteropods and hyperiids, while sockeye ate mostly hyperiids and pteropods, the share of which was much lower in zooplankton than in stomachs. In autumn, the feeding of chum salmon declined considerably, though the composition remained approximately the same. The share of chaetognaths in their food was much lower than in zooplankton.

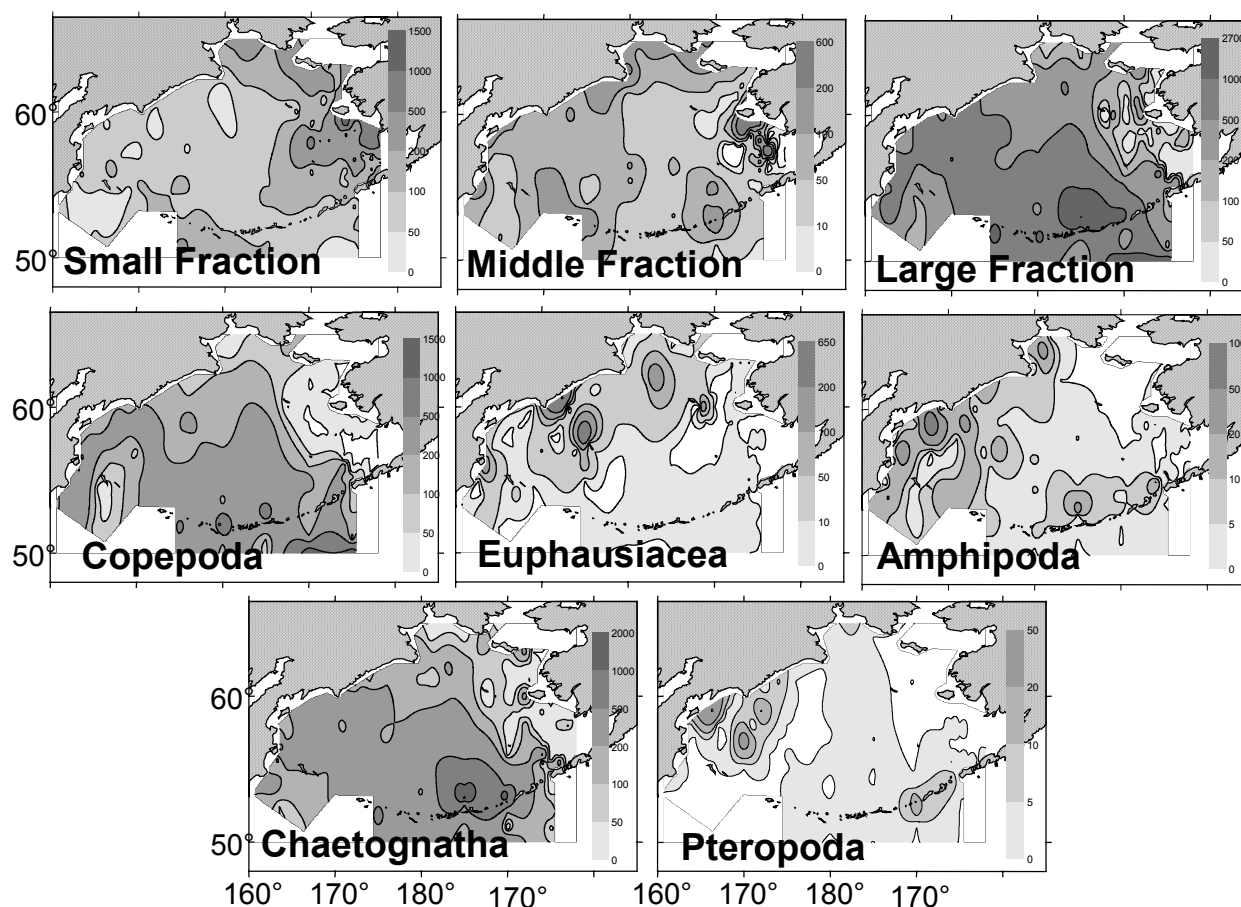
**Fig. 1. A:** Planktonic stations (BASIS), summer–autumn 2003 (Isobath 50, 200, 1000 m; 1 - "TINRO", Juday (BSD) Net, 14.09–25.10; 2 - "Kaiyo Maru", BSD and Norpac Nets, 30.08–19.09; 3 - "Sea Storm", BSD Net 150–0 m, 31.08–08.10). Areas: An - Anadyr bay, WB - western Bering Sea, WP - western Pacific, Ber - central Bering, Pac - central North Pacific, Br(sh) - Bristol shallow part, Br(d) - Bristol depth part, Nun - Nunivak area. **B:** The generalized map of surface currents in Bering Sea in warm half-year (Khen, 1988). Currents: 1-Attu, 2 - Central-Bering, 3 - West-Alaska, 4 - Navarin, 5 - Kamchatka.



**Table 1.** Composition of zooplankton of Bering Sea in autumn 2003 (with coefficients of catch). Areas: An - Anadyr bay, WB - western Bering Sea, WP - western Pacific, CB - central Bering, AT - Aleut-Pacific, Nun - Nunivak area, Br(d) - Bristol depth part, Br(sh) - Bristol shallow part.

Composition of Zooplankton	"Sea Storm"			"Kaiyo-Maru"		"TINRO" (day)			"ТИНРО" (night)		
	Br(sh)	Br(d)	Nun	CB	AT	An	WB	WP	An	WB	WP
<b>Total Biomass</b>	<b>661.7</b>	<b>349.8</b>	<b>339.2</b>	<b>1,004.4</b>	<b>713.9</b>	<b>471.9</b>	<b>718.1</b>	<b>498.2</b>	<b>892.3</b>	<b>716.4</b>	<b>684.5</b>
Small Fraction	514.7	217.4	187.4	88.3	95.7	144.1	64.8	49.2	147.7	64.5	60.5
Middle Fraction	89.9	15.6	47.6	58.9	37.0	94.6	77.4	61.9	83.0	75.3	55.2
<b>Large Fraction:</b>	<b>57.1</b>	<b>116.8</b>	<b>104.3</b>	<b>857.2</b>	<b>581.2</b>	<b>233.2</b>	<b>575.9</b>	<b>387.1</b>	<b>661.6</b>	<b>576.6</b>	<b>568.8</b>
Copepoda	1.6	41.6	5.1	316.5	356.1	93.6	188.3	202.3	97.0	217.9	301.5
Euphausiacea	0.1	1.1	12.3	6.2	3.4	34.3	40.7	20.9	284.1	65.9	90.9
Hyperiidea	0.5	1.3	0.2	9.0	4.1	7.3	14.9	8.9	8.8	16.4	8.8
Chaetognatha	29.7	69.4	51.9	508.7	206.9	92.0	296.0	143.2	131.4	247.5	156.2
Coelenterata	10.6	2.3	31.2	15.2	8.5	2.4	29.1	10.6	13.9	20.2	8.6
Other	14.5	1.0	3.6	1.6	2.2	3.6	6.9	1.2	126.4	8.7	2.8

**Fig. 2.** Distribution of the three biomass fractions of zooplankton and groups of the large fraction at 200 (bottom) – 0 m, day-time, mg/m<sup>3</sup>.



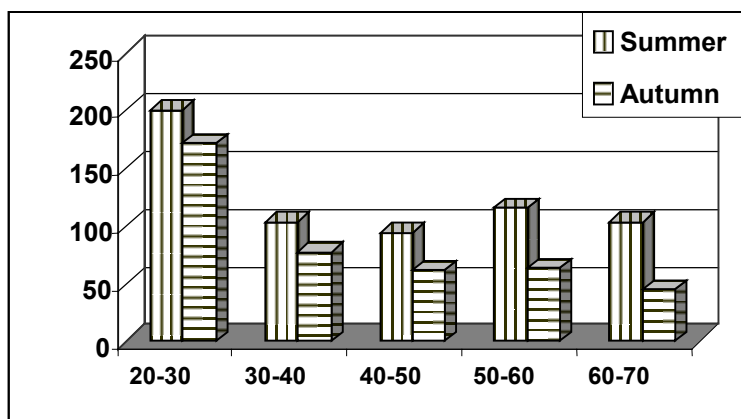
In the eastern part of the Sea, chum salmon, almost exclusively ate fish (pollock fingerlings and *Leuroglossus schmidti*), sockeye salmon preferred pollock fingerlings and crab larva. It was determined that only in sockeye salmon's food (the fish 15–20 cm long), zooplankton represented 30% (euphausiids), and this was similar to generally the typical composition of the plankton population, in which small-size zooplanktonic animals prevail.

Large fraction zooplankton was the food basis for chum and sockeye salmon (70–100%), while nekton represents only 0–30%. In the western part of the Bering Sea, there was a noticeable preference in food of chum salmon for pteropods and hyperiids, but for sockeye salmon there was an evident preference for hyperiids, the percentage for of which was always much lower in the plankton, than that observed in stomachs. The number of euphausiids in their food was also large especially for chum salmon. In some regions during some years, the percentage was as high as 50–60%.

In the autumn, the stomach contents of chum salmon (the size above 40 cm) decreased (Fig. 3). The share of squids rose considerably, while jellyfishes decreased with the amount of young fishes remained unchanged. The daily rhythmic of feeding in both species was similar. The least activity was observed at night while, the greatest occurred in the afternoon and in the evening. Almost all food was digested by dawn. In the central part of the Sea, coelenterates, pteropods, hyperiids and euphausiids were the major diet of chum salmon and euphausiids and hyperiids dominated for sockeye salmon. Small squids prevailed in the food of sockeye, and chum salmon. In the eastern part, chum salmon ate almost exclusively fish (juvenile pollock and sand lances), while sockeye salmon preferred juvenile pollock and crab megalops.

During the last 3 years, there has been a trend to decreased biomass of the preferred zooplankton. Such fluctuations are specific to the Far Eastern seas and take place regularly within the period of 5–7 years. Collecting of data for plankton and feeding of Pacific salmon only during the daytime is not sufficient to give an opportunity to study the daily rhythmic, and consequently, to calculate daily and monthly nutrition as the results underestimate the role of many other species (euphausiids, mysids and some species of copepod) in the feeding of nekton.

Fig. 3. Intensity of food of Chum salmon in western Bering Sea ( $^{\circ}/_{000}$ ).



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## New Information from Archival Tags from Bering Sea Tagging, 1998–2004

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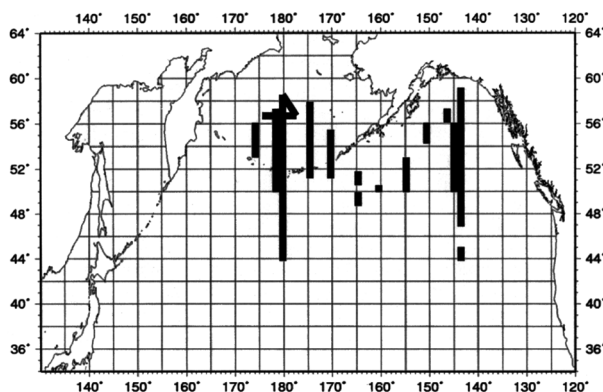
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**Keywords:** Salmon, archival data storage tags, behavior, migration

Scientists of North Pacific Anadromous Fish Commission nations have cooperated in the deployment of archival data storage tags (DSTs) on salmon in high seas waters since 1994 (Wada and Ueno 1999; Walker et al. 2000a, b; Friedland et al. 2001; Ishida et al. 2001; Tanaka 2003; Tanaka et al. 2005). We report results from archival tagging research under U.S. and North Pacific Research Board (NPRB) programs. Since 1998, 791 salmon have been tagged with DSTs in the Bering Sea, North Pacific Ocean, and Gulf of Alaska (Table 1, Fig. 1). Of these, 72 were recovered and returned, a 9.1% return rate. Funding from NPRB has allowed a larger number of DSTs to be placed on salmon in 2003 and 2004. The return rate has declined in recent years, as more immature fish were tagged. (Immature fish remain at sea at least one additional year and historically have had a much lower chance of being recaptured.) The tags were released during 17 cruises of one U.S. and three Japanese research vessels (Fig. 1). The highest number of tags was placed on chum salmon, which reflects the research priorities, areas, and times of the tagging vessels (Table 2). Forty-one tags were recovered from fish tagged in the Bering Sea, and five tags were recovered in Bering Sea waters from fish tagged in the North Pacific and Gulf of Alaska (Fig. 2). All but three of the recoveries have come from maturing fish that were at large for periods of one day to three months. Because most of the data are from a relatively short period in summer and fall at the end of the ocean phase for maturing salmon, the following observations may apply to only this life history period.

**Fig. 1.** Areas of U.S. and NPRB-funded high seas salmon tagging, 1998–2004.



**Table 1.** Number of U.S. and NPRB-funded data storage tags that were released and recovered and recovery rates, 1998–2004.

Year	Tags Released	Tags Recovered	Recovery Rate
1998	55	8	14.5
1999	89	17	19.1
2000	31	5	16.1
2001	70	2	2.9
2002	73	5	6.8
2003	167	12	7.2
2004	306	23	7.5
Total	791	72	9.1

**Table 2.** Number of U.S. and NPRB-funded data storage tags released and recovered by species, 1998–2004.

	Sockeye	Chum	Pink	Coho	Chinook	Steelhead
No. Tagged	173	316	130	67	86	19
No. Recovered	17	32	8	11	3	1
Recovery rate	9.8	10.1	6.2	16.4	3.5	5.3

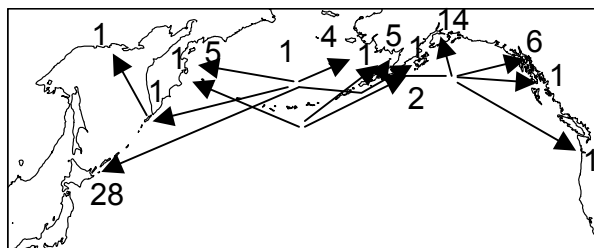
Data from recovered tags have yielded basic information about salmon behavior and migration (Fig. 3; Walker et al. 2000b). Salmon appear to undergo a period of recuperation from the trauma of tagging, when the fish remain at the surface. This period can be brief (on the order of days or hours) or more lengthy (greater than one week). Most fish exhibit a diurnal behavior pattern for some or all of the time they are at liberty. Typically fish remain at or near the surface at night and move vertically in the water column during the day. Most fish return to the surface on these vertical excursions, but individuals of some species may remain below the surface throughout the day. The migration of fish through different water masses can be discerned from changes in surface temperatures and differences in daily temperature ranges. Temperature ranges may vary widely between water masses, while maximum swimming depths remain fairly constant. This indicates differences in thermal stratification and mixing between water masses, and also indicates that during this period fish are choosing maximum depths and not temperature ranges.

Maturing chum salmon generally swim at maximum depths between 50 and 100 m below the surface, but can swim at depths over 300 m as they approach coastal areas. These extensive vertical movements may be thermoregulatory to avoid high surface temperatures. Diurnal behavior patterns are well-pronounced. Recoveries of Japanese and Sakhalin chum salmon indicate the fish migrate through an area of cold water with surface temperatures of 4°C or less on their return (Fig. 3). This area is likely in the Kuril Islands.

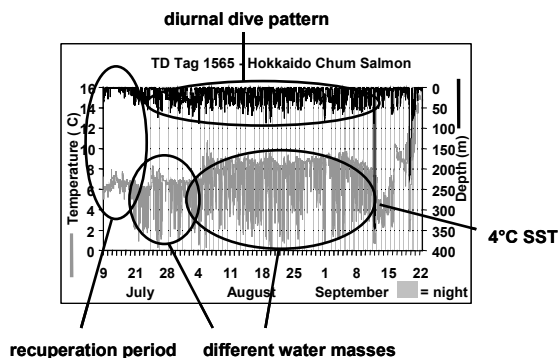
Maturing pink salmon also have strong diurnal behavior patterns, but may remain below the surface at depths of 40–60 m throughout the day. Maturing sockeye salmon generally swim at shallower maximum depths, between 20 and 30 m. They encounter small temperature ranges, because surface waters are usually well-mixed to these depths. Diurnal behavior patterns are not as strongly expressed as in chum and pink salmon. Maturing coho salmon have more variable diurnal behavior. In some fish, it is strongly expressed, while it is weaker in others. This difference may relate to stage and location of returning migration. Like pink salmon, coho salmon sometimes remain below the surface throughout the day, but they may remain there for more than a day. The maximum swimming depths of coho salmon are slightly deeper than those of pink salmon.

We have depth data from only one chinook salmon, but the pattern it displays is remarkable (Fig. 4). This fish was tagged in July 2002 in the Bering Sea and recovered in the Yukon River in June 2004. In spring and early summer the fish swam at depths over 350 m below the surface, the maximum depth the tag could record. During the first winter recorded on the tag, the fish remained at approximately 125 m for three months, where the temperature was a fairly uniform 4°C. During the second winter, the fish remained at or near the surface, while the temperature declined from 4°C to 1°C. The salmon exhibited differing diurnal behavior patterns at different times during the two years.

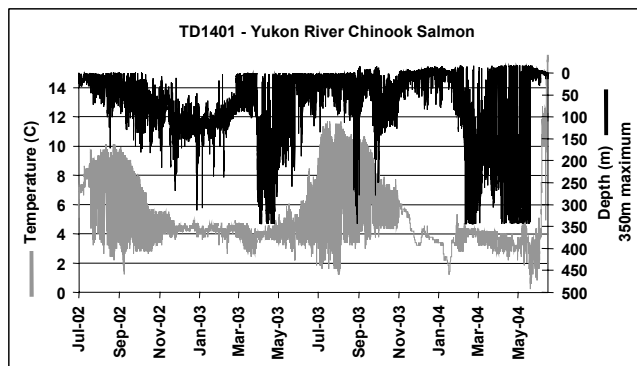
**Fig. 2.** General areas and numbers of recoveries of U.S. and NPRB-funded salmon data storage tags.



**Fig. 3.** Information about salmon behavior obtained from high seas salmon data storage tags. Chum salmon tagged in the Bering Sea (July 9, 2002) and recovered on the Nemuro coast of Hokkaido, Japan (September 24, 2002).



**Fig. 4.** Temperature and depth data record of a chinook salmon tagged in the Bering Sea July 2, 2002 and recovered in the Yukon River June 16, 2004.





Differences between species are summarized in Table 3. These differences are based on observations from a relatively small number of tag recoveries ( $n = 3$  to 15) and all come from the last part of the ocean life of maturing fish, except for one chinook salmon.

Future research with DSTs should include more tagging of immature salmon to discover how behavior changes at different life history periods. Tagging in fall may increase chances of recovery of immature fish. Tagging in spring should provide access to maturing stocks that return earlier than stocks tagged during previous cruises. Geographic locations of salmon as estimated from tags which record and interpret light data could provide useful general information on distribution and migration routes.

**Table 3.** Summary of salmon swimming depth below the surface and behavior obtained from data on archival tags.

Species	'Usual' Depth (m)	Max Depth (m)	Diurnal Pattern	N
Sockeye	20–30	30–85	weak to moderate	15
Pink	40–60	60–85	strong	6
Coho	30–70	80–120	weak to strong	11
Chum	60–70	100–345	strong	15
Chinook	variable	350+	variable	1
Steelhead	no data	no data	strong	1

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Peninsula, eastern Bristol Bay, western Bristol Bay and Norton Sound (Fig. 1). Mixture samples were grouped by geographic location (using features of the ocean floor including: the northeastern continental shelf, the Bowers Ridge north of the Aleutian Islands and the Shirshov Ridge in the west; Fig. 2), seasonal timing (August, September and October) and age (one ocean and two-plus ocean) and subjected to mixed-stock analyses.

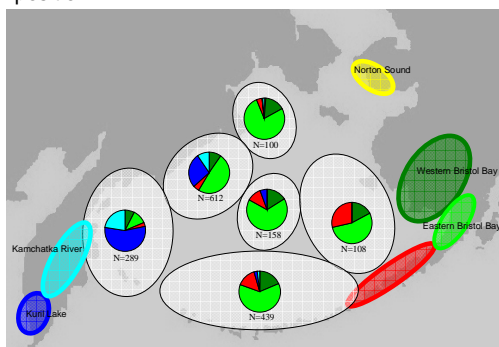
The most comprehensive data available throughout the Bering Sea were for August. Stock distributions in August show the highest proportions of western-originating stocks on the western side of the Bering Sea and the highest proportions of eastern-originating stocks on the eastern side (Fig. 3). When all samples are taken in combination, the eastern Bristol Bay stock is the most abundant reporting group. The next most common reporting group is composed of western Bristol Bay stocks. These results are consistent with expectations based on the proportions of sockeye salmon produced within the five regions (Bugaev 2004; Alaska Department of Fish and Game unpublished data). Although Russian sockeye salmon stocks contribute less than half of the stock mixtures in every sample except the most southwesterly sample, their presence in samples from the central Bering Sea basin and Aleutian Islands indicates that they migrate eastward at least half way across the Bering Sea. Alaskan sockeye appear to migrate throughout the Bering Sea and make up, almost exclusively, the stock proportions on the northeastern Continental Shelf including the western side near Russia.

Stock distributions divided into ages one and two-plus ocean fish showed generally higher proportions of Russian stocks in the two-plus ocean mixtures than in the one ocean mixtures (Figs. 4 and 5). This pattern may indicate that larger proportions of two-plus ocean fish from Alaska migrate south into the North Pacific relative to stocks originating from Russia or that Russian one ocean fish are in the North Pacific and migrate north as two-plus ocean age. Of the immature fish captured on the northeastern continental shelf, 89% were one ocean fish, so stock compositions could only be calculated on this age group (these were again almost exclusively Alaska-origin stocks). This pattern may indicate that one ocean fish favor different environmental variables than two-plus ocean fish and that Russian one ocean fish generally do not utilize the northeastern continental shelf.

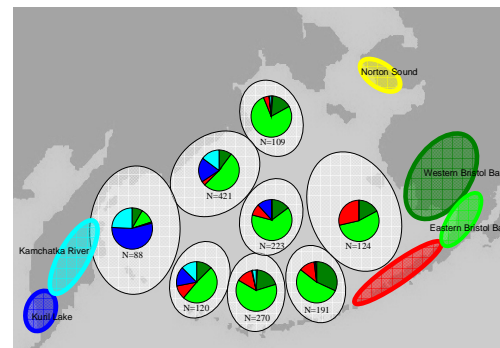
**Fig. 2.** Geographic features of the ocean floor in the Bering Sea used to divide samples of immature sockeye salmon captured during the BASIS cruises in 2002 and 2003 for mixed-stock analysis using genetic markers.



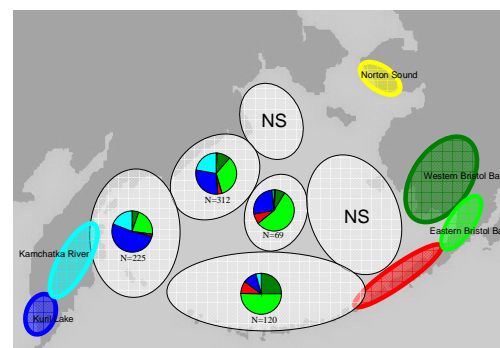
**Fig. 4.** Stock proportions of 1-ocean immature sockeye salmon sampled from throughout the Bering Sea during August, September and October of 2002 and 2003. "NS" indicates insufficient samples to estimate mixture composition.



**Fig. 3.** Stock proportions of immature sockeye salmon sampled from throughout the Bering Sea during August of 2002 and 2003. Baseline stocks were pooled into six reporting groups and are symbolized with colored ovals. Pale ovals under the pies represent the general area where stock mixtures were captured and pie colors correspond to reporting group colors.



**Fig. 5.** Stock proportions of two-plus ocean immature sockeye salmon sampled from throughout the Bering Sea during August of 2002 and 2003. "NS" indicates insufficient samples to estimate mixture composition.



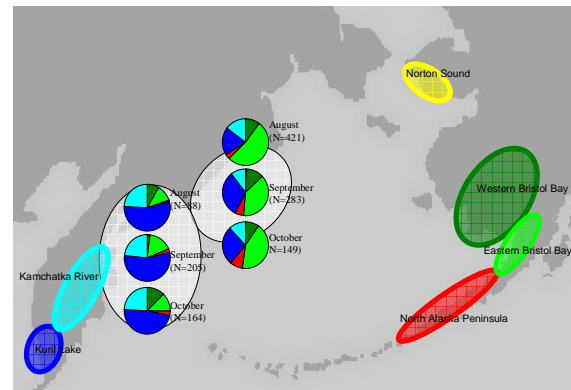
Stock distributions over time within locations off the Russian coast showed fairly stable compositions from August through October (Fig. 6). These data only represent ¼ of the year, and stock distributions may vary substantially within location over time if more samples were taken throughout the year. The consistent stock distribution over time does not necessarily indicate a lack of migration because co-migrating stocks might have little effect on stock distributions. Adding abundance information to the stock composition information could provide additional insight into migration patterns.

This project relied on the cooperation of BASIS partners from the United States, Russia and Japan to collect and share tissue samples for genetic analysis and specifically we would like to acknowledge the contributions from: T. Walker, K. Meyers, E. Farley, J. Murphy, L. Low, O. Temnykh, V. Sviridov, N. Klovatch, I. Glebov, N. Starovoytov, S. Urawa, and S. Abe. Genetic analysis was funded in part by the North Pacific Research Board grants R0205 and R0303.

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**Fig. 6.** Stock proportions of immature sockeye salmon sampled from western Bering Sea during August, September, and October of 2002 and 2003.



## Mechanisms of Salmon Homing Migration from Molecules to Behavior

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Keywords: Homing migration, behavior, hormone, olfaction, chum salmon

Salmon have an amazing ability to migrate thousands kilometers from the open ocean to their natal stream for reproduction after several years of oceanic feeding migration. It is now widely accepted that some specific factors of the natal stream are imprinted to particular nervous systems of juvenile salmon during downstream migration, and that adult salmon evoke these factors to recognize the natal stream during homing migration. A number of studies have investigated the amazing ability of salmon to migrate long distances from the ocean to their natal river for spawning (Ueda and Shoji 2002). For a better understanding of the mechanisms of salmon homing migration, three different analyses have recently been applied using Japanese chum salmon (*Oncorhynchus keta*) homing migration in Hokkaido, Japan.

The first is behavioral analysis of upstream tactics of chum salmon through a rehabilitated segment of the Shibetsu River by electromyogram (EMG) telemetry and micro-data logger tracking in collaboration with Yuya Makiguchi, Masumi Akita (Hokkaido University), Hisaya Nii, and Katsuya Nakao (Hokkaido Farming Fisheries Promotion Corporation). To restore the ecological condition of a previously channelized river to its more natural, meandering state, a segment of the Shibetsu River was reconstructed. We investigated the upstream tactics of chum salmon as they migrated up the channelized segment, reached the confluence point with the restructured segment, and then entered the rehabilitated area. Fish were radio tracked with EMG telemetry and micro-data loggers. The monitored salmon preferred to hold in deep, slow moving areas of the channelized river, and EMG telemetry data revealed that these extended holding times provided the fish with efficient rest. In the reconstructed segment, the fish swam at more shallow depths and against stronger currents. Although all fish chose to enter the reconstructed segment, few fish remained in the segment for long. This implies that the reconstructed area may not provide suitable holding sites for migrating salmon.

The second is endocrinological analysis of hormone profiles in the brain-pituitary-gonadal axis in collaboration with Tomoko Kitani (Hokkaido University), Masafumi Amano (Kitazato University), and Masatoshi Ban (National Salmon Resources Center). Gonadotropin-releasing hormone (GnRH) molecules produced in the various brain regions are considered to be involved in many physiological functions of teleost life cycle. In order to clarify GnRH roles on salmon homing migration, two molecular types of GnRH, salmon GnRH (sGnRH) and chicken GnRH-II (cGnRH-II) in different brain regions, as well as gonadotropin (GTH) and steroid hormones, were measured using specific time-resolved fluoroimmunoassay (TR-FIA) systems (Yamada et al. 2002; Leonard et al. 2002). Maturing chum salmon were caught at nine points from the Bering Sea to the Chitose River. After decapitation, the brain was divided into six regions: olfactory bulb (OB), telencephalon (TC), diencephalon (DC), optic tectum (OT), cerebellum (CB), and medulla oblongata (MO). During the spawning migration of chum salmon, sGnRH levels in OB, TC, and pituitary of both sexes increased from the coastal sea to the point where the Chitose River branches from the Ishikari River. Moreover, sGnRH levels in the pituitary tended to increase at the same time as the elevation in female pituitary GTH II and ovarian GTH I levels. The cGnRH-II level in MO was increased at the pre-spawning ground in both sexes, and levels of OT were also increased in males. Both GnRH levels in DC showed no significant changes during spawning migration. The GTH II levels in gonads were not detected though the sampling period. Serum steroid hormone levels showed profiles similar to previous observations (Ueda 1999); estradiol-17  $\beta$  in females and 11-ketotestosterone in males increased during vitellogenesis and spermatogenesis, respectively, and 17 $\alpha$ ,20 $\beta$ -dihydroxy-4-pregnen-3-one increased dramatically at the time of final gonadal maturation in both sexes. It is quite interesting to note that both sGnRH content in TC and serum testosterone level showed coincident peaks at the branch point of the Chitose River from the Ishikari River. These results confirm the previous findings that sGnRH plays a role in GTH secretion in the pituitary of chum salmon, and sGnRH and cGnRH-II might be involved in brain region-dependent roles of sexual maturation and behavior in salmonid fishes.

The third is olfactory analysis of the ability to discriminate the natal river in collaboration with Yuzo Yamamoto (Hokkaido University) and Takayuki Shoji (Tokai University). For upstream homing migration from the coastal area to the natal stream, the olfactory hypothesis proposed by Hasler and Wisby (1951) has been discussed in many behavioral and electrophysiological studies, but the odor substances of the home stream are still unknown. We found that the response to artificial stream water based on the compositions of amino acids and salts closely

resembled the response to the corresponding natural water (Shoji et al. 2000), and we carried out behavior experiments to test whether amino acid mixtures of the home stream have attractive effects on the upstream movement of chum salmon. Mature male chum salmon (mainly four year olds) were captured at the weir in the Osaru River, Hokkaido, Japan, in the late spawning season of 2002, transferred to the Toya Lake Station, Hokkaido University, and reared for several days before experiments. Behavior experiments were conducted in the two-choice test tank. Artificial home stream water was prepared by dissolving the amino acid and related-substance composition of the Osaru River in artificial freshwater. A total of 44 chum salmon was tested, and 28 fish (63.6%) showed upstream movement to one choice arm of the tank. Among those that moved, 24 fish (85.7%) were found in the arm with artificial home stream water, and four fish (14.3%) were observed in the arm with natural lake water. These results demonstrate clearly that artificial home stream water, reconstituted by the amino acid composition of the home stream, has attractive effects on the upstream-selective movement of chum salmon. We concluded that amino acids dissolved in the home stream water are home stream odorants, and the hypothesis that amino acids dissolved in stream waters are home stream substances for salmon homing is strongly supported by these results.

By means of these different new approaches, the following three topics will be future research projects on chum salmon homing migration in my laboratory:

- 1) What kinds of environmental factors might influence the endocrinological changes of salmon that initiate homing migration?
- 2) When, where, and why might salmon cease foraging behavior during the homing migration?
- 3) What kinds of sensory cues might salmon use to navigate for a migration of several thousands of kilometers, and how would endocrinological changes influence sensory cues during the homing migration?

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# Critical-Size, Critical-Period Hypothesis: An Example of the Relationship between Early Marine Growth of Juvenile Bristol Bay Sockeye Salmon, Subsequent Marine Survival, and Ocean Conditions

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**Keywords:** Early marine growth, survival, scale, sockeye salmon, Bristol Bay, ecosystem change

Bristol Bay sockeye salmon (*Oncorhynchus nerka*) from the eastern Bering Sea were used to test the critical-size, critical-period hypothesis (Beamish and Mahnken 2001; Beamish et al. 2004). We examined a time series (42 years) of survival (brood year return per spawner from the Kvichak and Egegik river systems in southwest Alaska) and early marine growth (mean circuli spacing for the first marine year) from preferred scales (Clutter and Whitesel 1956) collected from returning adult salmon to these river systems. Four major age classes of sockeye salmon return to Bristol Bay, including 1.2, 1.3, 2.2, and 2.3, where the numbers to the left and right of the decimal point indicate the number of years spent in freshwater lakes and the number of years in the ocean, respectively. The data were lagged to reflect growth during the first year at sea (1958–2000) for freshwater age 1.0 and 2.0 sockeye salmon. Early marine growth was compared with survival of adult sockeye salmon using regression analysis and was found not to be significantly related to survival of Bristol Bay sockeye salmon. We also compared early marine growth between river systems for each freshwater age class and between freshwater age classes. Average circuli spacing between Egegik and Kvichak age 1.0 and 2.0 salmon was relatively uniform as was average circuli spacing between age 1.0 and 2.0 fish. A lack of relationship between adult sockeye salmon survival and early marine growth as observed from scales of surviving adult sockeye salmon may indicate a threshold relationship between early marine growth and survival, implying that those fish failing to achieve a sufficient size undergo higher mortality rates (Crozier and Kennedy 1999). Moreover, the similarity in early marine growth between river systems and freshwater age classes is an indication that the early marine growth threshold is correlated among geographically well-separated river systems and between freshwater age classes.

The threshold size of sockeye salmon was compared to the size of juvenile Bristol Bay sockeye salmon collected during eastern Bering Sea research cruises in August–October of 2000–2004. The results indicate that juvenile sockeye salmon were significantly smaller during 2000 and 2001 and not significantly different during 2002–2004 than the threshold size. We speculate that the larger size of juvenile Bristol Bay sockeye salmon during 2002–2004 is related to higher early marine growth rates that may be due to improved or changing ocean conditions along the eastern Bering Sea shelf beginning in 2002. These results indicate that growth of juvenile Pacific salmon may be an excellent indicator of ecosystem change.

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# Density Dependent Growth of Pink Salmon *Oncorhynchus gorbuscha* in the Bering Sea

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Keywords: Pink salmon, density-dependent growth, Bering Sea

Growth variations of pink salmon and the factors influencing them were examined using data collected by Japanese salmon research vessels in the Bering Sea during 1974–1995. Catch-per-unit-effort (CPUE) of pink salmon changed differently for odd and even year stocks in the Bering Sea (Fig. 1). CPUE in odd years increased after 1989, but those in even years remained at a low level. Mean fork lengths of pink salmon in odd years were larger than those in even years from 1974 to 1987, but mean fork lengths in odd years decreased to the size of the fish in even years during 1989 and 1993 (Fig. 2). Scale measurement data indicated that coefficients of variation in the second year ocean growth (8.1–8.8%) were larger than those for coastal growth (3.6–4.8%) and the first year ocean growth (4.0–4.6%) for both stocks. CPUE of pink salmon showed a negative relationship with the coastal and second year ocean growth (Fig. 3, 4). Pink salmon growth partly showed a significant negative relationship with the CPUE of other salmon species, but was not significantly correlated to sea surface temperature and zooplankton biomass. These results suggest that the density of pink salmon is one of the factors influencing growth variations of pink salmon, especially in the coastal and second year ocean life.

Fig. 1. Year to year changes in CPUE of pink salmon.

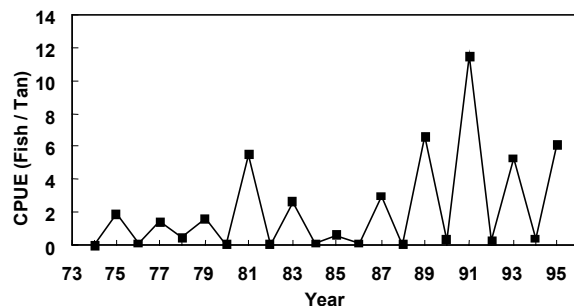


Fig. 2. Year to year changes in fork length of pink salmon.

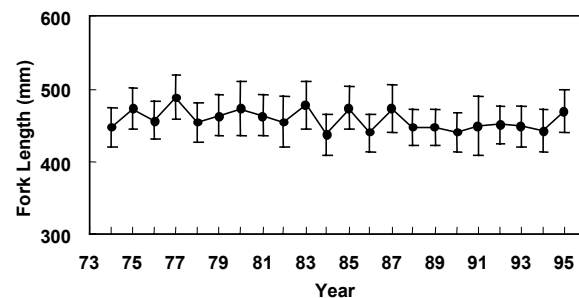


Fig. 3. Relationship between CPUE and coastal growth (W10) of pink salmon.

