

*NORTH
PACIFIC
ANADROMOUS
FISH
COMMISSION*



TECHNICAL REPORT 8

International Workshop on *Explanations for the High Abundance of Pink and Chum Salmon and Future Trends*

Technical Editors: Nancy D. Davis and Claudia Chan

Vancouver, Canada

International Workshop on *Explanation for the High Abundance of Pink and Chum Salmon and Future*

Nanaimo, British Columbia, Canada, October 30-31, 2011

ORGANIZING COMMITTEE

Richard J. Beamish (Chairperson): Pacific Biological Station, Fisheries and Oceans Canada

Alexander Bugaev: Kamchatka Fishery and Oceanography Research Institute, Russia

Sanae Chiba: Japan Agency for Marine-Earth Science and Technology, Japan

William Crawford: Institute of Ocean Sciences, Fisheries and Oceans Canada

Edward V. Farley, Jr.: Ted Stevens Marine Research Institute, National Marine Fisheries Service, U.S.A.

Toru Nagasawa: Hokkaido National Fisheries Research Institute, Fisheries Research Agency, Japan

Ki Baik Seong: National Fisheries Research and Development Institute, Korea

Nancy Davis: NPAFC Secretariat

NPAFC Secretariat

Vladimir Fedorenko, Executive Director

Nancy Davis, Deputy Director

Wakako Morris, Administrative Officer

Claudia Chan, Secretary

*NORTH
PACIFIC
ANADROMOUS
FISH
COMMISSION*



TECHNICAL REPORT 8

International Workshop on *Explanations for the High Abundance of Pink and Chum Salmon and Future Trends*

Nanaimo, British Columbia, Canada, October 30-31, 2011

Technical Editors: Nancy D. Davis and Claudia Chan

Published by: North Pacific Anadromous Fish Commission
Suite 502, 889 West Pender Street
Vancouver, B.C., V6C 3B2
Canada

Tel: (604) 775-5550
Fax: (604) 775-5577
E-mail: secretariat@npafc.org
Website: <http://www.npafc.org>

Preface

Total commercial catches of Pacific salmon (*Oncorhynchus* spp.) in the Subarctic North Pacific are at historic high levels, with recent catches over one million tonnes. High catches were caused by an increase of pink and chum salmon production, which represented over 80% of the total catch. At the same time Chinook, coho, and masu salmon have been decreasing in abundance. These trends in Pacific salmon catches are generally recognized to result from processes within the ocean that appear to improve the capacity to produce pink and chum salmon, perhaps decrease the capacity to produce Chinook and coho salmon, and contribute to recent extreme variability in sockeye salmon production. Understanding how future trends in ocean production capacity will change is important for hatchery programs, salmon industry, fishery managers, and conservation plans.

To identify what is known about the reasons for recent production trends and to identify future research needs, the North Pacific Anadromous Fish Commission (NPAFC) hosted an international workshop titled, “Explanations for the High Abundance of Pink and Chum Salmon and Future Trends”, on October 30-31, 2011, at the Vancouver Island Conference Centre in Nanaimo, BC, Canada.

Workshop objectives included the following:

- identify production trends of pink and chum salmon by region;
- identify reasons for high production of pink and chum salmon (and low production of other salmon species);
- predict future production of pink and chum salmon; and
- identify key areas of future research.

Over 100 international experts, scientists, fisheries officials, and industry representatives attended the workshop. Workshop participants presented 31 oral presentations and 18 posters on topics including trends of pink and chum salmon production by region; hatchery production; migration and distribution patterns during the marine life history; feeding, growth, and survival strategies; ecological capacity of the ocean to produce wild and hatchery pink and chum salmon; prediction and management of Pacific salmon production in a changing climate; and future research.

The workshop was co-sponsored by organizations concerned with salmon fisheries, conservation, and understanding North Pacific ecosystems. The NPAFC thanks these organizations for their strong support for the workshop.

Bering Sea Fishermen’s Association
 Fisheries and Oceans Canada
 North Pacific Marine Science Organization
 North Pacific Research Board

Pacific Fisheries Resource Conservation Council
 Pacific Salmon Foundation
 State of the Salmon

The workshop Organizing Committee consisted of Richard Beamish (chairperson), Aleksander Bugaev, Sanae Chiba, William Crawford, Nancy Davis, Edward Farley, Jr., Toru Nagasawa, and Ki Baik Seong. Dawn Steele was the note-taker during the workshop and her notes provided the basis for the workshop synopsis. Lana Fitzpatrick and Cheryl Ross (Pacific Biological Station), Lauren Fegan, Dan Fox, Peter Greene, Michael Friesen, and Kristy Todd (Vancouver Island University) are acknowledged for their assistance.

The following workshop panelists led discussions during the meeting.

Beverly Agler	William Heard	Kentaro Morita	Olga Temnykh
Richard Beamish	Masahide Kaeriyama	Toru Nagasawa	Shigehiko Urawa
Alexander Bugaev	Alexander Kaev	Joseph Orsi	Laurie Weitkamp
Sanae Chiba	Yury Khokhlov	Randall Peterman	Alex Wertheimer
William Crawford	Suam Kim	Vladimir Radchenko	
Edward Farley	Maxim Koval	Greg Ruggerone	

This technical report is a compilation of extended abstracts submitted by participants who made workshop presentations and concludes with a workshop synopsis. Material presented in this report has not been peer-reviewed and does not necessarily reflect the views of the NPAFC, the member countries, or agencies. Some investigations included here are preliminary. Abstracts have been edited for clarity and publication purposes. The technical report was reviewed and approved by an editorial committee that included Edward Farley, Jr., James Irvine, Jin Yeong Kim, Toru Nagasawa, and Vladimir Radchenko.

Nancy D. Davis
Deputy Director, NPAFC

Contents

Preface	i
Contents	ii
Extended Abstracts	
Topic 1: Trends of Pink and Chum Salmon Production by Region	
Observations and Speculations on the Reasons for Recent Increases in Pink Salmon Production <i>Richard J. Beamish</i>	1
Why Are Pink and Chum Salmon at Such High Abundance Levels in the Gulf of Alaska? <i>William R. Heard and Alex C. Wertheimer</i>	9
Temporal Patterns for Odd- and Even-Year Pink Salmon Conservation Units in British Columbia and Puget Sound (Washington State) <i>James R. Irvine, Catherine Michielsens, Bruce White, Pieter Van Will, and Michael O'Brien</i>	13
Abundance Dynamics of Pink Salmon, <i>Oncorhynchus gorbuscha</i> , as a Structured Process Determined by Many Factors <i>Vladimir I. Radchenko</i>	14
Trophic Link Between <i>Neocalanus</i> Copepods and Pink Salmon in the Western Subarctic North Pacific Based on Long-Term Nitrogen Stable Isotope Analysis <i>Sanae Chiba, Hiroya Sugisaki, Kazuaki Tadokoro, and Toru Nagasawa</i>	19
Production Trends of Pink Salmon in the Sakhalin-Kuril Region from the Viewpoint of Run Timing <i>Alexander M. Kaev</i>	21
Trends of Chum and Pink Salmon Production in Chukotka <i>Yury N. Khokhlov</i>	26
Fluctuation of Japanese Chum Salmon Returning Rate Related to Sea Surface Temperatures Along the Spawning Migration Route <i>Toru Nagasawa and Tomonori Azumaya</i>	28
Recent Patterns in Return Rate of Chum Salmon to Different Regions of Hokkaido <i>Yasuyuki Miyakoshi and Mitsuhiro Nagata</i>	29
Relationship Between Environmental Variability and Chum Salmon Production at the Southern Limit of Distribution in Asia <i>Suam Kim, Hyunju Seo, and Sukyung Kang</i>	32
An Assessment of the State of Chum Salmon Stocks From the East and West Coasts of Kamchatka <i>Lidia O. Zavarina</i>	35
Cyclic Fluctuations in Chum Salmon Abundance along the Pacific Coast of Hokkaido, Japan <i>Toshihiko Saito, Kyuji Watanabe, Kei Sasaki, Shigeto Kogarumai, and Shoko H. Morita</i>	36
Natural Reproduction of Pink Salmon (<i>Oncorhynchus gorbuscha</i>) on the Okhotsk coast of Hokkaido, Japan <i>Masaya Iida, Tsuyoshi Kato, and Hiroshi Tokuda</i>	38

Trends in Harvest and Escapement for Southeast Alaska Pink and Chum Salmon Stocks
Andrew W. Piston and Steven C. Heinl41

Topic 2: Hatchery Production

Salmon Culture Based on Preservation of Biological and Ecological Conditions of Aquatic Communities
Boris P. Safronenkov and Vladimir V. Volobuev42

Genetic Variation Between Collections of Hatchery and Wild Masu Salmon Inferred From Mitochondrial and Microsatellite DNA Analyses
Jeong-Nam Yu, Noriko Azuma, and Syuichi Abe46

Topic 3: Migration and Distribution Patterns During the Life History

Improved Genetic Stock Identification of Chum Salmon Through the PacSNP Collaboration
William D. Templin, Chris Habicht, Lisa W. Seeb, Shunpei Sato, Syuichi Abe, Kenneth Warheit, Jun Youn Park, and James E. Seeb49

Stock-Specific Summertime Distribution of Immature Chum Salmon in the Bering Sea as Inferred from SNP Markers
Shunpei Sato, Masahiro Kato, Kentaro Morita, and Shigehiko Urawa50

Status of Hatchery-Origin Chum Salmon in the Bering Sea Deduced From Otolith Mark Recoveries
Shigehiko Urawa, Shunpei Sato, Masaya Takahashi, and Toshihiko Saito52

Early Marine Residence of Juvenile Pink and Chum Salmon in the Northern California Current: Life at the Southern End of the Range
Laurie A. Weitkamp, Elizabeth A. Daly, and Joseph P. Fisher54

Distribution and Abundance of Juvenile Chum Salmon (*Oncorhynchus keta*) in Nemuro Bay, Eastern Hokkaido, Japan
Kiyoshi Kasugai, Mitsuru Torao, Hiroshi Kakizaki, Hiroshi Adachi, Hiromi Shinhama, Yutaka Ogasawara, Shinji Kawahara, Tsutomu Arauchi, and Mitsuhiro Nagata58

Polymorphism of Mitochondrial DNA (mtDNA) of the Cytb/D-loop Region in Pink Salmon Populations
Nina Yu. Shpigalskaya, Vladimir A. Brykov, Andrey D. Kukhlevsky, and Anna A. Chetvertak62

Identification of Pink Salmon Mixed-Stock Aggregations on the Basis of Mitochondrial DNA Polymorphism
Nina Yu. Shpigalskaya, Vladimir A. Brykov, Andrey D. Kukhlevsky, and Evgeny A. Shevlyakov64

Comparison of Even- and Odd-Year Broodlines of Pink Salmon Using Genotyping by Sequencing
Lisa W. Seeb, Ryan K. Waples, and James E. Seeb66

Differentiation of Local Pink Salmon Stocks on the Basis of Variations in Their Scale Structure
Vladimir A. Savin, Roman A. Shaporev, Ekaterina V. Savenkova, and Natalya V. Varnavskaya67

Assessing the Use of Otolith Microstructure for Identification of Regional Stock Complexes of Juvenile Chum Salmon
Alexandra I. Chistyakova, Roman A. Shaporev, and Natalya V. Varnavskaya71

Topic 4: Feeding, Growth, and Survival Strategies

Thermal Habitats of Pacific Salmon: Does Climate Change Benefit Pink and Chum Salmon?
Kentaro Morita74

Changes in Size, Age, and Intra-Annual Growth of Anadyr Chum Salmon (<i>Oncorhynchus keta</i>) from 1962 to 2010 <i>Alexander V. Zavolokin, Vladimir V. Kulik, and Yury N. Khokhlov</i>	76
Body Size Variation of Juvenile Chum Salmon Collected From Three Coastal Areas of Hokkaido, Northern Japan <i>Koh Hasegawa, Tomoki Sato, and Kei Sasaki</i>	81
Feeding Strategies and Trends of Pink and Chum Salmon Growth in the Marine Waters of Kamchatka <i>Vladimir I. Karpenko and Maxim V. Koval</i>	82
Lipid Content of Immature Chum Salmon (<i>Oncorhynchus keta</i>) Affected by Pink Salmon (<i>O. gorbuscha</i>) Abundance in the Central Bering Sea <i>Toshiki Kaga, Shunpei Sato, Tomonori Azumaya, Nancy D. Davis, and Masa-aki Fukuwaka</i>	87
Spatial Variability in Lipid Content and Fatty Acid Profiles of Macrozooplankton From Coastal British Columbia, Canada <i>Daniel P. Bevan, John F. Dower, Marc Trudel, and Asit Mazumder</i>	88
Food Supply of Pacific Salmon During Their Marine Period of Life in the North Pacific in 1980–2011 <i>Svetlana Naydenko</i>	89
Topic 5: Ecological Capacity of the Ocean to Produce Wild and Hatchery Pink and Chum Salmon	
Evidence for Bottom-Up Effects on Pink and Chum Salmon Abundance and the Consequences for Other Salmon Species <i>Gregory T. Ruggerone, Katherine W. Myers, Beverly A. Agler, and Jennifer L. Nielsen</i>	94
The Need for International Cooperation to Reduce Competition Among Salmon for a Common Pool of Prey Resources in the North Pacific Ocean <i>Randall M. Peterman, Carrie A. Holt, and Murray R. Rutherford</i>	99
Do Asian Pink Salmon Affect the Survival of Bristol Bay Sockeye Salmon? <i>Alex Wertheimer and Edward V. Farley, Jr.</i>	102
Historical Scale Growth of Bristol Bay and Yukon River, Alaska, Chum Salmon (<i>Oncorhynchus keta</i>) in Relationship to Climate and Inter- and Intra-Specific Competition <i>Beverly A. Agler, Gregory T. Ruggerone, and Lorna I. Wilson</i>	108
Density-dependent Growth of Salmon in the North Pacific Ocean: Implications of a Limited, Climatically Varying Carrying Capacity for Fisheries Management and International Governance <i>Gladys Oka, Carrie Holt, James R. Irvine, and Marc Trudel</i>	112
Topic 6: Prediction and Management of Pacific Salmon Production in a Changing Climate	
Recent Production Trends of Chum Salmon <i>Oncorhynchus keta</i> Under Conditions of Warming Climate <i>Yuxue Qin and Masahide Kaeriyama</i>	113
Ecosystem Approach for Management of Artificial Release of Chum Salmon from Japan Based on a Bioenergetic Model Coupled with NEMURO <i>Michio J. Kishi, Kenta Awa, Takeshi Miwa, Hiromichi Ueno, and Toru Nagasawa</i>	117
Forecast and Production Dynamics of the Pink Salmon of Kamchatka <i>Evgeny A. Shevlyakov and Maxim V. Koval</i>	121

The Association of Long-Term Changes in West Kamchatka Pink Salmon Catches with Climate Regime Shifts in the Northern Hemisphere
Andrei S. Krovnin and Nataliya V. Klovach 126

Recent Harvest Trends of Pink and Chum Salmon in Southeast Alaska: Can Marine Ecosystem Indicators Be Used as Predictive Tools for Management?
Joseph A. Orsi, Emily A. Fergusson, and Molly V. Sturdevant 130

Why Did the Chum Cross the Road? Genetics and Life History of Chum Salmon in the Southern Portion of Their Range
Orlay Johnson, Anna Elz, Jeffrey Hard, and David Stewart 135

Estimation of the Influence of Some Climatic Factors on the Abundance of Asian Pink and Chum Salmon
Alexander V. Bugaev and Oleg B. Tepnin 138

Cyclic Climate Changes and Production of Pacific Salmon: The Possibility of Forecasting
Leonid Klyashtorin and Natalia Klovach 142

Evaluation of the Habitat for Downstream Migration of Chum Salmon in the Wusuli River Using a Suitability Index
Wei Liu, Pei-Rong Zhan, Ji-Long Wang, and Xiong-Wei Liang..... 143

Transfer of Marine-Derived Nutrients by Pink Salmon (*Oncorhynchus gorbuscha*) to Terrestrial Ecosystems in the Shiretoko World Natural Heritage Area, Japan
Yosuke Koshino, Hideaki Kudo, and Masahide Kaeriyama 147

Wrap-Up Presentation Given at the Conclusion of the Workshop
James Balsiger 150

Workshop Synopsis
Nancy D. Davis and Richard J. Beamish..... 152

List of Participants 159

Observations and Speculations on the Reasons for Recent Increases in Pink Salmon Production

Richard J. Beamish

*Emeritus Scientist, Pacific Biological Station, Fisheries and Oceans Canada,
3190 Hammond Bay Road, Nanaimo, BC V9T 6N7, Canada*

Keywords: pink salmon, Strait of Georgia, Fraser River, intercirculi spacing, growth, life history strategy

“I for one am ready to give up research for a unique cause of dominance and concentrate rather on identifying which cause or causes operate on each individual stock” (Ricker 1962). This statement by one of the world’s foremost fisheries scientists summarizes the difficulty that researchers have understanding the biology and population dynamics of pink salmon. Made almost 50 years ago, the statement is mostly still true today.