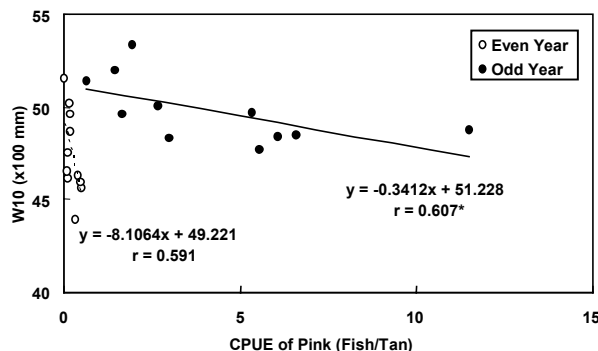
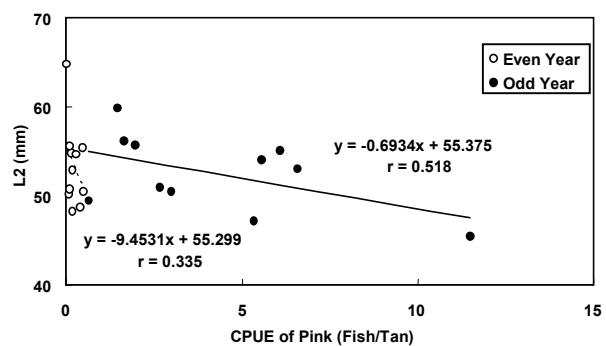


Fig. 4. Relationship between CPUE and the second year of ocean growth of pink salmon.





## Microsatellite Analysis and Stock Identification of Pacific Salmon Using Pacific Rim Baselines

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**Keywords:** Chum salmon, microsatellites, population structure, sockeye salmon, stock identification

DNA-level variation has been demonstrated to be very effective in determining population structure in Pacific salmon, and when applied to problems of estimation of stock composition in mixed-stock samples, has provided unprecedented levels of accuracy and precision in stock composition estimates based upon biological variation. It is also possible to identify the origins of individual salmon with a high degree of resolution. DNA-level variation (both microsatellite and major histocompatibility complex (MHC)) has been extensively applied in determination of stock composition and individual identification in samples from fisheries, providing detailed resolution of origin of fish in the samples not previously available from biological characters.

For sockeye salmon, tissue samples were collected from populations with a Pacific Rim distribution, and DNA was extracted from the samples as described by Withler et al. (2000). For the survey of baseline populations, PCR products at 14 microsatellite loci: *Ots2*, *Ots3* (Banks et al. 1999), *Ots100*, *Ots103*, *Ots107*, and *Ots108* (Beacham et al. 1998; Nelson and Beacham 1999), *Oki1* (two loci), *Oki6*, *Oki10*, *Oki16*, and *Oki29* (Smith et al. 1998), *One8* (Scribner et al. 1996), and *Omy77* (Morris et al. 1996) were size fractionated on denaturing polyacrylamide gels and allele sizes determined with the ABI 377 automated DNA sequencer. Allele sizes were determined with Genescan 3.1 and Genotyper 2.5 software (PE Biosystems, Foster City, CA). Genetic variation at the MHC class II *DAB-β1* locus (Miller et al. 2001) was surveyed by denaturing gradient gel electrophoresis (DGGE).  $\beta1$  alleles were separated by DGGE with the Bio-Rad (Hercules, CA) D Gene<sup>TM</sup> or D Code<sup>TM</sup> electrophoresis systems, with conditions determined by the methods of Miller et al. (1999). Fluorescently-multiplexed (FM)-DGGE (Miller et al. 2000) was used in the population survey.

The baseline survey consisted of analysis of over 48,000 sockeye salmon from 298 populations from Japan, Russia, Alaska, British Columbia, and Washington. Allele frequencies and sample sizes for all locations surveyed in this study are available at [http://www-sci.pac.dfo-mpo.gc.ca/mgl/default\\_e.htm](http://www-sci.pac.dfo-mpo.gc.ca/mgl/default_e.htm). Multipopulation mixtures of known origin were analyzed with Bayesian statistical techniques similar to those outlined by Pella and Masuda (2000). The estimated lake of origin was defined as the lake assigned the highest probability in the analysis.

Analysis of individuals within samples of known origin indicated that individual salmon can be identified to specific lake of origin with an accuracy > 90%, even with a Pacific Rim distribution of possible natal lakes. Accurate estimates of individual identification by lake of origin will be available as long as a particular lake is represented in the baseline used in the estimation.

The baseline survey for chum salmon consisted of analysis of over 24,000 individuals from over 200 populations in a Pacific Rim distribution of the populations. For the survey of baseline populations, PCR products at 13 microsatellite loci: *Ots3* (Banks et al. 1999), *Oke3* (Buchholz et al. 2001), *Oki2* (Smith et al. 1998), *Oki100* (Miller et al. unpublished data), *One101*, *One102*, *One103*, *One104*, *One111*, and *One114* (Olsen et al. 2000), *Ssa419* (Cairney et al. 2000), *Omy1011* (Rexroad et al. 2002) and *OtsG68* (Williamson et al. 2002) were size fractionated on denaturing polyacrylamide gels with the ABI 377 automated DNA sequencer.

Genotypic frequencies were determined at each locus in each population and the statistical package for the analysis of mixtures software program (SPAM version 3.7) was used to estimate stock composition of each mixture (Debevec et al. 2000). The Rannala and Mountain (1997) correction to baseline allele frequencies was used in the analysis in order to avoid the occurrence of fish in the mixed sample from a specific population having an allele not observed in the baseline samples from that population. All loci were considered to be in Hardy-Weinberg equilibrium, and expected genotypic frequencies were determined from the observed allele frequencies. Each baseline population was resampled with replacement in order to simulate random variation involved in the collection of the baseline samples before the estimation of stock composition of each simulated mixture. Simulated fishery samples of 150 fish were generated by randomly resampling with replacement the baseline populations in each drainage. Estimated stock composition of a simulated mixture was then determined, and the whole process was repeated 100 times to estimate the mean and standard deviation of the individual stock composition estimates.

Analysis of population structure indicated a strong regional component, with Japanese, Russian, Yukon River, southeast Alaska, British Columbia, and Washington populations forming distinct regional groups. Analysis of

simulated mixtures showed a high level of resolution among populations and regions. Regional estimates of stock composition were within 4% of actual values, and within 3% for specific populations in the baseline. Microsatellites have the potential to provide accurate estimates of stock composition to quite local areas, even if a Pacific Rim baseline is applied in the estimation procedure. The baselines outlined for both sockeye salmon and chum salmon would likely resolve the origin of salmon caught in Bering Sea locations.

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## Abundance Estimates of Eastern Bering Sea Juvenile Salmon

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**Keywords:** Juvenile salmon abundance, kriging, bootstrap, marine survival

The U.S. Bering-Aleutian Salmon International Survey (BASIS) was initiated in 2001 as a coordinated effort by North Pacific Anadromous Fish Commission member nations to define the role of salmon in the Bering Sea ecosystem. Abundance estimates of juvenile salmon support U.S. BASIS survey objectives by improving our understanding of marine survival in western Alaska salmon stocks and helping to define the role of these stocks in the pelagic ecosystem of the eastern Bering Sea shelf. In this report, we compare two different approaches used to estimate juvenile salmon abundance.

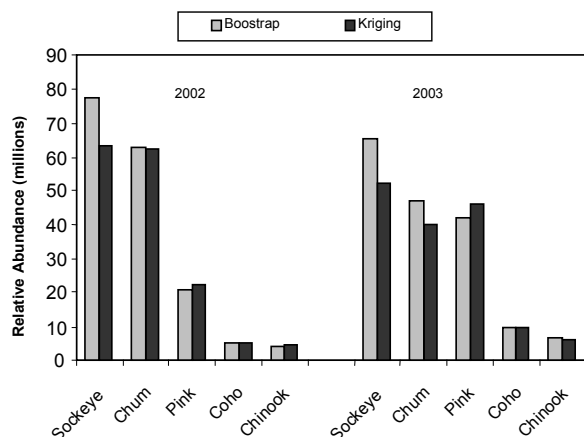
During 2002 and 2003, a total of 303 stations were sampled as part of the U.S. BASIS juvenile salmon surveys. Surface rope trawls (Cantrawl models 400/580 and 300/460) were fished by the F/V *Sea Storm* (Farley et al. 2003, 2004). The Cantrawl 400/580 had a typical mouth opening of 14 m H 52 m (vertical H horizontal) and the Cantrawl 300/460 had a typical mouth opening of 11 m H 56 m. The duration for all trawl hauls was 30 minutes and the average towing speed was 4.4 knots. Fishing effort was defined as the area swept by the trawl, and relative abundance (abundance relative to the fishing power of the trawl/vessel combination) of juvenile salmon was defined as the catch per unit of effort, or the number of individuals captured per square kilometer swept by the trawl.

A variety of methods have been developed to estimate abundance from research trawl surveys. Criteria used to select between different methods and to define the appropriateness of the methods are generally centered on the assumptions used to expand sample data to obtain population level statistics. These assumptions are addressed by the variability introduced through the selection of sample locations in design-based methods, and the variability introduced in the catching process in model-based estimators (Smith 1990).

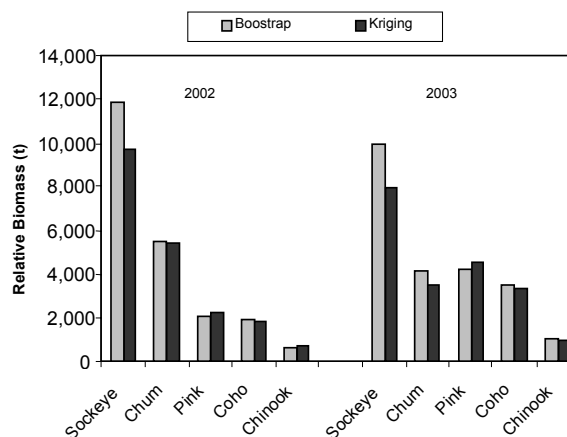
Population abundance estimates of juvenile salmon were similar when the design-based bootstrap estimator (Efron and Tibshirani 1993) and the model-based kriging estimator (Cressie 1991) were used (Fig. 1). Similarity in abundance estimates by both approaches greatly increases our confidence in the estimates of abundance. Similarity in the estimates indicates that results will not be dependent on criteria used to select the estimator. Similarity in the estimates also indicates that there is not a significant design-based or model-based bias in the estimates.

Although our abundance estimates represent an unknown fraction of the true abundance, if this fraction is assumed to be constant over time and species we can compare abundance levels between years and species. Both estimators identify sockeye salmon as the most abundant juvenile salmon species, followed closely by chum salmon in 2002, and by both pink and chum salmon in 2003. Relative biomass estimates of juvenile salmon differed from the pattern observed in abundance due to differences in average weight (Fig. 2). The numbers of pink and chum

**Fig. 1.** Relative abundance estimates of juvenile salmon on the eastern Bering Sea shelf during the 2002 and 2003 U.S. BASIS surveys.



**Fig. 2.** Relative biomass estimates (metric tons) of juvenile salmon on the eastern Bering Sea shelf during the 2002 and 2003 U.S. BASIS surveys.



salmon were surprisingly high considering the low numbers of pink and chum salmon returning to western Alaska. The likely contribution of pink and chum salmon from Russian stocks could explain the large numbers of juvenile pink and chum salmon in our survey area. However, even accounting for the presence of Russian-origin chum salmon stocks through genetic stock identification (Russian chum salmon contributions were estimated to be less than 10% in 2002), the abundance levels of juvenile chum salmon are still large relative to their historic return levels to western Alaska river systems. Comparable returns of chum and sockeye salmon to western Alaska is highly unlikely (historic returns differ by an order of magnitude); therefore, the abundance levels of juvenile chum and sockeye most likely reflect a higher subsequent marine mortality in chum salmon. Future work on juvenile salmon abundance will include selection of an optimal estimator of abundance, refining abundance estimates by freshwater age and stock structure, and comparisons with adult returns.

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## Abundance Estimates of Juvenile Pacific Salmon in the Eastern Okhotsk Sea and Western Bering Sea

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**Keywords:** Rope trawl, specifications, survey, calibration, salmon, juvenile, abundance

KamchatNIRO initiated trawl surveys to study the biology of juvenile salmon in the coastal waters of the Bering Sea and Okhotsk Sea in 1981. In 1985, the Experimental Commercial Fisheries Base of Kamchatka designed a pelagic rope trawl (54.4/192 m; 1,600–60 mm mesh net; 24 mm mesh liner) for specialized surveys of juvenile salmon by middle-class vessels (STR 503). In this paper, we summarize information on the calibration and testing of the 54.4/192-m trawl at sea, the results fall stock assessment surveys of juvenile salmon over a period of nearly 20 years, and the use of these data to forecast adult returns for some commercial stocks.

Surface trawling at sea is the most difficult type of trawl operation, as the process depends on many ambient factors—waves, surface currents, etc. The crew must consist of highly skilled specialists with extensive practical experience in calibration of the trawl system, i.e., the vessel, warps, trawl doors, cables, and the trawl net and ropes. The spatial position of a trawl during operation and its trajectory are determined by the correlation of static and hydrodynamic forces that bring the trawl system into equilibrium, when the doors enter the water and the head rope stays at the surface, and maintain stable movement of the trawl in the desired direction. For optimal for trawling, the designed size of the trawl opening and its injection into the surface layer are achieved by adjusting the head rope and angle of incidence of the trawl doors. If the system is unadjusted, the trawl either cannot move steadily along the surface or the length of warps is not sufficient to reach the designed opening.

Tests of the 54.4/192 trawl were conducted in the Okhotsk Sea in 1989 and 2003 (Table 1). The trawl design team had to calibrate the trawl on a regular basis, as the skills of crew members were not always adequate for such work. In 1989, 69 trawl operations, using spherical 4.2 m<sup>2</sup> trawl doors, were conducted aboard the RV *Professor Kaganovskiy*. The total catch of juvenile salmon was 32,112 fish (57% pink, 32% chum, 9% sockeye, and 1.6% coho, and both chinook and masu < 1%). Similar work was performed in 2003 by the STR 503 *Esso*, using two types of trawl doors (standard 3.3 m<sup>2</sup> spherical doors and V-shaped 4.0 m<sup>2</sup> vertical doors). In total, there were 77 test trawl operations, which were considered valid when the trawl doors entered the water and the head rope remained steadily on the surface. Juvenile salmon were caught in 69 trawl operations (25,590 fish, averaging 42% pink, 41% chum, 13% sockeye, 1.4% chinook, 1.8% coho, and 0.8% masu). We concluded that the 54.4/192-m trawl provides acceptable results for stock assessment and distribution studies of juvenile salmon provided that gear adjustments are performed by experts.

**Table 1.** Examples of the results of some test operations of the 54.4/192-m trawl by the STR 503 *Esso* in the Okhotsk Sea in 200: Oper. № = trawl operation number; Vert. open. = vertical opening of the net; Distance (m) = distance between the trawl doors and wing ends; Warp dist. = warp distance. Sock = sockeye; Chin = chinook.

Trawling parameters									Juvenile salmon catches					
Oper. №	Date (day.mo)	Speed (knots)	Vert. open. (m)	Distance (m)		Warp dist. angles (-)		Warp length (m)	Species (number of fish)					
				Trawl doors	Wing ends	Right	Left		Pink	Chum	Sock	Chin	Coho	Masu
1	26.9	4.5	28	50	23	12	0	200	-	1	-	-	71	-
10	29.9	4.8	27	85	39	9	10	245	229	127	-	-	-	1
20	3.10	5.2	28	67	31	0	13	260	176	116	-	-	-	1
30	8.10	5.4	30	80	37	9	12	200	1208	139	-	-	1	-
40	11.10	4.4	32	87	41	9	13	210	309	41	-	-	-	-
50	15.10	4.9	35	80	37	9	10	220	486	42	-	-	-	1
60	18.10	4.3	33	78	36	10	7	240	450	185	1	-	1	-
70	27.10	5.3	30	62	29	8	7	210	3	12	2	-	-	-

In the eastern Okhotsk Sea, we conducted 14 trawl surveys over a period of 13 years (two surveys in 1986). A total of 993 trawl operations were made, and total catches of six species of juvenile salmon were over 186,000 fish (54.3% pink, 34.6% chum, 6.3% sockeye, 2.9% coho, 1.7% chinook, and 0.2% masu salmon). In the southwestern Bering Sea, we performed 12 trawl surveys, consisting of 614 trawl operations, and total catches of five species of juvenile salmon were over 49,000 fish (75% pink, 19% chum, 1.9% sockeye, 1.8% coho, and 2.3% chinook).

Because of differences in the timing of downstream migrations, stock assessment surveys are usually performed 10–15 days earlier in Bering Sea (late August) than in the Okhotsk Sea (mid September). Seaward migration of salmon juveniles begins on both coasts of Kamchatka at almost the same time. However, sizes of some species in the Bering Sea and Okhotsk are not identical, as conditions for foraging in coastal waters and survey times are different. Usually, juvenile pink, chum and coho in the Okhotsk Sea are bigger (especially in weight) than in Bering Sea. However, sockeye and chinook are bigger in the Bering Sea than the Okhotsk Sea. In general, variation in body size is higher in the Okhotsk Sea than the Bering Sea.

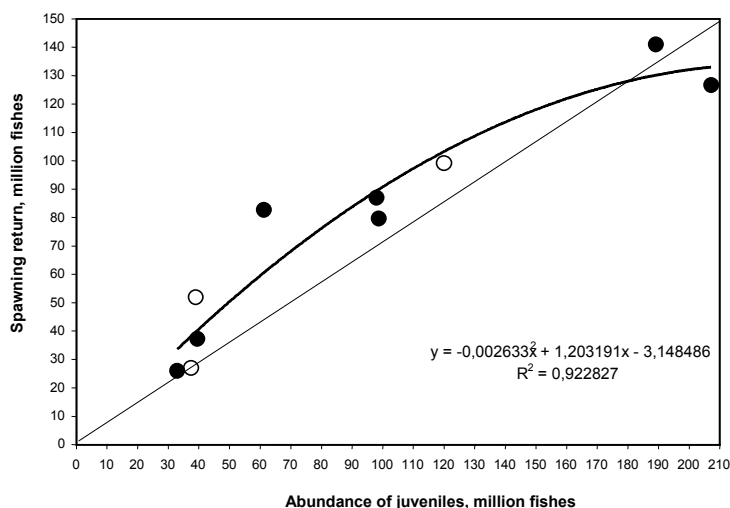
Distribution of stocks during survey operations also plays an important role in stock assessment surveys. The 54.4/192-m trawl was designed for species, such as pink and chum salmon that migrate from coast to the ocean as an entire stock rather than in separate groups. Downstream migration of pink salmon begins earlier, and hence their seaward migration begins earlier as well. As a rule, species with a long freshwater life period (sockeye, coho, chinook) migrate to the ocean in echelons, and fish of different ages may migrate at different times. Older fish abandon the coast earlier than younger fish. Freshwater age 0+ fish migrate later than older fish.

Because the timing of downstream migration and foraging in coastal waters differs for various species and age groups, duplicate surveys are needed to assess different cohorts. In recent years, duplicate surveys were performed in the Bering Sea (2000, 2002) and the Okhotsk Sea (2001, 2003), which enabled more accurate assessment of the abundance, direction of migration, and natural mortality of different cohorts.

Ocean stock assessment of juveniles in fall is the final stage for calculating the return ratio for mature fish and estimating the allowable catch. At present, these data are used only for pink salmon. In some areas, however, they can also be used for other species—only sockeye, chum and coho salmon, as biomass of chinook and masu salmon is too low. Trawl survey data on juvenile stock biomass are the foundation for preparation of a spawning run forecast for Kamchatka pink salmon. The following empirical formula is used to estimate spawning runs of West Kamchatka pink salmon (Fig. 1):  $Y = ax^2 + bx + c$ , where  $Y$  is the commercial (total) return (millions of fish), and  $x$  is the abundance of juveniles in fall season (millions of fish). The most regular and accurate results have been achieved for West Kamchatka stocks, where the deviation of actual return ratios from forecasted has rarely been higher than 30%. Such similarity between actual and forecasted data was also achieved for the northeastern Kamchatka stock in 1980s and 1990s, when ocean stock assessment surveys of juvenile salmon were performed on a regular basis.

In conclusion, the trawling methods described herein fulfill many theoretical and practical tasks associated with management of salmon stocks, including the collection of data on abundance and biological characteristics, annual assessment of distribution, migration, and foraging conditions, forecast information for commercial runs of certain stocks, and assessment of the role of juvenile salmon in coastal ecosystems.

**Fig 1.** Dependence of abundance of pink salmon in total spawning runs on abundance of juveniles in fall season (September–October). Closed circle—Western Kamchatka; Open circle—northeastern Kamchatka.



# Fluctuations of the Zooplankton Community during Early Ocean Life of Chum Salmon in the Coastal Waters of Eastern Hokkaido, Okhotsk Sea

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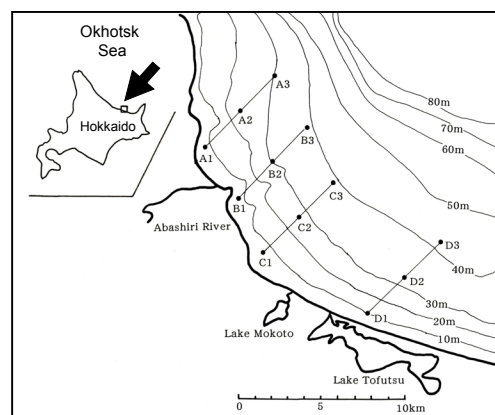
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**Keywords:** Temperature, salinity, dominant zooplankton, small zooplankton, large zooplankton, early marine survival

Ocean conditions during the period of early ocean residence of chum salmon, may be important in determining the early marine survival. The fluctuation of zooplankton abundance might be one of the most important factors affecting on the early survival of juvenile chum salmon as the main prey of juvenile chum salmon is zooplankton. The coastal waters in the Okhotsk Sea are covered with sea ice until early spring. Therefore chum juveniles in these coastal waters experience extreme changes in the ocean environment. We started a project in 2002 to clarify the relationships between the early life ecology of juvenile chum salmon and ocean environments (Nagata et al. 2004). The surveys were conducted every ten days throughout late April to middle July in 2002 and 2003, establishing twelve stations (10–40m depths) in Abashiri coastal waters of Okhotsk Sea (Fig. 1). Zooplankton were collected at each station using vertical hauls of a Norpac net (0.45m in mouth diameter, 0.33 mm mesh size) from the near sea bottom to the surface. Water temperature and salinity were measured using the Memory STD. Chum juveniles were collected using a surface trawl net.

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



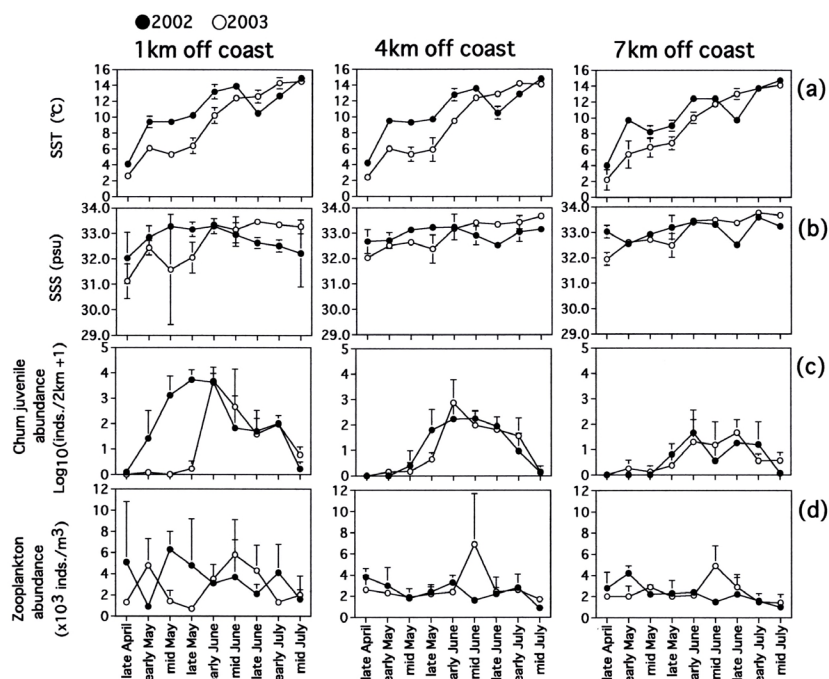
Average surface water temperature (SST: °C) ranged from 4.0 to 14.9°C in 2002 and from 2.2 to 14.5°C in 2003, respectively (Fig. 2a). SST was very low until late May in each area in 2003, increasing from early June rapidly. Average surface salinity (SSS: psu) ranged from 32.0 to 33.6 psu in 2002 and from 31.1 to 33.8 psu in 2003, respectively (Fig. 2b). SSS was also very low until late May in 2003, especially at 1 km off the coast. However, it increased from early June in each area. It was apparent that physical environments fluctuated largely in 2003 than 2002.

Chum juveniles were more abundant at 1 km off the coast, when the SST and SSS were 8–10°C and 33.0–33.5psu, respectively (Fig. 2c). These optimal values of SST and SSS for chum juveniles were similar to those reported by Irie (1990). The peaks of CPUE (about > 500 inds./2 km) were observed from middle May to early June in 2002 and from early to middle June in 2003, respectively. Although residence in the bay was longer in 2002 than 2003, chum juveniles were more abundant in the small littoral zone in 2003 (Nagata et al. in press). Total zooplankton abundances were higher at 1 km than 4 km and 7 km off the coast (Fig. 2d). At 1 km off the coast, the peak of total zooplankton was observed in late April ( $5.1 \times 10^3$  inds./m<sup>3</sup>) and middle May ( $6.3 \times 10^3$  inds./m<sup>3</sup>) in 2002 and, in early May ( $4.8 \times 10^3$  inds./m<sup>3</sup>) and middle June ( $5.8 \times 10^3$  inds./m<sup>3</sup>) in 2003. Both second peaks were coincident with the time when water temperature increased to 8–10°C and chum juveniles appeared in the bay. Nine dominant species in the zooplankton could be counted in both years (Fig. 3). These species could be classified into two groups. One is a cold water species including *Rathkea octopunctata*, *Pseudocalanus newmani*, *Acartia longiremis*, *Thysanoessa inermis*, and *Fritillaria borealis* f. *typica*, and the other is a warm water species including *Podon leuckarti*, *Evadne nordmanni*, *Mesocalanus tenuicornis* and *Oikopleura longicauda*. *R. octopunctata* (hydrozoans) was more predominant in 2003 than 2002, which was the important component of the first zooplankton peak in 2003. *T. inermis* egg (euphausiid) also appeared from late April to middle May, and contributed to the second peak in 2002. *P. newmani* was the most abundant species until middle June and in years. Abundance of this species at 1 km off the coast in the second peak reached to 35–54% in 2002 and 56–57% in 2003, respectively. *O. longicauda* or *F. borealis* f. *typica* (appendicularians) were also predominant in the second peak of zooplankton abundance. Composition of *P.*

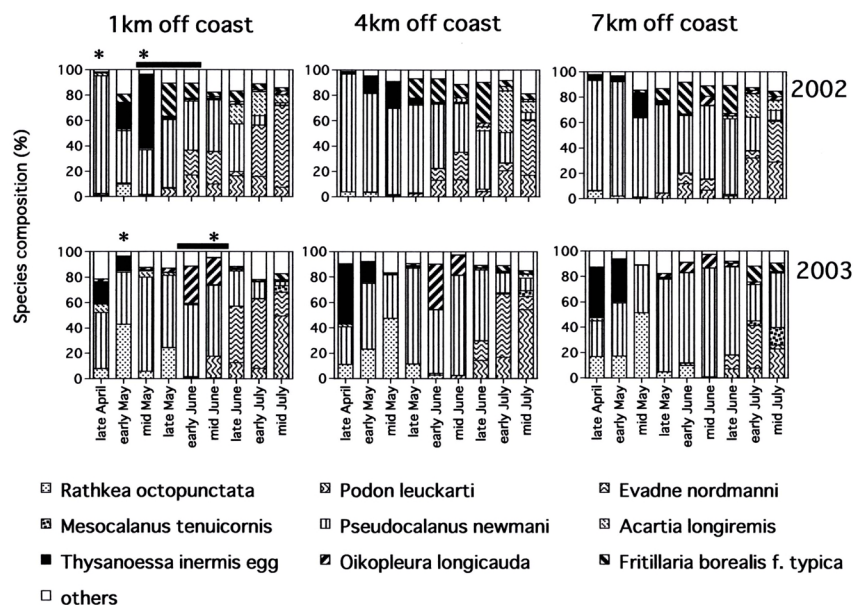


*leuckarti* and *E. nordmanni* (cladocerans) increased in early and middle July in both years. Either *A. longiremis* or *M. tenuicornis* (copepod) was predominant in early and middle July. In these dominant species, five species of *P. leuckarti*, *E. nordmanni*, *P. newmani*, *Oikopleura* spp. and *F. borealis* f. *typica* were also predominant in numerical composition of chum juvenile stomachs. In addition to these species, three cold water copepod species (*Tortanus discaudatus*, *Metridia pacifica*, *Neocalanus* spp.) were found to be in abundance. Although the electivity indices (Chesson's  $\alpha$ ) were not always high in the former five species, the indices were always high in the later three species which were not abundant in zooplankton numerical abundance. Although size measurements of zooplankton were not made in this study, the sizes were different between the former (< about 1 mm) and later species (1–5 mm).

**Fig. 2.** Averages of surface water temperature (a), surface salinity (b), catch of chum juveniles (c), abundance of total zooplankton (d) at 1 km, 4 km and 7 km off the Abashiri coast in 2002 and 2003. Bars indicate standard deviations.



**Fig. 3.** Changes in dominant species composition consisting of more than 10% in the average zooplankton abundance in each year at the 1 km, 4 km and 7 km off the Abashiri coast in 2002 and 2003. Symbols \* indicate the date when the total zooplankton abundance reached to the peak at 1 km off the coast. Horizontal bars indicate the date when the chum juveniles were abundant at 1 km off the coast.





Comparisons of the average abundances of these eight species during the chum juvenile residence periods showed that small size zooplankters were similar or higher in 2003 than 2002, however, the average abundance of large size zooplankton such as *Neocalanus* spp. was higher in 2002 than 2003.

The appearances of chum juveniles in the bay were synchronized with the increasing of small zooplankton such as cladocerans (*Podon*, *Evadne*), copepods (*Pseudocalanus*) and appendicularians (*Oikopleura*, *Fritillaria*), which were controlled by ocean conditions such as the water temperature and salinity. It was also known that chum juveniles began to expand their prey sizes when the fork length of juvenile reached to 50~60 mm (Okada and Taniguchi 1971). Although the abundance of the small size zooplankton dominating during the residence of chum juveniles might be fundamentally important, the considerations for the distribution and biomass of the large size zooplankton also may be important.

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# Feeding Habits of Chum Salmon *Oncorhynchus keta* in the Central Bering Sea during Summer, 2002

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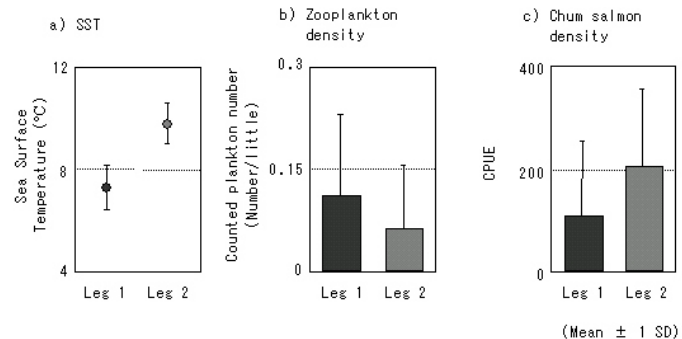
**Keywords:** Chum salmon, *Oncorhynchus keta*, feeding habits, seasonal diet shift, Bering Sea

From the late 1970s to 1990s, the abundance of chum salmon in the North Pacific Ocean and Bering Sea increased steadily, while the body sizes of returning fish decreased (Ishida et al. 1993, 2002). During the summer growth period, a substantial number of chum salmon and other species of Pacific salmon congregate in the Bering Sea to feed; therefore, density-dependent growth control is likely. To clarify the mechanisms of growth control, information on the pattern of food resource use is essential. Here, we describe ontogenetic, seasonal, and diel variations in food habits of chum salmon in the Bering Sea.

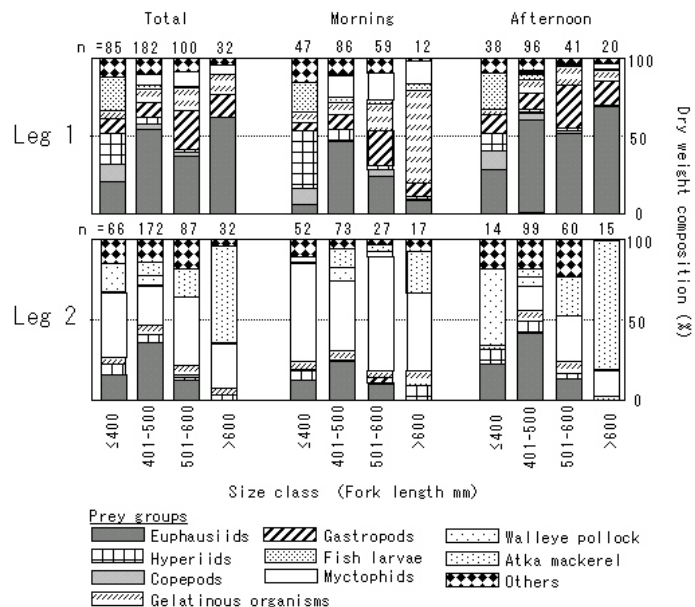
In 2002, we collected chum salmon during surveys by the RV *Kaiyo maru* from June 29 to July 15 (Leg 1; 24 trawl stations) and from August 16 to September 18 (Leg 2; 38 trawl stations) in the central Bering Sea. Fishing gear used was a surface trawl net with a mouth of ca. 50 x 50 m. Stomachs were collected from a maximum of 20–30 individuals at each station. The contents of each stomach were sorted to the lowest possible taxonomic groups, and the digestive stages and dry weight composition (*DWC*) were determined. *DWC* was compared among salmon size classes, legs, and time periods (morning and afternoon). To examine the oceanographic conditions, sea surface water temperature (SST) was measured at each sampling station; the zooplankton abundance in the surface layer was measured by an Electronic Particle Counting and sizing System (EPCS).

The abundance of chum salmon in the central Bering Sea doubled as SST increased from Leg 1 to Leg 2, while mean zooplankton abundance decreased by half (Fig. 1). The diets of chum salmon differed consistently between legs, and varied widely within each leg (Fig. 2). During Leg 1, the most important prey for all size classes of fish was zooplankton, mainly euphausiids. Gastropods, hyperiid amphipods, and copepods occurred frequently in salmon diets, although they represented relatively small fractions in *DWC*. During Leg 2, the dominant prey of chum salmon shifted from zooplankton to fish such as myctophids, walleye pollock, and Atka mackerel. The decrease of zooplankton in the diet of chum salmon from Leg 1 to Leg 2 reflects the seasonal reduction of zooplankton abundance in the study area. There was little ontogenetic dietary difference in the diets of chum salmon. All of the different age groups of chum salmon preyed on

**Fig. 1.** Changes in oceanographic conditions between Leg 1 (June 29–July 15) and Leg 2 (August 16–September 18) of the RV *Kaiyo maru* survey in the central Bering Sea in 2002; a) mean SST of the sampling stations, b) zooplankton density measured by EPCS, c) chum salmon density estimated by trawl survey.



**Fig. 2.** Diet of chum salmon expressed as prey dry weight composition for different fish size classes, cruise legs (Leg 1, June 29–July 15; Leg 2, August 16–September 18), and time of day.



euphausiids and myctophids, namely *Thysanoessa longipes* and *Stenobrachius leucopsarus*. *S. leucopsarus* was frequently ingested by the fish caught in the morning, and these stomach contents would reflect nighttime feeding. *S. leucopsarus* undertakes a diurnal vertical migration (DVM), whereas chum salmon persists above the thermocline (Ogura and Ishida 1995). Thus, the diurnal difference in chum salmon diets would reflect change in the vertical distribution of its prey. Furthermore, the average nighttime length changed remarkably in the Bering Sea between legs from 7 h (Leg 1) to 12 h (Leg 2). This seasonal lengthening would increase the probability of encounters with *S. leucopsarus* in the epipelagic zone, and then result in the increased ingestion by chum salmon observed during Leg 2. Chum salmon thus changed their main prey both seasonally and diurnally depending on the availability of prey. This flexibility seems to enable them to prosper in the subarctic Pacific Ocean.

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# Lipid and Moisture Content of Salmon Prey Organisms and Stomach Contents of Chum, Pink, and Sockeye Salmon in the Bering Sea

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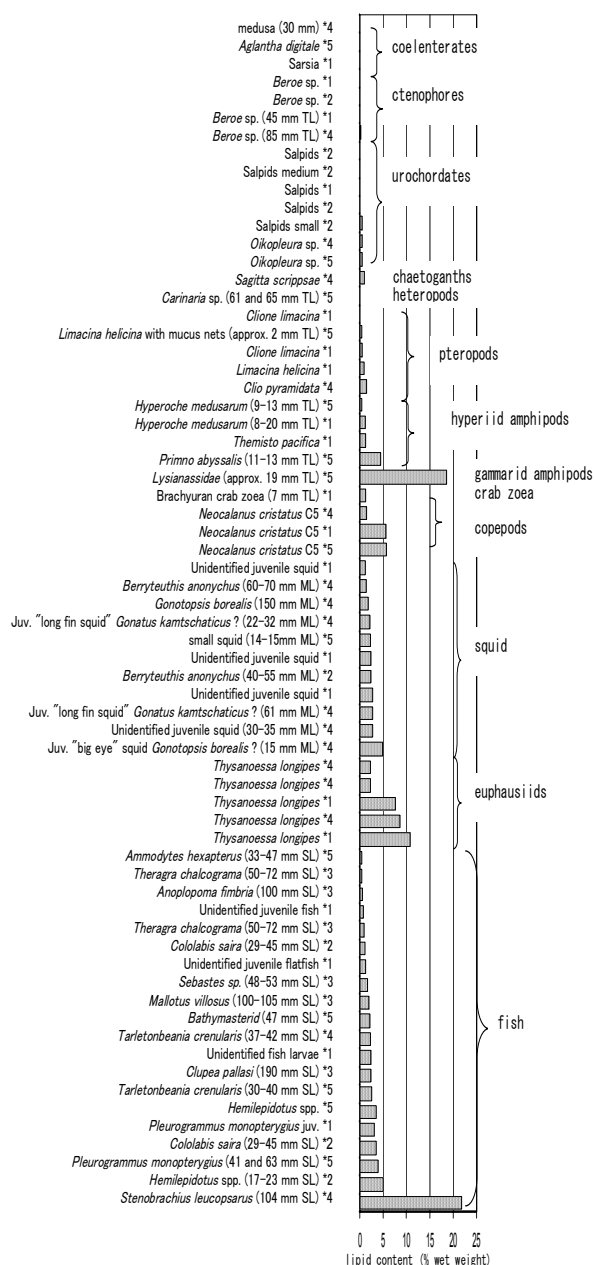
Keywords: Salmon prey, stomach contents, total lipid content, moisture

Lipids are a unique class of chemical compounds that all organisms require for survival. They are used primarily for energy storage, membrane structure, and hormones (Watanabe 1982). Recent results of studies investigating fish energy requirements have indicated that carnivorous fish, such as *Oncorhynchus*, have limited ability to utilize carbohydrates of high molecular weight as an energy source. Dietary lipids play an important role in providing energy, which spares dietary protein from being used as an energy source. Although the lipid content of prey is the salmon's primary energy source, currently there is little information on the lipid content of salmon prey consumed in the marine environment (Higgs et al. 1995). To estimate the nutritional value of salmon prey, total lipid and moisture contents were determined from samples of salmon prey and salmon stomach contents collected during summer 2001–2004 and fall 2002 in the Bering Sea and North Pacific Ocean.

Sixty-six samples of salmon prey organisms were collected from plankton nets and fresh stomach contents of chum, pink, and sockeye salmon during the summer (June and July) 2001, 2002, 2003 and 2004 research cruises of the R/V *Wakatake maru* and fall (October) 2002 research cruise of the F/V *Northwest Explorer* (Table 1). In addition, unsorted representative samples of the stomach contents (bolus) were collected at the same time from chum, pink, and sockeye salmon caught during these cruises (Table 1). Unsorted samples of the stomach contents and identified salmon prey were collected on board the ship and then frozen at -30°C for further processing at the National Salmon Resources Center, Sapporo (NASREC). Samples were freeze-dried for determination of moisture content. Total lipid was extracted from the dried sample and measured using the method of Nomura et al. (2004).

Total lipid content of 66 samples of salmon prey varied between 0% and 21.8% of wet weight (Fig. 1). Coelenterates (< 0.1%), ctenophores (< 0.1% to 0.2%), pteropods (< 0.1% to 1.5%), heteropods (< 0.1%), and urochordates (< 0.1 to 0.5%) had lower total lipid content and less variation in their lipid levels than other prey taxa. In contrast, euphausiids (2.2–10.7%), copepods (1.3–5.7%), cephalopods (1.2–4.9%), and pisces (2.3–21.8%) contained relatively high lipid content.

**Fig. 1.** Total lipid content of salmon prey organisms collected in the central North Pacific Ocean and Bering Sea, 2001–2004. Prey organisms are ordered by increasing lipid content within taxonomic group. The \* number refers to the group and sampling date shown in Table 1.



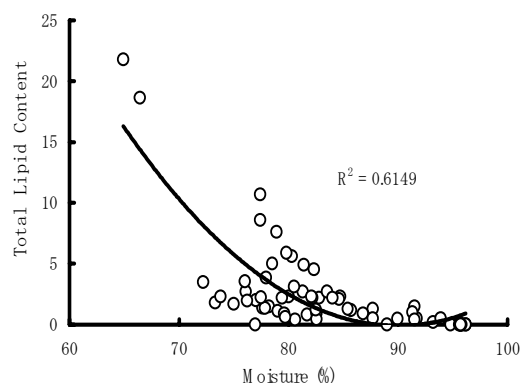
Moisture content decreased with increased lipid content in the prey (Fig. 2). Prey organisms containing low lipid levels (ctenophores, coelenterates, pteropods, and urochordates) contained particularly high moisture content. In contrast, euphausiids and the myctophid, *Stenobrachius leucopsarus*, contained high lipid levels and low moisture content.

The average moisture content of stomach contents in chum, pink, and sockeye salmon was 83.2% (n = 158), 89.1% (n = 97), and 88.3% (n = 84), respectively (Table 2). Minimum and maximum values for moisture content of stomach contents in chum, pink, and sockeye salmon were 58.6–94.0%, 70.5–89.8%, and 68.9–89.6%, respectively. During 2001–2003, average total lipid contained in stomach contents of chum, pink, and sockeye salmon ranged from 2.5–3.8% (n = 158), 2.4–3.4% (n = 97), and 2.9–3.4% (n = 84), respectively.

We determined lipid and moisture content of salmon prey genera because the chemical composition of most prey species of Pacific salmon is unknown. Copepods are the only prey group where lipid storage has been relatively well studied. For these organisms, lipid levels can trigger diapause through variations in cholesterol and fatty-acid derived hormone levels, determine over-wintering depth, and have an important role in the population adaptations to the hydrological condition of their habitat (Campbell 2004; Irigoien 2004).

Based on our assessment, coelenterates, ctenophores, pteropods, heteropods, and urochordates do not appear to be a good source of energy for salmon. In contrast, euphausiids, copepods, cephalopods and fish appear to be good energy source for salmon. For example, rainbow trout, chinook and coho salmon need 15–20% lipid in dry diet for maximum growth efficiency (Higgs et al. 1995). The lipid content we observed in euphausiids, copepods, cephalopods, and fish (Fig. 1) is almost identical to the optimal lipid content for growth of *Oncorhynchus* species in the wild (Higgs et al. 1995). Our conclusion is preliminary until additional data are obtained and seasonal changes in lipid and moisture contents of salmon prey are determined. In addition, prey fatty-acid composition is an important component to assessing the nutritive value of prey. Although some prey may not be a particularly good energy source, they might be nutritious if they are a source of essential fatty-acids to the salmon. Therefore, we recommend continued monitoring of the lipid content and measuring fatty acid composition of salmon prey and stomach contents at sampling opportunities throughout the year.

**Fig. 2.** Relationship between total lipid content (%) and moisture (%) of salmon prey organisms.



**Table 1.** Sampling date, season, research vessel, number of salmon prey samples, and number of salmon stomach samples collected in each sampling group.

Group	Year	Season	Date	Research Vessel	Salmon Prey Samples (n)	Salmon Stomach Samples (n)
1	2001	Summer	July 29–June 13	<i>Wakatake maru</i>	18	21
2	2002	Summer	June 28–July 13	<i>Wakatake maru</i>	9	141
3	2002	Fall	Sept. 8–Oct. 6	<i>Northwest Explorer</i>	6	98
4	2003	Summer	June 26–July 10	<i>Wakatake maru</i>	17	178
5	2004	Summer	June 26–July 9	<i>Wakatake maru</i>	16	0

**Table 2.** Maximum, minimum, and average of total lipid content (TL) as a percentage of wet matter in stomach contents of chum, pink, and sockeye salmon collected in the North Pacific Ocean and the Bering Sea from 2001–2003.

Year	Season	Species	n	TL (%)		
				Min.	Max.	Average (S.D.)
2001	Summer	Chum	21	0.4	9.1	2.5(2.0)
2002	Summer	Sockeye	27	1.2	11.8	3.8(2.1)
		Chum	99	0.3	10.0	3.1(1.5)
		Pink	15	0.7	12.6	2.9(2.8)
2002	Fall	Sockeye	26	0	9.5	2.5(2.0)
		Chum	72	0	13.8	3.4(3.6)
2003	Summer	Sockeye	31	1.2	7.7	3.1(1.4)
		Chum	65	0.6	6.3	2.4(1.2)
		Pink	82	0.3	15.9	3.4(2.4)

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## Origin of Immature Chum Salmon Collected in the Eastern Bering Sea and Aleutian Islands during the F/V *Northwest Explorer* BASIS Survey, Fall 2002

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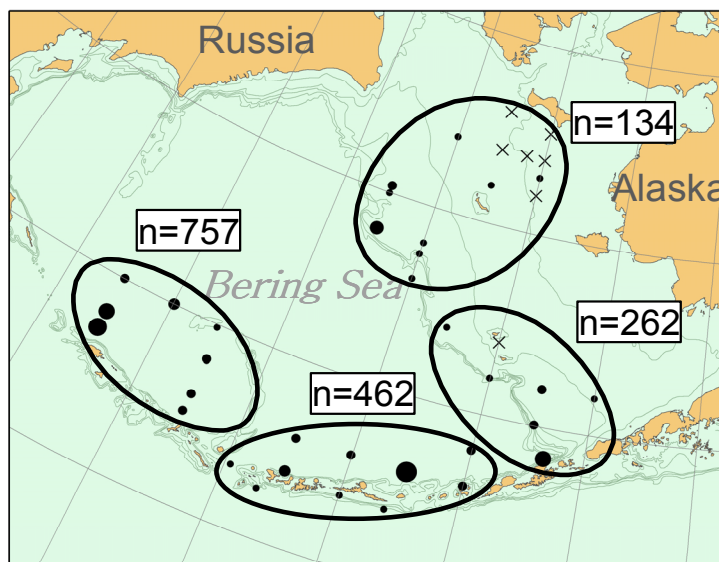
**Keywords:** Chum salmon, genetic stock identification, otolith thermal marks, Bering Sea, Aleutian Islands

Immature chum salmon were collected by the F/V *Northwest Explorer* between September 5 and October 8, during the 2002 BASIS survey across the eastern Bering Sea shelf and Aleutian Islands (for details, see Murphy et al. 2003). Approximately 1,600 fish were aged, checked for the presence of hatchery thermal marks, and genotyped for allozyme loci. Scale aging and otolith mark identification were done by the Alaska Department of Fish and Game's Mark, Tag, and Age Laboratory in Juneau, Alaska. Otoliths with thermal marks were compared with voucher specimens to verify hatchery of origin. Heart, liver, and muscle tissues were extracted and then analyzed with protein electrophoresis to identify genotypes for the 20 allozyme loci in the chum salmon coastwide genetic baseline (Kondzela et al. 2002). Genetic data were pooled into one of four geographic areas—western Aleutian Islands, eastern Aleutian Islands, southeastern Bering Sea shelf, and northeastern Bering Sea shelf. In the eastern and western Aleutian Islands, the catches were large enough to further stratify the data by ocean age. Regional origin estimates were made for each mixture collection using a conditional maximum likelihood method (Pella and Masuda model in SPAM v. 3.7, ADF&G 2001) and the full 356-population genetic baseline. The 95% non-symmetric confidence intervals were determined from 1000 bootstrap estimates in which the baseline and mixture were re-sampled.

Catches of immature chum salmon were much higher north of the Aleutian Island chain than from the Bering Sea shelf (Fig. 1). The predominant ocean age was 0.2 (65%)—a trait shared across all four areas—followed by ocean age 0.1, 0.3, and 0.4 (23%, 11%, and < 1%, respectively). Otolith marks were recovered from 17 immature hatchery chum salmon: seven marks from Alaskan hatcheries, four marks from Japanese hatcheries, two marks from Russian hatcheries, and four marks with multiple origins (Table 1). The four marks with multiple origins are the result of North American and Russian hatcheries releasing identically marked fish. These marks have a high probability of originating from North America due to the relatively small number of Russian marks released.

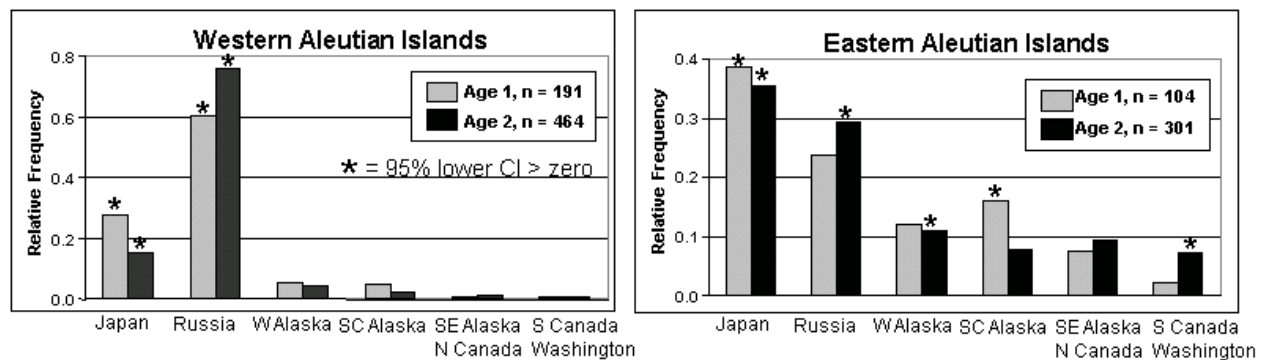
The majority of immature chum salmon in each mixture were of Asian origin (Table 2). Russian fish were the most abundant fraction in the western Aleutian Islands and the southeast Bering Sea shelf, whereas the component from Japan was greatest on the northeast Bering Sea shelf. More than 50% of the total catch of immature chum salmon were of Russian origin; more than 25% were from Japan, and each North American region contributed 5% or less. Small, but statistically significant estimates from southern North American populations were restricted to the eastern Aleutian Islands and southeastern Bering Sea shelf. Western and southcentral Alaska populations were detected at low levels in the eastern Aleutian Islands.

**Fig. 1.** Catches of immature chum salmon during the fall 2002 F/V *Northwest Explorer* BASIS survey grouped into the four geographic areas for which regional estimates of origin were made. Circle size is proportion to catch.



Within each of the Aleutian Island areas, ocean-age 0.1 and 0.2 fish shared similar stock estimates (Fig. 2). For example, in the eastern Aleutian Islands, the largest component for both ages was from Japan, with the next largest component from Russia. However, in the western Aleutian Islands, the largest component for both ages was from Russia, with a much smaller contribution for both ages from Japan and very small fractions from North American regions.

**Fig. 2.** Regional estimates of origin for ocean-age 0.1 and 0.2 immature chum salmon from the western and eastern Aleutian Island areas. W Alaska = western Alaska and fall Yukon; SC Alaska = Alaska Peninsula, Cook Inlet, Kodiak Island, and Prince William Sound; N Canada = northern British Columbia; S Canada = southern British Columbia.



**Table 1.** Otolith-marked hatchery fish recovered during the fall 2002 survey by the F/V *Northwest Explorer*. Length is fork length in mm; weight is body weight in g; release number is the number of marked fish released from the hatchery.

Country and Stock	Catch Location	Catch Date	Length	Weight	Age	Release Number	Mark
<i>Japan</i>							
Chitose 1999	55.00 N, 175.04 E	15 Sep	516	1569	0.2	4,914,000	2,6nH
Ichani 1999	52.99 N, 172.52 W	9 Sep	440	952	0.2	3,503,000	2,8nH
Ichani 1999	52.99 N, 172.52 W	9 Sep	430	1166	0.2	3,503,000	2,8nH
Ichani 1999	54.17 N, 166.80 W	22 Sep	463	1120	0.2	3,503,000	2,8nH
<i>Russia</i>							
Bereznykovsky 1999	51.86 N, 172.99 W	20 Sep	425	967	0.2	22,546,100	4H
Ola 2000	60.19 N, 177.51 W	30 Sep	372	620	0.1	2,370,000	6H
<i>United States</i>							
Hidden Falls 1998	56.01 N, 167.50 W	23 Sep	561	2362	0.3	48,905,343	3,3H
Hidden Falls 1998	58.99 N, 177.49 W	30 Sep	567	2262	0.3	48,905,343	3,3H
Hidden Falls 1999	54.17 N, 166.80 W	22 Sep	461	1139	0.2	38,689,735	3,3H
Macaulay 1998	56.01 N, 164.99 W	6 Oct	590	2630	0.3	11,355,272	6H
Macaulay 2000 (Limestone)	53.00 N, 170.00 W	8 Sep	357	470	0.1	15,144,122	5H5
Medvejie 2000	53.50 N, 172.51 E	17 Sep	378	616	0.1	13,174,000	4,3H
Wally Noerenberg 2000	53.00 N, 170.00 W	8 Sep	393	652	0.1	57,712,566	5,2H
<i>Multiple Origin</i>							
Hidden Falls 2000 (Takatz)	53.00 N, 170.00 W	8 Sep	384	618	0.1	41,925,974	4H
Bereznykovsky 2000						240,900	4H
Hidden Falls 2000 (Takatz)	60.19 N, 177.51 W	30 Sep	353	570	0.1	41,925,974	4H
Bereznykovsky 2000						240,900	4H
Macaulay 1999	54.17 N, 166.80 W	22 Sep	483	1418	0.2	44,496,455	6H
Yana 1999						39,100	6H
Macaulay 1999	54.17 N, 166.80 W	22 Sep	512	1611	0.2	44,496,455	6H
Yana 1999						39,100	6H



**Table 2.** Regional estimates of immature chum salmon caught in the eastern Bering Sea and Aleutian Islands during the 2002 fall survey by the F/V *Northwest Explorer*. Below each estimate is the 95% non-symmetric bootstrap confidence interval; estimates significantly greater than zero are in bold font.

Mixture sample	n	Regional Allocation					
		Japan	Russia	Western Alaska Fall Yukon	Southcentral Alaska	SE Alaska N. British Columbia	S. British Columbia Washington
<i>Western Aleutian Is.</i>							
Ocean age 0.1	192	<b>0.27</b> (0.17-0.39)	<b>0.60</b> (0.50-0.78)	0.05 (0-0.10)	0.05 (0-0.10)	0.01 (0-0.02)	0.01 (0-0.02)
Ocean age 0.2	464	<b>0.15</b> (0.05-0.20)	<b>0.76</b> (0.75-0.96)	0.04 (0-0.06)	0.02 (0-0.05)	0.01 (0-0.02)	0.01 (0-0.02)
Total	747	<b>0.18</b> (0.10-0.23)	<b>0.74</b> (0.72-0.89)	0.04 (0-0.06)	0.03 (0-0.05)	0.01 (0-0.01)	0.01 (0-0.02)
<i>Eastern Aleutian Is.</i>							
Ocean age 0.1	104	<b>0.39</b> (0.25-0.57)	0.24 (0-0.37)	0.12 (0-0.24)	0.16 (0-0.31)	0.07 (0-0.15)	0.02 (0-0.04)
Ocean age 0.2	300	<b>0.36</b> (0.26-0.45)	<b>0.29</b> (0.21-0.44)	<b>0.11</b> (0.02-0.18)	0.08 (0-0.24)	<b>0.09</b> (0.01-0.16)	<b>0.07</b> (0.003-0.11)
Total	457	<b>0.36</b> (0.28-0.45)	<b>0.32</b> (0.24-0.46)	<b>0.09</b> (0.01-0.14)	<b>0.09</b> (0.004-0.15)	<b>0.09</b> (0.003-0.14)	<b>0.05</b> (0.003-0.08)
<i>Southeast Bering shelf</i>	262	<b>0.20</b> (0.12-0.29)	<b>0.45</b> (0.36-0.62)	0.02 (0-0.04)	0.06 (0-0.13)	<b>0.14</b> (0.03-0.23)	<b>0.13</b> (0.03-0.19)
<i>Northeast Bering shelf</i>	131	<b>0.57</b> (0.44-0.73)	<b>0.28</b> (0.12-0.44)	0.08 (0-0.15)	0.02 (0-0.03)	0.04 (0-0.07)	0.02 (0-0.04)
Total catch (% total catch)	1597	423 (27%)	851 (53%)	85 (5%)	86 (5%)	86 (5%)	66 (4%)

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# First Record of Swimming Speed of a Pacific Salmon Undertaking Oceanic Migration from the Central Bering Sea to the Japanese Coast

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**Keywords:** Oceanic migration, swimming speed, chum salmon, orientation mechanism, foraging behaviour

Swimming speed of homing salmon is a key factor required to improve knowledge of the mechanism of their oceanic migration. If homing salmon are moving at their optimal cruising speed, then salmon would have to move along the shortest route from the open ocean to the spawning grounds. If orientation is less precise, swimming speed would have to exceed the optimal cruising speed to achieve observed ground speeds. This paper describes ca. 50 days of swimming behaviour of a chum salmon *Oncorhynchus keta* during 67 days of oceanic migration from the central Bering Sea to the Japanese coast. Our results are the first record of swimming speeds of homing salmon during the oceanic migration.

The study was conducted as part of a Japanese-U.S. cooperative high-seas salmonid research cruise. In June–July 2000, we caught chum salmon by longline in the central Bering Sea. Chum salmon caught in a healthy condition were put into a recovery tank immediately after removal from the longline. Scales were collected for age determination and for examination of scale patterns. Chum salmon with scale patterns typical of Japanese-origin fish were candidates for tagging. We selected 27 vigorous, maturing chum salmon, larger than 600 mm (fork length), older than ocean age-3 (fish spent three winters at sea) for tagging.

The data logger (Little Leonard Ltd., Tokyo, Japan, model UWE-200 PDT: 42 g in air, 13 g in water, 20 mm in diameter, and 90 mm length), which records swimming speed (through the water), depth, and temperature (Tanaka et al. 2001), was attached externally in the dorsal musculature of the fish, anterior to the dorsal fin (Tanaka et al. 2000). Tagged fish were released once they swam voluntarily. The logger sample rates were 5 sec for depth and speed and 1 min for ambient temperature.

After 67 days at liberty, one chum salmon released in the central Bering Sea (56°30'N 179°00'E) on July 9, 2000 was caught in a set-net on the east coast of Hokkaido Island of Japan (43°20'N 145°46'E) on September 16, 2000. The fork length at the time of release was 685 mm and the fish was an ocean age-4. The minimum distance over the ground between the release and recovery sites was 2,760 km. The recording period of depth and temperature was 52.9 days (22:47 hrs 9 July to 19:43 hrs 31 August), and swimming speed data was recorded for 42.1 days because the propeller sensor became blocked with debris at 01:00 hrs 21 August. We did not get any information about the fate of the other 26 salmon and loggers.

The chum salmon usually stayed shallower than 50 m ( $10.2 \pm 12.5$  m,  $n = 911,907$ ), though the fish conducted three exceptionally deep dives. Swimming speeds rarely exceeded 1.0 m/s, and horizontal speed was  $36.4 \pm 15.2$  km/day ( $n = 42$  days). Estimated horizontal distance was approximately 2,500 km, which was equivalent to 90 percent of the minimum distance between release and recovery site. Swimming depth and speed peaked around dawn and sunset, and there was a smaller peak around midnight. The fish showed sequential up-and-down movement near the thermocline during daytime. Diurnal patterns of movement suggest homing chum salmon have a time allocation strategy for foraging that is different between daytime and nighttime. Our findings indicate that over large distances of ocean, a homing salmon maintains a strong orientation to its homeward direction, and that passive transport by favorable water currents may help the homeward migration.

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## Origins and Distribution of Chum Salmon in the Central Bering Sea

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**Keywords:** Chum salmon, genetic stock identification, distribution, abundance, Bering Sea

The Bering Sea provides major feeding habitats for various salmon stocks originating from Asia and North America. A better understanding of salmon community structure will clarify the mechanisms of salmon population response to recent environmental changes. Chum salmon (*Oncorhynchus keta*) is a dominant pelagic fish in the Bering Sea during summer and fall especially after pink salmon (*O. gorbuscha*) have moved to coastal areas for spawning.

Genetic stock identification (GSI) techniques using allozyme variation have been established for estimating stock compositions of high-seas chum salmon (Seeb et al. 1995, 2004; Urawa et al. 1997, 1998; Wilmot et al. 1998; Winans et al. 1998; Seeb and Crane 1999a, 1999b). The present study was conducted to determine stock origin of chum salmon caught in the central Bering Sea by allozyme analysis.

Japanese BASIS troll surveys were conducted at 36 stations in the Bering Sea by the research vessel *Kaiyo maru* between August 21 and September 18, 2002 (Azumaya et al. 2003). We caught approximately 7,700 chum salmon, most of which were immature fish. For the genetic stock identification (GSI), tissue samples (liver, heart and muscle) were collected from 2,136 chum salmon, and immediately deep frozen until the analysis.

Selected samples were examined for protein electrophoretic variation on horizontal starch gels using standard procedures described by Aebersold et al. (1987). Standard nomenclature for loci and alleles was used as outlined in Shaklee et al. (1990). Alleles were compared and standardized for 20 polymorphic loci (ALAT\*, mAAT-1\*, sAAT-1,2\*, mAH-3\*, ESTD\*, G3PDH-2\*, GPI-A\*, GPIB-1,2, mIDHP-1\*, sIDHP-2\*, LDH-A1\*, LDHB-2\*, sMDHA-1\*, sMDHB-1,2\*, mMEP-2\*, sMEP-1\*, MPI\*, PEPA\*, PEPB-1\*, and PGDH\*).

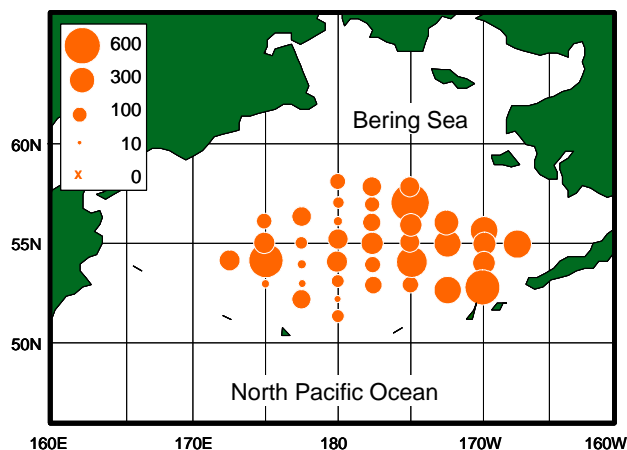
We used the simplified baseline data set (124 stock groups/20 loci) formulated in Seeb et al. (1997) with additional data from Japan. Estimates of stock contributions were made with a conditional maximum likelihood algorithm (Pella and Milner 1987) by using the Statistical Package for Analyzing Mixtures (SPAM version 3.5) developed by Debevec et al. (2000). Standard deviations of estimates were estimated by 1,000 bootstrap resamplings of the baseline and mixture samples. Based on genetic similarity and 100% simulation analysis among baseline stocks, 12 reporting regions were selected. These are five regions in Asia, 1) Japan, 2) Sakhalin, 3) Premorye, 4) Amur, 5) Northern Russia; and seven regions in North America, 6) NW Alaska summer, 7) Fall Yukon, 8) Alaska Peninsula/Kodiak Island, 9) Susitna, 10) Prince William Sound, 11) Southeast Alaska/North BC, 12) South BC/Washington. Estimates were made to individual stocks and then pooled to regional stock groups. Simulation studies indicated that most reporting regions showed greater than 90% accurate when true group contributions were 100%.

Chum salmon were widely distributed in the Bering Sea north of 52°N, and they were relatively abundant in the eastern waters off the continental shelf (Fig. 1). The mixture chum samples were 97% immature fish (Fig. 2), and the age composition was 29% ocean age .1, 54% ocean age .2, and 13% ocean age .3 fish (Fig. 3).

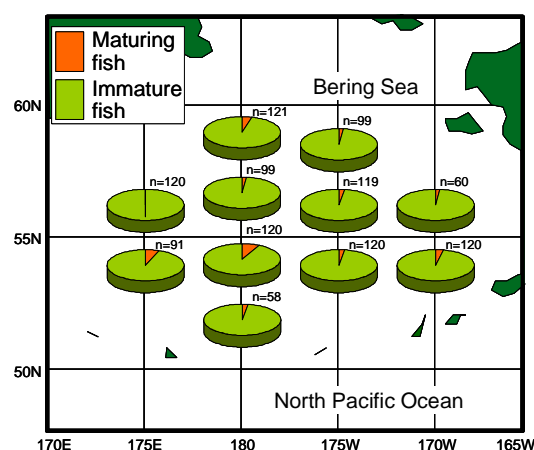
The estimated stock composition for all maturing chum salmon was 70% Japanese, 10% Russian, and 20% North American stocks, and 54% Japanese, 33% Russian, and 13% North American stocks for immature fish. The stock estimates of immature chum salmon were similar among three age groups (0.1, 0.2 and 0.3). Asian chum salmon were dominant in all 11 estimates, while North American stock contribution was 5–28% (Fig. 4). Asian chum salmon were widely distributed in the survey areas, being relatively abundant in eastern waters (Fig. 5). North American stocks were mainly distributed in eastern water. Regional stock composition estimates of immature chum salmon biomass in the whole survey areas were 47% Japanese, 34% Russian, and 19% North American stocks.

The previous genetic studies suggested that Japanese and Russian stocks are predominant in chum salmon mixtures caught in the central Bering Sea (Urawa et al. 1997, 1998; Winans et al. 1998). However, these study areas were limited to the international water. The present genetic estimates confirmed that Asian chum salmon are

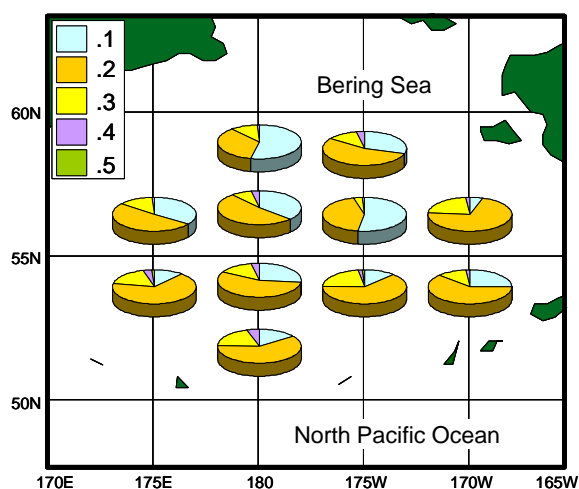
**Fig. 1.** CPUE distribution of chum salmon in the Bering Sea, August/September 2002. CPUE = number of catches per 1 h trawl by R/V *Kaiyo maru*.



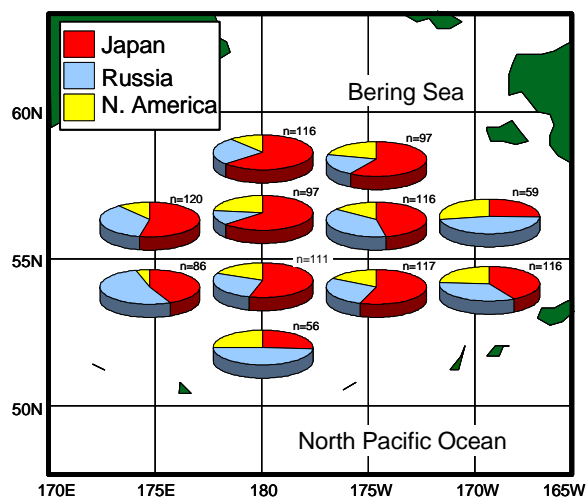
**Fig. 2.** Percent composition of maturing and immature chum salmon mixtures caught in the Bering Sea, August/September 2002.



**Fig. 3.** Percent composition of ocean age in chum salmon mixtures caught in the Bering Sea, August/September 2002.



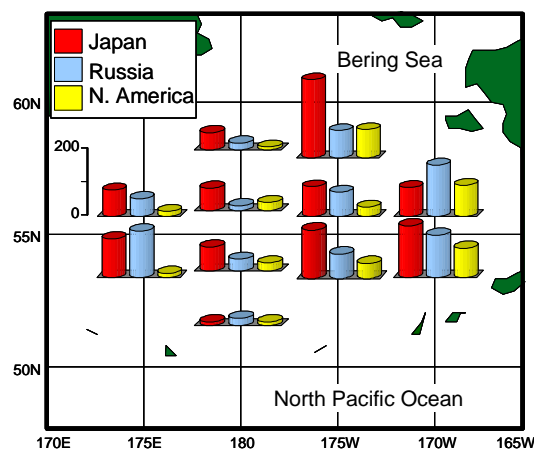
**Fig. 4.** GSI-estimated stock composition of immature chum salmon mixtures caught in the Bering Sea, August/September 2002.



abundant in wide areas of the Bering Sea. Wilmot et al. (1998) conducted genetic stock identification for chum salmon caught incidentally in the eastern Bering Sea trawl fisheries during the late summer and fall of 1994. Their estimates indicated 40% Japanese, 26% Russian, and 44% North American stocks in areas 521/541 west of 170°W, and 23% Japanese, 19% Russian and 58% North American stocks in areas 509/513/517 east of 170°W. Our results showed similar estimates in the former areas.

It is an important question why Asian chum salmon migrate so far to the eastern water. One reason may be related with their overwintering habitats. Urawa (2000) indicated that Japanese chum salmon spend the first winter in the western North Pacific and the following winters in the Gulf of Alaska. During the overwinter period, chum salmon prefer water with low temperatures between 4 and 6°C. The habitat in this temperature range was more widely available in the eastern North Pacific

**Fig. 5.** GSI-estimated CPUE of immature chum salmon by stocks in the Bering Sea, August/September 2002. CPUE = number of catches per 1 h trawl.



than the western North Pacific Ocean. For Japanese chum salmon in the eastern North Pacific, the shortest homing migration route is through the Bering Sea. Thus maturing fish as well as immature fish migrate from the eastern North Pacific to the Bering Sea in early summer, and immature fish may remain in the Bering Sea for further feeding. The Bering Sea is one of most productive ecosystems in the world, and provides favorite feeding habitats for salmon during summer and fall.

It is an interesting result that the contribution of chum salmon from the northwest Alaska including the Yukon River was extremely low (0.5% among immature fish), although these areas are geographically close to the Bering Sea. Urawa *et al.* (2000) made a GSI estimation that Northwest Alaskan chum salmon occupied 15% among immature chum salmon caught in the western and central Gulf of Alaska during summer. It is possible that juvenile chum salmon migrate from the northwest Alaska coast to the Gulf of Alaska for the first winter, and remain there until maturing.

The present study suggests that the oceanic migration and distribution pattern of chum salmon are apparently different among stocks. Further studies are requested to clarify factors affecting the migration and distribution of salmon in the ocean.