This workshop brings experts together to discuss why pink salmon throughout their distribution are either increasing in abundance or are at least not declining in abundance as are some other species of Pacific salmon. Bill Ricker’s thoughts identify the complexity of understanding the dynamics of pink salmon production. Thus, we are encouraging participants to think differently and to speculate, an exercise that is usually frowned upon by reviewers and editors. I will present information that was not published, mostly because it did not show much. However, I will speculate that what it does not show is the message.

Catches of Pacific salmon throughout the subarctic Pacific have increased in the past two decades with historic high catches in 1995, 2007 and 2009. The percentages of pink and chum salmon in these catches is 80%; with pink, chum, and sockeye salmon representing 96%. Since 1993, pink salmon represented 43% of the total catch and chum salmon 37%. There has been a dramatic increasing trend in the catches of pink salmon that spawn in odd-numbered years (odd-year pink salmon) but no apparent trend in the catch of even-year pink salmon (Fig. 1). In this paper, I look at the dynamics of pink salmon that enter the Strait of Georgia from the Fraser River and return as adults in the following year along with information on the population dynamics of pink salmon from the central coast area of British Columbia to speculate on why pink salmon are increasing in abundance and why one line of pink salmon is increasing and the other line is not.

Methods

The trawl and the structure of the juvenile Pacific salmon surveys are described in Beamish et al. (2000) and Sweeting et al. (2003). Juvenile pink salmon were caught in the top 30 m and mostly in the upper 15 m. All sets were 30 min, but catches may be standardized to 1 hr and identified as catch per unit effort or CPUE. Pink salmon spawn in the Fraser River in odd-numbered years with the juveniles entering the Strait of Georgia in even-numbered years. Almost all juvenile pink salmon in the Strait of Georgia originate in the Fraser River resulting in very few juveniles in the strait in odd-numbered years. The abundance of pink salmon fry leaving the Fraser River are estimated at Mission, approximately 100 km upstream from the mouth of the river using a trap (Vernon 1966; Grant and Pestal 2009).

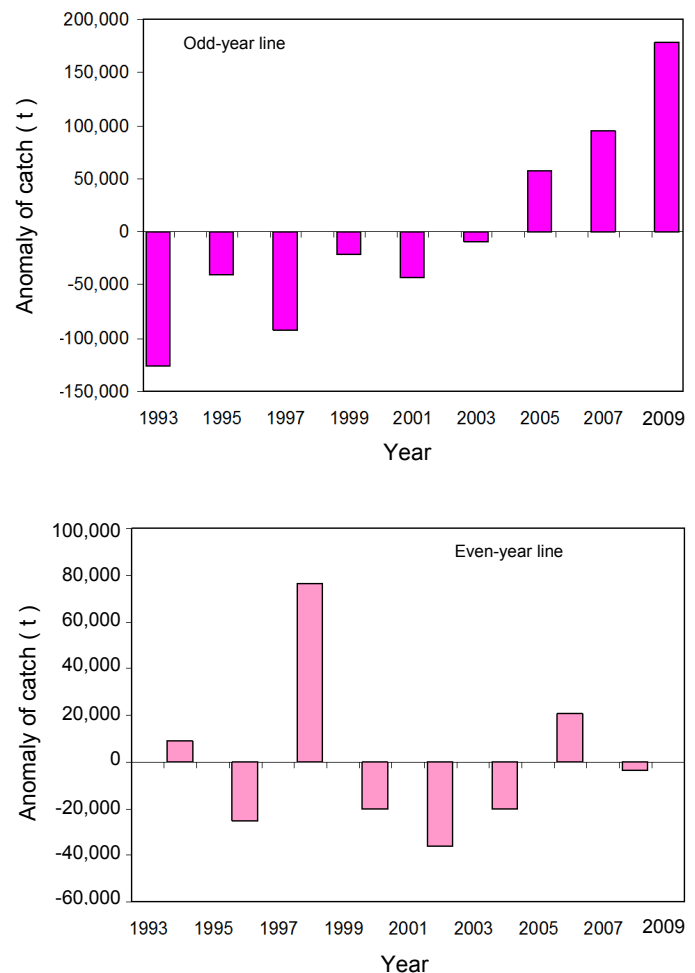


Fig. 1. Trends in the total catch by all countries of odd- and even-year pink salmon since 1993 shown as an anomaly. Data available at http://www.npafc.org/new/science_statistics.html

Scales were sampled from juvenile pink salmon caught in an area north of the Strait of Georgia (Beamish et al. 2006). Juvenile pink salmon were captured in a purse seine or beach seine. Scales from adult pink salmon were taken from fish in the Glendale River in August (Beamish et al. 2011; Jones and Beamish 2011). All scales were sampled from an area below the dorsal fin and just above the lateral line.

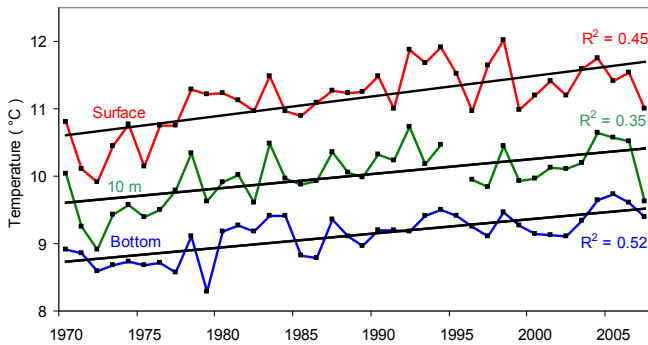


Fig. 2a. Average annual temperature in the Strait of Georgia measured at a site approximately in the middle of the strait.

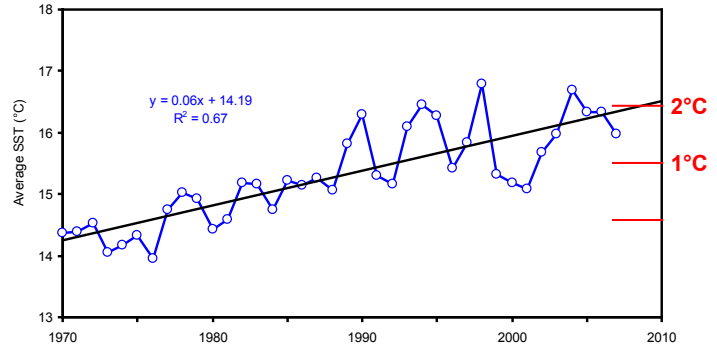


Fig. 2b. Average sea surface temperature from May to September collected at the same site in the Strait of Georgia as the data shown in Fig. 2a.

Background

The Strait of Georgia is warming, having increased about 1°C in the past 40 years and almost 2°C if only the surface waters during the early marine rearing period of juvenile Pacific salmon are considered (Fig. 2a, b). There also has been a trend toward earlier flows into the Strait of Georgia from the Fraser River (Fig. 3a, b). A cumulative sum analysis (Murdoch 1979; Noakes and Campbell 1992) indicates that the trend towards earlier flow from the Fraser River started about the mid 1980s (Fig. 3b). The changing flow pattern and the increasing temperature indicate it is likely that conditions experienced by juvenile pink salmon during the early marine period in the Strait of Georgia are also changing.

The total returns of pink salmon produced in the Fraser River increased after the 1977 regime shift, declined after the

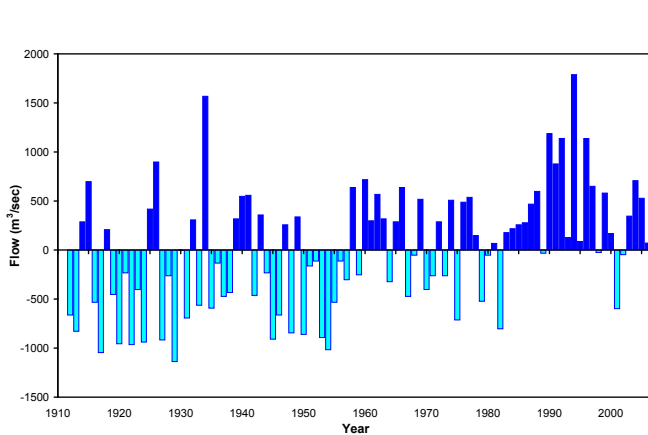


Fig. 3a. The anomaly of Fraser River flows in April from 1912 to 2005.

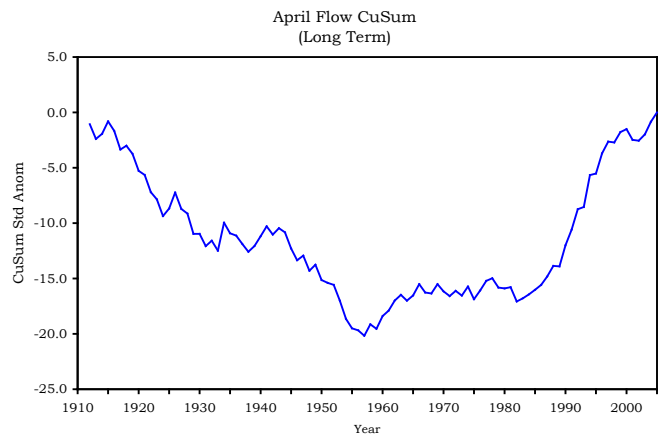


Fig. 3b. The cumulative sum (CuSum) of the Fraser River flow in April from 1912 to 2005. The CuSum analysis shows a declining flow from 1912 to the late 1950s, an average flow until the mid 1980s, and an increasing flow from the mid 1980s to the present.

1989 regime shift, and increased again after the 1998 regime shift (Fig. 4). In 2002, procedures for estimating escapements were abandoned, making an estimate of total returns problematic. Consequently, the estimates of the large returns in 2009 and 2011 could be larger. Despite the problems with total production estimates since 2002, there is agreement that production of pink salmon is currently at very high levels. The escapement to the Fraser River also increased over the period that total returns increased (Fig. 5). Estimates of pink salmon fry leaving the Fraser River also increased after the 1977 regime shift and again beginning in 2002 (Fig. 6). At the same time, exploitation rates decreased gradually until 1997 when they dropped abruptly to very low levels (Fig. 7; Grant and Pestal 2009).

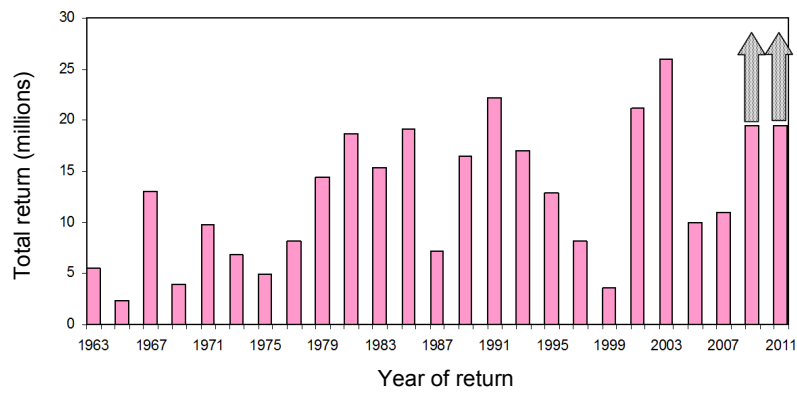


Fig. 4. Total returns of pink salmon to the Fraser River from 1963 to 2011. Arrows for 2009 and 2011 indicate that the true total could be larger.

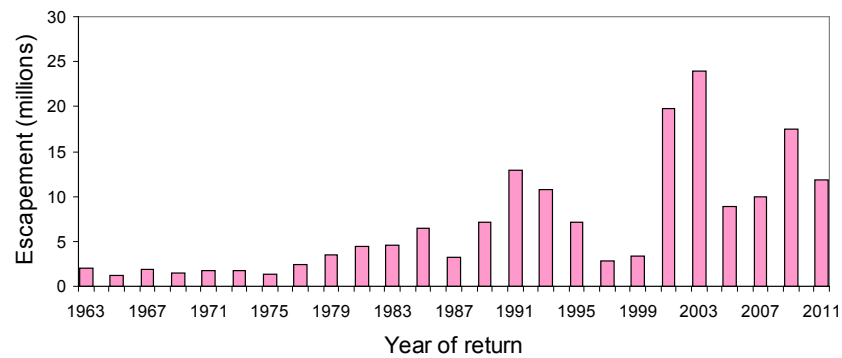


Fig. 5. Total escapement of pink salmon to the Fraser River from 1963 to 2011.

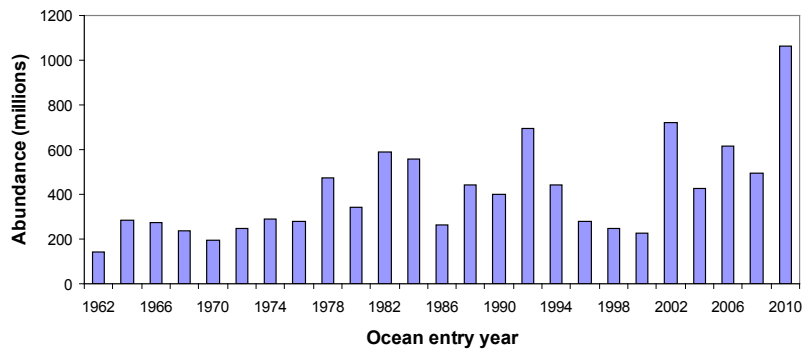


Fig. 6. Abundance estimate of Fraser River pink salmon fry at a trap located at Mission, approximately 100 km upriver from the mouth of the river.

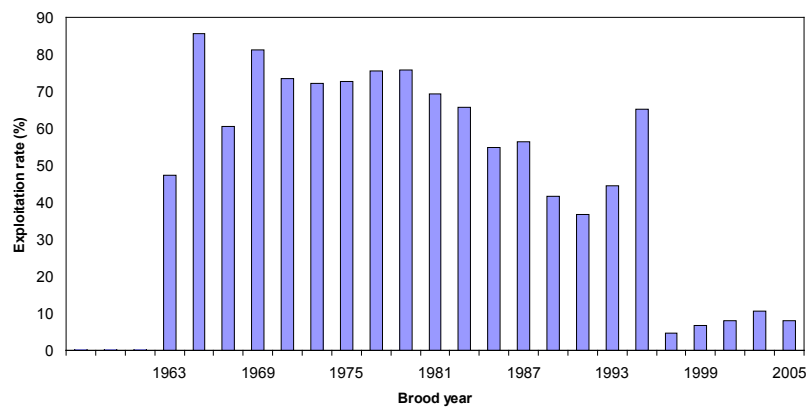


Fig. 7. Exploitation rate of pink salmon produced in the Fraser River from 1963 to 2005.

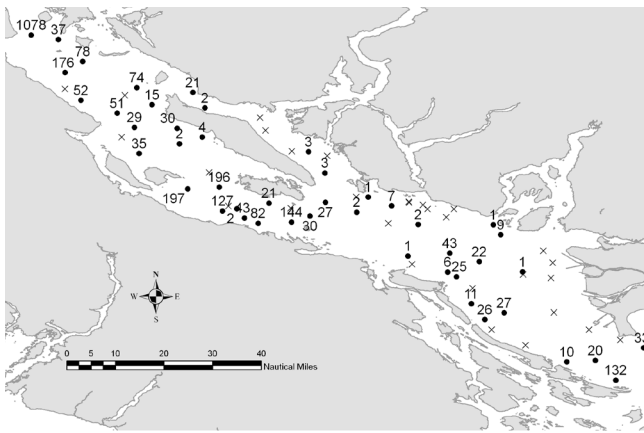


Fig. 8a. Number of juvenile pink salmon caught in the Strait of Georgia in July 2008 in a 30-min set.

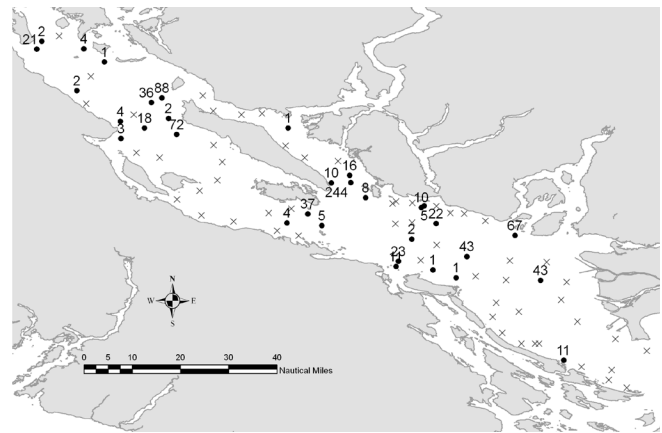


Fig. 8b. Number of juvenile pink salmon caught in the Strait of Georgia in September 2008 in a 30-min set.

Results and Discussion

Juvenile pink salmon were caught throughout the Strait of Georgia in July in even-numbered years as shown for 2008 (Fig. 8a, b). Juvenile pink salmon remained in the Strait of Georgia through to September, but the CPUE was diminished (Fig. 9). There was no relationship between the number of fry leaving the Fraser River and the CPUE in July (Fig. 10), except for 2010 when there was a very large abundance of fry and a very large CPUE. There also was no relationship between the survey CPUE and the total returns in the following year (Fig. 11). The average length of juvenile pink salmon in the July and September surveys also was not related to total return (Fig. 12). The average lengths of pink salmon in the July trawl surveys are longer than average lengths reported by Phillips and Barraclough (1978) and others, indicating that the fry may be finding more prey now than in the past. Therefore, there was no indication that the abundance or size of the juvenile pink salmon in the Strait of Georgia was related to the total return.