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## Distribution and Migration of Pink Salmon Juveniles in the Coastal Waters of Eastern Hokkaido, Okhotsk Sea

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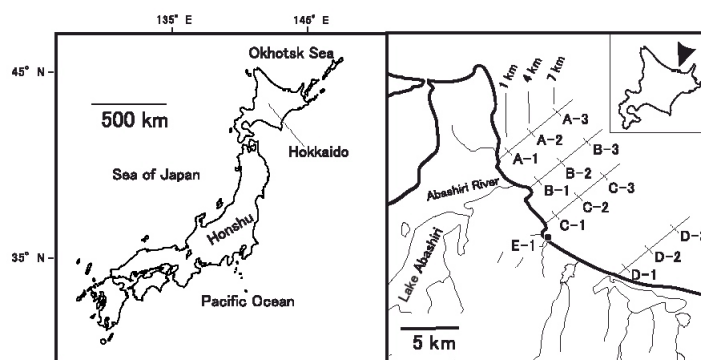


**Keywords:** Abundance, pink salmon, migration, surface seawater temperature

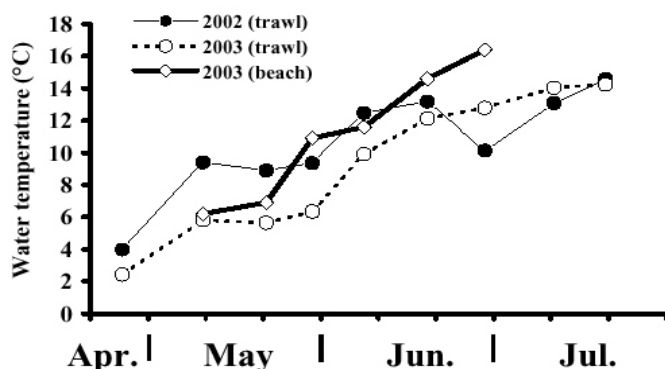
Pink salmon is considered to be specialized species of Pacific salmon, because they have a rigid two-year anadromous life cycle, a short freshwater residence, and two genetically isolated broodlines in North America and Asia. The geographical distribution of adult pink salmon migrating upstream in Japan includes part of the Pacific coast of northern Honshu and the Sea of Japan coast of Hokkaido; however, the main spawning grounds are located in rivers of the Okhotsk Sea coast of eastern Hokkaido. In Japan, pink salmon fry are produced by stock enhancement programs. Although the number of fry released in Hokkaido has been similar over the past 15 years, i.e., approximately 140 million fish, the commercial harvest of pink salmon has a unique biennial abundance cycle. Unfortunately, the exact cause of this fluctuation is unknown, because of the lack of information about Hokkaido pink salmon biology in relation to ocean conditions. Moreover, to elucidate the ecology of pink salmon in terms of growth and abundance, information about their distribution and offshore migration during early sea life is important, because high mortality is often suggested to occur soon after juveniles enter the ocean (Manzer and Shepard 1962; Parker 1968). In 2002, we began to investigate the distribution and migration patterns of juvenile pink salmon in the coastal waters of Abashiri on the Okhotsk Sea coast of eastern Hokkaido. Twelve study sites were established, including four at 1 km from shore (10–15 m depth), four at 4 km (20–30 m depth), and four at 7 km (30–40 m; Fig. 1). At each study site, two boats were used to tow a trawl net (8-m wide × 5-m deep net mouth; 5-mm mesh) along the 1–2 m surface layer for 2,000 m, at approximately 4–6 km/h during daylight. Nine seasonal surveys were carried out, approximately every ten days, from late April to mid July in 2002 and 2003. Surface seawater temperature (SST) was measured, and zooplankton was collected with a 0.45-m NORPAC net (0.33-mm mesh), towed vertically from the bottom to the surface at each study site. A beach seine (2-m wide × 13-m long; 3-mm mesh) was also used in shallow nearshore water in May and June 2003, at the same time that seasonal surveys were carried out and SSTs were measured. Fork length of up to 100 pink salmon juveniles from a single study site was measured in the laboratory. Data were analyzed for each offshore line (1-, 4-, and 7-km line) by calculating average values for the four sites. The number of pink salmon juveniles collected from each line during each seasonal survey was totaled, and SST was denoted by the average value for all twelve study sites.

Although SST during the two-year survey period at the trawl net study sites ranged from 2.2–14.9°C, the SSTs in May 2003 were much

**Fig. 1.** Locations of study sites for trawling (A, B, C, D) and beach seine sampling (E) in Abashiri, the Okhotsk Sea.



**Fig. 2.** Surface seawater temperature at offshore trawl (mean of 12 sites) and beach sites in shallow waters of Abashiri coast from late April to mid July 2002 and 2003.

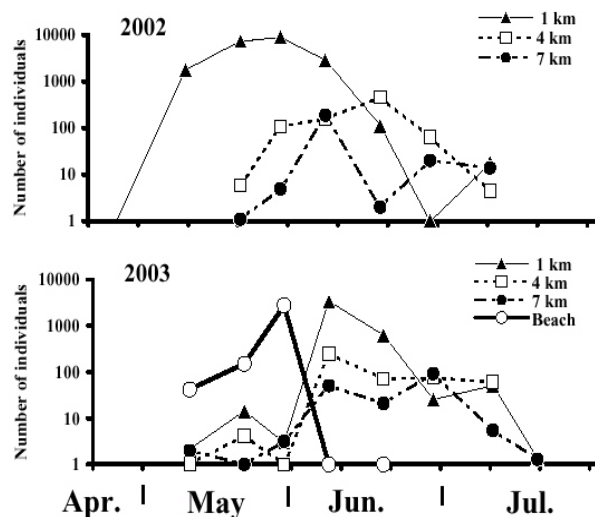




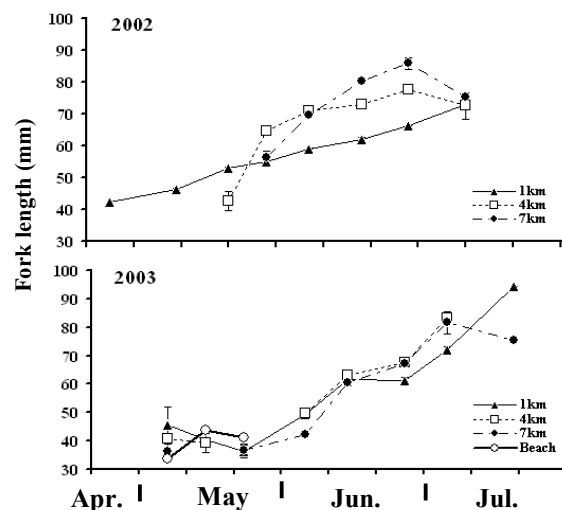
lower (5.3–6.8°C) than in 2002 (8.2–9.7°C; Fig. 2). An estimated 21,868 and 4,729 pink salmon juveniles in 2002 and 2003, respectively, were collected by trawling; however, a remarkable difference was observed in the annual timing and patterns of offshore migrations (Fig. 3). In 2002, juveniles began to migrate offshore in late May. The exodus began at the 1-km line, and then shifted to the offshore (4-km and 7-km) lines. Interestingly, juveniles captured offshore were larger than those captured near the shore in 2002. In June 2002, juveniles captured offshore were significantly longer (approximately 10–12 mm at 4 km; 11–20 mm at 7 km) than those captured at the 1-km line, indicating that the migration of pink salmon juveniles might be size dependent (Fig. 4). In contrast, catches of pink salmon juveniles by trawling along the coast were lower in May 2003 than in 2002. In late May 2003, however, pink salmon juveniles were caught near the shore by beach seine, prior to their offshore migration. The beach SST was 10.9°C, whereas the offshore SST was low (6.3°C) at that time. Offshore migration of juveniles in 2003 began in early June, and the exodus from the 1-, 4-, and 7-km lines occurred rapidly at the same time without size-dependent migration (Figs. 3 and 4). Most pink salmon juveniles left Abashiri coastal waters when they were 80-mm long; the SST was over 14°C at this time. In July, all juveniles had migrated offshore, prior to attaining a length of 100 mm. The maximum biomass of zooplankton in the ambient water was in May, and decreased rapidly thereafter. In 2002 the biomass of zooplankton from mid May to late May, when the majority of juveniles were collected on the 1-km line, ranged from 824 to 1688 mg/m<sup>3</sup>. Although changes in zooplankton biomass in May 2003 were large (571–2383 mg/m<sup>3</sup>), the biomass in early June, when the majority of fish were collected, was low (421–530 mg/m<sup>3</sup>) at each line.

Distribution and migration of pink salmon juveniles should be strongly related to SST; however, their subsequent survival may be related to zooplankton biomass just after entry in the ocean. Kobayashi (1968) reported that downstream migration of pink salmon fry occurred from early May to late May in a river on the Okhotsk Sea coast of Hokkaido. Therefore, the coastal environment in May must have an important influence on the survival of fry. Healey (1980) investigated the ecology of pink salmon juveniles in British Columbia in relation to their feeding conditions, and he suggested that the movement of pink juveniles away from the beaches in late May is not associated with poor conditions. However, movements in late June and early July may be a response to poor feeding conditions. On the other hand, Willette (2001) reported that low macrozooplankton density led to dispersion of juveniles from shallow near shore habitats. We will investigate pink salmon ecology, including their prey, in the future.

**Fig. 3.** Seasonal catch of pink salmon juveniles by trawl at 1-, 4-, and 7-km offshore survey lines and by beach seine in the shallow waters of Abashiri coast from late April to mid July 2002 and 2003.



**Fig. 4.** Average length ( $\pm$ SE) of pink salmon juveniles captured by trawl at 1-, 4-, and 7-km offshore trawl survey lines and by beach seine in shallow waters of Abashiri coast.



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## Relationship between the Distribution of Juvenile Chum Salmon in the Coastal Waters of Eastern Hokkaido and Water Temperature as Determined by Experimental Releases of Otolith-Marked Juveniles

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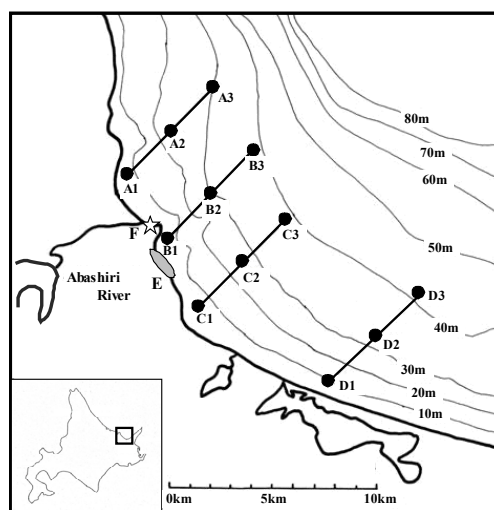


Keywords: ALC marking, hatchery chum salmon, distribution and abundance, SST, diet composition

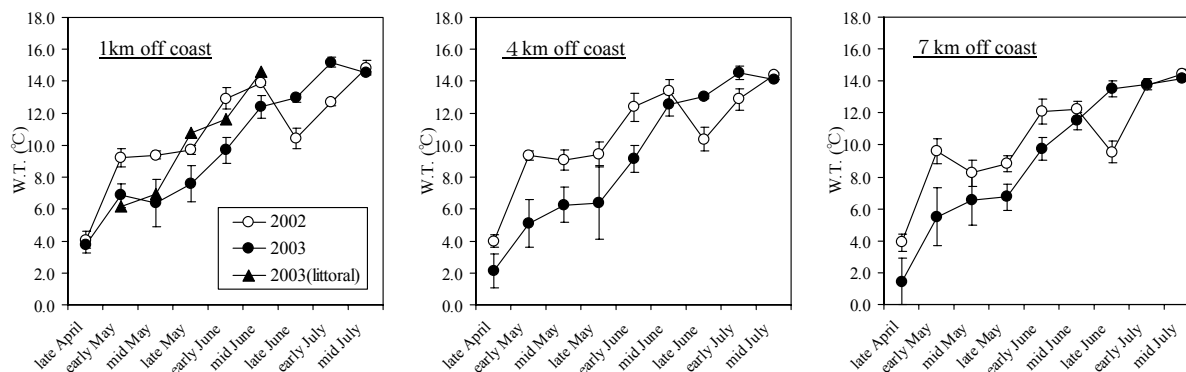
Numbers of hatchery-origin chum salmon in Hokkaido increased from ~10 million in the mid-1970s to ~40 million in the late 1980s. During the 1990s, returning chum salmon numbers fluctuated between 27 and 65 million with marine survivals varying between 2.6% and 5.9% despite at the same time there was a consistent annual release of ~1 billion juveniles from hatcheries (Nagata and Kaeriyama 2004). We started a project in 2002 to investigate marine mechanisms responsible for population fluctuations in hatchery-produced chum salmon. The otoliths of two million juveniles (46.6 mm mean fork length (FL)) were marked with 200 ppm ALC (alizarin complexone) solution at the fry eyed egg stage. These marked fish were released in mid-May 2002 into the Abashiri River where a total of 34 million hatchery juveniles were stocked every year. In 2003, 1.9 million (47.5 mm mean FL) and 1.4 million juveniles (47.6 mm mean FL) ALC-marked with different degree days were stocked in late April and mid-May, respectively. Twelve coastal sites (1–7km off the coast) as well as various temporary sites (mainly 2003) in littoral zones and in a fishing port were established in the Abashiri Bay of Okhotsk Sea to catch chum juveniles using a surface trawl net or beach seine (Fig. 1).

Surface seawater temperatures (SST) ranging from 8 to 13°C which are considered to be optimal for chum juveniles (Kaeriyama 1986; Irie 1990), were formed in the coastal waters from 1 km to 7 km off the coast during May and June in 2002. The early, warmer temperatures occurred because the Soya Warm Current arrived early (Fig. 2). In contrast, as the Soya Warm Current was delayed in 2003, a cold water mass < 8°C occupied the coastal waters in May. Nevertheless, the optimal SSTs from 7 to 11°C were found in the littoral zone and the fishing port.

**Fig. 1.** Maps showing the study sites including the fishin port(F), littoral areas(E), 1 km, 4 km and 7 km off the Abashiri coast (A-D) in the Okhotsk Sea.

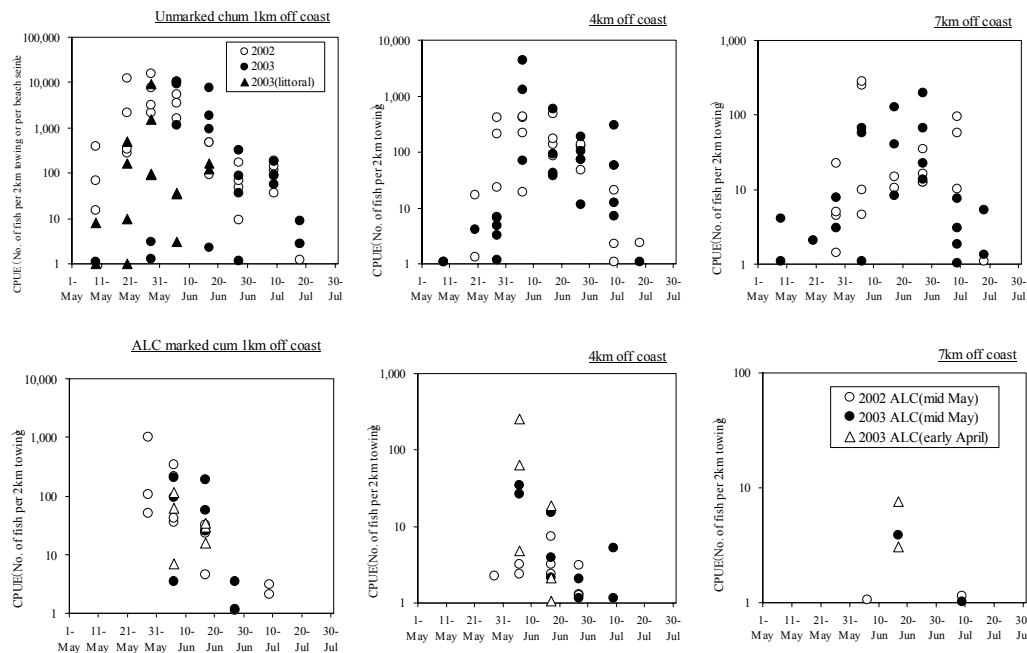


**Fig. 2.** Changes in mean values with SD of SST at the littoral sites, the 1 km, 4 km and 7 km off the Abashiri coast in the Okhotsk Sea in 2002 and 2003.

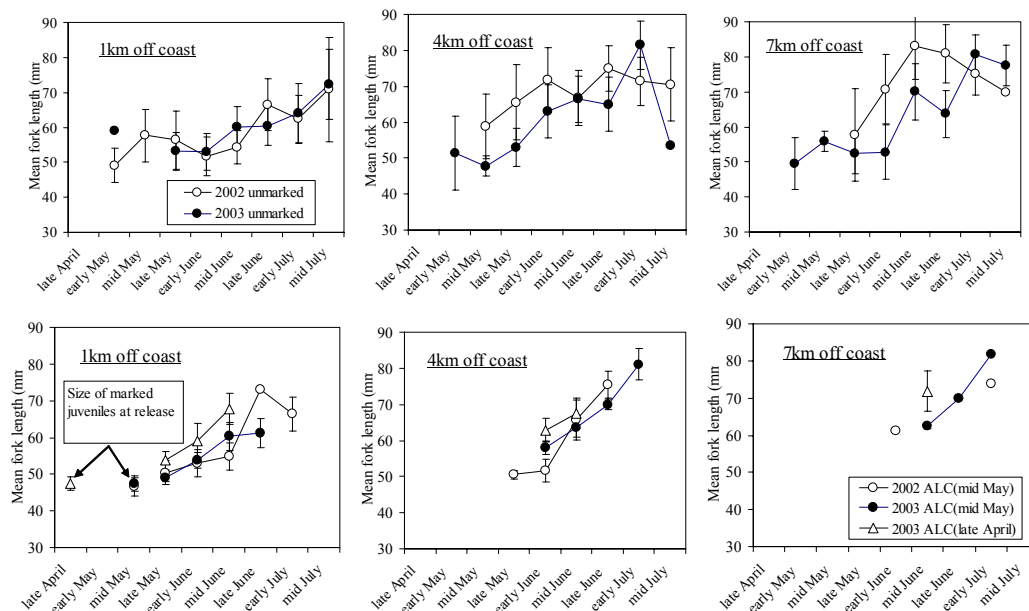


Unmarked chum juveniles were more abundant in the coastal waters from May to June in 2002, and first ALC marked juveniles were found 1 km off the coast in late May (Fig. 3). Although mean fork lengths of unmarked juveniles and ALC marked juveniles at every site tended to increase with elapsed time, fish 1 km off the coast were significantly smaller than those 4 and 7 km off the coast in June (Fig. 4). Bimodal fork length distributions were observed for unmarked juveniles from late May to mid June, but ALC marked juveniles showed unimodal length distribution and fell into the lower modal group in the length frequency distribution of unmarked juveniles, indicating that the upper modal group may have originated from the earlier stocked group, or were juveniles that grew fast and subsequently moved off the coast earlier (Nagata *et al.* 2004).

**Fig. 3.** Changes in CPUE (catch per unit effort, the number of juveniles per 2 km towing or per beach seine) of unmarked and ALC marked juvenile chum salmon captured at the littoral sites (beach seine), the 1 km, 4 km and 7 km off the Abashiri coast (trawl net) in the Okhotsk Sea in 2002 and 2003.



**Fig. 4.** Changes in mean fork length with SD of unmarked and ALC marked juvenile chum salmon captured at the 1 km, 4 km and 7 km off the Abashiri coast in the Okhotsk Sea in 2002 and 2003.

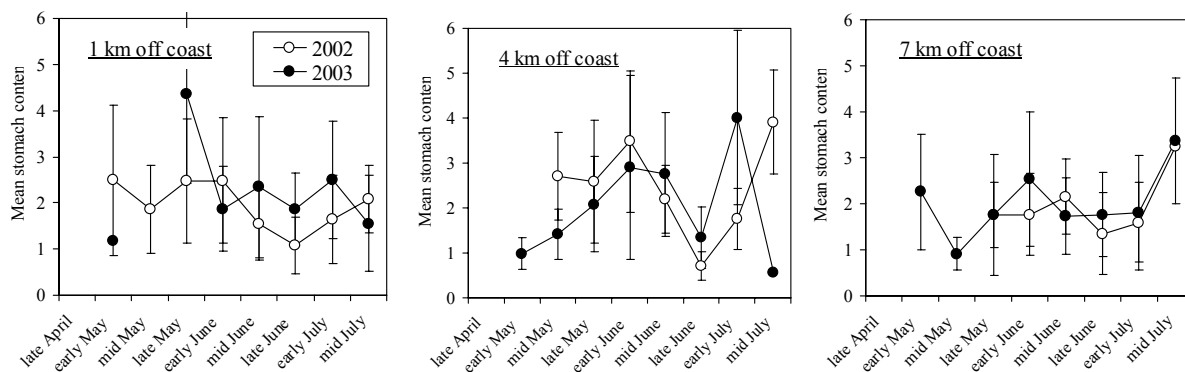


In contrast, most unmarked juveniles in 2003 occurred near the coast from early June, three weeks later than in 2002 (Fig. 3). ALC marked juveniles that were released early in late April 2003 were neither observed near the coast until early June, nor were the Late-stocked in mid May. The migration time for ALC marked juveniles in 2003 was ten days later than it was in 2002. More interestingly, many juveniles before moving to the coastal waters were found in littoral areas and the fishing port where SSTs were generally higher than in the coastal waters. This suggests that early-stocked juveniles stayed in the littoral zone for much longer than the late-stocked juveniles. Length frequencies of unmarked juveniles in 2003 remained unimodal until we finished our investigation, differing from the bimodal distribution in the 2002. Length frequency distributions of the two ALC marked groups overlapped, although mean fork length of early-stocked juveniles was 5 mm larger than that in late-stocked juveniles (Fig. 4). In addition, specific growth rate (SGR, 0.0051) for initial three weeks after stocking of early-stocked group in ALC marked juveniles 2003 captured 1km off the coast was lower than SGR (0.0062–0.0064) the late stocked groups in both years. Juveniles in both years rapidly disappeared from the coast after late June when SST > 13°C, although the earlier chum juveniles were stocked, the earlier they tended to move away.

Stomach content indices (stomach content weight x 100/body weight) for juvenile chum in both years were high in late May and early June, but they decreased in late June (Fig. 5). This decrease in stomach contents in both years was coincident with the rapid decrease in CPUE of juvenile chum and zooplankton abundance (Asami et al. 2005). Diet analysis revealed that juvenile chum salmon in the coastal waters in both years consumed primarily copepods (mainly *Pseudocalanus newmani*) early in the season, switching to cladocerans (mainly *Podon leuckarti*, *Evadne nordmanni*) and appendicularians (mainly *Oikopleura longicauda*, *Fritillaria borealis* f. *typica*) as these became more abundant in the sea (Asami et al. 2005). Diet composition of chum juveniles that stayed in the littoral zone in 2003 was different from that in the coastal waters, especially for juveniles in the littoral zone. These individuals in the littoral zone consumed more epibenthic crustaceans such as Harpacticoida copepods and amphipods, indicating that juvenile chum can change feeding behavior depending on nursery conditions.

Estuary residence or offshore movement of chum salmon juveniles after downstream migration may depend on seawater temperature, rather than fish size. Cold water masses < 8°C may restrict their offshore movement, and fry may remain in the littoral zone for long periods. In fact, early-stocked juveniles in the 2003 used the littoral zone as a nursery area for several weeks despite abundant zooplankton in the coastal waters (Asami et al. 2005). Their long stay in the relatively small littoral zone might have caused a decrease in feeding activity and growth due to the shortage of food amount with highly dense population and/or low water temperature in early periods. If this is true, the difference in migration pattern between early and late stocked juveniles may affect survival in early ocean life. This hypothesis will be testified from the coming data. As ALC marked chum salmon stocked at the different periods in 2002 and 2003 will return as three to five years old from 2004 to 2007.

**Fig. 5.** Changes in mean values with SD of stomach content index (stomach content weight x 100/body weight) of juvenile chum salmon captured at the 1 km, 4 km and 7 km off the Abashiri coast in Okhotsk Sea in 2002 and 2003.



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## Molecular Biological Study on Olfactory Imprinting Related Genes in Salmon

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**Keywords:** Imprinting, olfactory bulb, olfactory hypothesis, representational difference analysis, salmon

Anadromous salmon are well known for accurate homing migration to their natal river. Since Hasler and his co-workers proposed the olfactory hypothesis of salmon homing in 1950's, many behavioral and electrophysiological studies have reported the important functions of the olfactory system (olfactory epithelium, olfactory nerve, and olfactory bulb) in salmon.

Research on olfactory memory has been mainly investigated in mammals. It is generally thought to be formed by the long-term potentiation (LTP) in synapse. In teleost fish, LTP was detected in the olfactory bulb of lacustrine sockeye salmon (*Oncorhynchus nerka*) during the smolt stage (Satou et al. 1996).

It has been suggested that the down stream migration of salmonids is controlled by various hormones including growth hormone, thyroid hormone and adrenal cortex hormone (Iwata and Hirano 1991). Moreover, the thyroid hormone is thought to be necessary for imprinting to the natal river, because it is driven by facilitation of smolting and down stream migration (Dittman and Quinn 1996).

It is thought that the olfactory bulb of salmonids in term of imprinting may express specific genes in relation with nerves and endocrine systems, since more active nervous activities may occur in the olfactory bulb. By using subtractive method, we have tried to identify olfactory imprinting and homing specific genes in the olfactory bulb of lacustrine sockeye salmon.

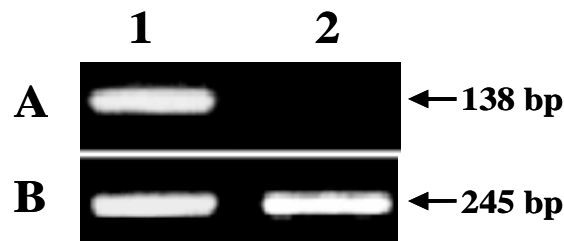
Lacustrine sockeye salmon of 1-year-old (1<sup>+</sup>) and 3-year-old (3<sup>+</sup>) reared at the Toya Lake Station, Faculty of Fisheries, Hokkaido University were used. We sampled 1<sup>+</sup> fish from April to June 2002 (parr-smolt transformation period) and 3<sup>+</sup> fish in June 2002 (feeding migration period). Fish were anesthetized with 4-allyl-2-methoxyphenol (eugenol), and then olfactory epithelium, gill, liver, heart, head kidney, testes and brain were surgically isolated. Brain tissue was cut into small regions; olfactory bulb, telencephalon, hypothalamus, optic tectum, cerebellum and medulla oblongata. Total RNA isolated from each tissue was reverse-transcribed into cDNA.

To identify a specific gene in the olfactory bulb of 1<sup>+</sup> fish, the subtractive hybridization technique of representational difference analysis (RDA) was carried out using the olfactory bulbs cDNA of 1<sup>+</sup> fish in May and 3<sup>+</sup> fish in June. The basic protocol of RDA method was followed from Niwa et al. (1997). After three cycles of subtractive enrichment, subtractive (1<sup>+</sup>) cDNA library was constructed. Approximately 1,000 clones from this library were picked up and differential screening was performed using subtractive (1<sup>+</sup>, 3<sup>+</sup>) cDNA as a probe. As a result, we obtained 10 clones which showed only the probe (1<sup>+</sup>) positive reaction. Sequence of these clones analysis was carried out using Genetix software (Software Development CO., LTD). The similarity search of the obtained cDNAs was done using the Internet server of the DNA Data Bank of Japan (DDBJ).

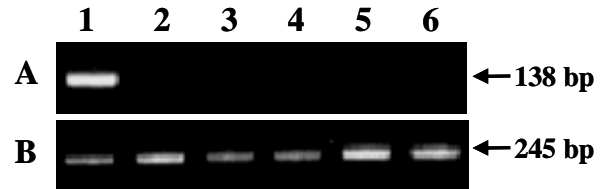
Four kinds of partial clones, which were selected from the result of similarity search, were analyzed by semi-quantitative reverse transcriptase-polymerase chain reaction (RT-PCR). A partial sequencing clone which showed the strongest identity to unknown genes of mouse, were expressed only in the olfactory bulb of 1<sup>+</sup> fish and designated as DNA 138 since its a 138 bp amplified fragment by RT-PCR (Fig. 1). Moreover, the expression of DNA 138 was analyzed in tissues of 1<sup>+</sup> fish in May, and in the olfactory bulb during the parr-smolt transformation (April–June). Semi-quantitative RT-PCR analysis showed that DNA 138 was expressed in the olfactory epithelium, hypothalamus, and medulla oblongata, but not in other body organs and brain regions (Fig. 2, 3). In the olfactory bulb, the gene expression was down-regulated as the fish transformed from a parr to a smolt (Fig. 4).

Further studies are being carried out to isolate the full-length of DNA 138 clone from cDNA libraries of the olfactory epithelium and whole brain, as well as to observe localization of DNA 138 mRNA using an *in situ* hybridization technique.

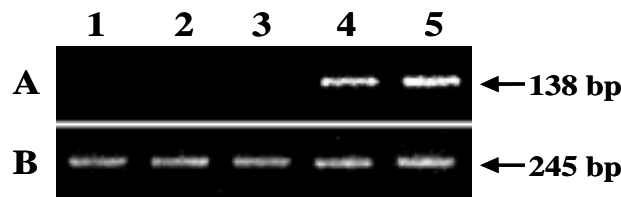
**Fig. 1.** Results of agarose gel electrophoresis of semi-quantitative RT-PCR products. DNA 138 (A) and beta-actin (B). Specific products for DNA 138 and beta-actin mRNAs were amplified from aliquots of the same mRNAs of the olfactory bulb of 1+ in May (lane 1) and 3+ fish (lane 2).



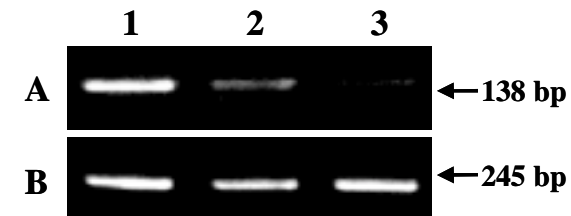
**Fig. 2.** Results of agarose gel electrophoresis of semi-quantitative RT-PCR products. DNA 138 (A) and beta-actin (B). Specific products for DNA 138 and beta-actin mRNAs were amplified from aliquots of the same mRNAs of the olfactory epithelium (lane 1), gill (lane 2), liver (lane 3), heart (lane 4), head kidney (lane 5) and testis (lane 6) of 1+ fish in May.



**Fig. 3.** Results of agarose gel electrophoresis of semi-quantitative RT-PCR products. DNA 138 (A) and beta-actin (B). Specific products for DNA 138 and beta-actin mRNAs were amplified from aliquots of the same mRNAs of the telencephalon (lane 1), hypothalamus (lane 2), optic tectum (lane 3), cerebellum (lane 4) and medulla oblongata (lane 5) of 1+ fish in May.



**Fig. 4.** Results of agarose gel electrophoresis of semi-quantitative RT-PCR products. DNA 138 (A) and beta-actin (B). Specific products for DNA 138 and beta-actin mRNAs were amplified from aliquots of the same mRNAs of the olfactory epithelium (lane 1), gill (lane 2), liver (lane 3), heart (lane 4), head kidney (lane 5) and testis (lane 6) of 1+ fish in May.



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# Physiological Study on Homing Related Olfactory Functions in Salmon

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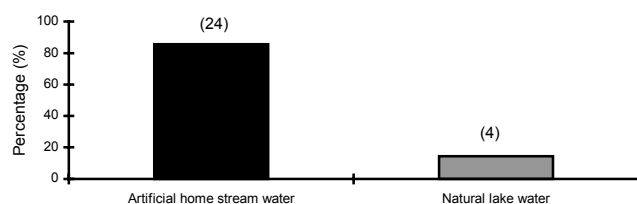


**Keywords:** Amino acids, odorants, home stream, homing migration, salmon

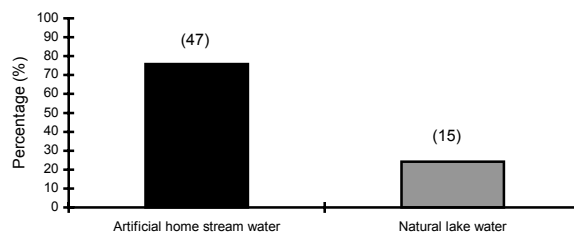
As for the upstream homing migration of salmon from the coastal sea to the home stream, the olfactory hypothesis, proposed by Hasler and Wisby (1951) has been discussed with many behavioral and electrophysiological studies (Hasler and Scholz 1983; Ueda 1985; Stabel 1992; Dittman et al. 1996; Ueda and Shoji 2002). However, these odor substances of home stream are still unknown. We analyzed the compositions of amino acids, inorganic cations and bile acids in waters from three streams flowing into Lake Toya (Shoji et al. 2000). Application of mixtures of bile acids or inorganic cations reconstituted from the compositions of the stream waters, to the olfactory epithelium of masu salmon (*Oncorhynchus masou*) induced only very small responses. On the other hand, application of mixtures of amino acids induced large responses. The response of masu salmon to artificial stream water based on the compositions of amino acids and salts closely resembled the response to the corresponding natural water. From these results of electrophysiological experiments, we proposed that amino acids dissolved in the home stream water were possible substances used by salmon for homing.

In present study, we carried out behavior experiments to test whether or not amino acids mixtures have attractive effects on chum salmon (*O. keta*) and lacustrine sockeye salmon (*O. nerka*) upstream selective movement. Behavior experiments were conducted in a 15 m long two-choice test tank consisting of two 12 m long water inlet arms and a 3 x 1.8 m pool, which has one outlet at the end of tank. Mature male chum salmon (mainly 4 year olds, average fork length 73.0 cm, and average body mass 4,252.5 g) were captured by the wire in Osaru River, transferred to the Toya Lake Station, Hokkaido University, and reared for several days before experiments. In addition, homing of mature landlocked sockeye salmon (average fork length 27.3 cm, and average body mass 220.4 g) to the Lake Shikotsu Hatchery were also used for test fish. The artificial home stream water was prepared to reflect the amino acid and related substance composition of the Osaru River waters and Lake Shikotsu Hatchery waters, and dissolved in artificial freshwater. In each experiment, three to four fish (chum salmon) or five to 10 fish (sockeye salmon) were placed in the pool in the early afternoon, reared for several hours, and the experiment started from evening to midnight. Each amino acid mixture was added to the water inlet of left or right arm for nine hours in the same concentration as natural water. The fish movement was monitored by a remote camera system, and the number of fish that moved to each arm was counted. Of the 44 male chum salmon that were tested, 28 fish showed up stream movement to one of the choice arm. Among these fish, 24 (86%) were found in the arm running artificial home stream water, and 4 fish (14.3%) were observed in the arm running natural water (Fig. 1). There was no selectivity between left and right arm when natural lake water flowed from two arms. In sockeye salmon, of the 151 fish tested, 61 fish were found in one of the choice arms and 47 (76%) of these fish were found in the arm running artificial home stream water, and 14 fish (24%) were observed in the arm running natural water (Fig. 2). There was no selectivity between left and right arm when natural lake water flowed from two arms. There is no difference between male and female in selectivity. Taken together, our results support the hypothesis that amino acids dissolved in the home stream water are possible cues used by salmon for homing.

**Fig. 1.** Selectivity of stream water in mature male chum salmon in two-choice water arm. The number in parenthesis indicates fish move to each stream water.



**Fig. 2.** Selectivity of stream water in mature sockeye salmon in two-choice water arm. The number in parenthesis indicates fish move to each stream water.



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## Spatial Distributions of Chum Salmon and Environments of their Habitat in the Bering Sea during Summer and Autumn

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**Keywords:** Numerical ocean model, chum salmon, summer, distribution, Bering Sea

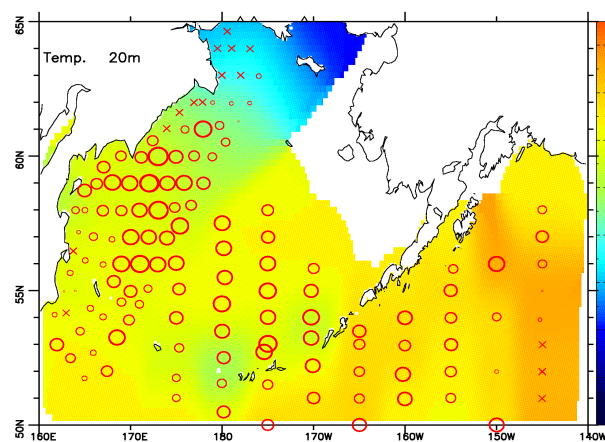
Chum salmon are widely distributed in the Bering Sea basin during summer. However, few immature chum salmon are distributed over the eastern Bering Sea shelf. The environmental limits of their distributions in summer are not well known. To understand the effects of environmental factors on distributions of chum salmon in the Bering Sea, we investigated the characteristics of water mass and distributions of chum salmon by using data from the Bering-Aleutian Salmon International Survey (BASIS) and on the seasonal change of sea conditions in the Bering Sea in a numerical ocean model.

Data on chum salmon and hydrographic data in summer were collected during BASIS fieldwork aboard the RV *Kaiyo maru* and RV *TINRO* in 2003. The initial temperature and salinity fields of the numerical ocean model were obtained from the Levitus climatology (Levitus 1984). The numerical model used in this study was the Princeton Ocean Model (POM) described by Blumberg and Mellor (1987). The POM model is a three dimensional, primitive-equation model. The model resolution was a  $1/6^\circ \times 1/6^\circ$  spherical grid, which was a constant 18.5 km in the meridional direction and varied from 14.2 km at the southern boundary to 6.3 km at the northern boundary in the zonal direction. The model topography was calculated by averaging 5-min horizontal resolution the ETOPO5 data around each model point. The wind stress was horizontally interpolated from the climatology data of Hellerman and Rosenstein (1983). The southern and northern boundaries and the eastern boundary at  $150^\circ \text{W}$ , except for the Alaskan Stream, were modeled as a vertical wall. The Alaskan Stream was modeled as a constant inflow of 15 SV ( $1 \text{ SV} = 10^6 \text{ m}^3 \text{ s}^{-1}$ ) from  $56.7^\circ \text{N}$  to  $57.5^\circ \text{N}$  along  $150^\circ \text{W}$ . The western boundary was modeled as outflow from the Kamchatka Peninsula to  $40^\circ \text{N}$  along  $150^\circ \text{E}$ . Computer runs of the model began at rest on 1 January. Water temperatures ( $T$ ) and salinities ( $S$ ) were held constant during the initial 30 days of the diagnostic run of the model. After that, the model was prognostically integrated by varying the wind stress. Then, Haney-type heat flux, which is an approximation for thermal forcing at the ocean's surface, was added to the model (Haney 1971).

Hydrographic observation stations and trawl surveys by the RV *Kaiyo maru* and RV *TINRO* covered the entire Bering Sea during summer 2003. The mixed-layer depth was 20–30 m in summer, and extended to a depth of 30–40 m in autumn. The distribution of chum salmon was limited by temperature rather than salinity, as indicated by a  $T-S$  diagram. In summer, catch-per-unit-effort (CPUE) of chum salmon was relatively low at water temperatures less than  $5^\circ \text{C}$  at a depth of 20 m in summer and at the surface in autumn (Fig. 1). Trawl survey data, which show that chum salmon are not distributed in water less than  $5^\circ \text{C}$  in winter, and archival tag data, which show that they do not remain for a long period of time in water less than  $5^\circ \text{C}$ , suggest that water temperatures less than  $5^\circ \text{C}$  are not physiologically optimal for chum salmon.

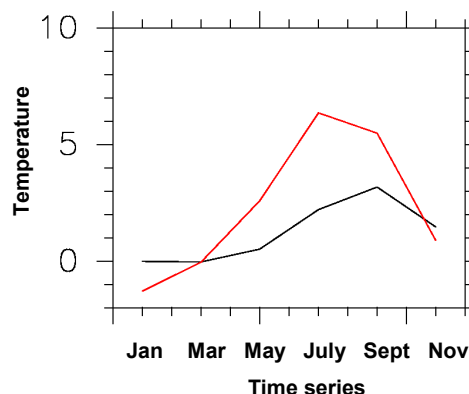
Water temperatures less than  $5^\circ \text{C}$  in the Bering Sea basin and eastern Bering Sea shelf in summer were reproduced by the model. Minimum

**Fig. 1.** Horizontal distribution of immature chum salmon in the Bering Sea and adjacent North Pacific waters in summer 2003. Few immature chum salmon were caught during BASIS surveys over the eastern Bering Sea shelf.



temperatures less than 5°C were formed at a depth of 150 m in the basin and near the bottom in the eastern Bering Sea shelf. Seasonal change in the difference of sea temperature between 5-m and 50-m depths was larger over the eastern Bering Sea shelf than in the Bering Sea basin (Fig. 2). This result indicates that the depth of thermocline in waters over the shelf was shallower than in the basin, and the gradient of the thermocline over the shelf was larger than in the basin. Assuming that chum salmon do not prefer sea temperatures less than 5°C, the vertical space available to chum salmon is relatively small in waters over the shelf. In conclusion, another reason why few immature chum salmon are distributed over the eastern Bering Sea shelf seems to be related to the vertical space above the thermocline.

**Fig. 2.** Seasonal change in the difference in water temperature between 5-m and 50-m depths (5m - 50m) in the Bering basin (black) and the eastern Bering Sea shelf (red).



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# Mitochondrial DNA Phylogeography of Chum Salmon in the Pacific Rim

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**Keywords:** mitochondrial DNA, chum salmon, phylogeography, nested clade phylogeographical analysis (NCPA)

Chum salmon (*Oncorhynchus keta*) are the most widely distributed species of salmon and trout (Salo, 1991). However, factors implicated in the geographical distribution of chum salmon populations are mostly unknown to date.

The present study aimed to clarify the influence of historical events on the genetic population structure of chum salmon around the Pacific Rim. We estimated the genetic relationship among populations of chum salmon, using the nucleotide sequence data of the mitochondrial (mt) DNA control region and genealogy and geographical distribution of mtDNA haplotypes from Sato et al. (2004) and newly analyzed data of 1,444 individuals from 28 populations (20 Russian and 8 North American populations).

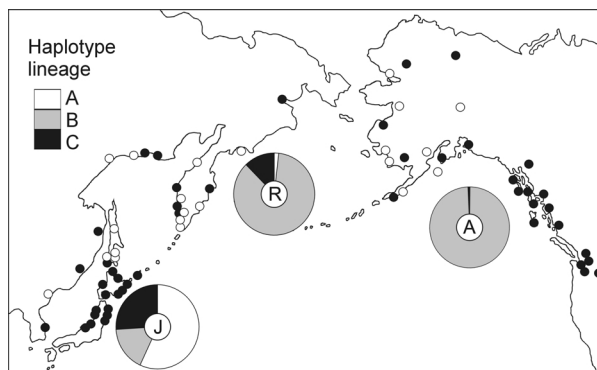
The mtDNA haplotypes of three clades (A, B, and C) observed in 28 additional populations were the same as those identified in previous results (Sato et al. 2004), and further advocated an association with geographic region, in that clade A and C haplotypes characterized Asian and Russian populations and clade B haplotype distinguishes North American population. Clade B is also the most frequent haplotype in Russia and a significant portion in Japan (Fig. 1).

Nucleotide diversity was highest in the clade B lineage ( $0.0047 \pm 0.00039$ ), followed by those of clade C ( $0.0033 \pm 0.00064$ ) and clade A ( $0.0031 \pm 0.00053$ ). Nucleotide divergence was also highest in clade B (0.0044), followed by those of clade C (0.0033) and clade A (0.0027). The number of net nucleotide substitution per sites between clade A and C (0.0019) was lower than those between clade A and B (0.0034) and between clade B and C (0.0052). This finding suggests that the genetic kinship is close between A and C but distant between B and C lineages.

The significant pairwise  $F_{ST}$  estimates were greater between Japan and North America (0.450–0.996) than between Japan and Russia (0.085–0.995) or Russia and North America (0.000–0.846). The relationship between genetic ( $F_{ST}$ ) and geographical distance among populations within three regions (Japan, Russia and North America) showed a clear regional equilibrium, suggesting influence of gene flow with isolation by distance rather than genetic drift on the population structure (Fig. 2).

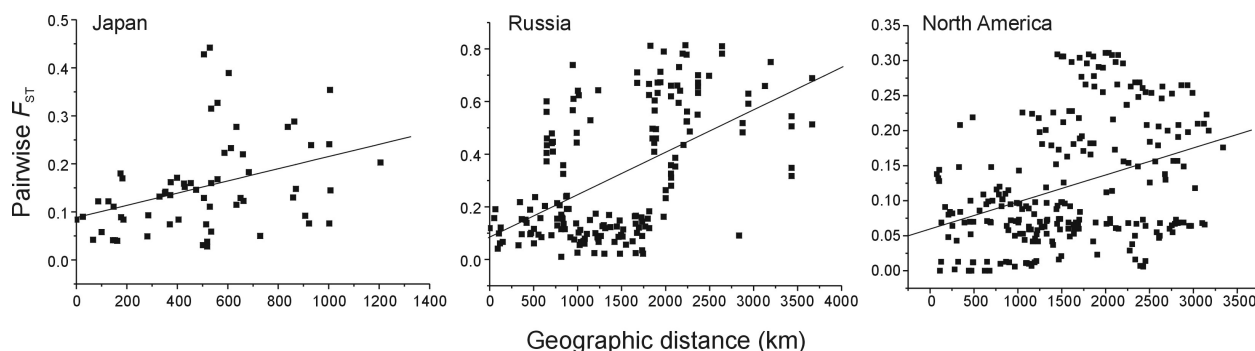
The geographical association of haplotypes was examined by nested clade phylogeographical analysis (NCPA; Templeton et al. 1987; Templeton 2004) and probable causes of associations of chum salmon populations in the Pacific Rim were inferred from mtDNA. The NCPA is a test for significant correlation of an independent variable (geographical distance for phylogeographic studies) with an intraspecific haplotype genealogy. The results of NCPA showed that observed geographical distribution of chum salmon haplotypes was influenced by the major process of contiguous range expansion. This process indicated that chum salmon dispersed from adjacent regions counterclockwise around the Pacific Rim from Japan to North America (Alaska Peninsula/Southcentral Alaska) via Russia (Sakhalin). This result may indicate historical demography of chum salmon driven by glaciation cycles and sea level changes during the Pleistocene, or even earlier, although historical factor(s) implicated in the formation of genetic structure within regional populations was not observed at present. The suggested dispersal route of chum

**Fig. 1.** Distribution of the three mtDNA lineages (A, B, and C) of chum salmon in the three regions (Japan/Korea = J, Russia = R, and North America = A) of the Pacific Rim. Dots indicate the sampling locations in the Pacific Rim: Open circles observed new sampling locations and closed circles indicated previous analysis locations reported by Sato et al. (2004).



salmon in the Pacific Rim seems overlap the hypothetical migration route of Japanese chum salmon from the Sea of Okhotsk to the Bering Sea and east to the Gulf of Alaska (Urawa 2000; Urawa et al. 2001). Furthermore, a previous study demonstrated that the surface circulation in the North Pacific Rim has been conserved since the Pleistocene (Romine 1985). All together, the present mtDNA phylogeographical study suggests Asian origin of chum salmon.

**Fig. 2.** Scatter-plots of pairwise population  $F_{ST}$  estimates against geographic distances (kilometers) separating each pairwise combination populations within each region. The scatter-plot of  $F_{ST}$  values and geographical distances for Japan, Russia and North America showed a clear association of genetic and geographical distance across all population range in each region, suggesting a regional equilibrium. The correlation coefficient was significantly positive for the populations of Japan ( $r = 0.37094$ ,  $p < 0.01$ ), Russia ( $r = 0.53542$ ,  $p < 0.0001$ ), and North America ( $r = 0.35903$ ,  $p < 0.0001$ ).



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## Genetic Stock Identification of Chum Salmon (*Oncorhynchus keta*) in the Bering Sea Using DNA Microarray

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

Molecular techniques to assess the genetic variation of fish populations are a promising means of genetic stock identification (GSI) of salmon (Ferguson et al. 1995). We recently showed 20 polymorphic nucleotide sites in the 5' half of the control region of the mitochondrial (mt) DNA (Sato et al. 2001). The observed single nucleotide polymorphisms (SNPs) have defined 30 haplotypes of three genealogical clades (A, B, and C) in more than 2,100 individuals from 48 populations in the Pacific Rim (Sato et al. 2004). The observed haplotypes were mostly associated with geographic regions. The haplotypes that belong to clade A and C characterized Asian populations, and clade B haplotypes distinguished North American populations. We developed a DNA microarray technique for rapid detection of 20 SNPs and accurate identification of 30 haplotypes in the mtDNA control region (Moriya et al. 2004, in press). In this study we estimate the stock composition of chum salmon in the Bering Sea using the DNA microarray method.

The DNA microarray analysis includes; 1) simultaneous PCR amplification and labeling of the 5' variable portion of the mtDNA control region with a pair of 5'-biotinylated and non-biotinylated primers, 2) two-hour hybridization of biotinylated PCR fragments with DNA microarray and subsequent short washing, and 3) visualization of hybridization signals colored by the conventional ABC (Avidin-Biotin Complex) method and computer-assisted comparison of scanner-taking signal images. The entire process of hybridization and detection was completed within eight hours.

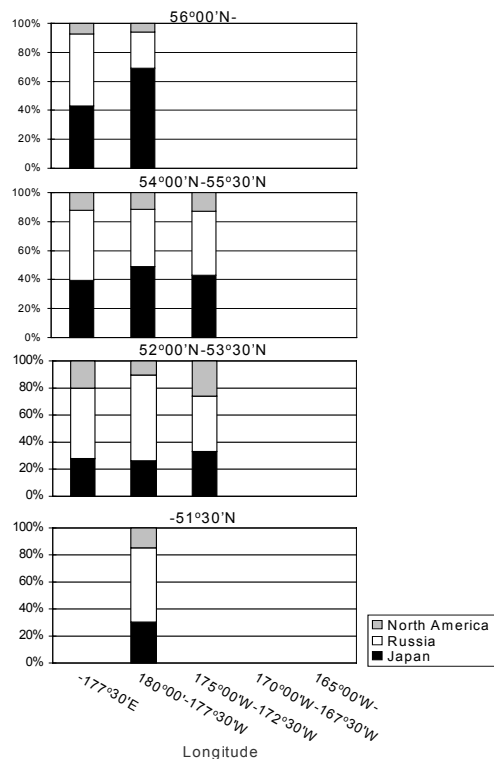
Samples of chum salmon were collected from the Bering Sea during research cruises of RV *Kaiyo maru* during September 2002 and 2003. A total of 978 chum salmon was sampled in 2002 from 18 stations in the Bering Sea (172°30'E to 172°30'W, 51°30' to 58°30'N), whereas a total of 1,254 chum salmon was collected in 2003 from 23 stations in the Bering Sea and the North Pacific Ocean (175°30'E to 165°00'W, 50°00' to 58°00'N).

Stock contributions of the mixed samples were estimated by a conditional maximum likelihood method (Pella and Milner 1987). A conjugate-gradient searching algorithm using a square root transformation was employed (Pella et al. 1996). Standard deviations 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 of Japan, Russia, and North America. Computations were performed with the Statistics Programs for Analyzing Mixtures (SPAM version 3.7, ADF&G 2003). For SPAM, we used the baseline data set of 48 populations of chum salmon in the Pacific Rim reported by Sato et al. (2004).

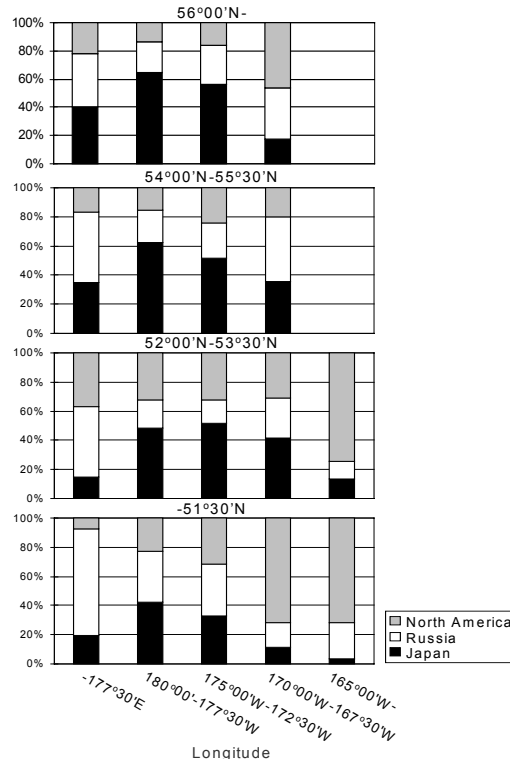
Japanese and Russian stocks were widely distributed in the survey areas (Fig. 1). The Japanese stocks were predominant in the central Bering Sea, comprising over 50% of sampled chum salmon between 180°00' to 177°30'W, 54°00' to 58°30'N. Russian stocks were predominant in the western Bering Sea (from 172°30'E to 177°30'E) and in the southern Bering Sea (from 51°30' to 53°30'N), exceeding 40% of the composition. Japanese stocks were abundant in the central Bering Sea (from 175°00'E to 172°30'W) (Fig. 2). Japanese stocks exceeded over 60% of chum salmon sampled in the northern Bering Sea (from 180°00' to 177°30'W, from 54°00' to 58°00'N). Russian stocks were predominant in the eastern Bering Sea (from 175°00'E to 177°30'E) and, increased in proportion southerly, reaching over 70% (from 50°00' to 51°30'N). North American stocks increased in proportion eastward, reaching over 70% of sampled salmon in the area around the Aleutian Islands (from 170°00'W to 165°00'W, from 50°00'N to 53°30'N).

These results suggest non-random distribution of Asian and North American stocks of chum salmon, in that the Japanese stocks were abundant in the central and northern areas of the Bering Sea, the Russian stocks were in the western area of the Bering Sea, the North American stocks were in the area around the Aleutian Island.

**Fig. 1.** Estimated stock composition of chum salmon mixtures collected in the Bering Sea in September 2002. The Japanese and Russian stocks were widely distributed in the survey areas. The Japanese stocks were predominant in the northern Bering Sea (from 54°00' to 58°30'N), the Russian stocks were in the southern Bering Sea (from 51°30' to 53°30'N). The Russian stocks were also predominant in the eastern Bering Sea.



**Fig. 2.** Estimated stock composition of chum salmon mixtures collected in the Bering Sea in September 2003. The Japanese stocks were predominant in the central and northern Bering Sea. The Russian stocks were predominant in the eastern Bering Sea (from 175°00'E to 177°30'E). The North American stocks were predominant in the area around the Aleutian Islands (from 170°00'W, to 53°30'N).



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# Identification Local Stocks of Sockeye and Chinook Salmon by Scale Pattern Analysis from Trawl Catches of R/V “*TINRO*” Worked by Program of the Bering-Aleutian Salmon International Survey (BASIS) in September–October 2002

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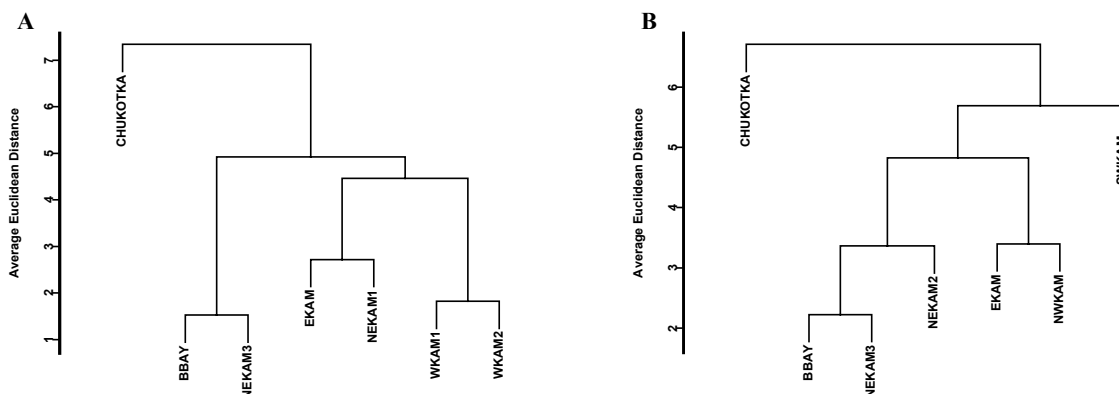
**Keywords:** Identification, local stocks, scale pattern analysis, scale baselines, age groups, simulation, cluster analysis, maximum likelihood estimate

In this work, we used sockeye and chinook salmon scales collected from Asian and North American rivers and off-shore catches in June–August 2001–2002 as baselines. The total number of standard scales was: sockeye salmon–1,954 specimens (including 1,571 fish from 12 stocks in Kamchatka, 183 fish from two stocks in Chukotka and 200 fish from Bristol Bay), chinook salmon–1,528 specimens (including 887 fish from eight stocks in Kamchatka and 641 fish from three Alaskan stocks). Scale samples of ocean caught immature sockeye and chinook salmon were collected during the Bering-Aleutian Salmon International Survey (BASIS) trawl surveys conducted by the R/V “*TINRO*” in the Russian Exclusive Economic Zone in September–October 2002. Total sample size used for the mixture analysis of ocean caught immature salmon was: sockeye salmon–1,307 aged specimens and 854 identified specimens, chinook salmon–229 aged specimens and 91 identified specimens.

Age estimation and analysis of scale criteria were made on the basis of NPAFC standard methods (Davis et al. 1990). Scale structure analysis included measuring the following parameters: freshwater growth zone (radius), the first ocean year growth zone (width, number of circuli, intercirculi spacing combined by triplets). Data baselines were formed using cluster analysis of scale standards by dominant age groups (MathSoft 1997). The discrimination power of scales was determined on a simulated baseline and mixture using maximum likelihood (Millar 1987, 1990).

Results of the cluster analysis indicate that sockeye and chinook salmon stocks diverged between west and east Kamchatka (Figs. 1 and 2). Sockeye salmon stocks from Alaska were closer to the local stocks of Olutorsko-Navarinski district. The stocks from the Olutorsko-Navarinski district will most likely be identified as Bristol Bay sockeye in a mixed fishery due to the large abundance Bristol Bay sockeye salmon relative to North-East Kamchatka sockeye salmon stocks. For chinook salmon the difference between Asian and American stocks is more evident. The discrimination power of simulated baseline was about 93% for sockeye salmon and about 85% for chinook salmon.

**Fig. 1.** A hierarchical clustering dendrograms of the scale pattern baselines of sockeye salmon for the age groups 1.3 (A) and 2.3 (B). **Asia** – EKAM – *Eastern Kamchatka* (river Kamchatka), NEKAM1-NEKAM3 – *North-Eastern Kamchatka* (1 – Karaginski Bay (rivers Khailula and Dranka), 2 – Olutorski Bay (river Anana), 3 – Navarinski district (river Severnaya)), WKAM1-WKAM2 – *Western Kamchatka* (1 – Sobolevski district (rivers Icha, Krutogorova and Vorovskaya, 2 – Bolsheretski district (rivers Bolshaya and Kikhchik)), NWKAM – *North-Western Kamchatka* (river Palana), SWKAM – *South-Western Kamchatka* (river Ozernaya), CHUKOTKA – *Chukotka* (rivers Meynypilgyn and Nygchekveem). **North America** – BBAY – *Central Alaska* (Bristol Bay (Port Moller)).

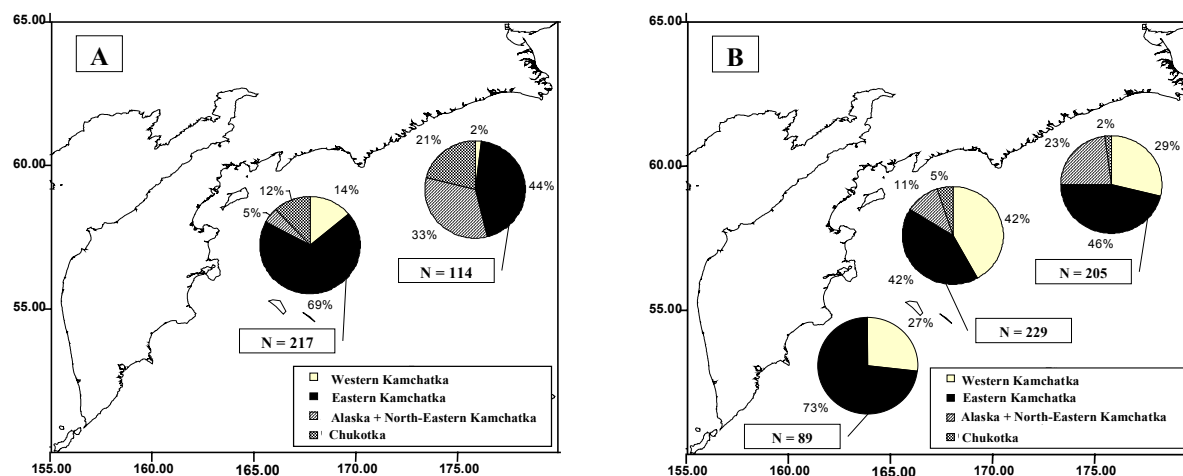


Identification of local sockeye and chinook salmon stocks was carried out by age groups .1 and .2. These groups are the most abundant for both species. Results of the stock identification analyses have demonstrated that Asian stocks of both species were predominant in the Western Bering Sea in September-October. However, stock composition differed among age groups, indicating that the area of the Bering Sea utilized by different age-classes varied during the period of ocean feeding.

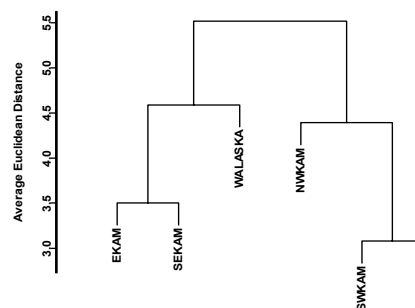
The majority of the sockeye salmon catch was represented by the Eastern Kamchatka complex, ranging from 44 to 69% in age .1 and from 42 to 73% in age .2 (Fig. 3). Contributions of Western Kamchatka and Chukotka complexes were considerably lower and more unstable over the analysis by age groups. In the first case, their contribution was from 2 to 14% and from 27 to 42% for age .1 and .2 fish, respectively. In the second case, their contribution ranged from 12 to 21% and from 2 to 5% for the same age groups. Bristol Bay sockeye salmon was most frequent in the area located to the North-East of Olutorski Cape, i.e. closer to the Economic Zone of the USA. They represented 33 and 23% for age groups .1 and .2, respectively. Southward, in the area of Karaginski Bay, the frequency of Bristol Bay sockeye salmon by these age groups was not over 5 and 11%. These ratios general fits the known distribution and migration of age .1 and .2 Asian and American sockeye salmon during the fall feeding period in the Western Bering Sea.

The sample size for assessing the stock composition of chinook salmon in a mixed fishery was not sufficiently large; therefore only preliminary data for the South-Western Bering Sea have been presented in this work (Fig. 4). East Kamchatka stocks were predominant in this region, with Kamchatka River chinook salmon contributing up to 90% of the total Asian river and off-shore catches. For the age groups .1 and .2, the contribution of East Kamchatka stocks was 59 and 67%, respectively. Western Kamchatka chinook salmon did not represent more than 10–20%. The contribution of West Alaskan stocks in the catches was up to 21–23%. It is not excluded that real contribution of American chinook salmon in trawl catches could be higher and could get up to 30–40%, as the results of the mixed fishery simulations have shown that the West Alaska stocks can be misclassified as East Kamchatka stocks. Moreover, the assessment of chinook salmon biomass obtained from the trawl survey of R/V "TINRO" in 2002 (Temnykh et al. 2003) demonstrate rather high level, which does not completely agree with known abundance of this species in Asia.

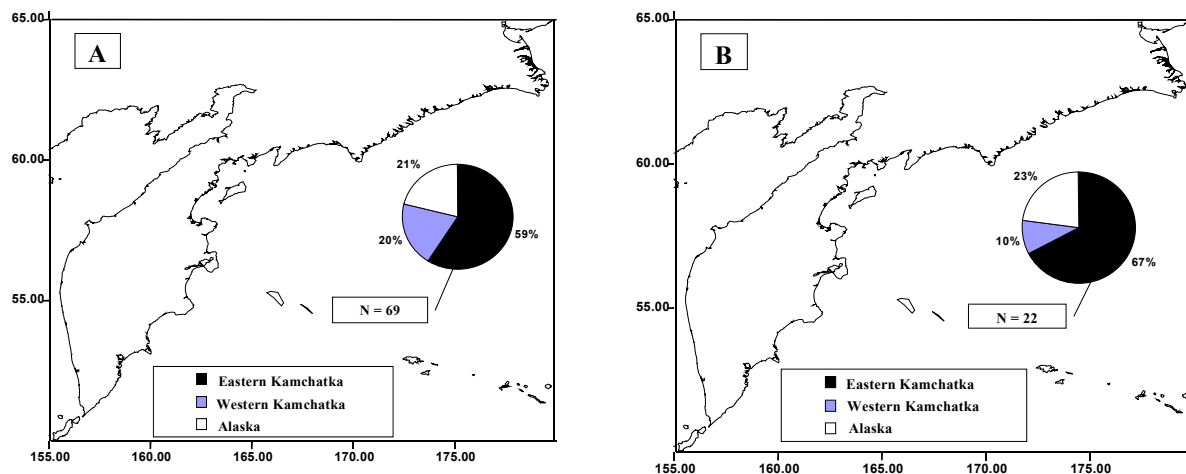
**Fig. 3.** Distribution of principal complexes of immature sockeye salmon local stocks in the western part of the Bering Sea and adjacent waters of the north-western part of the Pacific Ocean from trawl catches in September–October 2002. A – age groups 1.1 and 2.1, B – age groups 1.2 and 2.2.



**Fig. 2.** A hierarchical clustering dendrograms of the scale pattern baselines of chinook salmon combined by age groups 1.2, 1.3 and 1.4. **Asia** – EKAM – *Eastern Kamchatka* (river Kamchatka), SEKAM – *South-Eastern Kamchatka* (river Avacha), WKAM – *Western Kamchatka* (Sobolevski district (rivers Pymta and Vorovskaya)), NWKAM – *North-Western Kamchatka* (river Palana), SWKAM – *South-Western Kamchatka* (Bolsheretski district (rivers Bolshaya, Kikhchik and Utka)). **North America** – WALASKA – *Western Alaska* (rivers Yukon, Kuskokwim and Nushagak).



**Fig. 4.** Distribution of principal complexes of immature chinook salmon local stocks in the western part of the Bering Sea from trawl catches in September–October 2002. A – age groups 1.1, B – age groups 1.2.



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# Dynamics of the Biological Structure of Commercial Stocks of Asian Coho Salmon in the Pacific Waters off Kamchatka and the Western Bering Sea

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**Keywords:** Coho salmon, Kamchatka, Bering Sea, marine distribution, migration, age, growth

Kamchatka is a major region of natural reproduction and commercial fishing for coho salmon. The continuing decrease in the abundance of coho salmon stocks in Kamchatka necessitates more careful analysis of the changes that occur in spawning stocks, studies on the mechanisms that regulate stock abundance, and the development of conservation measures. The marine period of life of coho salmon remains poorly studied. Mostly, the complete marine period was studied by Birman (1985), Mathews and Ishida (1989), Ogura et al. (1991), Glebov (2000), and Erokhin (2002). The problem of stock identification of coho salmon was addressed by Zorbidi (1990) and Zorbidi and Antonov (2001).

This work is based on extensive scientific data collected by the author over many years (1993–2002) during the period of anadromous migrations of coho salmon in the Pacific waters off Kamchatka and in the Western Bering Sea. The qualitative structure of prespawning stocks of coho salmon in 1993–2002 showed significant temporal and spatial variations. Throughout the area in June–August, the age and sex ratio, size, weight, maturity, and growth rate of coho salmon varied by stock. The distribution of these stocks was very dynamic. Changes in biological parameters occurred at relatively small spatial and temporal scales (e.g., one area during one month), indicating extensive mixing among migrating cohorts of different populations.

Spring–summer anadromous migrations to the shores of Kamchatka occurred in different periods. Mixed aggregations of various cohorts and populations of migrants appeared first in the Pacific waters off Kamchatka and in the Western Bering Sea, and then in the Sea of Okhotsk, although they were sometimes later in these areas than in the vicinity of the northern Kuril Islands. The earliest migrations of spawning cohorts from southern oceanic districts to the Russian Economic Zone near the northern Kurils (Pacific side) started in mid June. After this, cohorts migrating from the east first appeared near the shores of southeast Kamchatka in mid July, and then one part migrated to the north along the shores of East Kamchatka, and the other part migrated to the Sea of Okhotsk. Males and less mature fish dominated the earliest spawning cohorts. To some extent, the females were usually more mature than males. Average (1993–2002) sex ratios of aggregations in the Pacific waters off Kamchatka showed a high percentage of males (53.0%) in July, and a lower percentage (up to 42.8% males) in September.

Temporal and spatial dynamics of the abundance of males and females may not be clear because of the presence of cohorts migrating at different times. For example, in the western Bering Sea females were dominant in prespawning aggregations in June (48.8% males), and males gained dominance only in early August (51.0%). There was a significant reduction in the percentage of males in September at the end of spawning migrations of summer coho salmon.

A tendency for the maturity coefficient (MC) to increase in the same area and time period was obvious. In the Pacific waters off Kamchatka, the MC of age 2.1+ females in the earliest cohorts ranged from 3.73 to 11.6, and that of males from 2.55 to 7.22. In September, the MC increased up to 5.16–12.8 for females, and 5.61–9.0 for males. In the western Bering Sea, the percentages of maturing fish in July were relatively high (7.3–9.4% females; 5.38–6.4% males). Whereas the MC in July was 1.5–2 times lower near the northern Kurils, than in areas situated to the north.

A standard set of age groups occurred throughout the study area (Table 1). Fish that spent two years in freshwater were dominant in all marine areas, as in areas of downstream migration. The age composition in marine aggregations, however, demonstrated spatial heterogeneity. Two age groups, 1.1+ and 2.1+, were dominant, however, in the western Bering Sea the percentage of age 2.1+ fish was higher. Age 3.1+ fish occurred in this area in relatively high numbers during the main part of the run in August. As shown in Table 1, there was a transformation in the age composition of migrating cohorts during the run. Jacks (age-0+), not found in catches in the other areas, appeared in the Pacific waters off Kamchatka by late August and early September, and also in the Bering Sea by late June and early July; and apparently, jacks did not undertake any long-distance feeding migrations. Moreover, the stocks in the western Bering Sea were characterized by a relatively high percentage of fish that spent two years in the sea (1.2+ and 2.2+; Table 1).

**Table 1.** Dynamics of age structure in marine aggregations of coho salmon in the Pacific Ocean waters adjacent to Kamchatka and the western Bering Sea (average %, 1993–2002).

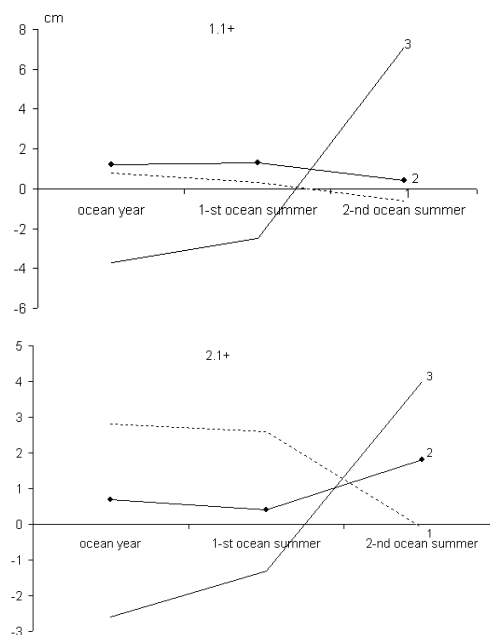
Western Bering Sea (average %, 1955-1992)									
Month	10-day period	Age (%)							
		1.1+	2.1+	3.1+	1.2+	2.2+	1.0+	2.0+	3.0+
Pacific Ocean waters adjacent to Kamchatka									
July	mid	26.4	70.6	3.0					
	late	40.6	53.9	5.5					
August	early	47.7	49.1	2.8	0.7				
	late	54.8	40.5	3.7	1.0				
September	early	44.6	41.1	6.8	0.9	-	0.3		0.9
Western Bering Sea									
June		48.8	45.3	4.3	-	1.2	-	0.4	-
July	late	22.2	77.8	-	-	-	-	-	-
August	mid	38.8	50.0	8.2	-	2.0	-	-	-
	late	31.7	62.6	2.9	1.0	1.8	-	-	-

Although significant inter-annual variations occurred in all biological parameters, condition factor, length, and weight of migrants increased in recent years, as a result of favorable ocean feeding conditions. In Pacific waters off Kamchatka, average condition factor increased from 1.25 to 1.32 in 2000–2002, and average body length increased from 59.3 cm to 60.8 cm. At the same time, condition factor and body length of coho salmon in aggregations in the western Bering Sea also increased (1.33 until 2000; 1.36 in 2001–2002). Large variations in condition factor and body length were observed in the region southeast of Kamchatka only during one month, and were due to the migration of fish of different stocks of origin.