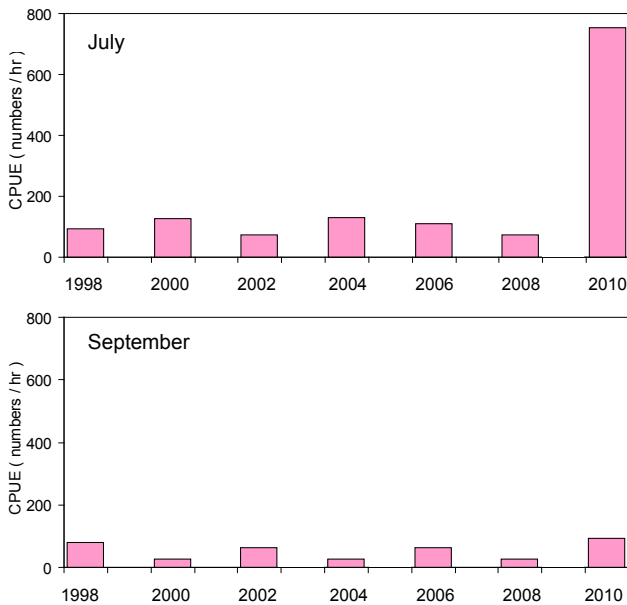


Fig. 9. Catch per unit effort (CPUE) of pink salmon in the Strait of Georgia for July and September, 1998-2010.

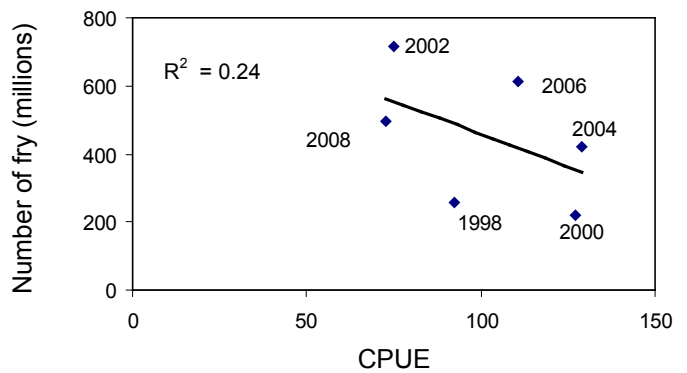


Fig. 10. Number of pink salmon fry moving downstream in the Fraser River compared to CPUE in the Strait of Georgia July trawl survey, 1998-2008.

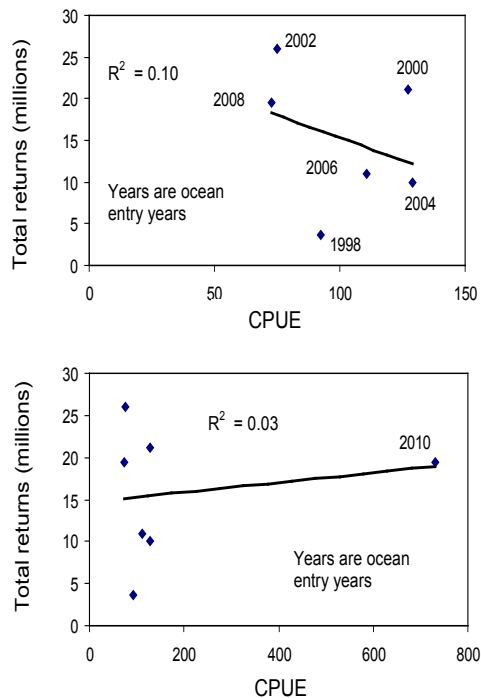


Fig. 11. Total return of pink salmon to the Fraser River compared to CPUE in the Strait of Georgia trawl survey in July (top panel) and including the estimate for the return year of 2011 and ocean entry year of 2010 (bottom panel).

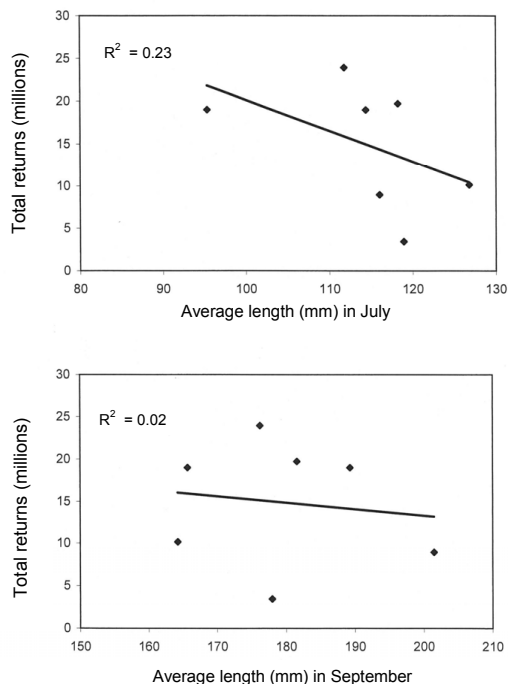


Fig. 12. Comparison of the total return of pink salmon to the Fraser River and the average length of the juveniles in the Strait of Georgia trawl surveys in July (top panel) and September (bottom panel).

Beamish et al. (2004) showed that there is a weak stock and recruitment relationship for pink salmon from the Fraser River. The relationship strengthened and changed significantly when estimated by regimes (Fig. 13). This indicated that large-scale atmospheric processes affected the productivity of pink salmon from the Fraser River. The existence of a weak stock-recruitment relationship also identified an association between the number of spawning females and total returns. This relationship also exists between the counts of fry for all years and total return (Fig. 14). It appeared, therefore, that pink salmon production in Fraser River populations was related to the number of spawning females, but the variability of the relationship was affected by ocean conditions outside of the Strait of Georgia and by large-scale climatic trends. Thus, the increasing production of pink salmon from the Fraser River since the late 1970s would result from improved fry production and improved ocean conditions both inside and outside of the Strait of Georgia. The increased escapements in the last decade would produce even larger abundances of fry.

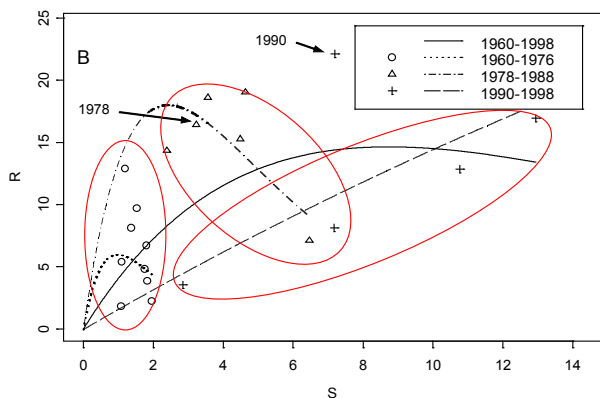


Fig. 13. Overall and regime-dependent relationships between stock (S) and recruitment (R) for pink salmon. From Beamish et al. (2004). Circled areas contain data for specific regimes.

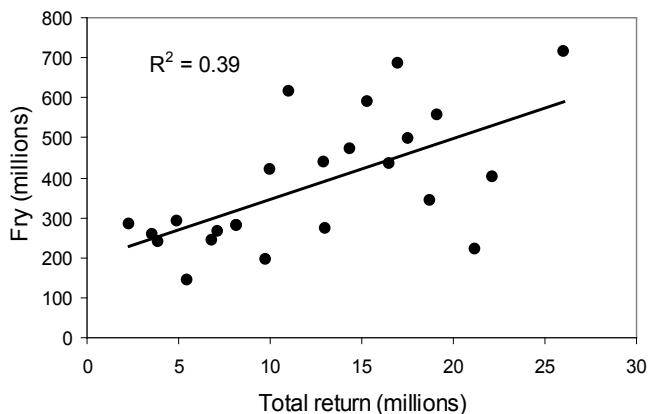


Fig. 14. Relationship between downstream counts of pink salmon fry at the trap at Mission and the total return of adults to the Fraser River one year later, 1962-2008.

The study of the intercirculi spaces of pink salmon scales collected from an area north of the Strait of Georgia on the east side of Queen Charlotte Strait used samples collected from juveniles in 2003 and 2005 and from adults in 2004 and 2006. In 2003, a sample of 134 juveniles had an average intercirculi spacing for the first five circuli that was not different than the spacing measured in the adults returning in the next year in 2004 (Fig. 15). However, when the study was repeated in 2005 and 2006, the returning adults in 2006 had significantly larger average intercirculi spacing than observed for juveniles in the previous year and for juveniles in 2003 (t -test, $p < 0.001$; Fig. 15). In 2003 and 2004, the adult return was approximately

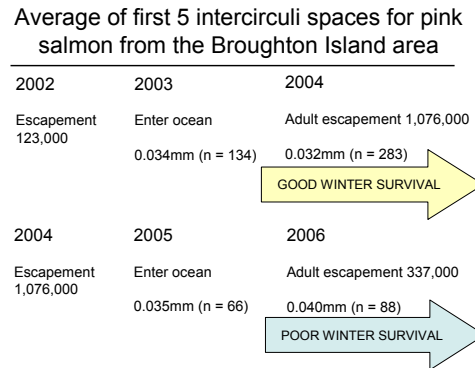


Fig. 15. The average intercirculi spacing of the first five circuli on pink salmon scales of returning adults is larger in years when total survival is poor.

nine times larger than the escapement that produced the return. In 2005 and 2006, the adult return was about one third the size of the escapement that produced the brood year. I interpret these results to indicate that in years when the winter survival is high, as in 2003-2004, the slower growing fish survive almost as well as the faster growing fish. However, when winter survival is poor, as in 2005-2006, the smaller fish do not survive as well according to the critical-size critical-period hypothesis (Beamish and Mahnken 2001) and the average intercirculi spacing for the first five circuli of the surviving adults is larger. Blackbourn and Tasaka (1990) measured the intercirculi spacing on scales of pink salmon returning to the Fraser River from 1963 to 1981. They reported that the distance from the tenth circulus to the outside edge of the marine annulus was significantly and negatively related to total production and marine survival. The negative relationship indicates a larger distance when there is lower survival. The response is similar to the findings in our study in the Queen Charlotte Strait area. Cross et al. (2008) conducted a similar circuli spacing study of the early marine growth of pink salmon in Prince William Sound. They observed that in years of poorer survival, the pink salmon that survived to return as adults had wider intercirculi spacing in the early marine period. In years of very good survival there was no difference in the intercirculi spacing. These were virtually identical to the results depicted in Fig. 16. In the Cross et al. (2008) study, their size related relationship was for hatchery pink salmon. They did not observe a relationship between the circuli spacing and survival of wild pink salmon; however, they also did not have estimates of total survival of wild pink salmon. Importantly, they also reported that the size difference was not evident until after the juvenile pink salmon left the coastal area (after October). The somewhat counterintuitive interpretation by these three studies indicates what I think is an important aspect of the biology of pink salmon and that is highly relevant to their recent survival trends.

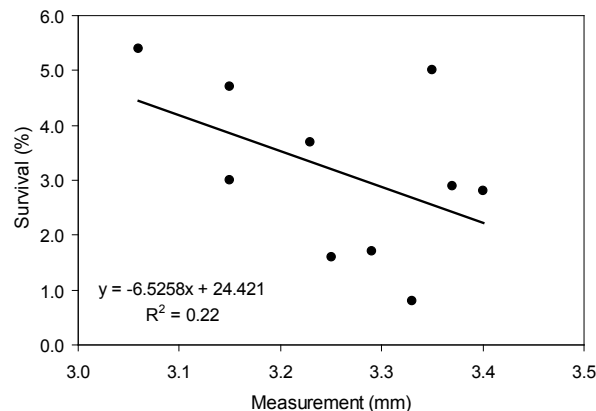


Fig. 16. Relationship between growth from the tenth circuli to the annulus and survival for pink salmon in the odd-numbered return years from 1963 to 1981 (data from Blackbourn and Tsaka 1990).

The observations from the Strait of Georgia studies and from the circuli-spacing studies can be interpreted to indicate that pink salmon differ from other Pacific salmon in the way they utilize energy in the early marine period. It is speculation, but juvenile pink salmon may use more of the energy from prey for growth and less for the storage of lipids. This would make them more dependent on the abundance of prey during the late fall and winter and would explain the absence of relationships between growth in the early marine period and survival in the Strait of Georgia. At the beginning of this paper, I wrote that the message in the data that did not appear to show very much was what it did not show. The lack of a relationship between pink salmon survival and growth in the early marine period, despite some evidence of increased growth, was an indication that the mechanisms regulating survival could be different than other Pacific salmon and that feeding conditions in the winter were critical. Dependency on finding prey in the late fall and winter would reduce the resilience to ocean conditions that result in poor plankton production in the winter and lead to greater variation in survival, which is characteristic of pink salmon population dynamics.

In general, pink salmon depend on fresh water less than the other species of Pacific salmon. In fresh water, they spawn close to the ocean and enter the ocean early and quickly. In the ocean, pink salmon have a variable diet as they feed more on particular sizes of prey rather than on particular prey (Brodeur and Pearcy 1990). The recent increase in odd-year pink salmon production would result from increased prey production during the late fall and winter as a consequence of the changing climate. These improved feeding conditions and a metabolic focus on growth would allow pink salmon to grow more in the early marine period and in the winter. Thus, in general, pink salmon have evolved to find prey faster, to feed more frequently, and the odd-year line could use more energy for growth and less for lipid storage. This strategy makes pink salmon more dependent on lower trophic level prey, leaving little ability to buffer their diets with the consumption of higher trophic levels in periods of poor plankton production. The life history strategy benefits from a warming ocean, which results in more favourable ocean winters than unfavourable. The resilience of the pink salmon life history strategy and the warming in the Strait of Georgia and the open ocean ensures that years of good production quickly follow years of poor production.

It is known that there are major genetic differences between the odd- and even-year lines of pink salmon (Apsinwall 1974; Beacham and Murray 1988; Beacham et al. 2012). Another speculation could be that incorporated in these genetic differences is the different metabolic strategy in which the even-year pink salmon use more of their energy during the summer for lipid storage than the odd-year pink salmon. Even-year pink salmon would take less risks metabolically than odd-year pink salmon, resulting in even-year pink salmon receiving less of an advantage of warmer and more productive winters. This difference, if it is valid, does not explain all of the differences associated with dominance between the two lines, but it may explain why even-year pink salmon are not increasing in synchrony with odd-year pink salmon in the total catches by all countries. It may also explain why odd-year pink salmon grow to larger sizes than even-year pink salmon (Godfrey 1959; Ricker et al. 1978). Fraser River pink salmon, according to these speculations, are increasing in abundance because they are odd-year pink salmon, escapements are increasing, and the Strait of Georgia and open ocean provide a favourable environment for survival.

Conclusion

Pink salmon in general and odd-year pink salmon in particular depend on fresh water for production, which is a function of the number of spawning females, but their life history strategy depends more on the marine period. This life history strategy is more closely matched to the current changes in climate and ocean conditions than other species of Pacific salmon because they could also use more of their energy for growth during the early marine period than other Pacific salmon. This strategy would place a dependency on finding adequate prey during the winter, but recent climate changes could result in more frequent encounters of optimal feeding conditions in the early marine period and in the winter. The lack of synchrony between the odd and even lines of pink salmon could indicate a fundamental genetic difference in the use of energy for growth or storage between the two lines during the early marine period and extending into the ocean winter.

Acknowledgements

Chrys Neville and Rusty Sweeting assisted with the preparation of figures and Rusty Sweeting was the Chief Scientist on the trawl surveys in the Strait of Georgia that sampled pink salmon. Elysha Gordon made the scale intercirculi measurements. Dave Blackbourn provided a most helpful report. Lana Fitzpatrick helped to prepare the final manuscript. Mark Saunders provided financial support for the analysis and reporting. Terry Beacham provided good advice.