Improvement in marine trophic conditions is shown by data on the growth rates of migrants in the Pacific waters off East Kamchatka and in the western Bering Sea. Coho salmon in the western Bering Sea had a high growth rate while at sea. For example, in 2000–2002 the average increase in body length of 2.1+ fish in the year of migration was approximately 2 cm higher than in 1993–1999 (23.4 cm). However, fish with a different characteristic growth rate occurred during the same period in the aggregations near the southeast part of Kamchatka (Fig. 1). Everywhere, throughout the study area, we found a group of fish that had apparently overwintered in the Bering Sea and nearby the Aleutian Islands, identified by the small increment of scale growth (only 5–6 circuli) in the year of migration.

The marine growth characteristics of coho salmon differed to some extent depending on their age. As a rule, older (age 2.1+) fish in the earliest migrating cohorts had different characteristics of marine growth, lower condition factor, and higher maturity than younger (age 1.1+) fish (Fig. 1). This indicates that older and younger age groups of coho salmon may feed in different locations.

Variations in the biological parameters of aggregations near southeast Kamchatka, especially temporal variations, were mostly due to mixing of Okhotsk Sea and East Kamchatka stocks of coho salmon.

**Fig. 1.** Parameters of coho salmon growth by age group, 1.1+ (top panel) and 2.1+ (bottom panel), and marine life stage (1<sup>st</sup> ocean year, 1<sup>st</sup> ocean summer, 2<sup>nd</sup> ocean summer) in different regions of the North Pacific Ocean and Bering Sea in 2001–2002 (deviations from average body length data, 1993–2002). 1 –Pacific Ocean waters adjacent to Kamchatka; 2 – western Bering Sea; 3 – Southeast Kamchatka.

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## Influence of Marine Feeding Area on Lipid Accumulation in Juvenile Coho Salmon

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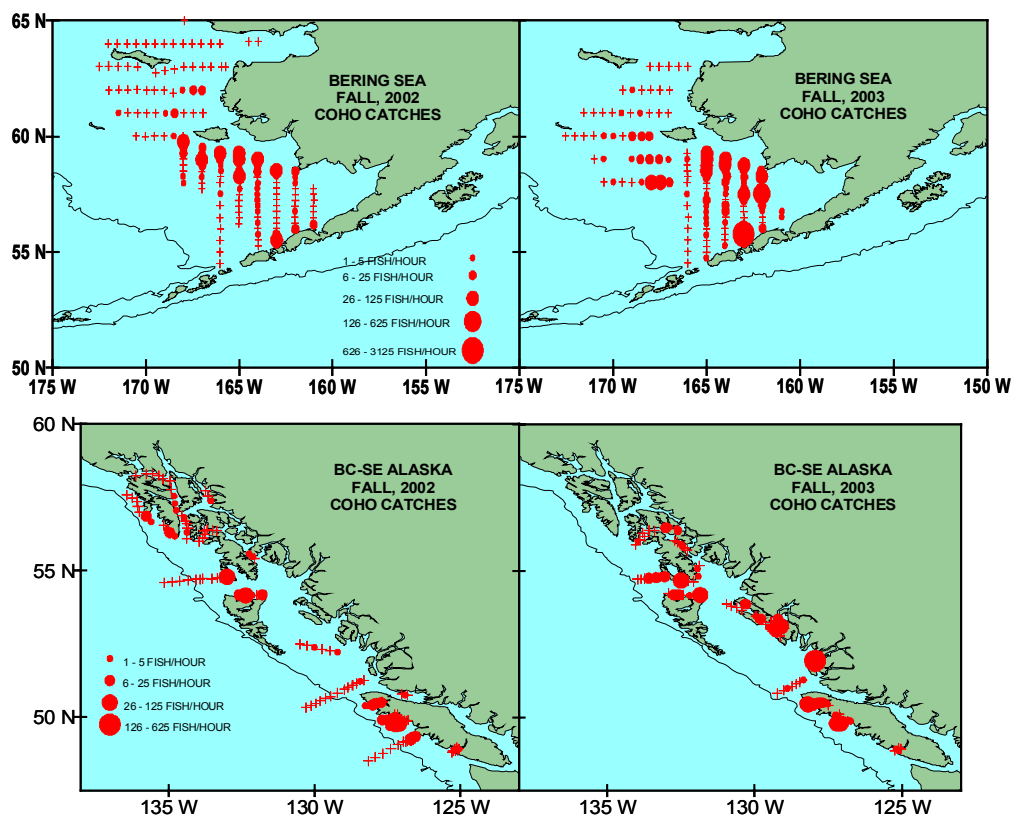


**Keywords:** Lipids, growth, latitude, countergradient, Pacific salmon, coho salmon, Bering Sea, Pacific Ocean

The succession of seasons is accompanied by predictable changes in the environment. In general, food production increases in the spring to reach a maximum during summer, and then declines in the fall before reaching minimal values during winter. Hence, fish often face food shortages during winter and must rely on the reserves accumulated during summer to fuel their metabolic functions. As the duration of winter increases with latitude in the northern hemisphere, fish living at the northern end of their distribution must accumulate higher lipid reserves during the growing season to survive over winter (Conover and Present 1990). Here, we tested the hypothesis that lipid accumulation in Pacific salmon increases with latitude during summer.

Juvenile coho salmon (*Oncorhynchus kisutch*) were collected in the Eastern Bering Sea (BS), in southeastern Alaska (SEA), and on the west coast of Vancouver Island (WCVI) using a rope trawl in September–November 2002–2003 (Fig. 1). Growth rates of juvenile coho salmon were estimated assuming that WCVI, SEA, and BS coho smolts migrated to sea at an average size of 100 mm on May 1, May 15, and June 1, respectively, as coho smolts generally migrate to sea later in the spring in northern latitudes (Sandercock 1991). In this study, percent dry weight

**Fig. 1.** Distribution of the juvenile coho salmon collected in the Bering Sea, southeast Alaska, and on the west coast of Vancouver Island in September–November 2002–2003. Salmon were collected with the FV *Sea Storm* in the Bering Sea, and with the CCGS *W.E. Ricker* in southeast Alaska and on the west coast of Vancouver Island. Catches are expressed in the number of fish caught per hour.



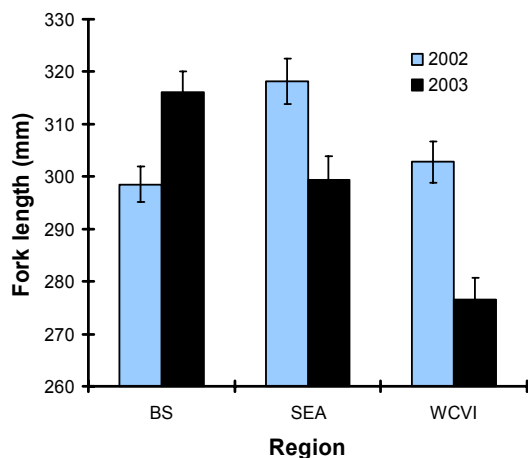
in the whole fish was used as an indicator of lipid contents, as lipids and caloric contents are strongly positively correlated to percent dry weight in juvenile coho salmon (Trudel et al. 2005). Percent dry weight (*PDRY*, %) can be converted to lipid contents (*LIP*, %) using the following equation derived on ocean caught coho salmon (Trudel et al. 2005):  $LIP = -10.3 + 0.55 \cdot PDRY$ .

BS coho were larger in 2003 than in 2002 (Fig. 2). The opposite pattern was observed for WCVI and SEA coho (Fig. 2). Juvenile coho salmon grew faster in the BS than in WCVI or SEA, with growth rates approaching  $2 \text{ mm} \cdot \text{d}^{-1}$  compared to  $1.2 \text{ mm} \cdot \text{d}^{-1}$  for southern regions. In addition, percent dry weight was also higher in the BS, averaging around 25% (Fig. 3). Lipids represented about 3.5% of the wet weight of BS coho, compared to about 3% for SEA and WCVI. These results support the hypothesis that lipid accumulation and growth varies inversely with the length of the growing season in salmon. This may be an adaptive response to survive more severe winter conditions in northern latitudes where temperature is colder and day length is shorter. Alternatively, this may reflect differences in prey lipid contents among regions, as lipid contents is generally higher in northern than southern copepods (Båmstedt 1986).

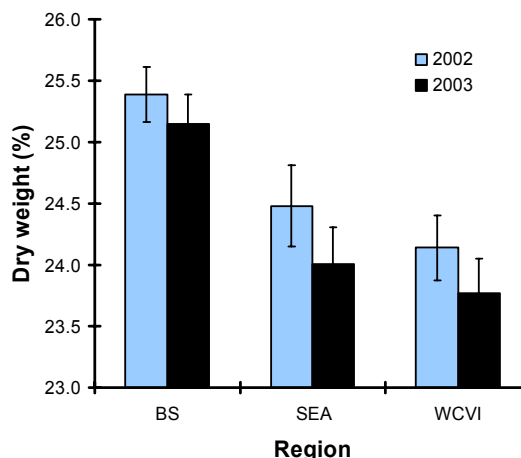
Several years of observations will be needed to understand the mechanisms regulating salmon populations in the Bering Sea. Until these long term data set become available, the comparative method used in this study may provide valuable insight for assessing the effects of ocean conditions and climate on juvenile salmon in this area.

We thank the crew of the FV *Sea Storm* and of the CCGS *W.E. Ricker*, as well as the numerous technicians for their assistance with the field work and laboratory analysis. Funding was provided by Fisheries and Oceans Canada, the Bonneville Power Administration, the Ocean Carrying Capacity Program (National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory, Juneau, Alaska, U.S.A.), GLOBEC, and by the Yukon River Drainage Fisheries Association (YRDFA).

**Fig. 2.** Average fork length of juvenile coho salmon collected in the Bering Sea (BS), southeast Alaska (SEA), and on the west coast of Vancouver Island (WCVI) in September–November 2002–2003. The average fork length varied significantly among years ( $F = 7.1$ ;  $p < 0.01$ ) and regions ( $F = 13.2$ ;  $p < 0.0001$ ). The error bar represents  $\pm 1 \text{ SE}$ .



**Fig. 3.** Average dry weight (% of wet weight) of juvenile coho salmon collected in the Bering Sea (BS), southeast Alaska (SEA), and on the west coast of Vancouver Island (WCVI) in September–November 2002–2003. Percent dry weight varied significantly among regions ( $F = 12.9$ ;  $p < 0.01$ ), but not between years ( $F = 2.4$ ;  $p > 0.1$ ). The error bar represents  $\pm 1 \text{ SE}$ .



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## Composition Changes in Retinal Pigments According to Habitat of Chum and Pink Salmon

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Keywords: Chum salmon; pink salmon; visual pigment; habitat

In order to investigate changes in the composition of retinal pigments according to habitats of chum (*Oncorhynchus keta*) and pink (*O. gorbuscha*) salmon, their rhodopsin ratio was analyzed by sampling individual fish before release from the hatchery, during the feeding and homing migration, and after return to their natal river. The ratio in both species increased gradually in sea water. However, the ratio decreased after return to their natal river. Moreover, the ratio in chum salmon was always slightly higher than that in pink salmon in sea water. The difference per individual in the ratio was largest in the case of individuals caught with a set net during the homing migration.

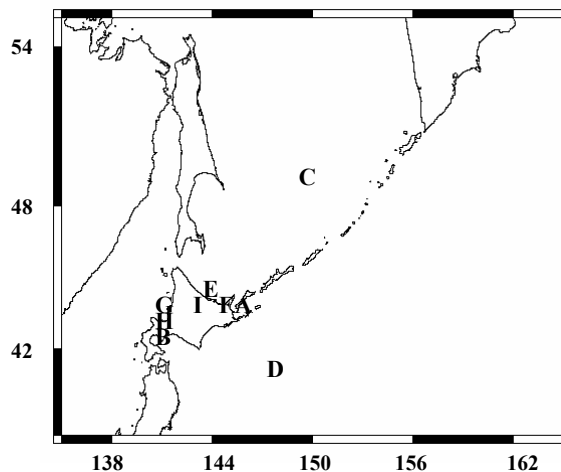
Visual pigments consist of a chromophoric group with a specific protein, opsin, in a lipoprotein complex. Various kinds of pigments with different absorption spectra are distributed over the whole animal kingdom, although opsin differs interspecifically. Spectral sensitivity in scotopic conditions can be analysed by measuring the absorption spectrum of visual pigment located in the outer segments of the rods. Photosensitive visual pigments are classified into rhodopsin, a vitamin A<sub>1</sub>-based pigment, and porphyropsin, a vitamin A<sub>2</sub>-based pigment. Most marine fishes have rhodopsin, while most freshwater fishes have porphyropsin. The absorption spectrum of visual pigment that each fish has is closely related to the light condition in the fish's environment. For example, the  $\lambda_{\max}$  (wavelength of peak absorbance) of a fish living in the deep sea is shifted to the short wavelengths compared with that of a coastal species. Some fishes have both visual pigments in the retina. The proportions of these two visual pigments can change with differing habitat. For examples, the dominant retinal pigment of ayu (*Plecoglossus altivelis*) changes from rhodopsin in sea water to porphyropsin in fresh water (Hasegawa and Miyaguchi 1997). In pink and chum salmon, the  $\lambda_{\max}$  of rhodopsin is 503 nm and the  $\lambda_{\max}$  of porphyropsin is 527 nm. Our objective was to examine whether the composition of visual pigment in chum and pink salmon changes by habitat, as in the ayu.

The life stages of pink and chum salmon investigated in this report ranged from eyed egg to spawning adult. Individuals before release were produced in hatcheries at Chitose and at the Kitami branch office of the National Salmon Resources Center. Juveniles after release were caught in coastal areas of Shibetsu and Shiraoi with a small round-haul net, a pair trawl net, and a set net. Young chum and pink salmon were caught in the Sea of Okhotsk with a trawl net (Hasegawa et al. 2002). Individuals during their feeding or homing migration were caught in the North Pacific Ocean with a drift gillnet. Spawning individuals were caught in the coastal areas of Shari and Atsuta with a set net, as well as in the Shari, Tokoro, and Chitose rivers. The locations of sampling areas are shown in Fig. 1.

Retinal and 3-dehydroretinal, which are the chromophores of visual pigment, were analyzed by essentially the same method as Suzuki and Makino-Tasaka (1983). An example of the chromatogram of chum salmon just before release is shown in Fig. 2.

The changes in visual pigment composition in chum and pink salmon are shown in Fig. 3. After being released, chum and pink salmon move to the offshore habitat. In connection with this migration, their rhodopsin ratio increases gradually. However, for chum and pink salmon returning to the coast for spawning, an increase in porphyropsin was observed. The rhodopsin ratio for chum salmon was always higher than that of pink salmon in the sea life stage. Visual pigment composition of individuals returning to their natal river is reversed, and porphyropsin is highest. Moreover, the rhodopsin ratio of pink salmon is

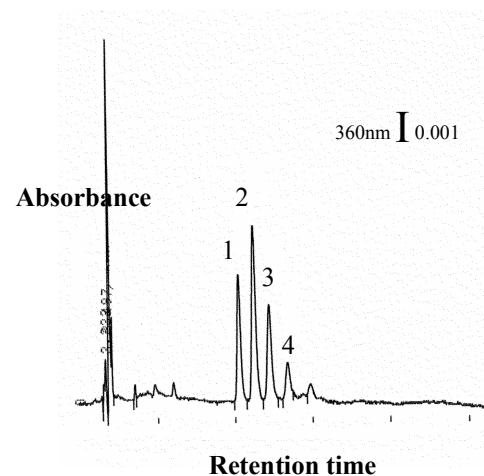
Fig. 1. Research area for the composition of visual pigments. A—offshore Shibetsu, B—offshore Shiraoi, C—Sea of Okhotsk, D—North Pacific Ocean, E—Tokoro R., F—Shari R. and set net, G—Atsuta, H, Chitose, I—Kitami.



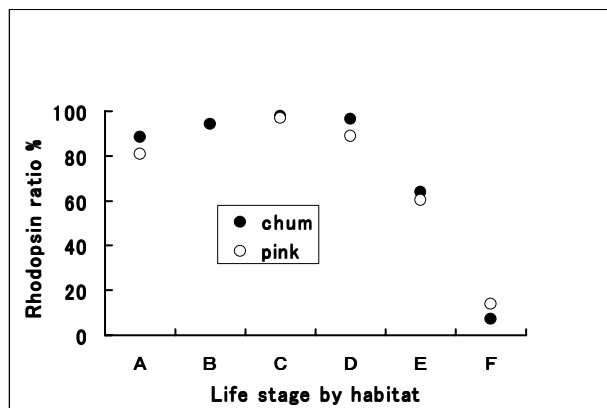
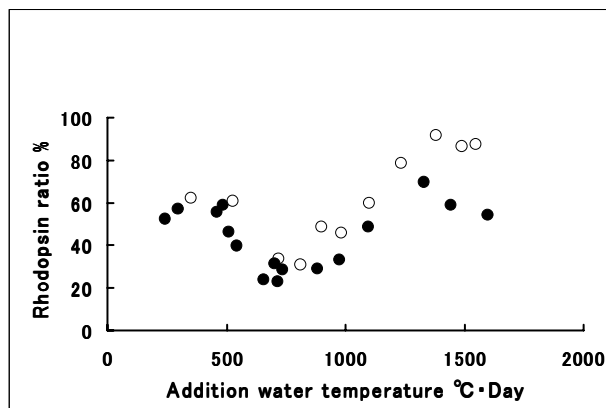
always higher than that of chum salmon in fresh water. Based on other knowledge about the relation between the spectral sensitivity of fishes and their habitat depth (Kobayashi 1962), the selection depth of chum salmon in the sea is deeper than that of pink salmon. It is supposed that the selection depth of chum salmon in fresh water is shallower than that of pink salmon. The difference between species in selection depth may be the most important consideration when determining the abundance of these two species in the ocean.

Furthermore, the difference per individual in visual pigment composition (standard deviation of the rhodopsin ratio) of both species was largest for caught by set net when they returned to the coast for spawning (life stage E, Fig. 3). It is thought that the rhodopsin ratio decreases just before salmon ascend the river to spawn, and higher values are maintained in fish that go further south. Individuals on a homing migration may be contained by capture in a set net. The abundance of the resources of local origin may be correctly estimated using the differences in rhodopsin ratios of individuals between catches in each set net laid along the northern coast of Japan.

**Fig. 2.** Example of the chromatogram of a hatchery chum salmon just before release. 1—11-cis-retinaloxime, 2—11-cis-3-dehydroretinaloxime, 3—all-trans-retinaloxime, 4—all-trans-3-dehydroretinaloxime.



**Fig. 3.** Composition changes in retinal pigments in the hatchery (left view) and after release (right view). A—Japan coast after release, B—migrating north (maybe Honshu origin), C—in the Sea of Okhotsk before winter, D—during feeding or homing migration (caught by drift gillnet in the North Pacific Ocean), E—during homing migration (caught by set net), F—in river before spawning.



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## Factors that Affect the First Year Growth of Chum Salmon Released from Japanese Hatcheries

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Keywords: Chum salmon, first year growth, hatcheries, sea surface temperature

Increased abundance has been related to reduced adult size in a number of studies from the mid-1960s to the mid-1990s (Kaeriyama 1989, 1998, 1999; Ishida et al. 1993; Bigler et al. 1996). The authors suggested that density-dependent processes play important roles in regulating their ocean growth because these reductions in size occurred simultaneously in geographically widespread populations. However, salmon abundance is generally thought to be determined during their coastal residence period (e.g., Mueter et al. 2002). Accordingly, salmon abundance in the Bering Sea would be related to the abundance of survivors in the coastal waters. From this point of view, the density-dependent growth in the Bering Sea would also be related to the coastal events in different regions of the Pacific Rim. Thus, studies of density-dependent processes during the early ocean life of salmon are indispensable. In the present study, year-to-year variations in growth at age 0.1 (hereafter the first year growth) were investigated using age 0.3 chum salmon of 1977–1999 brood years returning to five rivers (Ishikari, Shari, Nishibetu, Tokachi, and Yurappu Rivers) in Hokkaido, Japan.

The first year growth of individual fish was estimated by their scale increments at age 0.1 (i.e., radius at the first annulus). Scale measurements were conducted using a microscope ( $\times 25$ ) equipped with a scale measurement system (ARP/W, Version 3.20. Ratoc system engineering Co. Ltd., Tokyo, Japan). The measurements were directly used as an indicator for the first year growth of individual fish. Although sample size varied from six to 114 between sexes, as well as among the populations and brood years, 202 (87.8%) of 230 samples (2 sexes  $\times$  5 populations  $\times$  23 brood years) consisted of more than 30 fish. In total, scales from 10,917 fish were measured. Brood-year averages were then obtained for both sexes from the five populations.

Annual variations in the first year growth were compared between male and female within each population as well as among the populations, by using the correlation analysis of Pyper and Peterman (1998). The method adjusts degrees of freedom for significance tests, taking autocorrelation of data into account. I selected it rather than the standard product-moment correlation analysis because some of the time series of the brood-year averages showed significantly autocorrelation. The brood-year averages were significantly correlated within each population ( $r = 0.70\text{--}0.94$ ,  $p < 0.01$  for all tests), but not completely synchronous among the populations ( $r = -0.15\text{--}0.79$ , some tests were not significant). These results indicate that the first year growth varied showing some different patterns among the populations. A factor analysis was applied on the brood-year averages to group populations showing a similar trend in the growth. Three factors were observed. As result of the factor loadings, the factor 1 was associated with the growth of Shari, Nishibetu, and Tokachi populations, and the factor 2 and 3 were linked with that of Ishikari and Yurappu populations, respectively.

Although each factor grouped populations according to similarities in the first year growth, the factor analysis cannot identify mechanisms. To understand possible components of the factors, I examined relationships between the factors and effects of hatchery programs and ocean conditions. As effects of hatchery programs, I considered the following two variables: (1) the number of released chum fry from Hokkaido and (2) the brood-year averages of size at release for each population. Effects of ocean conditions were evaluated by sea surface temperature (SST) in the following five areas: mean March–July SST in (1) Japan Sea coast (JS area;  $43\text{--}46^\circ\text{N}$ ,  $140\text{--}142^\circ\text{E}$ ); (2) Okhotsk Sea coast (OH area;  $43\text{--}46^\circ\text{N}$ ,  $142\text{--}147^\circ\text{E}$ ); (3) East and (4) West of Erimo Peninsula coasts (EP and WP areas;  $41\text{--}43^\circ\text{N}$ ,  $143\text{--}146^\circ\text{E}$  and  $41\text{--}43^\circ\text{N}$ ,  $140\text{--}143^\circ\text{E}$ , respectively); and (5) mean August–November SST in the Okhotsk Sea (Okhotsk Sea;  $46\text{--}59^\circ\text{N}$ ,  $142\text{--}157^\circ\text{E}$ ). The areas where SST were analyzed corresponded approximately to areas that juvenile salmon occupied during their early ocean life. Original SST data, expressed as ten-day mean SSTs for  $1^\circ \times 1^\circ$  mesh, were provided by the Japan meteorological agency (Near-GOOS Regional real time database). For the hatchery and SST variables, time series that corresponded to 1977–1999 brood years were prepared, and then they were utilized as independent variables for constructing multiple regression models that incorporated each factor as dependent variable. Variable selection for each model was carried out with a stepwise method. As result of multiple regression analyses, the factor 1 was more strongly affected by the mean size at release of Shari, Nishibetu and Tokachi populations, indicating a possibility that release of chum fry with larger size contributed to increasing

the first year growth of those populations. The factor 2 was positively related to the SST in the JS area, where chum salmon released from Ishikari River are distributed before leaving from Japan. However, since the value of the coefficient of determination ( $R^2$ ) was extremely low ( $R^2 = 0.14$ ), the model was thought to poorly explain the appropriate components that affected the growth of Ishikari population. The factor 3 was positively linked with the SST in the Okhotsk Sea, and negatively related to the number of released chum fry and the SST in the EP area. Among those variables, the number of released chum fry was the most influential variable. Although the number of released chum fry is not a direct indicator for abundance of juvenile salmon during early ocean life, this result indicates that density-dependent growth may have occurred in Yurappu population.

The present study suggests that the factors affecting the first year growth of chum salmon are probably different among populations. Included in these factors are effects of hatchery programs as well as ocean conditions.

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## Trawl Comparisons and Fishing Power Corrections for the F/V *Northwest Explorer*, R/V *TINRO*, and R/V *Kaiyo maru* during the 2002 BASIS Survey

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Keywords: Fishing power, vessel calibration, trawl design

BASIS (Bering-Aleutian Salmon International Survey) research vessels, F/V *Northwest Explorer* (United States), R/V *TINRO* (Russia), and R/V *Kaiyo maru* (Japan), completed joint trawling at twelve stations in the Bering Sea between September 12 and September 18 during 2002. The *Kaiyo maru* and the *Northwest Explorer* completed joint trawling at five stations, the *Northwest Explorer* and the *TINRO* completed joint trawling at six stations, and all three vessels completed joint trawling at one station. Four of the six stations sampled by the *Northwest Explorer* and the *TINRO* were part of a diel study, where the same station was sampled four times (every six hours for 24 hours). Trawls differed in their headrope length and number of wingtips; trawls were configured with different bridle lengths, warp lengths, door sizes, and footrope weights; and vessels differed in their size and horsepower. These differences resulted in differences in sampling depth (vertical opening of the trawl), trawl width, warp length, and trawling speed. Catch rates were standardized for the average area swept during each trawl haul by all three vessels (0.37 km<sup>2</sup> of seawater). Immature chum salmon (*Oncorhynchus keta*), sockeye salmon (*O. nerka*), chinook salmon (*O. tshawytscha*), and juvenile Atka mackerel (*Pleurogrammus monopterygius*) were the primary species and life-history stages caught during the trawl comparisons.

Generalized linear models were used to fit fishing power models to catch and catch rates with a robust maximum likelihood approach. The *Kaiyo maru* had the largest fishing power for both catch and catch rates, followed by the *TINRO* and the *Northwest Explorer*. The largest difference in fishing power consistently occurred between the *Kaiyo maru* and the *Northwest Explorer*. The *TINRO* and the *Northwest Explorer* were most similar in their fishing power for salmon, whereas the *Kaiyo maru* and *TINRO* were most similar in their fishing power for Atka mackerel. Fishing power corrections were larger for catch than catch per unit of effort (CPUE) due to different effort levels by each vessel. Fishing power coefficients for CPUE of all species were significant at the  $p < 0.10$  level; however, only Atka mackerel was significant at the  $p < 0.05$  level.

Although large differences exist in the sampling characteristics of pelagic trawls used by BASIS vessels (particularly with respect to sampling depth, or vertical trawl opening), fishing power models provide reasonable corrections for differences in fishing power. However, caution should be used when applying these fishing power correction terms because the small number of stations used to compute fishing power estimates limits our ability to ensure that correction terms are applicable to other areas and times.

## Single Nucleotide Polymorphisms (SNPs) Provide Standard DNA Data for Bering-Aleutian Salmon International Survey (BASIS) Studies

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**Keywords:** DNA, single nucleotide polymorphism, SNP, stock identification

Migratory studies of Chinook *Oncorhynchus tshawytscha*, chum *O. keta*, and sockeye *O. nerka* salmon require markers for which a large number of individuals can be processed in a relatively short time. Genetic markers, especially allozymes, have provided substantial insight into key questions asked by BASIS investigators (see Kondzela et al. 2002; Urawa et al. 2004; Seeb et al. 2004). However, issues of sample collection and preservation as well as a desire for increased resolution have driven efforts to develop DNA markers to describe discrete aggregations of stocks. Given the multi-jurisdictional geographic range of these species, it is desirable that genetic markers and the corresponding data be transportable across laboratories. Allozymes meet these criteria while most DNA markers do not. To solve this DNA standardization dilemma, we are continuing to develop single nucleotide polymorphism (SNP) genotyping assays based upon the 5'-nuclease reaction.

Various approaches to DNA analysis, each with advantages, were used to study Pacific salmon during the last decade.

Initially the most common approach was the collection of SNP data that was obtained by restriction length polymorphism assays (RFLPs; e.g. Cronin et al. 1993; Park et al. 1993; Seeb and Crane 1999), amplification fragment length polymorphism assays (AFLPs; see Flannery et al. 2002), or DNA sequencing (e.g. Sato et al. 2004). SNP data were collected on mitochondrial DNA, nuclear DNA, neutral genes, and selected genes such as MHC (Kim et al. 1999), providing opportunities for extremely high resolution. Despite the great potential for these markers, application to fisheries issues was often hampered by slow throughput.

Minisatellite analysis (Beacham 1996) was explored and discarded; however, microsatellite analysis became popular because of both its relatively high throughput and resolution (e.g., Scribner et al. 1998; Beacham et al. 2001; Habicht et al. 2004). An important limitation of microsatellites in the context of inter-agency BASIS research is the difficulty of data standardization among laboratories. Standardization of data among laboratories is essential for two reasons. First it obviates the need for every agency to spend the resources to create independent and redundant baseline data. Second, standardization is prerequisite for reproducibility of data among laboratories, thus enabling treaty partners to independently evaluate one another's fishery estimates. Despite over a decade of use, no inter-laboratory standardized microsatellite database exists for any species of Pacific salmon. Technical hurdles have proven daunting and expensive to overcome.

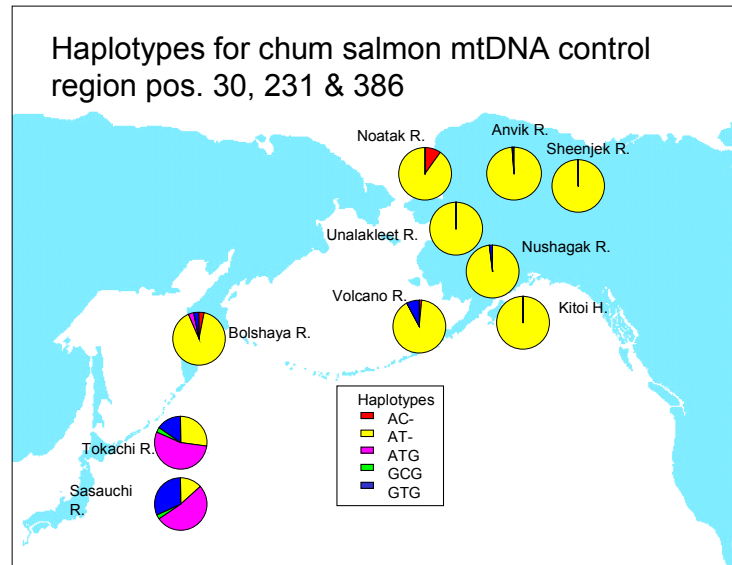
Recent developments in DNA chemistry produced high throughput SNP genotyping technologies such as the 5'-nuclease reaction (see Morin et al. 1999, Ranade et al. 2001) and DNA microarray analysis (Moriya et al. 2004). These approaches offer efficient genotyping to capture the high resolution provided by the various RFLP, AFLP, and sequencing assays. No technically difficult or expensive standardization is required because resulting data are the actual DNA sequence and are automatically standard from lab to lab. We conducted a comparison between the SNP scores obtained using the 5'-nuclease reaction at Alaska Department of Fish and Game and DNA microarray at Hokkaido University and observed 99.4% identity (see Fig. 1). The fact that both laboratories are using SNPs allows the two baselines to be merged, saving each laboratory the resources that would otherwise be spent to genotype each other's collections.

The most significant limitation of SNPs presently is that the paucity of DNA sequence data in some salmonid species means that extensive development is required to identify informative loci. Using a targeted gene approach (cf., Elfsrom et al. in press) and the wealth of sequence data available for rainbow trout *O. mykiss* and Atlantic

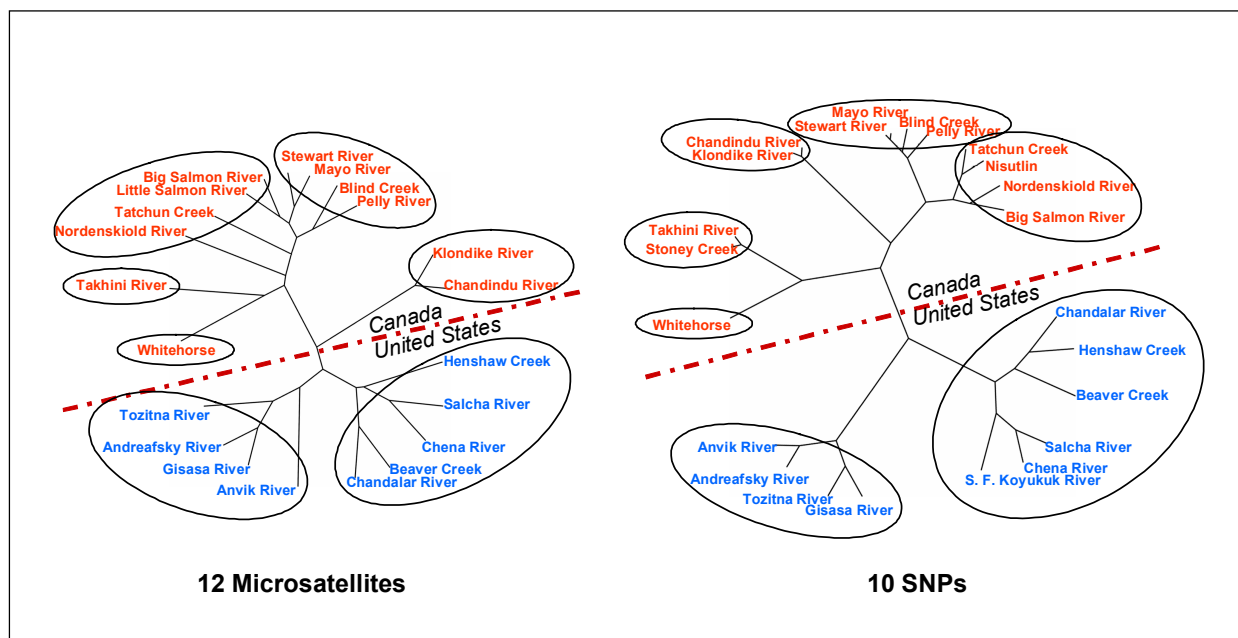
salmon *Salmo salar*, we have identified in excess of 100 SNPs each in Chinook, chum, and sockeye salmon. From these we have designed 5'-nuclease assays for 19 SNPs in Chinook salmon, 27 in chum salmon, and 26 in sockeye salmon (see Smith *et al.* 2004a, 2004b). Using these assays a single technician with one thermal cycler can generate 3840 genotypes in a 7.5hr day. Based on studies in other organisms, we anticipate that 20–40 SNPs will be sufficient to accurately and precisely discriminate salmon populations at a scale useful for Pacific Rim analyses (Werner *et al.* 2004, *i.e.*, see Fig. 2).

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**Fig. 1.** Automatic Standardization. SNP data reflects the actual DNA sequence regardless of the hardware and chemistry used to collect those data. We compared SNP scores using DNA microarray at Hokkaido University with those obtained using the 5'-nuclease reaction at Alaska Department of Fish and Game. We examined three SNPs that discriminate Asian and Alaskan stocks of chum salmon; 1142 of 1149 bases were scored identically (99.4% accuracy).



**Fig. 2.** Resolution. SNPs and microsatellites show similar resolution for Canadian (red) and Alaskan (blue) stocks of Chinook salmon from the Yukon River.



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## Changes in Chum Salmon Plasma Levels of Steroid Hormones during Onset of the Spawning Migration in the Bering Sea

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**Keywords:** Migration, chum salmon, Bering Sea, maturation, testosterone, 11-ketotestosterone, estradiol-17 $\beta$ , HPG-axis

After a few years of oceanic life, Japanese chum salmon migrate to their natal rivers from the Bering Sea. Previous studies have demonstrated involvement of the brain-pituitary-gonadal (HPG) axis in regulation of the spawning migration. In homing chum salmon, expression of genes encoding salmon gonadotropin-releasing hormone (GnRH) was elevated in the forebrain during upstream migration from the coast to the natal hatchery (Onuma et al. 2004, in press). In the pituitary, amounts of mRNA encoding gonadotropin (GTH) II $\beta$  and somatolactin were elevated in stocks migrating a long river (Kitahashi et al. 1998; Taniyama et al. 1999) and a short river upstream (Onuma et al. 2003b). Plasma levels of testosterone (T), 11-ketotestosterone (11KT) and estradiol-17 $\beta$  (E2) decreased along with final gonadal maturation, while those of 17 $\alpha$ -20 $\beta$ -dihydroxy-4-pregnen-3-one (DHP) and cortisol elevated at the final phases of the spawning migration (Onuma et al. 2003a, b).