REFERENCES

- Aspinwall, N. 1974. Genetic analysis of North American populations of pink salmon, *Oncorhynchus gorbuscha*; possible evidence for the neutral mutation-random drift hypothesis. *Evolution* 28: 295-305.
- Beacham, T.D., and C.B. Murray. 1988. Variation in developmental biology of pink salmon (*Oncorhynchus gorbuscha*) in British Columbia. *Can. J. Zool.* 66: 2634-2648.
- Beacham, T.D., B. McIntosh, C. MacConachie, B. Spilsted, and B.A. White (almost in press). 2012. Pink salmon (*Oncorhynchus gorbuscha*) population structure in British Columbia and Washington as determined by microsatellites.
- Beamish, R.J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. *Prog. Oceanogr.* 49: 423-437.
- Beamish, R.J., D. McCaughran, J.R. King, R.M. Sweeting and G.A. McFarlane. 2000. Estimating the abundance of juvenile coho salmon in the Strait of Georgia by means of surface trawls. *N. Am. J. Fish. Manage.* 20: 369-375.
- Beamish, R.J., J.T. Schnute, A.J. Cass, C.M. Neville, and R.M. Sweeting. 2004. The influence of climate on the stock and recruitment of pink and sockeye salmon from the Fraser River, British Columbia, Canada. *Trans. Am. Fish. Soc.* 133: 1396-1412.
- Beamish, R.J., S. Jones, C. Neville, R. Sweeting, G. Karreman, S. Saksida, and E. Gordon. 2006. Exceptional marine survival of pink salmon that entered the marine environment in 2003 suggests that farmed Atlantic salmon and Pacific salmon can coexist successfully in a marine ecosystem on the Pacific coast of Canada. *ICES J. Mar. Sci.* 63: 1326-1337.
- Beamish, R., E. Gordon, J. Wade, B. Pennell, C. Neville, K. Lange, R. Sweeting, and S. Jones. 2011. The winter infection of sea lice on salmon in farms in a coastal inlet in British Columbia and possible causes. *J. Aquacult. Res. Devel.* 2: 107. doi:10.4172/2155-9546.1000107
- Blackbourn, D.J., and M.B. Tasaka. 1990. Marine scale growth in Fraser River pink salmon: a comparison with sockeye salmon growth and other biological parameters. *In Proceedings of the 14th Northeast Pacific Pink and Chum Workshop. Edited by P.A. Knutsen. Washington State Department of Fisheries, Olympia.* pp. 58-63.
- Brodeur, R.D., and W.G. Pearcy. 1990. Trophic relations of juvenile Pacific salmon off the Oregon and Washington coast. *Fish. Bull.* 88(4): 617-636.
- Cross, A.D., D.A. Beauchamp, K.W. Myers, and J.H. Moss. 2008. Early marine growth of pink salmon in Prince William Sound and the coastal Gulf of Alaska during years of low and high survival. *Trans. Am. Fish. Soc.* 137: 927-939.
- Godfrey, H. 1959. Variations in annual average weight of British Columbia pink salmon, 1944-1958. *J. Fish. Res. Board Can.* 16: 329-337.
- Grant, S., and G. Pestal. 2009. Certification unit profile: Fraser River pink salmon. *Can. Man. Rep. Fish. Aquat. Sci. No.* 2875.
- Jones, S.R.M., and R.J. Beamish. 2011. *Lepeophtheirus salmonis* on salmonids in the Northeast Pacific Ocean. *In Salmon lice: an integrated approach to understanding parasite abundance and distribution. Edited by S.R.M. Jones and R.J. Beamish. Wiley-Blackwell Publishing.* pp 307-329.
- Murdoch, J. 1979. Control charts. MacMillan Press, London.
- Noakes, D.J., and A. Campbell. 1992. Use of geoduck clams to indicate changes in the marine environment of Ladysmith Harbour, British Columbia. *Environmetrics* 3: 81-97.
- Phillips, A.C., and W.E. Barraclough. 1978. Early marine growth of juvenile Pacific salmon in the Strait of Georgia and Saanich Inlet, British Columbia. *Fish. Mar. Serv. Tech. Rep. No.* 830.
- Ricker, W.E. 1962. Regulation of the abundance of pink salmon populations. *In Symposium on pink salmon, Vancouver, October 13-15, 1960. Edited by N.J. Wilimovsky, Inst. Fish., UBC, Vancouver.*
- Ricker, W.E., H.T. Bilton, and K.V. Aro. 1978. Causes of the decrease in size of pink salmon (*Oncorhynchus gorbuscha*). *Fish. Mar. Serv. Tech. Rep. No.* 820.
- Sweeting, R.M., R.J. Beamish, D.J. Noakes, and C.M. Neville. 2003. Replacement of wild coho salmon by hatchery-reared coho salmon in the Strait of Georgia over the past three decades. *N. Am. J. Fish. Manage.* 23: 492-502.
- Vernon, E.H. 1966. Enumeration of migrant pink salmon fry in the Fraser River estuary. *Int. Pac. Salmon Fish. Comm. Bull. No.* 19.

Why Are Pink and Chum Salmon at Such High Abundance Levels in the Gulf of Alaska?

William R. Heard¹ and Alex C. Wertheimer²

¹*U.S. Department of Commerce, NOAA, NMFS, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Pt. Lena Loop Road, Juneau, Alaska 99801, USA*

²*Fishheads Technical Services, 17200 Andreanoff Drive, Juneau, Alaska 99801, USA*

Key words: PDO, pink salmon, chum salmon, hatcheries, marine survival patterns, pteropods, odd-even year synchrony

Historically pink and chum salmon likely have always been the most abundant salmon species in the Gulf of Alaska (GOA). Factors accounting for this include biology requiring less extensive freshwater life history that affords opportunities for producing large numbers of juveniles. Most GOA pink and chum salmon originate from many regions throughout Alaska and British Columbia. Not all, however, originate from North America. Some East Kamchatka pink salmon (Royce et al. 1968) and Japanese chum salmon (Urawa et al. 2009) occur in western parts of the GOA.

Abundance levels of pink and chum salmon in the GOA have fluctuated greatly over the past 110 years. We used long-term Alaska harvest data (1900-2010) as a run-strength proxy to examine changes in periods of abundance. Relatively high levels from around 1910 through 1940 occurred when pink and chum salmon harvests collectively were in excess of 70 million fish. Annual harvest during the following three decades, 1950-1970, fell below 25 million throughout Alaska. However, subsequent to this low abundance period, harvest levels rebounded strongly and have reached record levels of 160 million fish in some years (Fig. 1).

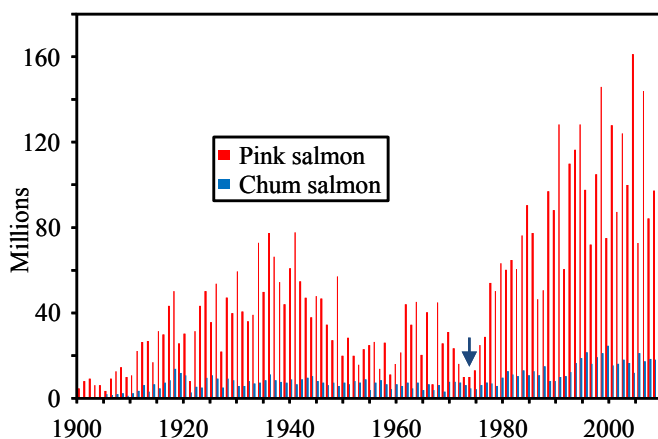


Fig. 1. Commercial harvest of Alaska pink and chum salmon, 1900-2010. Arrow denotes low point in harvest, start of modern hatcheries in Alaska, and 1976-1977 PDO regime shift.

The primary purpose of this report is to explore some of the potential causes of this recent prolong period of high abundance and to examine some basin-, regional-, and local-scale influences on marine survival.

Two important 1970s events have played significant roles in recent high GOA pink and chum salmon abundances. First was the major 1976-1977 regime shift, characterized by a general sea surface temperature (SST) warming trend reflected in the Pacific Decadal Oscillation (PDO; Mantua et al. 1997). Increased marine survival rates and higher abundance levels of many pink and chum salmon stocks in the GOA followed this basin-scale event. While there have been other minor regime shifts since then, none have yet reversed the current overall trend of high abundance levels in the GOA.

The second major event was developments, beginning in the 1970s in Alaska, allowing private non-profit (PNP) hatcheries, including those operated by regional aquaculture associations, to produce salmon for benefit of common property fisheries (McGee 2004). These programs now support 31 hatcheries that released 1.6 billion juvenile salmon into GOA waters in 2010. Of the total number released, pink and chum salmon releases represent 55% and 39%, respectively (White 2011). Alaska PNP statutes allow operators to harvest some returning hatchery fish in designated areas to help pay for operations, which is similar to procedures in prefectural cooperative hatcheries in Japan (Heard 2011). There is no doubt that hatcheries, in Alaska and elsewhere, have significant impacts on GOA salmon abundance. Eggers (2009) concluded that hatcheries, since the mid-1990s, constitute at least 37% of the total salmon biomass in the North Pacific Ocean.

We examined long-term commercial harvest patterns and effects of hatcheries beginning in 1979 on pink and chum salmon harvests in three regions in Alaska: Southeast (SEAK), Prince William Sound (PWS), and Kodiak (KOD). The SEAK pink salmon showed a distinctive high-low-high cyclic harvest pattern with minimal influence from hatcheries (Fig. 2a); PWS pink salmon had a moderate level of pre-hatchery fluctuations followed by dramatic increases in harvest due to hatcheries since the mid-1990s (Fig. 2b); and KOD pink salmon had a pattern intermediate of the other

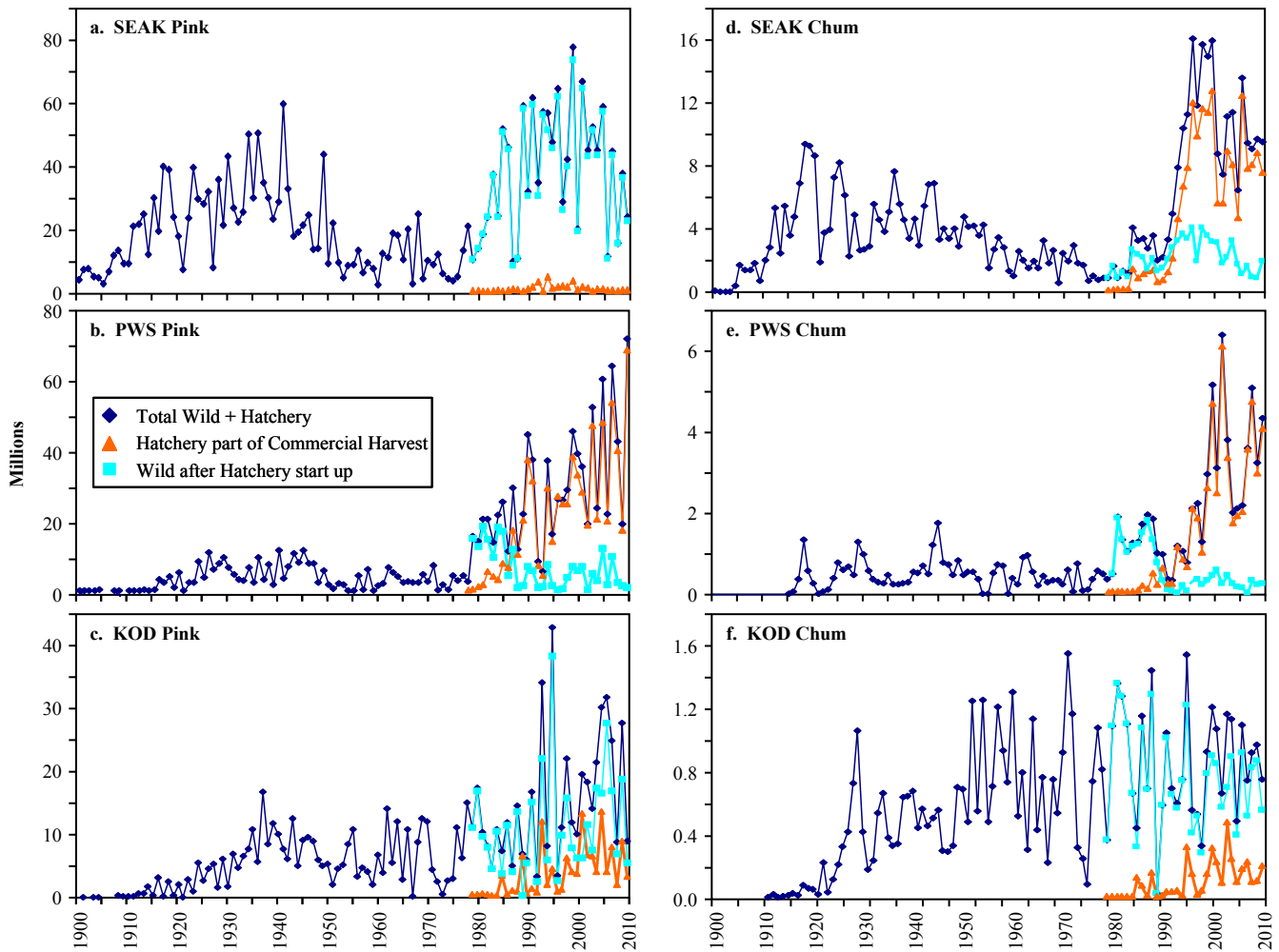


Fig. 2. Commercial pink (a-c) and chum (d-f) salmon harvest in Southeast Alaska (SEAK), Prince William Sound (PWS), and Kodiak (KOD), Alaska, 1900-2010, including hatchery contributions beginning in 1979. Note: Scale of Y-axes vary.

two regions (Fig. 2c). The SEAK chum salmon had long pre-hatchery declining harvest trends followed by a strong rebound due to hatchery production after 1990 (Fig. 2d); PWS chum salmon had moderate pre-hatchery fluctuations, then significant increases following the start of hatchery production (Fig. 2e); and KOD chum salmon had wide pre-hatchery fluctuations, then moderate hatchery increases in recent years (Fig. 2f).

We examined variations in hatchery survival patterns of pink and chum salmon released at different locations. For pink salmon, coefficients of pair-wise correlations dropped off quickly with increased distance between release sites. Most correlations between sites located within 105 km were ~0.5-0.6, while those located > 150 km were < 0.25. Highly correlated sites were all within PWS, but even within this region there was a wide range in co-variation among sites. There was little correlation between PWS, KOD, and SEAK release sites and low but negative correlation between SEAK and KOD release sites (Fig. 3).

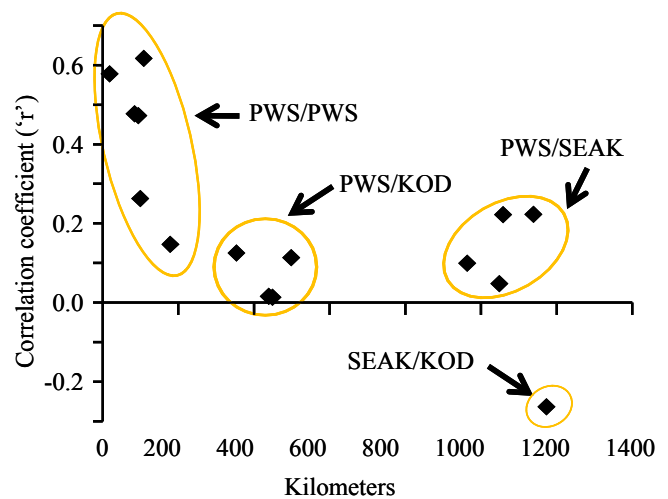


Fig. 3. Correlation coefficients relating survival of Alaska hatchery pink salmon releases from different locations and distances between release sites. PWS=Prince William Sound, KOD=Kodiak, and SEAK=Southeast Alaska.

For chum salmon, there was considerable variability in pair-wise correlations between release sites located relatively close in the same region: within 120 km, correlations ranged from 0.2-0.9 (Fig. 4). There was also a clear decreasing correlation with distance. The percentage of pair-wise correlation coefficients with $r > 0.5$ was 67% for release sites within 120 km, 31% for sites located 120-500 km apart, and only 3% for sites located > 500 km apart.

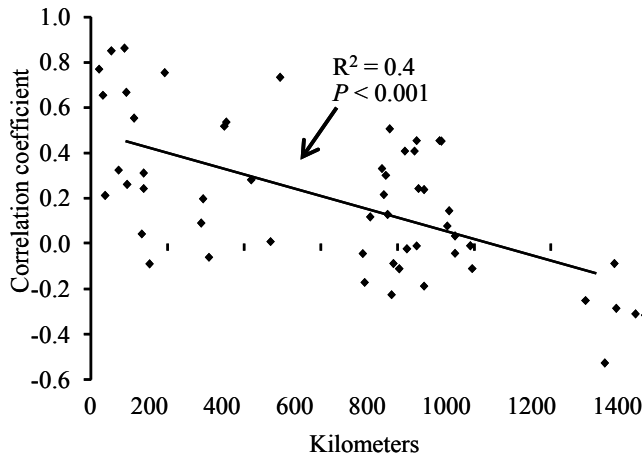


Fig. 4. Correlation coefficients relating survival of Alaska hatchery summer chum salmon releases and distances between release sites.

Differences in chum salmon survival trends by release site, even within 100 km, can be large. The PNP programs near Juneau release chum salmon reared from a common brood using similar rearing and release strategies at four release sites: Limestone, Gastineau, Amalga, and Boat Harbor. Survival rates from three sites (shown in blue) have correlation coefficients from 0.7-0.8, and the Limestone site (shown in red) has coefficients of only 0.2-0.3 with the other sites (Fig. 5). Marine survival rates at the Limestone site are also significantly less and average one-half to one-third the rate of the other sites, even though it is located within 40-100 km of the others.

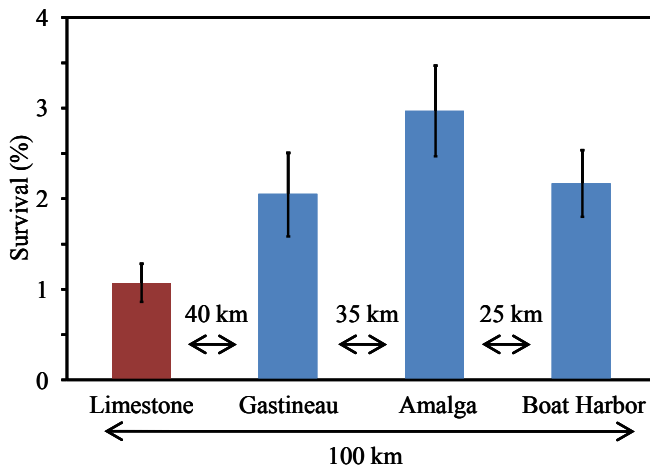


Fig. 5. Average survival rates (%) of summer chum salmon released at four private non-profit (PNP) hatchery sites located within 100 km of each other.

These findings illustrate how local effects can have large-scale impacts on trends and magnitude of survival are consistent with other studies on temporal variations in salmon survival (Pyper et al. 2001; Mueter et al. 2005; Farley 2010). However, temporal variations in marine survival rates and high or low correlation coefficients among different local or regional areas do not negate larger basin-scale climatic influences on overall production levels of pink and chum salmon in the GOA. Prevailing basin-scale conditions likely determine relative environmental factors that favor a higher or lower range or level of potential survival for juvenile salmon from different regions. Regarding long-standing continued influence of the 1976-1977 regime shift on salmon production in GOA, Minobe (1997) suggested major basin-scale climatic oscillations over the North Pacific Ocean could last 50 years or longer.

Recent 1999-2004 studies on PWS hatchery pink salmon by Armstrong et al. (2005, 2008), Cross et al. (2008, 2009), and Bond (2011) found high and low survival between brood lines associated with juvenile diets. They found high survival with pteropod-dominated diets and higher gut fullness and low survival with copepod-dominated diets and lower gut fullness. Even-odd year cycles from 2002 to 2007 illustrate an almost perfect parallel synchronous marine survival and adult return pattern between brood lines (Fig. 6). Within this time period, there were three even-numbered years of 3% survival and 30 million fish returning to PWS, versus three odd-numbered years of 8-9% survival and 50 million fish returning. Release timing, release numbers, and sizes of hatchery releases were similar in all six years. Could this biennial pattern be caused by something as simple as pteropods versus copepods in diets, and if so, what drives the biennial variability in pteropod abundance?

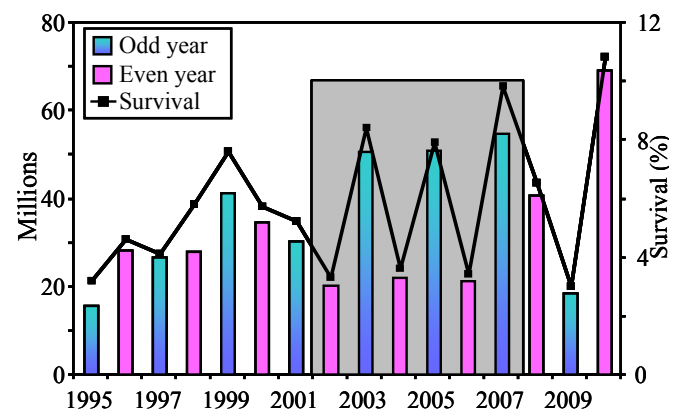


Fig. 6. Prince William Sound (PWS) pink salmon hatchery survival rates, 1995-2010, and a six-year period of low-high synchrony between even- and odd-year brood lines presumably due to diets.

In summary, we conclude a favorable ocean environment following the 1976-1977 regime shift and SST warming trend has contributed to increased productivity of both wild stocks and large-scale hatchery releases of pink and chum salmon in the GOA. Improved management of wild stocks, cessation

of high-seas interceptions through INPFC and NPAFC efforts, and improved fish-culture technologies have also helped produce historically high harvest levels throughout GOA regions.

REFERENCES

- Armstrong, J.L., J.J. Boldt, A.D. Cross, J.H. Moss, N.D. Davis, K.W. Myers, R.V. Walker, D.A. Beauchamp, and L.J. Haldorson. 2005. Distribution, size, and interannual, seasonal and diel food habits of northern Gulf of Alaska juvenile pink salmon, *Oncorhynchus gorbuscha*. *Deep-Sea Res. II* 205: 247-265.
- Armstrong, J.L., K.W. Myers, D.A. Beauchamp, N.D. Davis, R.V. Walker, J.L. Boldt, J.J. Piccolo, L.J. Haldorson, and J.H. Moss. 2008. Interannual and spatial feeding patterns of hatchery and wild juvenile pink salmon in the Gulf of Alaska in years of low and high survival. *Trans. Am. Fish. Soc.* 137: 1299-1316.
- Bond, N. 2011. The coastal Gulf of Alaska program: progress and perplexity. *J. Mar. Edu.* 27(2): 15-18.
- Cross, A.D., D.A. Beauchamp, K.W. Myers, and J.H. Moss. 2008. Early marine growth of pink salmon in Prince William Sound and the coastal Gulf of Alaska during years of low and high survival. *Trans. Am. Fish. Soc.* 127: 929-939.
- Cross, A.D., D.A. Beauchamp, J.H. Moss, and K.W. Myers. 2009. Interannual variability in early marine growth, size-selective mortality, and marine survival for Prince William Sound pink salmon. *Mar. Coast. Fish. Dynam. Manag. Ecosys. Sci.* 1: 57-70.
- Eggers, D.M. 2009. Historical biomass of pink, chum, and sockeye salmon in the North Pacific Ocean. *Am. Fish. Soc. Symp.* 70: 267-305.
- Farley, E.V., Jr. 2010. Hatchery pink salmon. *In Marine ecosystems of the North Pacific Ocean, 2003-2008. Edited by S.M. McKinnell, and M.J. Dagg.* PICES Sp. Pub. 4: 176-179.
- Heard, W.R. 2011. A comparison of salmon hatchery programs in Alaska and Japan. *In Interactions of fisheries and fishing communities related to aquaculture. Edited by R. Stickney, R. Iwamoto, and M. Rust.* NOAA Tech. Memo. NMFS-F/SPO-113: 71-78.
- Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific inter-decadal climate oscillation with impacts on salmon production. *Bull. Am. Meteorol. Soc.* 78: 1069-1079.
- McGee, S.G. 2004. Salmon hatcheries in Alaska—plans, permits, and policies designed to provide protection for wild stocks. *Am. Fish. Soc. Symp.* 44: 317-331.
- Minobe, S. 1997. A 50-70 year climatic oscillation over the North Pacific and North America. *Geophys. Res. Lett.* 24: 683-686.
- Mueter, F.J., B.J. Pyper, and R.M. Peterman. 2005. Relationships between coastal ocean conditions and survival rates of Northeast Pacific salmon at multiple lags. *Trans. Am. Fish. Soc.* 134: 105-119.
- Pyper, B.J., F.J. Mueter, R.M. Peterman, D.J. Blackburn, and C.C. Wood. 2001. Spatial covariation in survival rates of Northeast Pacific pink salmon (*Oncorhynchus gorbuscha*). *Can. Fish. Aquat. Sci.* 58: 1501-1515.
- Royce, W.F., L.S. Smith, and A.C. Hartt. 1968. Models of oceanic migrations of Pacific salmon and comments on guidance mechanisms. *Fish. Bull. (U.S.)* 66: 441-462.
- Urawa, S., S. Sato, P.A. Crane, B. Agler, R. Josephson and T. Azumaya. 2009. Stock-specific ocean distribution and migration of chum salmon in the Bering Sea and North Pacific Ocean. *N. Pac. Anad. Fish Comm. Bull.* 5: 131-146.
- White, B. 2011. Alaska salmon fisheries enhancement program 2010 annual report. Alaska Department of Fish and Game Fishery Management Report No. 11-04. 47 pp.

Temporal Patterns for Odd- and Even-Year Pink Salmon Conservation Units in British Columbia and Puget Sound (Washington State)

James R. Irvine¹, Catherine Michielsens², Bruce White², Pieter Van Will³, and Michael O'Brien¹

¹*Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo, BC V9T 6N7, Canada*

²*Pacific Salmon Commission, 600 - 1155 Robson Street Vancouver, BC V6E 1B5, Canada*

³*Fisheries and Oceans Canada, Box 2159, 8585 Wollason Rd., Port Hardy, BC V0N 2P0, Canada*

Keywords: conservation unit, pink salmon, escapement, Fraser River, Puget Sound

We assembled pink salmon escapement data for Conservation Units (CUs) in British Columbia (1953-2011) and Puget Sound (1959-2009), identified those streams with data for two-thirds or more of the years, and imputed values for missing years of data. We accounted for fish in the remaining streams by multiplying annual reconstructed estimates for each CU by a scaling factor that assumed relative abundance within the CU remained stable across years. In general, these data-limited streams were low production systems containing few pink salmon. We assessed escapement trends for each CU using the entire time series as well as the most recent 20 years. There were significant positive trends for many of the odd-year returning CUs, but only rarely for even-year CUs. Odd-year CUs did better than even-year CUs in five of the eight areas containing both, even-year CUs did best in one area, and there was no difference between even and odd-year CUs in the remaining two areas. The generated time series of fishery exploitation for Fraser River pink salmon and other odd-year southern Canadian populations indicated that increases in spawner abundance were partly due to decreased fishery exploitation. Coinciding with increasing spawner numbers, we observed mean body sizes of returning pink salmon have been declining within the available datasets (Fraser River, 1959-2009; Puget Sound, 1973-2009). Fry abundance indices for the Fraser River and Puget Sound allowed us to estimate temporal patterns of freshwater (i.e., index of fry numbers produced per adult) and post-fry (i.e., primarily marine) productivity (i.e., adults produced per index of fry abundance). In both the Fraser River and Puget Sound, freshwater productivity has been declining as spawner abundance has been increasing (i.e., there is a negative anomaly from the average fry/adult ratio). Density dependence, as assumed in a Ricker model, explains negative anomalies at high spawner numbers and positive anomalies at low spawner numbers. Taking density dependence into account, we saw no further signs for increased freshwater productivity. We conclude pink salmon populations in the southern portion of their range in the eastern North Pacific are increasing, similar to populations further north and west, but the mechanisms responsible for these increases likely differ among areas. In the southeastern North Pacific, increasing pink salmon abundance is more likely a response to declining fishery exploitation than to enhancement, which is minimal. Increasing escapement apparently causes a density-dependent decline in freshwater productivity that suggests to us that fishing opportunities exist.

Abundance Dynamics of Pink Salmon, *Oncorhynchus gorbuscha*, as a Structured Process Determined by Many Factors

Vladimir I. Radchenko

*Pacific Scientific Research Fisheries Center (TINRO-center),
 4 Shevchenko Alley, Vladivostok 690950, Russia*

Keywords: pink salmon, mortality, life strategy, energy content

Despite the fact that pink salmon is a fish species with a short-cycle life span, its stock abundance dynamics exhibit features typical of common pelagic fish species with an average life-cycle duration. Interchanging periods of high and low pink salmon abundance levels relate to positive and negative stock abundance trends inherent for major regional groups, Asian and American parts of aggregate stocks, and for pink salmon species as a whole (Radchenko et al. 2007). This feature of pink salmon abundance dynamics is determined by structural organization of the species and its populations. Major regional groups of pink salmon are divided into temporally isolated even- and odd-year populations. The life cycle of pink salmon can be conditionally divided into two periods: freshwater (including spawning, embryonic, and downstream migration phases) and marine (including inshore, marine waters in marginal seas, and oceanic phases). The phases repeat in reverse order until fish return from the sea and reach their spawning grounds. Most stocks, in turn, are separated by paired seasonal races with distinct morphological characteristics and spawning areas within river basins.

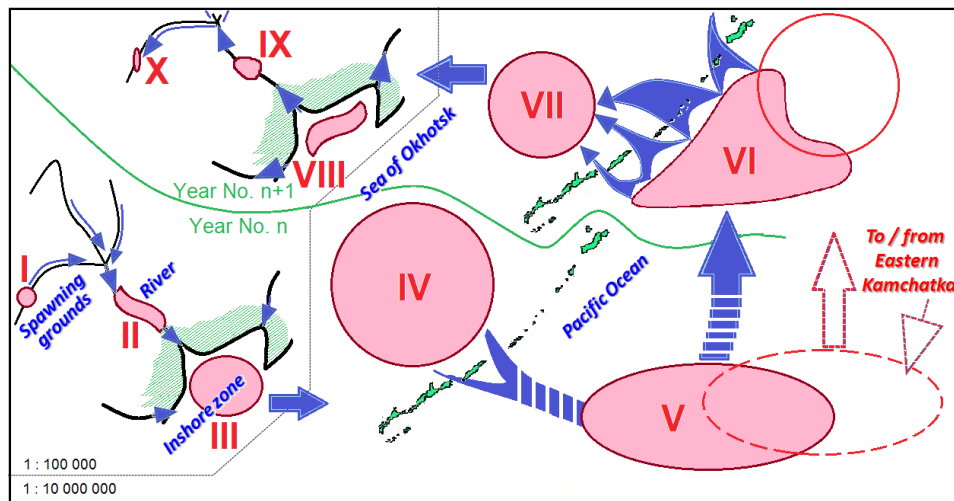


Fig. 1. Pattern of pink salmon migrations during the life-cycle phases of aggregate stocks of the Sea of Okhotsk. Selected life-cycle phases are indicated by Roman numerals.

For the purposes of assessing factors affecting mortality, abundance, and biomass losses on the basis of the pink salmon life cycle, I used typical data from an aggregated stock of Sea of Okhotsk pink salmon as an example (Fig. 1). The average abundance dynamics are based on data for 22 pink salmon generations spawning in 1989 to 2010 (Table 1). Average numbers and biomass estimates were calculated based on survey data, fishery statistics, and published literature.

Table 1. Abundance dynamics of an average pink salmon generation throughout the different life-cycle phases using the aggregate stocks of the Sea of Okhotsk. Data are shown for generations of fish spawning in the years 1989-2008.

Phases	I	II	III	IV	V	VI	VII	VIII	IX	X
Numbers, million fish*	21,448	3,860	1,136	1,020	730	418	300	176	65	52
Biomass, 1,000 mt	3.4	0.7	3.3	157.1	351.9	465.3	401.6	245.1	84.5	65
Number of cases	22	22	1	20	1	7	6	20	22	22

* including roe during first phase

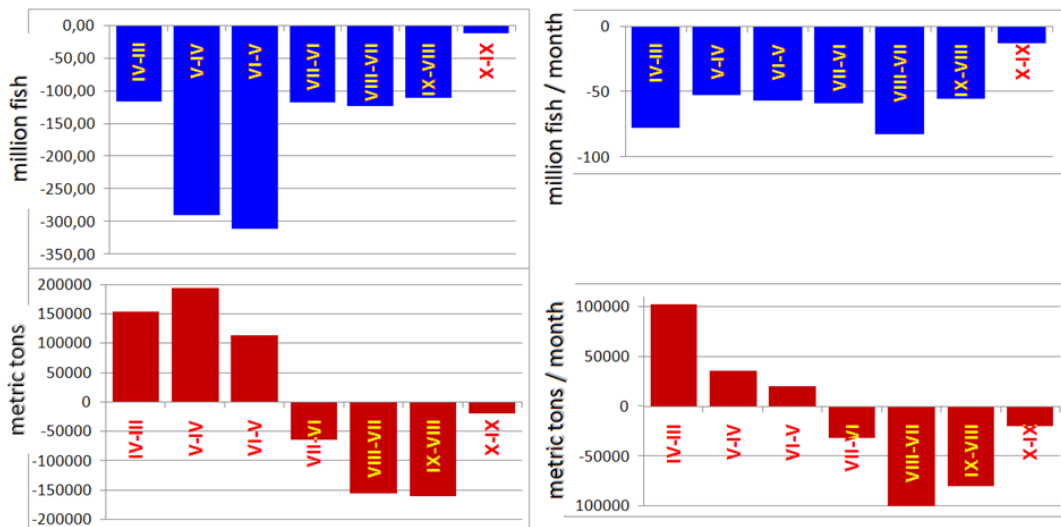


Fig. 2. Abundance and biomass losses of an average generation Sea of Okhotsk pink salmon between phases III and X. Total (left panels) and amount relative to one month (right panels). Data are shown for generations of fish spawning in 1989-2008.

Higher mortality rates occur in the first life-cycle phase and there is a gradual decrease in abundance observed during phases III to VIII (Fig. 2). Significant loss occurs in phases III and IV, which is explained by the critical size hypothesis, and occurs again during phases V and VI in the pre-anadromous migrations in the ocean. Total biomass increases until phase VI due to somatic growth. The surplus is then converted from somatic tissue into gonadal development as the fish begins to mature. Distinctions between the phases are more balanced, if estimated values are determined on the basis of the same time period (e.g., relative to one month). Based on monthly relative values, the most intensive growth of biomass occurs during phases III and IV (first marine summer). Relative biomass and abundance decrease most significantly during the prespawning migrations in the coastal zone (i.e., during phases VII and VIII). Fishery mortality notably contributes to total mortality during the prespawning migrations in the coastal zone, and natural mortality also increases during this period (Radchenko 2007).

The multiple factors effecting pink salmon abundance dynamics during the different life-cycle phases were summarized from the literature (Table 2; see reviews by Shuntov and Temnykh 2008, 2012). The strength of the factor's effect was roughly defined in the following manner: strong – if mass mortality was fixed under the factor's influence; moderate – if estimates suggest notable changes in fish abundance under the factor's influence; and low – if the exact calculation is unavailable or the factor's effect is evaluated as insignificant. The physiological alterations of fish during phases III, VII, and VIII are included due to the significant increase in salmon vulnerability to mortality at those stages. Phase III is divided into two parts (IIIa and IIIb) to emphasize the time period just after entering the sea, when pink salmon mortality is characterized by the highest rates.