Plasma levels of sex steroid hormones of chum salmon in the North Pacific Ocean were lower when compared to those of pre-spawning fish (Ueda et al., 1984; Ueda 1998). In farmed masu salmon, plasma levels of T, 11KT and E2 elevated with gonadal maturation from June through August (Munakata et al. 2001; Kitahashi et al. 2004). These results suggest involvement of the HPG-axis in initiation of the spawning migration in the Bering Sea. However, previous studies regarded all offshore fish as one sexually immature group (Ueda et al. 1984; Ueda 1998), which was insufficient to assess the neuroendocrine events associated with onset of the spawning migration. Therefore, in this study we examined changes in chum salmon plasma levels of steroid hormones in fish of several ages in the Bering Sea.

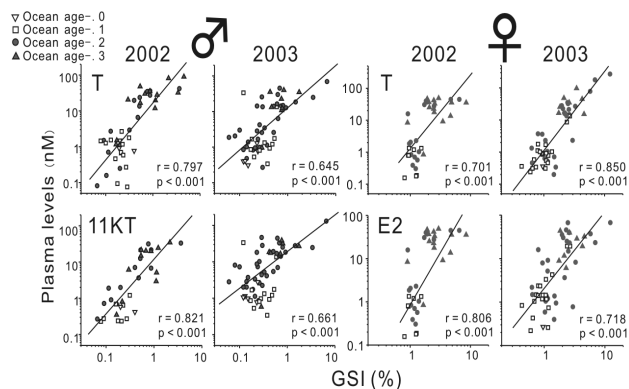
Chum salmon in the Bering Sea were sampled along the 180°-longitude line from late-June through mid-July 2001–2003 during the cruise of research vessel (RV) *Wakatake maru*. In September 2002 and 2003, fish were sampled during the cruise of RV *Kaiyo maru*. In addition, pre-spawning fish were sampled at seven locations along the homing pathway to their natal hatchery in Hokkaido, from mid-September through early-October 2001–2003. Blood samples were collected from the caudal vasculature, kept on ice, and centrifuged to obtain plasma. Gonadal maturity was assessed using gonadosomatic indices (GSI, gonad weight/body weight  $\times$  100). Fish age was determined by examination of scale patterns. Plasma levels of T, 11-KT, E2 and DHP were determined by enzyme immunoassays. Mitochondrial DNA haplotypes of genealogical clades were determined to distinguish between clade A (Japanese population) and clade B (Japanese, Russian and North American populations) by the recently developed DNA microarray hybridization method (Moriya et al. in press).

On the basis of GSI, most ocean age -1 chum salmon in the Bering Sea were immature from late-June through mid-July, while ocean age -2 and -3 fish comprised several populations of immature and maturing fish (Fig. 1). In September, almost all fish were immature regardless of the age. These results indicated that most maturing fish already departed the survey areas for their natal river by the end of summer.

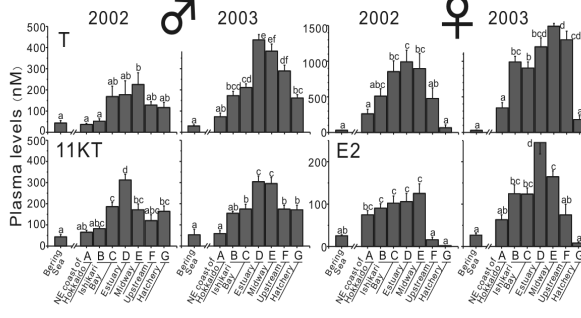
Plasma levels of T, 11KT and E2 were positively correlated with GSI in both sexes (Fig. 2). The levels of T and 11KT in immature male chum salmon were about 1 nM, while those of maturing fish were more than 10 nM. The levels of T and E2 in female fish showed a 10- to 50-fold elevation coincident with gonadal maturation. The levels of most ocean age -1 fish were less than 1 nM, and in ocean age -2 fish, the levels were variable among individuals. The levels of T and E2 in ocean age -3 female fish were more than 10 nM. In contrast, DHP levels showed no correlation with GSI.

Plasma sex steroid hormone levels in maturing chum salmon in the Bering Sea (male, GSI > 1.0; female, GSI > 2.0) were compared with the levels of pre-spawning fish during their upstream migration (Fig. 4). Elevated T and 11KT levels in male maturing fish in the Bering Sea were similar to those in pre-spawning fish captured at the coast of Hokkaido. Levels of T and E2 showed 2- to 10-fold elevation in female maturing fish until they approached the coast. Afterward, the levels increased in both sexes until fish had reached midway up their natal river, and then levels decreased during further upstream migration to the hatchery. In contrast, levels of DHP were elevated at the natal hatchery during final gonadal maturation.

**Fig. 2.** Scatterplots relating GSI (%) and plasma levels (nM) of steroid hormones in chum salmon captured in the Bering Sea. Note the levels of T, 11KT and E2 are elevated with increasing fish age and GSI.



**Fig. 4.** Histograms indicating plasma levels (nM) of sex steroid hormones in maturing fish caught in the Bering Sea (male, GSI > 1.0; female, GSI > 2.0) and along the spawning migration pathway. Each value represents the mean standard error. Significant differences identified by letter combinations ( $p < 0.05$  one-way ANOVA, Tukey test).



These results clearly indicate that levels of T, 11KT and E2 become elevated in the Bering Sea during onset of the spawning migration to the natal river, regardless of the chum salmon source population. Levels of approximately 10 nM stimulated synthesis and release of GnRH (Breton and Sambroni 1996) and GTHs (Ando et al. 2003, 2004) in farmed fish that were immature and in the early phases of sexual maturation. Therefore, we suggest that activation of the HPG-axis occurs in the Bering Sea when chum salmon initiate their spawning migration, as was observed from June through August in farmed masu salmon (Munakata et al. 2001; Kitahashi et al. 2004). Changes in expression of genes encoding neurohormone and pituitary hormone prior to onset of chum salmon spawning migrations are under investigation.

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## Comparative Population Genetics of Chum and Masu Salmon Using Mitochondrial DNA Sequence Variation

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**Keywords:** Chum salmon, masu salmon, mitochondrial DNA control region, nucleotide sequence variation, genetic population structure

Using nucleotide sequence variations found in the 5' half of the control region of the mitochondrial (mt) DNA, genetic diversity of chum (*Oncorhynchus keta*) and masu salmon (*O. masou*) was compared to get an insight into the specific difference, if any, in the genetic population structure of these two Pacific salmon species with different lifetime characteristics. Polymerase chain reaction (PCR)-based direct sequence analysis was successfully performed with the primers, tRNA<sup>thr</sup>-2 and tRNA<sup>phe</sup>-2, originally designed for chum salmon (Sato et al. 2001) and other sequencing primers for each species. Occasional occurrence of larger PCR products than regular-sized amplified fragments of about 1.0 kb were found in each population of masu salmon, whereas no size polymorphisms of PCR products were observed in chum salmon which constantly showed the regular PCR fragments. The occurrence of such irregular-sized fragments in masu salmon ranged from 3.3% to 12.5% in each population examined. Sequence analysis with primers of tRNA<sup>pro</sup>-3, Okdl-L1, Omdl-H1 (designed for masu salmon), and tRNA<sup>phe</sup>-2 revealed that the irregular-sized PCR fragments were due to the occurrence of one to five repeats of an 80 bp unit in the 3' portion of the control region. Except for the observed sequence repeats, the structure of masu salmon control region and its flanking gene order were in keeping with the previous findings (Shedlock et al. 1992). Thus, sequence analysis excluded the 3' portion occasionally containing varying number of the 80 bp repeats in masu salmon.

As reported previously, chum salmon showed 20 variable nucleotide sites in the target mtDNA region, which defined a total of 30 haplotypes in more than 3,200 individuals representing 76 populations in the Pacific Rim (Yoon et al. 2004). On the other hand, the same mtDNA region disclosed 128 variable nucleotide sites, which defined a total of 51 haplotypes in 688 individuals from 11 Japanese, six Russian populations and one Korean population in masu salmon. Parsimony network analysis of the 30 haplotypes in chum salmon showed the presence of three clades (A, B and C) (Sato et al. 2001, 2004). However, phylogenetic relationship of the 51 haplotypes in masu salmon was not well-resolved using available network programs employed, probably because of an excess of non-informative indels. Instead, an unrooted NJ consensus tree suggested at least nine clades of masu salmon mtDNA haplotypes.

The observed haplotype diversity was larger in the populations of masu salmon (range 0.72–0.93) than chum salmon (range 0.24–0.61) (Yoon et al. 2004) (Table 1). The analysis of molecular variance (AMOVA), contingency  $\chi^2$  test, and pairwise population  $F_{ST}$  estimation showed a distinct genetic differentiation among Japanese, Russian

**Table 1.** Haplotype and nucleotide diversities of chum and masu salmon.

Population	Diversities	
	Haplotype	Nucleotide
<b>Chum</b>		
Japan	0.61±0.001	0.0021
Russia	0.36±0.001	0.0017
North America	0.24±0.001	0.0006
<b>Masu</b>		
Japan	0.93±0.003	0.1076
Russia	0.85±0.003	0.0110
Korea	0.72±0.003	0.0123

and North American populations in chum salmon and a weak but significant differentiation between local populations within each region (Sato et al. 2004; Yoon et al. 2004). Similar population genetic analyses in masu salmon also showed a genetic differentiation between Japanese and Russian populations. However, the population structure of masu salmon within Japan was notably different from the structure of chum salmon. In chum salmon, the AMOVA inferred a genetic differentiation among the populations from three regions, i.e. Hokkaido, Pacific Ocean coast in Honshu and Sea of Japan coast in Honshu, with a substantial statistical support (Sato et al. 2001). On the other hand, in masu salmon, no such genetic differentiation was observed in the sets of populations between the Hokkaido and the Honshu populations. Although there was a highly significant heterogeneity in the haplotype frequency ( $p < 0.001$ ) revealed with the contingency  $\chi^2$  test for the entire set of populations in Japan, such significant heterogeneity was not observed for the sets of populations from Honshu and the Sea of Okhotsk coast in Hokkaido ( $p > 0.05$ ). Likewise, AMOVAs revealed the population structure between the two geographic groups of the Sea of Japan coast and Okhotsk-Pacific Ocean coasts, but failed to show the structure between Hokkaido and Honshu, within Hokkaido, and within Honshu, as shown in Fig. 1. These results suggest a distinct genetic differentiation in masu salmon along the two coastal sides from north to south of Japanese Archipelago.

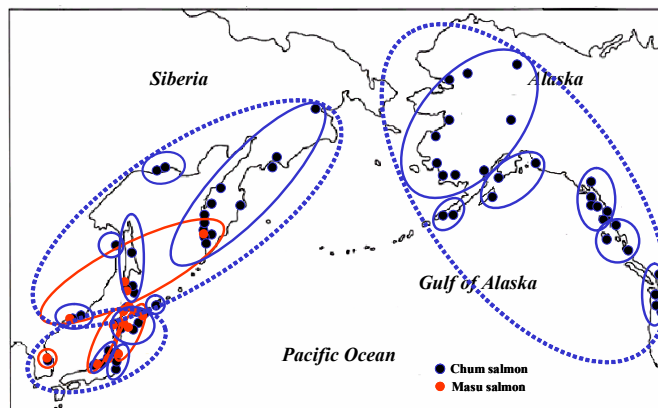
The high genetic divergence and the significant differences in haplotype frequencies in masu salmon river populations which is in contrast with that of chum salmon populations that exhibit a high degree of genetic similarity, suggest that each river of masu salmon has its own genetic traits probably due to a more precise homing ability than chum salmon. Further, this result supports Waples (1995) who claims that population structures of Pacific Salmon are strongly influenced by the ability of salmon to home to their native stream.

In conclusion, the present mtDNA sequence analysis revealed notable differences in both the structure of the control region at a molecular level and the genetic population structure between chum and masu salmon. It remains to be elucidated whether the observed difference in the population structure of these two species is related to their evolutionary history.

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**Fig. 1.** The results of AMOVAs in chum and masu salmon. In chum salmon, the AMOVA inferred a distinct genetic differentiation among Japanese, Russian and North American populations and a weak but significant differentiation between local populations within each region (Sato et al. 2004, Yoon et al. 2004). Similarly, a genetic differentiation between Japanese and Russian populations of masu salmon was apparent. However, the population structure of masu salmon within Japan was notably different from the structure of chum salmon. In chum salmon, a genetic differentiation was found among the populations from Hokkaido, Pacific Ocean coast in Honshu and Sea of Japan coast in Honshu (Sato et al. 2001). On the other hand, in masu salmon, AMOVAs revealed the population structure between the two geographic groups of the Sea of Japan coast and Okhotsk-Pacific Ocean coasts, but failed to show the structure between Hokkaido and Honshu, within Hokkaido, and within Honshu.



## Some Methodical Aspects for Identification of Local Stocks of Pacific Salmon by Scale Pattern Analysis

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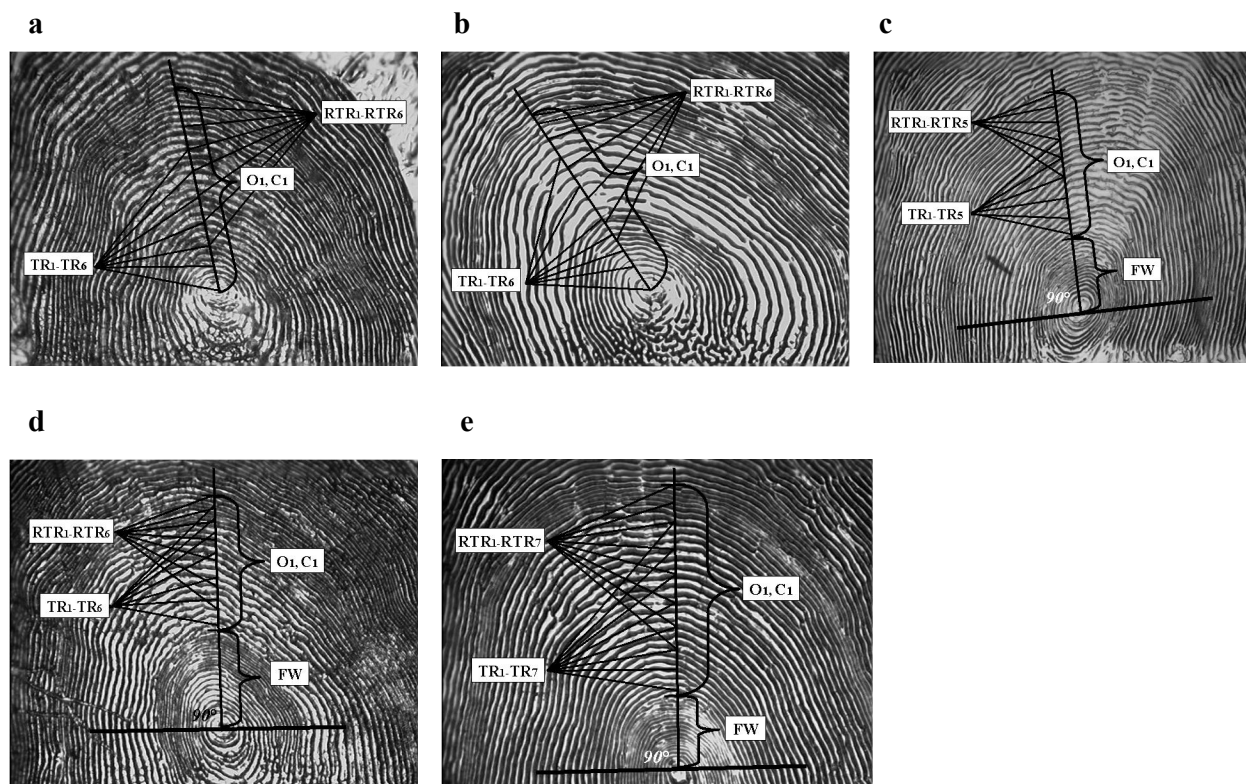


**Keywords:** Salmon, stock, identification, scales, standardization, measurement, annual variation

One of the most important methodical aspects for identification of local stocks of Pacific salmon by scale pattern analysis is the standardization of scale measurement criteria. In this regard, analysis of scale structure should purposefully use standard techniques that enable comparison of results between studies. In this paper, I recommend standardized scale measurement criteria for the five most abundant species of Pacific salmon in Asia and North America, and evaluate potential problems in baseline data related to annual variation in scale growth.

The measurement schemes recommended for each species are quite similar in the structure (Fig. 1). Traditionally, pink and chum salmon scales are measured on an axis directed from the focus along the maximum radius of the first ocean annulus (Fig. 1a,b), and chinook, sockeye, and coho salmon scales are measured on an axis perpendicular to a reference line that delimits the scale pocket (Fig. 1c,d,e). Similar criteria for all species are the width (O1) and the number of circuli (C1) in the first ocean zone. In all cases when there is a period of freshwater growth, the total radius of the freshwater zone (FW) has been measured, including annual zones and circuli distances in the year of smoltification (plus growth). In my view, the subdivision of the freshwater zone into these finer structural elements is not useful. For example, in particular years some local salmon stocks may include a number of fish that do not have plus growth or the growth increment may be impossible to discern visually on adult scales, which makes application of a standard approach impossible. Improved measurements of intercirculus distances in the first ocean year are accomplished by grouping circuli in triplets (TR) from the first ocean circulus and by reconstructed reverse triplets (RTR) from the last circulus of the first ocean year.

**Fig. 1.** Image of a scale and the criteria used for identification of local stocks of Pacific salmon in the ocean period of life: a—Pink salmon, b—Chum salmon, c—Chinook salmon, d—Sockeye salmon, e—Coho salmon.

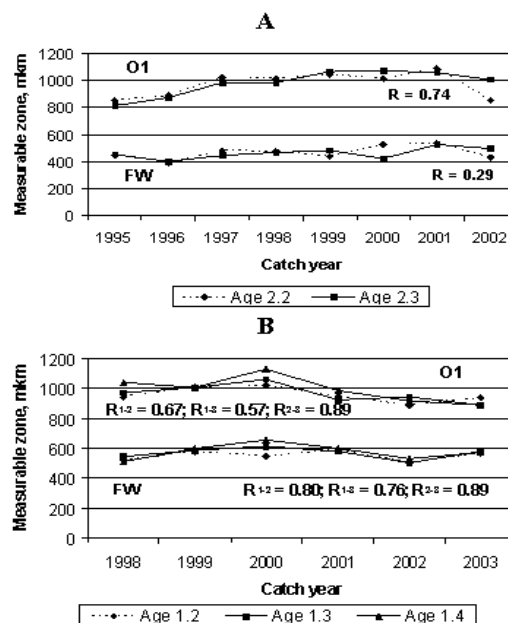


Aside from measurement techniques, there are several other problems that may influence the results of stock identification to a greater or lesser extent. One of these problems is interannual variation in growth rates, and subsequent variation in the formation of scale structures. This may necessitate the creation of a new baseline for each age group in each year. Nevertheless, many scientists have described a visible divergence in the growth rates of particular local stocks of salmon during the second year of feeding in the ocean. These differences in growth rates can be expressed directly as size-weight parameters of fish, as well as in the formation of scale structural elements (Krogus 1960; Grachev 1967; Zorbidi 1978; Walker et al. 1998; Isakov et al. 2000; and many others). This effect leads to the suggestion that the freshwater and first ocean zones of salmon scales are the most stable measures relative to temporal variation.

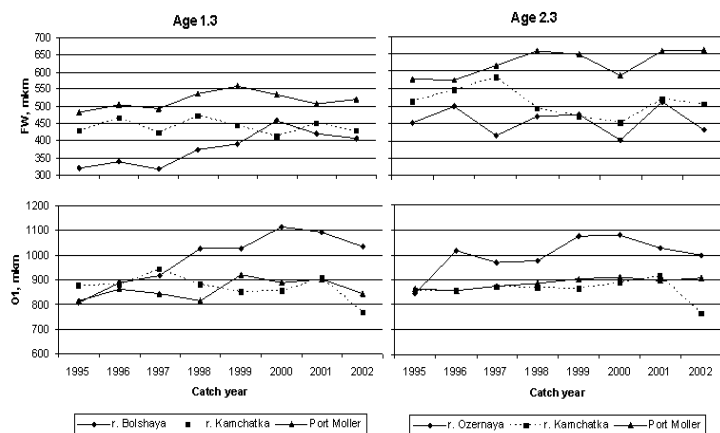
From a time series of sockeye and chinook salmon scale measurement data, one can trace some conformities in interannual variations of two principal scale parameters, that is, the radius of the freshwater zone (FW) and the size of first ocean year zone (O1; Fig. 2). Despite the fact that individuals of various generations are represented in the catches, annual variations in FW and O1 were not that large. Furthermore, in many cases sockeye salmon and chinook salmon showed highly consistent positive relations between respective parameters for various age groups. In this case the time series of data do not show unique relations between age groups, and these results indicate that the use of different baselines for these age groups is not necessary. Clearly, the scale parameters of individual stocks of sockeye salmon and chinook salmon by age groups .2, .3 and .4 do not demonstrate visible deviations for adjoining generations. This does not exclude the possibility that all of the high correlation coefficients noted in Fig. 2 occurred by chance, because conditions of feeding during freshwater and ocean periods are to some extent different for different generations. Thus, despite interannual variations the use of scale baselines from various age groups collected in adjoining years seems to be quite justified for identification of the same local stocks. Possible differences are not considered essential, especially if the standard error of scale method itself is taken into account.

Given this conclusion, the problem remains as to how to estimate the extent of stability in interannual differences and interactions between salmon scale variables at the level of local stocks when developing baselines. When the number of scale samples for each year is large enough, various statistical methods have been used to

**Fig. 2.** Dynamics of variations of freshwater (FW) and the first ocean (O1) zone radii in year of catch by dominant age groups: A—Sockeye salmon (Ozernaya R. (scale test sample from adjacent waters of northern Kuril Islands; for each sample  $n > 100$ ), B—Chinook salmon (Kamchatka R., for each sample  $n = 50-100$ ).



**Fig. 3.** Dynamics of variations in freshwater (FW) and first ocean (O1) growth zone radii for some Asian (Bolshaya and Kamchatka rivers) and North American (Port Moller, Alaska) sockeye salmon stocks by dominant age groups (for each sample  $n = 100$ ).



determine the extent of similarity or difference between the variables used. This problem is more important, however, when the number of scales in baseline samples are deficient, which raises several questions: how stable are the differences in scale structure between certain salmon stocks over time? Is it possible to use scale baselines of adjoining years for identification of catches, when taking into account the interannual variations of a different local stocks? The answers to these questions are not simple. There are studies, nevertheless, where the scale phenotypes of some local stocks were shown to be quite stable over time (Krogus 1958; Birman 1968; Kulikova 1970; Mosher 1972; Bugaev 1995; and others).

In this paper, I addressed these questions by analyzing data from the largest sockeye salmon stocks in Kamchatka and Alaska.

Conformities in the dynamics of the mean values of two scale pattern variables, FW and O1, are shown in Fig. 3. Both variables are prone to interannual variations in all of the stocks that were analyzed. The statistical significance of these differences is not shown in this example, nevertheless, as a rule the principal differences in these variables remained characteristic of individual stocks throughout the period of observation. For example, ages 1.3 and 2.3 sockeye salmon from West Kamchatka (Bolshaya River and Ozeraya River) usually had the minimum values of FW and maximum values of O1, whereas Bristol Bay (Port Moller) sockeye salmon in all cases had the maximum values of FW. For East Kamchatka (Kamchatka River) sockeye salmon, mean values of FW and O1 were intermediate to those of other stocks, and the probability of stock identification errors were highest for this stock. The stability in the dynamics of variables shown by this analysis, even when interannual variations are taken into account, confirms the option to use scale baselines of adjoining years when the number of scale samples is deficient.

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## **A Relational Database on the Abundance, Distribution, and Environmental Conditions of Pacific Salmon at Sea**

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**Keywords:** RDBaseMIL, relational, database, tables, records, key fields, links

Since 1955, the Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO) has investigated the marine life of Pacific salmon in various areas of the North Pacific Ocean. One of the objectives of this research was to get information about the abundance of salmon (and other species) collected with various fishing gears (gillnets, trawls, and seines). In addition, the scientists of the Laboratory of Marine Salmon Investigations (MIL) at KamchatNIRO collected biological information on Pacific salmon including biometric data (length, mass, etc.), biochemical composition of salmon and their prey, food habits (stomach content analysis), forage base data (zooplankton samples obtained using different plankton nets), tagging data, meteorological and hydrological observations in the study areas, etc.

The data collected in the field and in the laboratory during these surveys were presented in annual scientific reports in the 1950–1990s for one or more years of observation. Since then, the data have been kept in the laboratory in the form of gillnet and trawl cards, journals of biological analyses, cards of plankton processing and feeding, etc. Clearly, it is very problematic to retrieve the desired information by working with all the mediums at the same time.

The emergence of personal computers has allowed scientists to keep primary data in electronic form and access the necessary data much more effectively. Most of the KamchatNIRO laboratories, including the laboratory of MIL, have been using MS Excel for that purpose for almost 10 years, where primary data were kept in the form of electronic tables, and as a rule, on separate sheets and files. The format and contents of the data kept in these files varied among scientists in relation to their research needs and objectives. With the accumulation of primary data kept in MS Excel files, the problem of searching and selecting the necessary information occurred again, because MS Excel is not designed for keeping and processing massive databases and has limited connection between separate files.

MS Access is one of the most popular software among computer applications available for mass data processing. It was designed as a full-range Relational Database Management System (RDBMS) containing all the necessary means for data access and processing. MS Access has an advantage over similar products as it was created in Microsoft Office environment. Thus, data can be easily converted into MS Excel tables or MS Word files. In addition, MS Access allows to work out a run-time version of RDBMS, which can be realized with richer RDBMS. Thus, to manage the data reported in paper and electronic formats by the laboratory of MIL, we developed a relational database using Microsoft Access 2000/2002. Here, the author presents the structure of the database containing all the primary data collected by the laboratory of MIL.

For the convenience of describing the scheme of the Database, we saved the main tables used for keeping unique records and key fields connecting them (Fig. 1). For the demonstration of the RDBaseMIL's General scheme (Fig. 1), I have left only 20 basic tables (cruise data, station data, biometric data etc.) because the other 15 tables are auxiliary (i.e. vessel list, catching devices list, standard fishing areas list etc.). The complete version of the database RDBaseMIL contains 35 tables.

At the first stage, the main tasks for the author were to develop a scheme of the data, which will be included into the shareable database, and to adopt the scheme for a multi-user environment. While developing a relational database, it is quite difficult to foresee all the main tasks that will be performed with the application, and especially those tasks that are not currently used but that may appear in the future. That is why it is very important to create at the first stage a flexible database scheme that allows the addition of new components without changing the basic structure at the next stages.

The primary data kept in the laboratory were analyzed. Then some versions of the scheme were tested. As a result, the author has chosen the scheme given below. In our opinion, the scheme allows to solve the main tasks of the database and to insert all the necessary additions and updates (to create new fields and tables) (Fig. 1).

To adopt the database in a multi-users environment the following procedures were made: 1) A new MS Access file with the MDB extension was created (named RDBaseMILtbl). Then, 15 main tables of the database were imported into it. They contained the primary data collected during the scientific surveys of the laboratory of MIL;

2) Links with the RDBaseMILtbl tables of KamchatNIRO net file were connected with the main file RDBaseMIL.mdb, which contains all the “reference” tables.

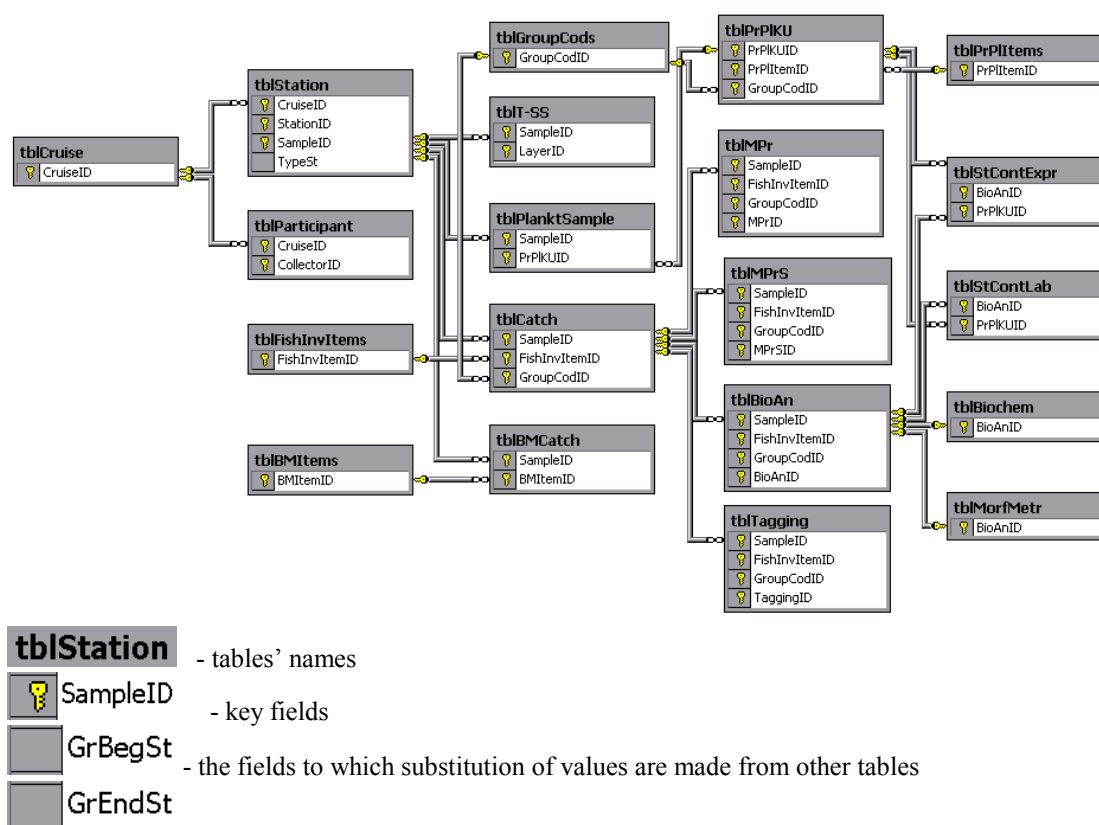
RDBaseMIL.mdb files are installed in the computers of the scientists having access to the database. It allows several users to access the database simultaneously. The users can view, add and review data of the database, depending on their accessibility to the database and their affiliation.

Primarily, the project was developed for the scientists from the laboratory of MIL for their work during cruises. The main step used to build this database was by manually entering the raw data using the keyboard. For this purpose, MS Access has special objects, called “forms”. This is why that when the database was designed a special attention was paid to these objects, as the information, obtained during cruises can be overwhelming. Maintainability of the “forms” greatly influences on the results of the work of scientists, because the data are entered manually.

In conclusion we would like to add that this version of the relational data base RDBaseMIL is not final, because we can encounter new inevitable tasks, not provided by the database. In our opinion, today’s scheme of the project is optimal and «normalized», because it allows to input the primary data of the laboratory and create new tables, without changing the base structure of the database RDBaseMIL. Now the database is being implemented for a more effective usage, but its base structure remains.

The detailed description of the database RDBaseMIL was submitted in the following document: Koval, M.V. A Relational Database on the Abundance, Distribution, and Environmental Conditions of Pacific Salmon at Sea (NPFAC Doc. 800). 30p. Kamchatka Research Institute of Fisheries & Oceanography (KamchatNIRO), Russia, Petropavlovsk-Kamchatsky.

Fig.1. General scheme of the relational database RDBaseMIL (the basic tables).



Description of links:

link “one-to-many” (each record of the table A (from side 1) can have several records of the table B (from side ∞), but a record of the table B cannot have more than one record in the table A.

link «one-to-one» (each record of the table A can have only one record of the table B and vice versa)

# Fish Communities of the Upper Epipelagic Layer of the Bering Sea during the Period of Anadromous and Catadromous Migrations of Pacific Salmon

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**Keywords:** Fish communities, biomass, salmon, comparative trawling

In accordance with the BASIS program, expeditionary research on the upper epipelagic layers (0–50 m) of the western Bering Sea was carried out by scientists aboard the RV *TINRO* in autumn 2002–2003 and summer 2003. The methods of our investigations are reported by Temnykh et al. (2002). Here, we use trawl catch data from the *TINRO* surveys to describe the species composition of upper epipelagic fish communities during the period of salmon migrations in the western Bering Sea. In addition, we analyze the results of joint trawl fishing operations by Russian, Japanese, and U.S. vessels in autumn 2002, and discuss a number of methodological problems revealed by our findings.

In autumn, the number of fish species composing upper epipelagic communities was the same in 2002 and 2003 (48 species; 23–28 families; Table 1). However, the qualitative composition of species in these years was slightly different. The coefficient of Serensen-Chekanovsky, which is often used for comparing the qualitative composition of fauna (Kafanov and Kudryashov 2000), was 0.79. In summer 2003, the composition of upper epipelagic communities consisted of 52 species of fish and other nekton. This composition was only slightly different than in autumn 2002–2003. The Serensen-Chekanovsky coefficients were 0.70 for comparisons of summer and autumn surveys in 2003, and 0.78 for comparisons of summer 2003 and autumn 2002 surveys. Several species of fish caught only in summer 2003 were not listed in Table 1, that is: Salmonidae: *Salvelinus malma*; Hemitripterae: *Hemitripterus villosus*; Psychrolutidae: *Malacocottus* sp.; Stichaeidae: *Stichaeidae* spp.; Icosteidae: *Icosteus aenigmaticus*; and Anarhichadidae: *Anarhichas orientalis*.

**Table 1.** A list of fish species captured during the BASIS survey by the RV *TINRO* in autumn 2002 and 2003. The year in parentheses indicates species was caught only in that year; species without indication of year were caught in both 2002 and 2003.

Family	Genus and species	Family	Genus and species
Petromyzonidae	<i>Lampetra tridentatus</i> ; <i>Lampetra camtschatica</i>	Gasterosteidae	<i>Gasterosteus aculeatus</i>
Lamnidae	<i>Lamna ditropis</i> (2003)	Sebastidae	<i>Sebastes</i> sp.
Squalidae	<i>Squalus acanthias</i> (2003); <i>Somniosus pacificus</i> (2002)	Anoplopomatidae	<i>Anoplopoma fimbria</i>
Clupeidae	<i>Clupea pallasii</i>	Hexagrammidae	<i>Pleurogrammus monopterygius</i>
Engraulidae	<i>Engraulis japonicus</i>	Cottidae	<i>Gymnacanthus detrisus</i> (2003), <i>Hemilepidotus jordani</i> (2003), <i>H. sp.</i> (2002), <i>Melletes papilio</i> , <i>Myoxocephalus verrucosus</i> , <i>M. polyacanthocephalus</i> , <i>M. sp.</i> (2002), <i>Triglops pingelii</i> (2002), <i>T. sp.</i> (2002)
Salmonidae	<i>Oncorhynchus gorbuscha</i> , <i>O. keta</i> , <i>O. kisutch</i> , <i>O. nerka</i> , <i>O. tshawytscha</i>	Hemitripterae	<i>Blepsias bilobus</i> , <i>Nautichthys pribilovius</i> (2003)
Osmeridae	<i>Mallotus villosus</i> , <i>Osmerus mordax dentex</i>	Agonidae	<i>Aspidophoroides bartoni</i> (2002), <i>Podothecus veteris</i> , <i>Pallasina aix</i> (2002)
Microstomiidae	<i>Leuroglossus Schmidt</i> , <i>Lipolagus ochotensis</i>	Cyclopteridae	<i>Aptocyclus ventricosus</i> , <i>Eumicrotremus orbis</i> , <i>E. birulai</i> (2002)
Notosudidae	<i>Scopelosaurus harryi</i>	Liparidae	<i>Liparis gibbus</i> , <i>Liparis</i> spp.
Anopteroideae	<i>Anopterus nikparini</i> (2003)	Stichaeidae	<i>Leptoclinus maculatus</i> , <i>Lumpenus sagitta</i> (2003)
Alepisauridae	<i>Alepisaurus ferox</i> (2002)	Zaproridae	<i>Zaprora silenus</i>
Paralepididae	<i>Lestidium ringens</i> (2003)	Ammodytidae	<i>Ammodytes hexapterus</i>
Myctophidae	<i>Diaphus theta</i> , <i>Stenobrachius leucopsarus</i> , <i>Tarletonbeania crenularis</i>	Anarhichadidae	<i>Anarchichthys ocellatus</i> (2003)
Gadidae	<i>Theragra chalcogramma</i> , <i>Boreogadus saida</i> , <i>Eleginus gracilis</i>	Pleuronectidae	<i>Hippoglossoides robustus</i> , <i>Reinhardtius hippoglossoides</i> , <i>Pleuronectidae</i> gen. sp. (2002), <i>Limanda sakhalinensis</i> (2002)
Scomberesocidae	<i>Cololabis saira</i> (2003)		

Considering only the abundance of all species in the RV *TINRO* catches, our results confirm that the base of upper epipelagic fish communities was composed of about 10 species in autumn 2002–2003 and summer 2003 (Table 2). In autumn 2002, *Stenobrachius leucopsarus* (39.7%), *Theragra chalcogramma* (17.9%), *Oncorhynchus keta* (12.9%), *Pleurogrammus monopterygius* (10.9%), *O. nerka* (7.0%), and *Mallotus villosus* (6.6%) were the dominant species. In autumn 2003, there were no substantial migrations of mezopelagic fish in the upper epipelagic layers, which are usually associated with the characteristics of water dynamics (Radchenko and Ivanov 1997). At the same time, a large transport of pollock fingerlings (694.4 t) from the eastern Bering Sea to Anadirskiy Bay was observed. This is why, in comparison with autumn 2002, the base structure (94%) of dominant species in autumn 2003 had changed to *T. chalcogramma* (49.8%), *O. keta* (18.3%), *M. villosus* (13.7%), *O. nerka* (6.5%), *Leuroglossus schmidtii* (3.8%), and *O. tshawytscha* (1.9%). The abundance of Pacific salmon was very high, and their total biomass was 563.1 t (21.8% of total for all species) in autumn 2002 and 399.1 tons (28.1% of total) in autumn 2003. The biomass of Pacific salmon was mainly composed of immature fish, which were concentrated in deep-water regions. In summer 2003, the biomass of Pacific salmon was large (842.3 t; 77.5% of total for all species). The large biomass of salmon was associated with high intensity inflow of Pacific water into the western Bering Sea in summer 2003, and was also observed from eastern to western parts of the region. During this period, the extremely high biomass of Pacific salmon was composed of both immature and maturing fish. Among Pacific salmon, *O. keta*, *O. nerka*, and *O. gorbuscha* were the dominant species, and *O. tshawytscha* also made up a considerable part of the catch. In summer 2003, the base structure (92.2% of dominant species) was composed of *O. keta* (63.0%), *P. monopterygius* (11%), *O. nerka* (7.8%), *O. tshawytscha* (4.7%), mezopelagic fishes (3.6%, approximately in equal share, *L. schmidtii* and *S. leucopsarus*), and *T. chalcogramma* (2.8%).