All influencing factors are conditionally combined into three groups: (1) density dependent factors, (2) factors with an abundance/biomass level of fish to trigger the effect, and (3) density independent factors, with no abundance/biomass level to trigger the effect. Food supply conditions are usually regarded as a density dependent factor, whereby a portion of the fish population is supported by the supply and the unsupported portion is eliminated. The degree of population damage done by parasites and diseases is also density dependent. Environmental conditions are mainly formed by factors with a trigger level. For example, spawning ground conditions stabilize spawner abundance at some optimal level that corresponds to the hydrological conditions of a particular year. The predation effect is generally density independent because it is mostly determined by predator abundance and distribution. The first group of influencing factors forms the bulk of resources, the second group determines conditions. The second and third groups determine the so-called carrying capacity.

Regional factors affect pink salmon abundance during the first and last phases of the life span. These factors determine the regional peculiarities in abundance dynamics for distinct pink salmon groupings. Between life-cycle phases IV and VII, factors contribute to sea-basin scale dynamics. It is remarkable that density dependent factors are more significant during the second and third portions of the life span, while density independent factors predominate during the first portion. Factors during the initial life-cycle stages of approximately eight months duration form the basic level of the generation's abundance. Thus, juvenile pink salmon abundance during the fall trawl surveys in the southern Sea of Okhotsk was estimated at 250-450 million fish for the 1989-1991 generations. Such an amount of pink salmon could not ensure a powerful prespawning approach to inshore areas. For the subsequent 19 generations, juvenile pink salmon abundance did not fall below 800 million fish and averaged 1,184 million fish.

Table 2. Phases of the pink salmon life-cycle and factors affecting mortality rates using the aggregate stocks of the Sea of Okhotsk. Factors with a trigger level of fish abundance/biomass to start their effect are shown in italics; density dependent factors are shown in bold; density independent factors are shown in plain text.

Phase	Life stage	Factor affecting mortality rates	Strength of the factor
I	Embryonic	<i>Hydrological regime of spawning grounds (straight freezing danger);</i> Predators and scavengers;	Moderate Low
II	Freshwater	Hydrological regime of river (powerful flood danger)	Moderate
IIIa	Estuary	<i>Hydrological regime of estuary during fry entering in sea water (shock danger due to water temperature distinctions in rivers and inshore zone);</i> Predation by near-coastal piscivorous fish and bird species; Readiness to the exogenous feeding; Osmoregulatory system alteration in the salty environment	Strong locally Moderate Moderate Moderate
IIIb	Early marine	<i>Hydrological regime of inshore zone (seasonal sea surface layer heating rates);</i> Food supply in the inshore zone; Predation by near-coastal piscivorous fish and birds;	Low Moderate Low
IV	Marine	Food supply in the open sea waters; Competitive relationships with other planktivorous fish and invertebrates; Predation by pelagic piscivorous fish and marine mammals	Low Moderate Low
V	Oceanic (wintering)	<i>Hydrological regime of oceanic waters off Kurile Islands (water T°, currents and hydrological fronts expression);</i> <i>Hydrological regime of wintering zone in Pacific Ocean (hydrological fronts expression and location);</i> Food supply in the open ocean (related to subarctic waters transport); Competitive relationships with other planktivorous fish and invertebrates; Predation by pelagic piscivorous fish and marine mammals; Parasites and diseases	Moderate Moderate Moderate Low Moderate Low
VI	Oceanic (pre-anadromous migrations)	<i>Hydrological regime of oceanic waters off Kurile Islands (water T°, including gradients near the Kurile straits, currents and hydrological fronts expression);</i> Food supply in the open ocean; Competitive relationships with other planktivorous fish and invertebrates; Predation by pelagic piscivorous fish and marine mammals; Parasites and diseases	Moderate Low Low Moderate Low
VII	Marine	<i>Okhotsk Sea epipelagic layer hydrological regime (heated layer thickness);</i> Food supply in the open sea; Predation by pelagic piscivorous fish and marine mammals; Parasites and diseases; Availability of native region spawning rivers (complex of factors); Metabolism alteration (linear growth cessation and intensive maturing)	Low Moderate Low Moderate Moderate Moderate
VIII	Inshore	<i>Hydrological regime of inshore zone (water T°, heated layer thickness);</i> Complex of factors determining maturity rates; Anthropogenic factors (fishery); Predation by marine mammals; Parasites and diseases	Moderate Moderate Moderate Moderate Moderate
IX	Freshwater	<i>Hydrological regime of rivers (spawning grounds availability);</i> Anthropogenic factors (fishery; poaching); Predation by terrestrial mammals and birds; Parasites and diseases	Moderate Moderate Lowering Strong
X	Spawn	<i>Hydrological regime of spawning grounds (spawning success);</i> Anthropogenic factors (poaching); Parasites and diseases (pre-spawning die-offs)	Strong Moderate Strong

Large-scale factors influence pink salmon aggregate stocks and smooth fluctuations in total abundance. For example, large-scale factors supported pink salmon returns to the Sea of Okhotsk basin of 152 million adult fish from an estimated 1570 million juveniles (as estimated in the fall survey) for brood year 1998, and 252 million adult fish from an estimated 1000 million juveniles for brood year 2007. Mortality rates totaled 90-91% from fall to the next year's prespawning approach for fish spawning in 1998-2002, and mortality rates decreased to 75-77% for two generations of pink salmon spawning in 2007 or 2008. Effects of large-scale factors with harmonics generated from multiple years of variability are not enough to induce immediate salmon mortality. However, for future reproductive success pink salmon sacrifice about 82.7% of the total abundance in one marine year, as compared to mature herring losses of 20-27% in year classes aged 5-8 including fishery mortality, and walleye pollock annual mortality in the northern Sea of Okhotsk of about 26-30% for year classes aged 4-6. The distinctions among these species are determined by their different life strategies.

According to the critical size hypothesis, smaller individuals in the salmon cohort may not have sufficient energy reserves to survive late fall and winter in the ocean (Farley et al. 2007). Linear size is used as a proxy for estimation of accumulated energy resources. In my opinion, this point of view does not lose validity for the subsequent phases of the life cycle. Salmon need large energy resources to cover the enormous distances of the oceanic migration route and to overcome opposing water flow and rapids in spawning rivers. According to Shuntov and Temnykh (2012), the main features of the salmon life-history strategy were shaped in the historical period, when the near-coastal zone was densely populated by common fish species. Consequently, salmon were forced to choose a remote area in the open ocean for feeding migrations. This marathon life strategy is expressed most strongly in the features of pink salmon because it has the shortest life span.

Several studies consider salmon starvation in the ocean as a cause of enhanced mortality during winter (Nomura et al. 2000; Nomura and Kaga 2007). What does "starvation" really mean for salmon? Dwelling in conditions with an absolute absence of food? Insufficient amount or nutritional quality of food organisms? These conditions are not likely what starvation means for salmon. It is likely that starvation for salmon means a bigger energy expenditure for feeding (including searching for and capture of prey) than the caloric and nutritional content of the food. Some rare organic compounds and micro-elements also can be important for growth and development. Several facts support this hypothesis: no exhausted salmon specimens were caught over the many years of ecosystem surveys by TINRO; consumption by salmon does not exceed 3-5% of plankton biomass and 0.1-0.3% of plankton production; salmon usually consume preferred diet items, like hyperiids; and their diurnal feeding dynamics usually follows a one-peak pattern (Shuntov and Temnykh 2012). Salmon are flexible and react to poor food conditions by changing their body content and postponing gonadal development. Under laboratory conditions, chum salmon exhibited a 40% decline in body energy content and a 9% increase in moisture content after 45 days of starvation, but the fish remained alive and demonstrated slow linear growth (Fergusson et al. 2010).

Salmon at sea are active visual feeders with individual (not schooling) behaviors. Their preferred prey is not evenly distributed in the epipelagic layer. Most likely, forage organisms aggregate in thin lenses, on the surface of bacterial films, at the border between different water masses, etc. In relation to these types of prey aggregations, the inter-specific competition between salmon and abundant pelagic planktivorous fish can exhibit an aspect other than food supply exhaustion. Abundant pollock, herring, or sardine aggregations can destroy the fine structure of forage fields that would otherwise be suitable for energetically-beneficial salmon feeding. That is a reason why areas of high Pacific salmon catches do not overlap the areas of high catches of other pelagic fish during trawl surveys. Intra-specific competition can also act in this manner. In the last two odd-numbered years and the highest pink salmon abundance of adults approaching the coast, the southern Kuril stock, which is a late seasonal race and is the last to return, was notably lower in abundance than expected: in 2009 – lower by 44% and in 2011 – lower by 86%. Furthermore, Fulton's condition factor was low for the less mature cohort of pink salmon during the migration flow to the coastline. It would be useful to estimate the caloric content of pink salmon sampled from the later part of the migration in years of high total abundance to determine if body condition decreases over the duration of the migration.

Salmon are susceptible to relatively high mortality during catch-and-release fisheries in fresh waters (Reiss et al. 2011). This is surprising, considering their viability after wounds caused by predatory fish and marine mammals at sea. Unexpected energy loss related to salmon fighting the fishing line can be critically important for spawning success. Most salmon species do not feed in rivers, so their "batteries" cannot be "charged" there. It must be noted that mortality estimates do not include fish that are released soon after capture and are flushed downstream by the flow and may die sometime thereafter.

Analysis of the salmon life strategy has brought us to reconsideration of the carrying capacity term for this group of fish. While theoretical reasoning uses total fish biomass as the measure of carrying capacity, biomass consists of individual fish, and, in reality, salmon explore their surroundings individually. The individual characteristics of each fish determine whether it will attain the subsequent stage in its life span. This is one of the differences between salmon and common schooling pelagic fish species like sardine, anchovy, herring, etc. If a salmon population includes a significant portion of fish with sub-optimal physiological characteristics for further development, then notable abundance fluctuations become possible if variations of environmental conditions predominate at a critical juncture for these fish. Even a small enhancement

of conditions can support a notable portion of the salmon population, but the same degree of worsening conditions could eliminate most of them.

Since the 1980s, pink salmon abundance trends for large regional groupings have been characterized by increased positive and negative deviations from average values. Thus, pink salmon catch in Aniva Bay has exceeded the expected value by 50,000 tons and exceeded the historical maximum for the even-year broodline by 5.5 times in 2006. This year (2011), the negative deviation was 25,100 tons in Aniva Bay. Expected excess catch on Iturup Island (positive deviation) was 23,900 tons in 2007, and negative deviations of the same magnitude (23,800 tons) was observed for four consecutive years.

Observed fluctuations in pink salmon abundance has coincided with intensification of pink salmon hatchery programs around the Pacific Rim (Beamish et al. 1997; Ruggerone et al. 2010), and both the western and eastern North Pacific are characterized by a notable portion of total pink salmon abundance comprising hatchery fish. It is possible to consider the genetic and physiological diversity of young salmon as a source of the observed deviations from expected returns. However, large deviations in abundance have likewise been observed on the coast of eastern and western Kamchatka, which are without notable pink salmon hatchery enhancement. Perhaps some factors of hatchery enhancement are so widespread as to influence pink salmon stocks that do not originate from regions of intense artificial production.

Relevant scientific directions in the study of pink salmon dynamics include research in the following areas: (1) establish a data series on salmon energy contents in the ocean and coastal areas, (2) develop simple indices of optimal physiological condition for different stages of the pink salmon life cycle, (3) conduct comparative studies for different periods of the migration flow to benefit natural mortality forecasts and spatial differentiation of seasonal races and regional groupings, and (4) develop new information on wild/hatchery salmon relationships. Studies of the quantitative distribution of juvenile Pacific salmon in the inshore zone and in the wintering areas of North Pacific Ocean must also be continued.

REFERENCES:

- Beamish, R.J., C. Mahnken, and C.M. Neville. 1997. Hatchery and wild production of Pacific salmon in relation to large-scale, natural shifts in the productivity of the marine environment. *ICES J. Mar. Sci.* 54: 1200-1215.
- Farley, E.V., J.H. Moss, and R.J. Beamish. 2007. A review of the critical size, critical period hypothesis for juvenile Pacific salmon. *N. Pac. Anadr. Fish Comm. Bull.* 4: 311–317.
- Fergusson, E.A., M.V. Sturdevant, and J.A. Orsi. 2010. Effects of starvation on energy density of juvenile chum salmon (*Oncorhynchus keta*) captured in the marine waters of southeastern Alaska. *Alaska Fish. Bull.* 108(2): 218–225.
- Nomura, T., and T. Kaga. 2007. Trophic status of young ocean chum salmon estimated by lipid analysis. *N. Pac. Anadr. Fish Comm. Tech. Rep.* 7: 99–100.
- Nomura, T., S. Urawa, and Y. Ueno. 2000. Variations in muscle lipid content of high-seas chum and pink salmon in winter. *N. Pac. Anadr. Fish Comm. Bull.* 2: 347–352.
- Radchenko, V.I. 2007. Pink salmon abundance dynamics in the Sea of Okhotsk basin during the first half of 2000s. *Bulletin of the implementation of the “Concept of the Far Eastern Basin Program of Pacific Salmon Research”*. No. 2: 27-35 (in Russian).
- Radchenko, V.I., O.S. Temnykh, and V.V. Lapko. 2007. Pink salmon trends in abundance and biological characteristics in the North Pacific. *N. Pac. Anadr. Fish Comm. Bull.* 4: 7-21.
- Reiss, P., M. Reiss, and J. Reiss. 2011. Catch and release fishing effectiveness and mortality. Electronic publication: <http://www.acuteangling.com/Reference/C&RMortality.html>
- Ruggerone, G.T., R.M. Peterman, B. Dorner, and K.W. Myers. 2010. Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific ocean. *Mar. Coast. Fish. Dynam. Manage. Ecosys. Sci.* 2: 306-328. (Available at afs.journals.org/doi/pdf/10.1577/C09-054.1).
- Shuntov V.P., and O.S. Temnykh. 2008. Pacific salmon in marine and oceanic ecosystems. Vol. 1. TINRO-Center, Vladivostok. 481 pp. (In Russian).
- Shuntov V.P., and O.S. Temnykh. 2012. Pacific salmon in marine and oceanic ecosystems. Vol. 2. TINRO-Center Vladivostok. (In Russian).

Trophic Link Between *Neocalanus* Copepods and Pink Salmon in the Western Subarctic North Pacific Based on Long-Term Nitrogen Stable Isotope Analysis

Sanae Chiba¹, Hiroya Sugisaki², Kazuaki Tadokoro³ and Toru Nagasawa⁴

¹Research Institute of Global Change, JAMSTEC, 3173-25 Showa-machi, Kanazawa-ku, Yokohama, Kanagawa 236-0001, Japan

²National Research Institute of Fisheries Science, FRA, 2-12-4 Fukuura, Kanazawa, Yokohama, Kanagawa 236-8648, Japan

³Tohoku National Fisheries Research Institute, 3-27-5, Shinhama-cho, Shiogama, Miyagi 985-0001, Japan

⁴Hokkaido National Fisheries Research Institute, 2-2 Nakanoshima, Toyohiraku, Sapporo, Hokkaido 062-0922, Japan

Keywords: nitrogen stable isotope, pink salmon, *Neocalanus*, bottom-up control, western subarctic North Pacific

We have been conducting analyses of long-term changes in the lower trophic level ecosystems of the western North Pacific using the Odate Collection, a historical zooplankton sample and data set (Odate and Maita 1994). We detected a significant correlation between zooplankton biomass and the decadal water temperature anomaly from winter to spring, which was closely related to Pacific Decadal Oscillation (Chiba et al. 2006). Zooplankton biomass and Japanese pink salmon (*Oncorhynchus gorbuscha*) catch markedly increased in the 1990s (Chiba et al. 2008; Yatsu et al. 2008), roughly coinciding with the 1988/89 regime shift and wintertime warming. In this study, we investigated the possible link between decadal variation of zooplankton and pink salmon abundance using nitrogen stable isotope analyses.

It is well documented that the amount of nitrogen stable isotope ($\delta^{15}\text{N}$) contained in plants and animals indicates the trophic position of an organism in the ecosystem because the concentration increases approximately 3.4‰ with the increase of one trophic level. Assuming that pink salmon feed on copepods, we expected that the time-series variation in $\delta^{15}\text{N}$ of copepods and salmon might indicate the trophic interaction between them and the bottom-up control of pink salmon production. We measured $\delta^{15}\text{N}$ in four dominant copepods species, *Neocalanus cristatus*, *N. plumchrus*, *N. flemingeri* and *Eucalanus bungii*, from the Odate Collection and in pink salmon scales collected in the offshore area west of 180°. Interannual variation in the amount of $\delta^{15}\text{N}$ was compared for the years 1960 to 2002. We used whole pink salmon scales collected from maturing females (age-1). Thus the concentration of nitrogen stable isotope was the average accumulated during the life span until the time of capture.

The time-series of the averaged $\delta^{15}\text{N}$ anomaly for copepods and pink salmon showed a marked decline in the 1990s by 2~3 ‰ (Fig. 1). This decline coincided with the timing of increase in the biomass of copepods and fish, which indicates a possible bottom-up control mechanism for the enhanced salmon production in the 1990s. Considering the $\delta^{15}\text{N}$ in the four copepods species varied in a similar manner, we think it is plausible that declines in copepod $\delta^{15}\text{N}$ was a response to common environmental forcing rather than from a species-specific ecological or biological trait. These copepod species are reported to shift their feeding strategy to more omnivory, depending on ambient

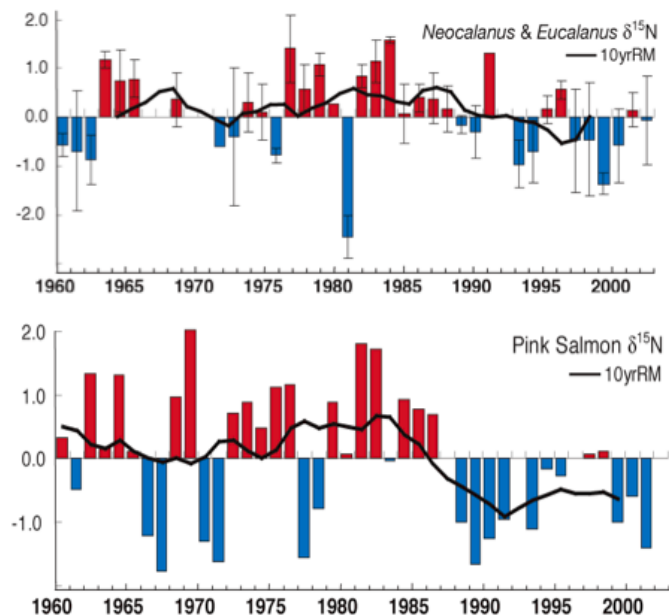


Fig. 1 Time-series anomaly and 10-year running mean of average $\delta^{15}\text{N}$ contained in four copepods species, *Neocalanus cristatus*, *N. flemingeri*, *N. plumchrus* and *Eucalanus bungii* (upper panel) and in pink salmon scales collected in the western North Pacific (lower panel).

phytoplankton availability (Kobari et al. 2003). As a 3 % decline of $\delta^{15}\text{N}$ is equivalent to a decline of roughly one trophic level, our results suggested copepods might have fed more heavily on phytoplankton in the 1990s, as compared to the previous decade, due to increased phytoplankton abundance. Did phytoplankton abundance really increase in the 1990s?

After the 1988/89 regime shift, the wintertime conditions in the western North Pacific were warm with a shallow mixed layer depth. Water column stability and light availability increased during winter and this condition was thought to trigger an earlier phytoplankton bloom. We observed increased wintertime Chl *a* and decreased springtime and annual mean Chl *a* in samples from the 1990s (Chiba et al. 2008; Fig. 2). An early bloom and a continuous moderate supply of phytoplankton might be a better match with reproduction and survival of copepods, and other herbivorous zooplankton prey of salmon, that results in benefits to pink salmon production.

This study revealed possible bottom-up control of pink salmon production that is driven by decadal climatic forcing over the North Pacific. We demonstrated the usefulness of measuring $\delta^{15}\text{N}$ in zooplankton and fish as an indicator of the linkage between lower and higher trophic levels. However, there is a problem in applying conventional methods of $\delta^{15}\text{N}$ determination. The $\delta^{15}\text{N}$ concentration in zooplankton varies not only by changes in trophic position, but also varies depending on environmental factors, such as source water concentration of nitrate and/or ^{15}N , physiological state of phytoplankton, and other factors. This deficiency often makes it difficult to interpret results from this type of analysis. Methods for amino-acid analysis of $\delta^{15}\text{N}$ concentration has recently been developed to solve this problem by producing results solely based on the trophic level of an organism, rather than environmental and physiological factors (Chikaraishi et al. 2009). Extensive monitoring of zooplankton in the subarctic North Pacific by ships equipped with a continuous plankton recorder (CPR) has been conducted every year since 2000. As a recommendation, we propose future routine analysis of amino acid $\delta^{15}\text{N}$ of zooplankton collected by CPR and salmon samples to obtain a better understanding of the mechanism of interannual salmon stock variation in the North Pacific.

REFERENCES

- Chiba, S., K. Tadokoro, H. Sugisaki, and T. Saino. 2006. Effects of decadal climate change on zooplankton over the last 50 years in the western subarctic North Pacific. *Global Change Biol.* 12(5): 907-920.
- Chiba, S., N.M. Aita, K. Tadokoro, T. Saino, H. Sugisaki, and K. Nakata. 2008. From climate regime shifts to plankton phenology: synthesis of recent progress in retrospective studies of the western North Pacific. *Prog. Oceanogr.* 77: 112-126.
- Chikaraishi, Y., N.O. Ogawa, Y. Kashiya, Y. Takano, H. Suga, A. Tomitani, H. Miyashita, H. Kitazato, and N. Ohkouchi. 2009. Determination of aquatic food-web structure based on compound-specific nitrogen isotopic composition of amino acids. *Limnol. Oceanogr. Methods* 7: 740-750.
- Kobari, T., A. Shinada, and A. Tsuda. 2003. Functional roles of interzonal migrating mesozooplankton in the western subarctic Pacific. *Prog. Oceanogr.* 57: 279-298.
- Odate, T., and Y. Maita. 1994. Microzooplankton biomass in the western North Pacific Ocean in spring 1985. *Bull. Fac. Fish. Hokkaido Univ.* 45: 39-47.
- Yatsu, A., K.Y. Aydin, J.R. King, G.A. McFarlane, S. Chiba, K. Tadokoro, M. Kaeriyama, and Y. Watanabe. 2008. Mechanisms of fish population dynamics to climatic forcing: comparative study on selected stocks representing five life-history strategies in the North Pacific. *Prog. Oceanogr.* 77: 252-268.

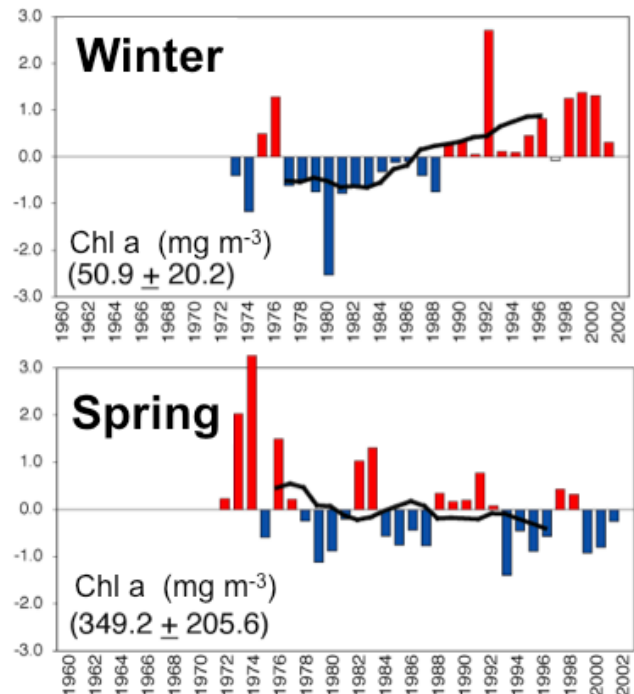


Fig. 2 Time-series anomaly of phytoplankton abundance (Chl *a*: mg m⁻³) during winter (upper panel) and spring (lower panel) in the western North Pacific.

Production Trends of Pink Salmon in the Sakhalin-Kuril Region from the Viewpoint of Run Timing

Alexander M. Kaev

*Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO),
 196, Komsomolskaya Str., Yuzhno-Sakhalinsk 693016, Russia*

Keywords: pink salmon, Sakhalin-Kuril region, abundance, body size, migration timing, long-term trends, early and late forms

There are two abundant species of Pacific salmon in the Sakhalin-Kuril region: pink and chum salmon. This paper presents information only on pink production trends because changes in chum salmon abundance are determined mainly by the activity of hatcheries (Kaev 2010a). Pink salmon exhibit rapid growth, short life, and great variability in their abundance, so this species attracts the attention of researchers as a possible indicator of environmental processes. Southern areas of the Sakhalin-Kuril region are important because these areas have a high abundance of pink salmon and the longest continuous record of pink salmon biological data. For this analysis, stocks were analyzed from three southern areas in the region, southeastern Sakhalin, Aniva Bay, and Iturup Island (Fig. 1).

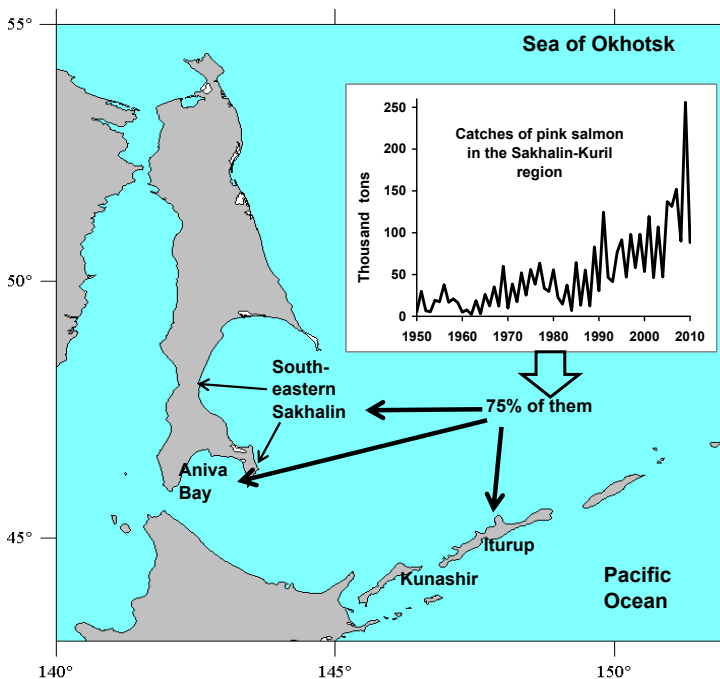


Fig.1. Study area of pink salmon biological characteristics in south-eastern Sakhalin and Iturup Island and catches of pink salmon in the Sakhalin-Kuril region (inset).

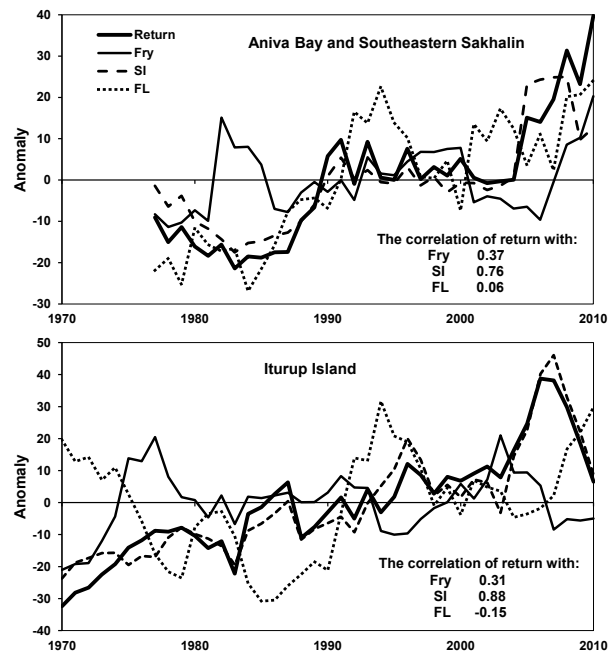


Fig. 2. Annual changes in fry abundance (Fry), adult returns (Return), marine survival (SI), and fish length (FL) for south Sakhalin and Iturup Island pink salmon, 1970-2010.

In the past 20 years, there has been a high abundance and large body size of pink salmon returning to South Sakhalin and Iturup Island (Fig. 2). For a better view of long-term changes, the data are presented as a 4-year running average because pink salmon have odd- and even-numbered year generations. High correlations should be expected between returns and a marine survival index, and low correlations expected between returns and fry abundance and fish length. Many researchers have compared changes in Pacific salmon abundance with global climatic indices. For example, a detailed report on chum salmon abundance related to climate was presented by Kaeriyama et al. (2009). I want to draw attention to environmental conditions as they relate to pink salmon abundance and biological characteristics.

The following indicators were used for the analysis.

Reproduction Index (RI): Ratio between the number of downstream pink fry migrants and the number of pink salmon escapement for spawning (SakhNIRO data).

Survival Index (SI): Percentage of pink salmon returns to the total number of wild and hatchery fry migrants (SakhNIRO data).

Cold Type (CT): Number of “cold” decades in atmospheric processes over the Okhotsk and Japan Seas in October-March (TINRO-Center).

Pacific Decadal Oscillation (PDO): Pacific Decadal Oscillation (University of Washington: <http://jisao.washington.edu/pdo>).

Sea Surface Temperature (SST): Temperature in summer and autumn in the southern Okhotsk Sea (NOAA Earth System Research Laboratory: NCEP/NCAR Reanalysis Project).

Wolf number (W): Numerical index of the number of sunspots (The Solar Influences Data Analysis Center, SIDC).

Let's consider the correlation between changes in pink salmon indices and the “cold type” winter index (Table 1). I regard the reduction in generations that survived in cold winters as a casual coincidence in the general process of forming the abundance of pink salmon. The correlation between the number of cold winters and fry abundance is weak and has different signs for Iturup and Sakhalin. In addition, cold or warm winters have no significant effect on survival for the period between downstream migration and spawning (RI).

Table 1. Correlation between the number of “cold” decades in winter and pink salmon reproduction index (RI), abundance of pink fry migrants (Fry), and return of adult pink salmon to South Sakhalin and Iturup Island (Return).

Area	Actual values			Trends (related to 4 values)		
	RI	Fry	Return	RI	Fry	Return
South Sakhalin	-0.04	-0.08	-0.38	-0.23	-0.40	-0.64
Iturup Island	0.03	0.13	-0.17	-0.09	0.14	-0.30

Next let's consider the correlation between changes in pink salmon indices and the PDO (Table 2). Please note the following nuances. Correlation with the PDO is weaker for survival rates than for abundance of pink salmon returns. Clearly, pink salmon returns first depend on fry abundance and then on their marine survival. The relationship between the PDO and abundance and survival of pink salmon from the different areas vary, and the correlation with fish length is almost equal for the two areas. It is clear that similar changes in fish length reflect similar habitat conditions in the open sea. The index of survival seems to be more associated with the coastal lifespan, where local provincial factors are of great importance.

Table 2. Correlation between the PDO (winter-summer) and abundance of pink fry migrants (Fry), marine survival (SI), return of adults (Return), and pink salmon fork length (FL) of fish returning to South Sakhalin and Iturup Island.

Area	Actual values				Trends (related to 4 values)			
	Fry	SI	Return	FL	Fry	SI	Return	FL
South Sakhalin	-0.00	-0.25	-0.47	-0.18	-0.24	-0.53	-0.71	-0.48
Iturup Island	-0.03	0.07	0.05	-0.16	0.23	0.21	0.29	-0.44

Correlations between Sea of Okhotsk sea surface temperatures (SST) and pink salmon indices indicate the relationship with adult returns was higher than with survival (Table 3). The relationship between SST and the survival index was stronger than survival with cold winters (Table 1) or the PDO (Table 2), but the relationship between SST and survival was insufficient for reliable forecasting because of the large variance in some years (Fig. 3).

Table 3. Correlation between sea surface temperatures (SST) in the Sea of Okhotsk and marine survival (SI), return of adults (Return), and pink salmon fork length (FL) of fish returning to South Sakhalin and Iturup Island.

Areas	Actual values			Trends (related to 4 values)		
	SI	Return	FL	SI	Return	FL
South Sakhalin	0.44	0.59	0.19	0.58	0.79	0.60
Iturup Island	0.29	0.31	0.25	0.58	0.56	0.55

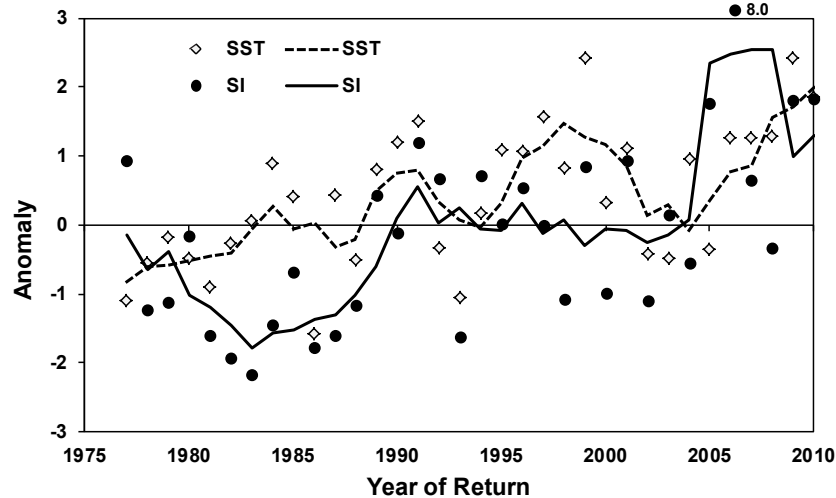


Fig. 3. Annual changes in marine survival (SI) of pink salmon from southern Sakhalin and sea surface temperature (SST) in the southern Okhotsk Sea, 1977-2010.