According to Temnykh (2004), there has been a considerable increase (2–3 times) in the biomass of Pacific salmon in the western Bering Sea compared to the level of biomass in the 1980s and first half of the 1990s, and this is connected with an increase in the abundance of chum and sockeye salmon. Our investigations proved that in many respects Pacific salmon determined the structure of fish communities of the upper epipelagic layer in the western Bering Sea during autumn 2002 and summer-autumn 2003. The main result of our research was that in the upper epipelagic layer in the western Bering Sea there was a high total abundance of Pacific salmon within a low level of fish productivity, due to the decrease of pollock and Pacific herring resources.

In autumn 2002, for the first time we received data on comparative trawl catching ability during joint epipelagic surveys by Russian, U.S., and Japanese vessels (Tables 3 and 4). A comparative analysis of data on the structure of the catches, according to the results of consistent trawling, revealed a number of problems with the methods used to obtain primary data. We think that the methods used to conduct epipelagic surveys on U.S. and Japanese vessels decrease the scientific and applied value of the data for use in biocenosis investigations. The abundance of nekton, especially mezopelagic species, was greatly underestimated because U.S. and Japanese vessels trawled only during the day time. The trawl used by the *Northwest Explorer* had a small vertical spread that allowed fishing only in the upper 30-m epipelagic layer, which is not deep enough for salmon surveys. The distance between stations during Japanese research vessel surveys was too large (60-nm latitude and almost 100-nm longitude), which allows abundance to be estimated only for widely-spread and major species in the area.

**Table 2.** Composition, biomass ( $\times 10^3$  t) and ratio (%) of fishes (species and group) in the upper epipelagic layer (0–50 m) of the Russian part of the Bering Sea in autumn (August 31–October 10) 2002 and summer (July 15–August 24) and autumn (September 14–October 25) 2003.

Species and group	Autumn 2002		Summer 2003		Autumn 2003	
	Biomass ( $\times 10^3$ t)	%	Biomass ( $\times 10^3$ t)	%	Biomass ( $\times 10^3$ t)	%
<i>Oncorhynchus keta</i>	334.3	12.9	684.5	63	260.1	18.3
<i>O. nerka</i>	180.5	7	84.2	7.8	92.4	6.5
<i>O. gorbuscha</i>	26.1	1	18.8	1.7	15.6	1.1
<i>O. tshawytscha</i>	20	0.8	51.2	4.7	26.7	1.9
<i>O. kisutch</i>	2.2	0.1	3.6	0.3	4.3	0.3
<i>Theragra chalcogramma</i>	464.4	17.9	29.9	2.8	709.9	49.8
<i>Pleurogrammus monopterygius</i>	281.5	10.9	119.6	11.0	14.3	1.0
<i>Mesopelagic fishes</i>	1050.9	40.6	38.9	3.6	71.4	5.0
<i>Mallotus villosus</i>	171.4	6.6	2.7	0.2	195.2	13.7
<i>Clupea pallasii</i>	23.6	0.9	10.2	0.9	10.6	0.7
<i>Lamna ditropis</i>	4.9	0.2	6	0.6	5.7	0.4
Other fishes	27.3	1.1	36.3	3.4	17.9	1.3
Total fishes	2587.1	100	1085.9	100	1424.1	100
Number of trawl operations	78		71		71	

Ratios of the approximate abundance of salmon and juvenile Atka mackerel in catches by U.S., Japanese, and Russian vessels are given in Table 5. At first examination, these ratios could be considered as calibration factors that standardize the amounts of catches on different vessels. These coefficients could be used to correct estimates of the abundance of major species of nekton, when combining the results from all surveys in Bering Sea. However, the total number of operations for calibrating the trawls used by each ship was small, and that is why we consider the total value of the abundance of each species to be an approximate estimate. We need multi-dimensional experiments and a greater number of joint trawl operations to obtain more exact results in the future. In fact, it is very important to define the abundance ratios of all salmon species at different epipelagic depths. A multi-dimensional experiment with catches at different depth levels during a 24-hr period for many days at one station, perhaps, will permit us to obtain data on the vertical distribution of salmon and associated species of nekton.

**Table 3.** Research period and number of joint trawl operations used to compare trawl catches by three vessels in the Bering Sea, September 2002.

Vessels involved in synchronous research	Research period	Number of joint trawl operations
<i>Northwest Explorer</i> & <i>Kaiyo maru</i>	September 12–14	5
<i>TINRO</i> & <i>Northwest Explorer</i>	September 16–17	6
<i>TINRO</i> , <i>Northwest Explorer</i> , & <i>Kaiyo maru</i>	September 15	1

**Table 4.** Ratios of the main parameters of trawling (% by value fit with parameter of RV *TINRO*) for three trawl vessels used for BASIS cruises in September 2002.

Parameter of trawling	<i>Northwest Explorer</i>	<i>Kaiyo maru</i>	<i>TINRO</i>
Towing speed (knots)	89.5	116.8	100.0
Warps length, m	141.7	92.7	100.0
Vertical trawl mouth opening, m	45.9	135.6	100.0
Horizontal trawl mouth opening, m	143.1	158.9	100.0
Volume trawled during towing, km <sup>3</sup>	58.4	251.1	100.0
Square trawled during towing, km <sup>2</sup>	128.5	186.0	100.0

**Table 5.** Ratios of the abundance of salmon (*Oncorhynchus* spp.) and Atka mackerel (*Pleurogrammus monopterygius*) in catches by U.S. (*Northwest Explorer*), Japanese (*Kaiyo maru*), and Russian (*TINRO*) vessels (catches of RV *TINRO* adjusted to 100%). Inds. = number of individuals.

Vessel	Abundance							
	<i>O. keta</i>		<i>O. nerka</i>		<i>O. tshawytscha</i>		<i>Pleurogrammus monopterygius</i>	
	Inds./km <sup>2</sup>	%	Inds./km <sup>2</sup>	%	Inds./km <sup>2</sup>	%	Inds./km <sup>2</sup>	%
<i>NW Explorer</i>	774.0	65	62.0	187	12.0	37	12186	17
<i>Kaiyo maru</i>	1294.0	108	6.0	18	-	-	147333	208
<i>TINRO</i>	1194.0	100	33.0	100	32.0	100	70709	100
<i>NW Explorer</i>	875.0	76	33.0	92	16.5	63	4321	19
<i>TINRO</i>	1145.0	100	36.0	100	26.0	100	22762	100
<i>NW Explorer</i>	337.0	60	11.8	102	13.7	48	2241	15
<i>Kaiyo maru</i>	564.0	100	11.5	100	28.5	100	20609	100

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## Estimates of Diurnal Variation in Pacific Salmon Catch Rates Based on TINRO-Centre Trawl Survey Data

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**Keywords:** Pacific salmon, catch rates, fishing power correction factors, diurnal vertical migrations

To incorporate the survey data of the TINRO-Centre into a single dataset with the data from other scientific institutions, we have to take into account the time at which the sample was obtained. Also in order to estimate species abundance correctly we have to account for possible diel changes in the level of catches. The purpose of this study was to compare the CPUE values for daytime and nighttime trawling based on the original data collected at TINRO-Centre complex epipelagic surveys.

The original CPUE data collected by RV *TINRO*, RV *Professor Kaganovsky*, RV *Professor Kizevetter*, RV *Professor Levanidov*, and RV *Professor Soldatov* during the complex epipelagic surveys conducted in the Bering, Okhotsk and Japan Seas, and adjacent Pacific waters in 1991–2002 were analyzed for daytime and nighttime trawling. All of the epipelagic surveys that contained at least one of the investigated species and size-age groups (juveniles, immature, mature) were considered. Particular emphasis was given to data on Pacific salmon. It is well known (Birman 1985; Shuntov et al. 1993a, 1993b; Ogura 1994) that Pacific salmon reside mostly in the upper 30–50 meters layer, which is effectively fished by the trawls used by TINRO-Centre.

The average values of relative abundance were calculated separately for daytime and nighttime trawling in each area that was surveyed (Bering, Okhotsk and Japan Seas, Pacific Ocean). The ratios of these values (daytime CPUEs/nighttime CPUEs) were estimated as a fishing power correction factors for each species. A similar approach was employed previously when calculating fishing power differences for various trawls (Wilderbuer et al. 1998; von Szalay and Brown 2001).

The Shapiro-Wilk W test showed that CPUEs were not normally distributed. As a consequence, the nonparametric Mann-Whitney U test was used to test for differences in daytime and nighttime CPUEs. Similar statistical procedures were used previously in studies on diurnal variation in salmon catch obtained with drift gillnets (Eriksen and Marshall 1997).

Summary data on relative abundance estimates are presented in Table 1. Special emphasis was given to the results obtained for the first type of trawling selection (headrope depth during the trawling less or equal 25 m, depth at trawling location is more or equal 500 m and segregation of trawling into the daytime and nighttime trawling was done using the NOAA Calculator). The results obtained for the other three types of trawling selections were quite similar and provide additional support of our results.

During the comparison of nighttime and daytime trawling, it was found that, for most of the species studied, the abundance of salmon in the daytime trawling catch was higher compared with nighttime catches (Table 1). Also differences between nighttime and daytime abundance estimates were usually statistically significant (Table 2) for all the species studied (.0+ pink salmon, .0+ chum salmon, n.0+ sockeye salmon, n.0+ coho salmon and n.0+ masu salmon, mature pink and coho salmon) the CPUEs, except for immature Chinook salmon. In general, catches were lower at night than during the day. Also the investigated species appeared less frequently in catches at night than during the day. Some species were caught only during daytime and did not appear in night catches at several sampling sites.

The results obtained from the trawling classification based on mesopelagic fish species presence/absence (the second type of trawlings selection) also showed lower CPUEs at night (Table 1). The results obtained from the third and fourth types of trawling showed that the decrease in the CPUE of Pacific salmon and other investigated species at night was typical of the shelf areas as well (no restrictions on depth at trawling location were imposed during the selection of trawling).

We verified our assumption that the lower nighttime CPUEs values were observed for all the types of trawls used in the surveys. Significant differences were observed between daytime and nighttime catches when the number of sets performed by a given type of trawl was sufficiently large. For the trawl PT/TM 108/528, which was used most frequently, differences between daytime and nighttime catches were significant for most species (Table 2): juvenile pink salmon ( $P = 0.03$ ), mature pink salmon ( $P < 0.005$ ), n.0+ coho salmon ( $P < 0.005$ ), mature coho salmon ( $P < 0.005$ ), n.0+ sockeye salmon ( $P = 0.02$ ). Also, an examination of Figures 1 and 2 showed a clear decrease of CPUEs at nighttime for all types of trawl.

**Table 1.** Ratios of species frequencies between daytime and nighttime trawling (%d/%n) and average values of fishing power correction factors for all the surveys (CPUEd/n).

Species	Size-age group	%d/%n 25-500	%d/%n meso	CPUEd/n 25-500	CPUEd/n meso	CPUEd/n 25-0	CPUEd/n 0-0
<i>O. gorbuscha</i>	.0+	1.0	1.0	1.3	1.6	1.4	1.6
	mature	1.1	1.0	1.7	1.8	2.2	2.2
<i>O. keta</i>	.0+	1.2	1.1	1.7	2.0	1.7	1.8
<i>O. kisutch</i>	n.0+	2.5	2.3	14.6	10.3	7.9	5.1
	mature	2.1	3.4	4.9	8.0	4.1	6.8
<i>O. masou</i>	n.0+	1.6	2.0	2.5	2.6	4.4	2.7
<i>O. nerka</i>	n.0+	2.4	2.7	5.8	4.0	6.7	5.7

Legend. %d/%n<sub>25-500</sub> - ratios of species frequencies between daytime and nighttime trawling (only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used, segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator); %d/%n<sub>meso</sub> - ratios of species frequencies between daytime and nighttime trawling (only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used; trawling that contained mesopelagic fish species were considered nighttime trawling and all others - daytime trawling); CPUEd/n<sub>25-500</sub> - average values of fishing power correction factors for all the surveys (only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used, segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator); CPUEd/n<sub>meso</sub> - only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used, trawling that contained mesopelagic fish species were considered nighttime trawling and all others - daytime trawling; CPUEd/n<sub>25-0</sub> - only trawling with trawl headrope depth < = 25 m were used (no restrictions on depth at trawling location), segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator; CPUEd/n<sub>0-0</sub> - only trawling with trawl headrope depth = 0 m were used (no restrictions on depth at trawling location), segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator.

**Table 2.** Mann-Whitney probabilities of equal day/night CPUEs for the surveys' joint datasets.

Species	Size-age group	P <sub>25-500</sub>	P <sub>meso</sub>	P <sub>25-0</sub>	P <sub>0-0</sub>	P <sub>PT **</sub> 108/528	P <sub>PT **</sub> 80/396
<i>O. gorbuscha</i>	.0+	<b>0.01*</b>	<b>0.00*</b>	<b>0.02*</b>	0.07	<b>0.03*</b>	
	mature	<b>0.00*</b>	<b>0.00*</b>	<b>0.00*</b>	<b>0.00*</b>	<b>0.00*</b>	<b>0.00*</b>
<i>O. keta</i>	.0+	0.29	<b>0.01*</b>	0.90	0.59		
<i>O. kisutch</i>	n.0+	<b>0.00*</b>	0.28	<b>0.00*</b>	<b>0.00*</b>	<b>0.00*</b>	
	mature	<b>0.00*</b>	<b>0.00*</b>	<b>0.00*</b>	<b>0.00*</b>	<b>0.00*</b>	
<i>O. masou</i>	n.0+	0.55	0.28	<b>0.02*</b>	0.08		
<i>O. nerka</i>	n.0+	0.09	<b>0.05*</b>	<b>0.03*</b>	0.08	<b>0.02*</b>	
<i>O. tshawytscha</i>	immature	0.29	0.20	0.17	<b>0.02*</b>		

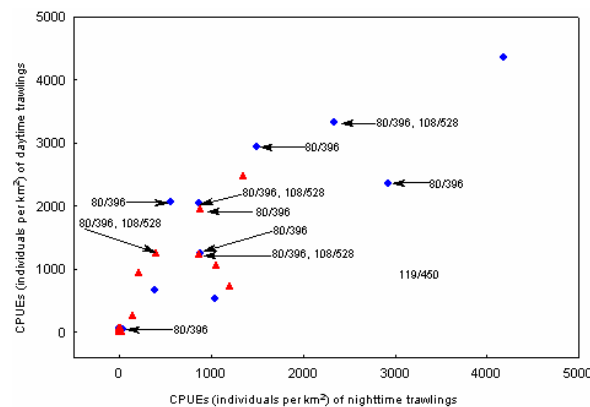
Legend. P < 0.05 are marked by \*; \*\* - only P < 0.05 are provided for these columns (only trawling done by the PT 108/528 and PT 80/396 trawls were used for comparisons); P<sub>25-500</sub> - null-hypothesis probabilities (only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used, segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator); P<sub>meso</sub> - only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used; trawling that contained mesopelagic fish species were considered nighttime trawling and all others - daytime trawling); P<sub>25-0</sub> - only trawling with trawl headrope depth < = 25 m were used (no restrictions on depth at trawling location), segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator; P<sub>0-0</sub> - only trawling with trawl headrope depth = 0 m were used (no restrictions on depth at trawling location), segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator. P = 0.00 designates P < 0.005.

Evidently, the decrease of CPUEs at nighttime is due to the diurnal vertical migrations and behavior of the investigated species. Most likely, the nighttime migration of the investigated species brings them closer to the surface, which results in a higher avoidance of the trawl. We consider that during nighttime the maximum horizontal spread of trawl becomes more distant from the major concentrations of fish. This results in smaller CPUEs. Such explanation agrees quite well with the data from literature on diurnal vertical migrations of Pacific salmon. The decrease of CPUEs at nighttime can not be a result of species migration to the deeper water layers. It has been reported that the average depth used by Pacific salmon species was less for the nighttime period (Ogura and Ishida 1992; Ishida et al. 1998; Wada and Ueno 1999; Walker et al. 2000, 2001; Friedland et al. 2001). On the other hand, chinook salmon do not have any clear tendency to migrate closer to the sea surface during the nighttime and tend to be deeper than the other species (Ogura 1994; Radchenko and Glebov 1998; Murphy and Heard 2001).

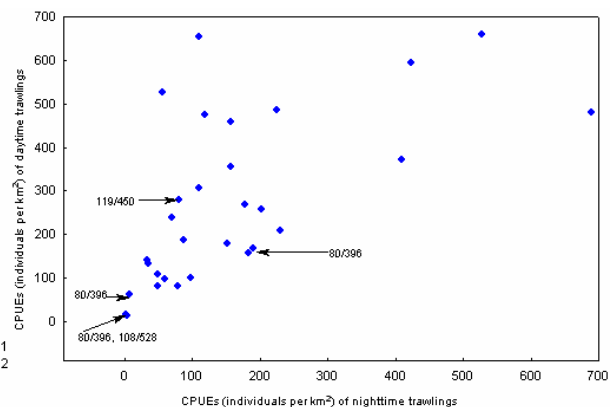
The hydrodynamic plate that is mounted on the headrope and used during the epipelagic trawling at TINRO-Centre surveys creates turbidity at the surface. This may frighten the fish away. Also, the research vessel itself will frighten away fish that are located closer to the surface compared to fish that are deeper.

The results we obtained in this study suggest that there is significant diurnal variation in CPUEs of the investigated species. In the light of this we can conclude that it is necessary to introduce species-specific fishing power correction factors in order to make daytime and nighttime trawling comparable.

**Fig. 1.** Juvenile pink (1) and chum (2) salmon CPUEs (individuals per km<sup>2</sup>) of daytime (vertical axis) and nighttime (horizontal axis) trawling plotted for every survey. Numbers designate the trawl type used for specific surveys (except for the most common trawl - PT 108/528).



**Fig. 2.** Mature pink salmon CPUEs (individuals per km<sup>2</sup>) of daytime (vertical axis) and nighttime (horizontal axis) trawling plotted for every survey. Numbers designate the trawl type used for specific surveys (except for the most common trawl - PT 108/528).



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# Natural Spawning of Chum Salmon in the Toyohira River, Hokkaido

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**Keywords:** Chum salmon, hatchery, spawning, habitat, temperature, run restoration

The Toyohira River runs through Sapporo city, and is a tributary of the Ishikari River, which flows into the Japan Sea. Although wild chum salmon in this river had become extinct in 1950s by urbanization, the people of Sapporo city have stocked hatchery juveniles to restore the run since 1979. The activity is called the “Come Back Salmon Program”. Recently, about 200 thousand juvenile chum salmon are released by the Sapporo Salmon Museum, and thousands of adults spawn naturally in the river. The released juveniles are transplanted from the Chitose River, which is a tributary of the Ishikari River system.

Hatchery programs may change genetic and phenotypic traits of salmonids (Waples 1991). Breeding behavior is also different between hatchery and wild fish (Fleming and Gross 1992). The objective of this study is to clarify information on the spawning habitat of stocked chum salmon in Japan.

From September 2003 to January 2004, a mapping survey of chum salmon redds was carried out semimonthly by walking along the Toyohira River. The number of adult returns was supposed to be twice the number of redds. We defined the early run as the salmon spawning from September to October and the late run as fish reproducing from November to January. Hourly water temperatures in redds and in river water were recorded from late January to mid March 2004. To measure temperature, a standpipe was inserted into the redd as deep as 30 cm, and a data logger (Onset Tidbit) was installed at a depth of 25 cm from the gravel surface.

Adult chum salmon in the Toyohira River returned from September to early in January. The peak of spawning was late in October. Different patterns in the reproduction period were observed between natural spawners and their parents that reproduced artificially. Spawning habitat was different, depending on run timing. The early run fish migrated to upper reaches, but the late run fish stayed in lower reaches. The water temperature in redds of the early run fish was almost same as the river water temperature. On the other hand, late run fish used high temperature areas for spawning. These results indicate that the early fish spawned in areas of the river bed with sub-surface river water seepage, and the late fish made redds where ground water is upwelling.

This difference in spawning habitat is similar to that between summer-run and fall-run chum salmon in wild populations. Thus, there is a possibility that wild chum salmon populations could be recovered by stocking hatchery fish in Japan. To identify whether adult chum salmon in the Toyohira River are of wild or hatchery origin, the adipose fins of all released hatchery fry were clipped starting in 2004.

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## Workshop Review

The Bering-Aleutian Salmon International Survey (BASIS) was “born” in 2000, when then Lieutenant Governor of Alaska Fran Ulmer was President of the North Pacific Anadromous Fish Commission (NPAFC). In fact, it was President Ulmer who proposed that the NPAFC Parties initiate a large-scale collaborative research effort in the Bering Sea to learn the causes of declining abundance of salmon returns to Japan, Russia, and western Alaska. As the “mother” of BASIS, the Organizing Committee’s decision to invite her to present a keynote address at the 2004 BASIS Workshop in Sapporo was very appropriate. Her presentation focused on the reasons why BASIS “is greater than just the sum of its parts”. She stated that with recent publications by the U.S. Commission on Ocean Policy and the Pew Oceans Commission on the status of the world’s oceans, that “the remarkable level of collaboration and cooperation” exhibited by BASIS “is now more than ever” highly pertinent. Understanding changes in the Bering Sea, as well as understanding changes in the rest of the world’s oceans, will require international scientific collaboration. In her concluding remarks, she encouraged workshop participants to educate “policy makers, regulators, fishermen, community leaders, university faculty, foundation and grant giving organizations and media representatives” about BASIS.

The second keynote address by Vyacheslav Shuntov and Olga Temnykh, TINRO-Centre, and presented by Dr. Temnykh discussed the status of Pacific salmon in North Pacific pelagic communities. Dr. Shuntov and his colleagues from the Laboratory of Applied Biocenology at TINRO-Centre have been involved in North Pacific marine ecosystem research for more than 20 years. Drs. Shuntov and Temnykh reviewed scientific data in support of their hypothesis that salmon abundance is currently “below the North Pacific carrying capacity, and that salmon do not overpopulate epipelagic ecosystems”. In spite of changes in various components of the zooplankton community, their research indicates that salmon in the western Bering Sea, especially pink and chum salmon, have fared well over the long term due to their high plasticity of food habits.

Following the keynote addresses, national overviews of BASIS research were presented by Japan, Russia, and the United States. As part of the BASIS Science Plan, synoptic research vessel surveys of the entire Bering Sea were implemented by the national Parties of NPAFC in 2002 by using a Russian vessel to survey the western Bering Sea, a Japanese vessel to survey the central Bering Sea, and U.S. vessels to survey the eastern Bering Sea in summer-fall seasons. Surveys by all three countries are ecosystem studies that include salmon and forage fish, plankton, and oceanographic observations.

Japan has a long history of salmon research on the high seas that started in 1952. Toru Nagasawa, Hokkaido National Fisheries Research Institute, analyzed Japanese salmon research vessel data from 1972-2000 and compared these observations with the results of recent BASIS surveys. An important conclusion from his presentation is that winter and spring surveys need to be added to the BASIS program.

Olga Temnykh reviewed the history of marine salmon investigations by Russia in the western Bering Sea. In the 1970s KamchatNIRO started intensive studies on salmon in estuaries and on the western Bering Sea shelf. In the early 1980s they introduced surface trawling in their research, and in 1986 these studies were expanded into larger ecosystem studies by TINRO-Centre in Vladivostok. Comparative assessments of epipelagic nekton and plankton biomass in relation to abundance of salmon from these earlier studies were contrasted with the results of BASIS surveys.

Jack Helle, Auke Bay Laboratory, provided an overview of U.S. BASIS research. The United States initiated small scale studies on juvenile sockeye salmon in the eastern Bering Sea in 1966–1972. More comprehensive research was begun in 1999 on sockeye salmon in Bristol Bay, and this research was expanded into the BASIS program in 2002 to include all species of Pacific salmon in the eastern Bering Sea. Dr. Helle also provided an update on recent climate change in the Bering Sea ecosystem, and concluded that “the success of BASIS at a time of major ecological change suggests that BASIS should be extended beyond 2006”.

The results of BASIS oceanographic and primary production research were presented by Lisa Eisner (Auke Bay Laboratory), Akira Kusaka (Hokkaido National Fisheries Research Institute), and Gennady Khen (TINRO-Centre). Comprehensive studies include observations on ocean temperature, salinity, currents, stratification, frontal boundaries, nutrients, and phytoplankton and zooplankton biomass and taxonomy. These oceanographic variables

are being monitored for yearly and long-term changes and compared to salmon distribution and abundance. Dr. Kusaka noted there have been few surveys such as BASIS that provide comprehensive hydrographical observations over large areas of the Western Aleutian Basin, and these data can be used “to estimate the thermohaline and flow structures that influence salmon migrations and distributions”. Dr. Khen reported that “BASIS investigations (2002–2003) have coincided with warming and intensification of water exchange between the Pacific and the Bering Sea”—a fact that has important implications for salmon production. Dr. Eisner concluded that in the eastern Bering Sea “the higher temperatures and lack of extensive coccolithophores blooms may have contributed to higher juvenile sockeye salmon survival during 2002 and 2003”.

Food habits of salmon in the Bering Sea have been studied by Japan, Russia, and the United States for many years; and the coordinated research on food habits within BASIS has resulted in a wealth of additional data. Nancy Davis, University of Washington, reviewed the scientific literature (1960–present) on Bering Sea salmon food habits studies, which provide substantial information on salmon prey, diet overlap, ration, and bioenergetics that is useful to BASIS investigators. An important conclusion by Anatoly Volkov, TINRO-Centre, who analysed 2003 BASIS samples collected aboard Russian, Japanese, and U.S. vessels, is that daytime plankton and food habits data are not sufficient to estimate the quantity of many prey species (e.g., euphausiids, mysids and some species of copepod) in the diets of salmon and other nekton. Clearly, more research needs to be done on diel feeding habits, as salmon frequently make deep dives during the day and stay near the surface at night. Are salmon feeding during these deep dives or conserving energy in the colder deep water? Masahide Kaeriyama, Hokkaido Tokai University, recommended “seasonal basin-scale process studies to investigate the effects of climate-induced changes in feeding conditions (especially prey composition and availability) and density-dependent interactions among species, size, age, and maturity groups, and stocks of salmon that migrate between the Bering Sea and Gulf of Alaska”. BASIS is also providing valuable new information on trophic interactions between salmon and other pelagic species. Naoki Tanimata suggested that “more research is needed to better understand the role of northern lampfish (*Stenobrachius leucopsarus*), which is one of the most abundant species in the Bering Sea pelagic ecosystem, especially regarding its role as a potential competitor with salmon”.

One important objective of BASIS research is to gain a better understanding of the distribution and migration patterns of Asian and North American salmon stocks in the Bering Sea, and their relation to the Bering Sea ecosystem. Robert Walker, University of Washington, reviewed new information from archival tagging studies of the depth and temperature distribution of salmon in the Bering Sea. Each salmon species appears to have characteristic patterns of diurnal vertical migration, and as individual fish migrate through different water masses they appear to be “choosing maximum depths and not temperature ranges”. New advances in genetic stock identification techniques are rapidly improving our ability to accurately identify the geographic region or river of origin of salmon caught at sea. Chris Habicht, Alaska Department of Fish and Game, provided significant new information on the migration patterns of sockeye salmon stocks in the Bering Sea, as determined by analysis of 2002–2003 BASIS samples with a DNA (microsatellite and single nucleotide polymorphism) baseline. The results show intermingling of immature Russian and Alaskan sockeye salmon in the western and central Bering Sea in August–October. In addition, Hiroshi Ueda, Hokkaido University, summarized his groundbreaking research results and future projects on mechanisms of homing migration in Japanese chum salmon at sea.

BASIS research on growth and energetics of salmon is improving our ability to detect changes in the Bering Sea ecosystem and to predict the effects of these changes on marine survival and density-dependent growth of salmon. Ed Farley, Auke Bay Laboratory, is using BASIS data to test relationships between early marine growth of juvenile Bristol Bay sockeye salmon, ocean conditions, and subsequent marine survival. He speculated that large body sizes of juvenile sockeye salmon in the southeastern Bering Sea, since the start of BASIS research in 2002, indicate high growth rates and improved or changing ocean conditions, and that “growth of juvenile Pacific salmon may be an excellent indicator of ecosystem change”. Yukimasa Ishida, National Research Institute of Fisheries Science, concluded from a retrospective analysis of Japanese salmon research vessel data (1974–1995) that density is one of the factors influencing growth variations of juvenile and maturing pink salmon in the Bering Sea.

Standardization of BASIS data, sampling gear, and analytical methods is a critical aspect of BASIS research. Terry Beacham, Pacific Biological Station, reviewed progress on the development and testing of a Pacific Rim microsatellite DNA baseline for sockeye salmon, which has “the potential to provide accurate estimates of stock composition to quite local areas”. Jim Murphy, Auke Bay Laboratory, compared two different approaches used to estimate juvenile salmon abundance. His future work “will include selection of an optimal estimator of abundance, refining abundance estimates by freshwater age and stock structure, and comparisons with adult returns”. Vladimir Karpenko, KamchatNIRO, summarized information (1981–present) on the use of trawl methods, which “fulfill

many theoretical and practical tasks associated with management of salmon stocks, including the collection of data on abundance and biological characteristics, annual assessment of distribution, migration, and foraging conditions, forecast information for commercial runs of certain stocks, and assessment of the role of juvenile salmon in coastal ecosystems”.

In addition to the 20 oral presentations reviewed above, there were 27 poster presentations pertaining to various aspects of BASIS or related research on salmon that are included as extended abstracts in this volume.

The workshop concluded with a panel discussion. Questions posed and discussed by panel members included:

1. Are the mission and objectives of BASIS clear? How well do they fit the objectives of the national programs that are currently funding BASIS?
2. What can we do to increase funding for BASIS research from the national Parties of NPAFC or from outside sources?
3. What can we do to improve BASIS research vessel cruise planning and coordination? In particular, NPAFC provides a good forum for these activities, but at present BASIS depends on a small number of people to accomplish a large amount of work.
4. What are the major problems limiting exchanges of BASIS samples and data? Would additional funding help to resolve this matter?
5. Are BASIS researchers publishing their results in the peer-reviewed scientific literature?
6. Who and what is being reported to people who make the decisions to fund research?

These questions resulted in a lively discussion among workshop participants. Policy makers in attendance described their needs for a BASIS report, written by scientists in layman’s terms, which could be used to justify and obtain more funding. In addition, BASIS scientists were encouraged to give the NPAFC’s External Funding Working Group specific proposals that identify needs and set priorities. Fund-raising methods used successfully by other organizations were discussed. It was noted that some organizations hire public relations experts to write science plans and research results in layman’s terms, as well as to print and distribute reports and brochures to potential donors. Collaboration with non-governmental salmon conservation organizations, which have large amounts of funding to synthesize, publish, and distribute data, was suggested as another possible approach.

At the time of this workshop, BASIS scientists were just completing their third season of fieldwork in the Bering Sea. The major objective of holding this BASIS workshop was to provide scientists with an opportunity to meet among themselves to discuss and evaluate their preliminary scientific results, as well as to plan future research collaboration and cooperation. Goals and objectives for future BASIS research proposed during the panel session included:

1. Evaluate interactions of hatchery and wild chum salmon in the eastern and western Bering Sea, including development of a Pacific Rim DNA baseline for chum salmon;
2. Increase oceanographic data collection, especially investigations of diurnal and vertical distribution of zooplankton and the availability and caloric content of salmon prey;
3. Continue collection of BASIS data time series;
4. Increase seasonal sampling (winter and spring);
5. Expand archival and data storage tagging efforts and improve methods of live capture;
6. Continue calibration of BASIS plankton and trawl gear;
7. Develop schemes and models reflecting the place and role of salmon in the trophic structure of the Bering Sea pelagic community and ecosystem;
8. Emphasize ecosystem research on how climate change in the Bering Sea will affect NPAFC nations and their salmon returns.

At the close of the workshop, all participants expressed their gratitude to the local organizing committee and the NPAFC Secretariat staff for their efforts that contributed greatly to the success of this workshop.

John H. (Jack) Helle – *Chair of the BASIS Working Group*  
Loh-Lee Low – *Chair of the Committee on Scientific Research and Statistics*  
Katherine W. Myers – *Member of the Workshop Organizing Committee*



## APPENDIX 1

## List of Participants

<i>Canada:</i>	Beacham, Terry Beamish, Richard Jones, Russ Kristianson, Gerry Young, Tim	<i>Russia:</i>	Akinicheva, Elena Antonov, Nickolay Gritsenko, Oleg Ivanchenko, Victor Ivanov, Oleg Kae, Alexander Karpenko, Vladimir Khen, Gennady Klovatch, Natalia Lapko, Victor Melnikov, Igor Temnykh, Olga Varnavskaya, Natalia Volkov, Anatoly Volvenko, Igor
<i>Japan:</i>	Abe, Syuiti Ando, Daisei Asami, Hiroki Azumaya, Tomonori Ban, Masatoshi Edpalina, Rizalita Hasegawa, Ei-ichi Hino, Hiroshi Ishida, Yukimasa Ito, Jun Jodo, Aya Kaeriyama, Masahide Kanno, Michiyo Kawana, Morihiko Kusaka, Akira Maekawa, Koji Mayama, Hiroshi Moriya, Shogo Nagasawa, Toru Nagata, Mitsuhiro Nakata, Akifumi Nomura, Tetsuichi Ogawa, Yoshihide Onuma, Takeshi Sakai, Osamu Tanaka, Hideji Tanimata, Naoki Saito, Toshihiko Sato, Shunpei Seki, Jiro Suzuki, Toshiya Ueda, Hiroshi Urano, Akihisa Urawa, Shigehiko Yamamoto, Yuza	<i>United States:</i>	Agler, Bev Augerot, Xanthippe Austerman, Alan Backus, Edward Davis, Jack Davis, Nancy Eggers, Douglas Eisner, Lisa Farley, Edward Gillis, Karen Habicht, Chris Hagen, Peter Helle, Jack Heard, William Low, Loh-Lee Murphy, Jim Myers, John Myers, Kate Niemeier, Paul Pattillo, Patrick Seeb, Jim Sproul, John Stark, Thomas Ulmer, Fran Volk, Eric Walker, Trey White, John Wilmot, Richard Zimmerman, Chris
<i>Korea:</i>	Kang, Sukyung Park, Jung Youn Yoon, Moon-Geun	<i>NPAFC Secretariat:</i>	Fedorenko, Vladimir Morris, Wakako Uoya, Toshinori