When compared with global climate indices, the same (positive or negative) changes in pink salmon from different areas are noted for fish length, which is explained by their living in similar conditions in the ocean. But changes in the timing of pink salmon approaches to the coast are worth considering. Changes in direction of long-term trends in pink length and migration timing occur more or less simultaneously for pink salmon in different areas. However, the coherence of changes in pink salmon migration timing in different areas is easily criticized because the correlation is much weaker (0.29) than the relationship between changes in fish length (0.79).

When studying these trends and relationships (e.g., Tables 1, 2, and 3), indices characterizing the whole stock of pink salmon are generally used. However, a stock of pink salmon is not uniform. In Eastern Sakhalin and Iturup Island, there are two forms of pink salmon: an early and a late migratory form that follow each other in return to freshwater. Until now, these forms have been most heavily studied in two areas: Aniva Bay and Iturup Island (Kaev 2010b). To identify the different forms, catch dynamics, proportion of males, and fish length are used. The appearance of the late form is usually accompanied by a significant increase in male size, while the length of females may remain unchanged. Pink salmon females of the late form have a lower fecundity per unit body length, but absolute fecundity may not change very much. The ratio of early to late forms in the migratory flow of pink salmon to Aniva Bay and Iturup Island may vary greatly by year (Fig. 4).

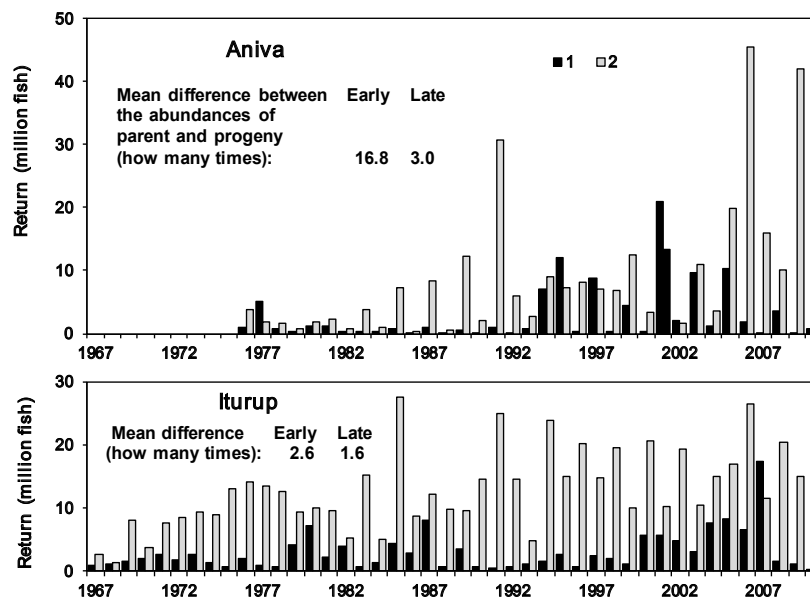


Fig. 4. Ratio of early (1, black column) and late (2, grey column) forms of pink salmon in Aniva Bay and Iturup Island, 1967-2010.

Annual changes in pink salmon length and migration timing for the two areas were calculated for the total run of fish and separately for the late form (Fig. 5). Regarding the late form of pink salmon, changes in fork length and particularly in migration timing have become more coherent in the two areas. Judging from the fact that mean abundance of the early form is lower and annual variability is greater (Fig. 4); the larger number of eggs produced by early-form females reflects a higher mortality. Long-term trends in abundance of both forms in Aniva Bay and on Iturup Island are weakly correlated with climatic indices and with area.

For a long time, it was not clear why researchers have failed to identify a pink salmon biological response to counteract worsening ocean feeding conditions, as has been shown for chum salmon. But this study of early and late forms of pink salmon has provided some interesting results on this subject. I observed that females become relatively larger than males when growth is slowed (Kaev 2010b). As there is a positive relationship between female length and fecundity, this feature may be a population response that supports reproduction when feeding conditions change for the worse.

Study of the early and late forms of pink salmon has yielded another result. Direction (positive or negative) of long-term fluctuations in the proportion of the two forms coincide with each other only for particular time periods in the areas studied (Aniva Bay and Iturup Island; Fig. 6). Fluctuations in abundance over time indicate the early form of pink salmon is less resistant to environmental change. A synchronous decline in the proportion of the early form in several areas can be viewed as a warning of a forthcoming reduction in the total abundance of pink salmon. During a previous synchronous decrease in the proportion of the early form, pink salmon abundance declined in the 1980s, especially on Sakhalin, and there was a change in the dominant pink salmon line on Iturup Island in 1993. Since 2005, a synchronous decrease in the proportion of the early form has been observed. This may forecast a future reduction in total pink salmon catches, and it seems that this process has already started.

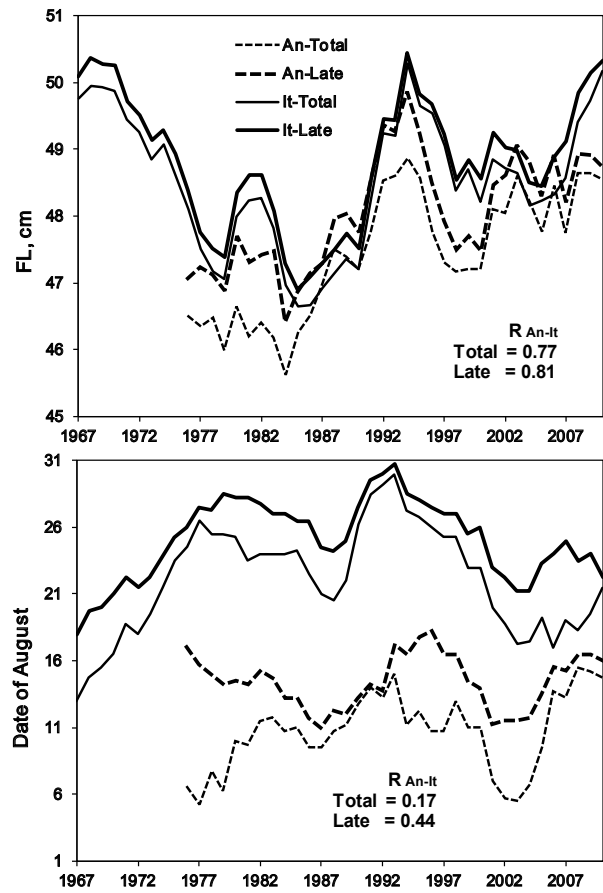


Fig. 5. Annual changes (smoothed as the 4-year running average) in the total run (Total) and the late form (Late) of pink salmon fork length (FL; upper panel) and migration timing (D: date of 50% capture; lower panel) in Aniva Bay (An) and Iturup Island (It), 1967-2010.

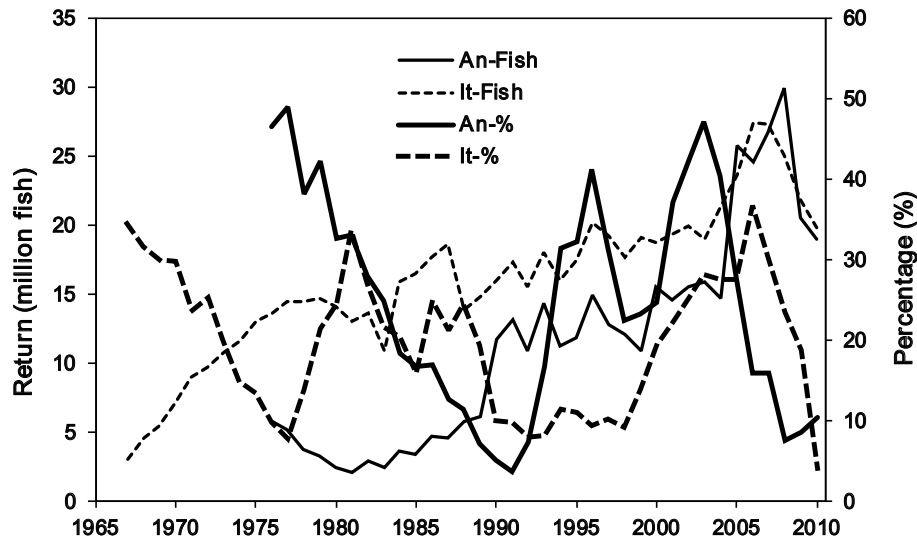


Fig. 6. Annual changes (smoothed as the 4-year running average) in return (Fish) and proportion of the early form of pink salmon (%) in Aniva Bay (An) and Iturup Island (It), 1967-2010.

According to some researchers (e.g., Sukhanov and Tiller 2000) the 11-year solar cycle is related to long-term changes in salmon abundance. As noted, there have been decreases in catch dynamics during which a short-term or periodic change in dominant lines has occurred that coincided with solar activity maxima (Fig. 7). The next-to-last decrease occurred during a decline in solar activity, and the last decline occurred during a solar activity minimum. I interpret this to mean there is no explicit synchronization between solar activity and pink salmon abundance in the southern Sakhalin area.

The magnitude of recent fluctuations in abundance between parent and progeny generations and between even- and odd-year lines is striking. These abrupt changes in catch are a sign of environmental instability that coincided with a subsequent synchronous decline in the proportion of the early form of pink salmon in different areas. If this hypothesis is true, the statistical evidence will not be available soon. Currently, this is only my intuitive sense of the link between the environment and pink salmon abundance. I proceed with the assumption that pink salmon respond to environmental processes earlier than we will notice these processes. After all, pink salmon experience and respond to the environment quicker than we can observe it with our standard research methods (Rachlin et al. 1987).

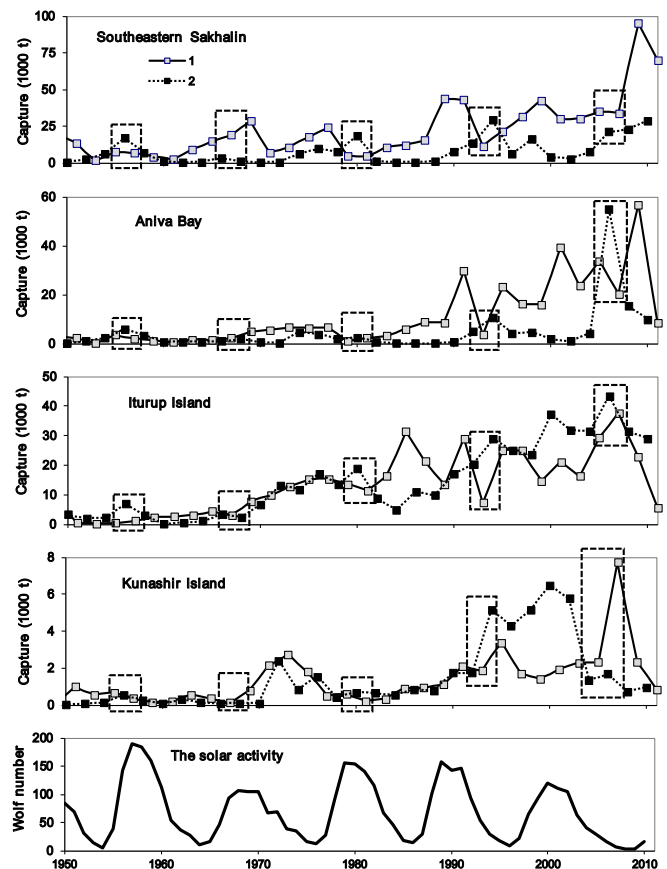


Fig. 7. Solar activity and dynamics of pink salmon catches in odd- (1, grey squares) and even- (2, black squares) numbered years in southern areas of the Sakhalin region, 1950-2011. Boxes highlight synchronous decreases and a shift in the dominant line of pink salmon.

REFERENCES

- Kaeriyama, M., H. Kudo, and H. Seo. 2009. Global warming effects on the early ocean life of Hokkaido chum salmon. *In* Understanding ecosystem dynamics and pursuing ecosystem approaches to management. PICES Annual Meeting Abstracts October 23 - November 1, 2009. Jeju, Republic of Korea. p. 45.
- Kaev, A.M. 2010a. Significance of pink and chum salmon hatchery for their fishery in Sakhalin Region. *Rybnoye Khoziaystvo (Fisheries)* 5: 57–61. (In Russian).
- Kaev A.M. 2010b. Some questions on pink salmon stock dynamics in relation with its temporal structure. *In* Conception of the Far East Basin Program for studying Pacific salmon. Bull. 5: 89–96. TINRO Publishing, Vladivostok. (In Russian).
- Rachlin, J.W., A. Pappantoniou, and B.E. Warkentine. 1987. A bias estimator of the environmental resource base in diet preference studies with fish. *J. Freshwater Ecol.* 4: 23–31.
- Sukhanov, V.V., and I.V. Tiller. 2000. Spectral analysis of catch fluctuations in Kamchatka salmonid fishes. *Vopr. Ichthyologii* 40: 241–246. (In Russian)

Trends of Chum and Pink Salmon Production in Chukotka

Yury N. Khokhlov

*Chukotka Branch, Pacific Scientific Research Fisheries Center (TINRO-Center), 56, Otko St.,
Anadyr, Chukotsky Autonomous Region 689000, Russia*

Keywords: chum salmon, pink salmon, abundance, catch, Anadyr, Chukotka

Chukotka is a unique region in the Russian Far East where there are no hatcheries and salmon catches are low. Anadyr River chum salmon average approximately 90% of the total Chukotka salmon catch and abundance in even-numbered years. There are millions of fish that return annually, and in the last eight years the annual run of Anadyr chum salmon numbered about 3 million. The share of Anadyr chum within the total chum salmon catch in the Russian Far East from 1971 to 2010 varied from 0.2 to 27.8% and averaged 9.95%.

Anadyr chum salmon spawn in various locations and sometimes individual spawning grounds are located at considerable distances from one another. The large spatial separation of spawning areas initially led researchers to assume the presence of subpopulations, or even separate populations, in the stock structure of Anadyr chum salmon. But recent genetic results have shown the absence of significant distinctions between samples of Anadyr chum salmon from different spawning areas. Thus, for estimations of abundance Anadyr chum salmon are not divided into separate groups.

Chum salmon abundance is estimated on the basis of catches by beach seines and observations of fish in index areas in the middle section of the Anadyr River. To examine long-period fluctuations in Anadyr chum salmon abundance, a one-hundred year series of annual catch data were smoothed using an un-weighted sliding average. Results show there is a 40- to 50-year fluctuation in abundance of Anadyr chum salmon (Fig. 1). Anadyr chum salmon abundance increased in the 1930s-1940s and again in the 1980s, with annual catches averaging about 5000 tonnes and 4000 tonnes, respectively, during the two peak periods. According to this pattern of fluctuation, one would expect the next peak in abundance to occur about 2026-2036, but current and future natural processes, such as the climate warming currently observed in Chukotka, will need to be taken into account in order to make informed forecasts.

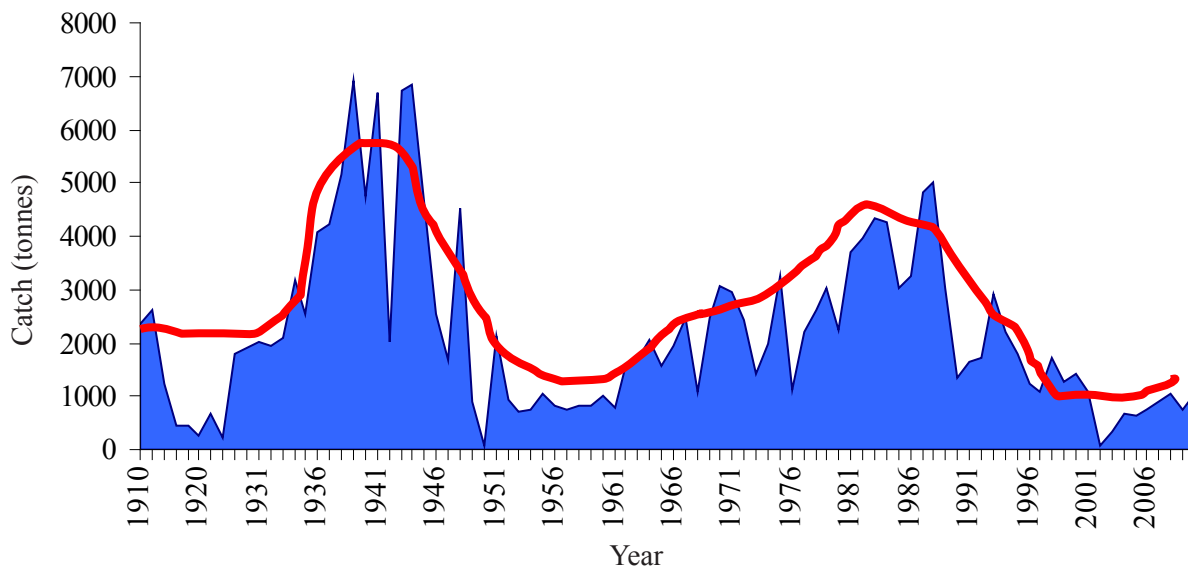


Fig. 1. Annual catch as a measure of abundance of Anadyr River chum salmon, 1910-2011. Red line indicates data smoothed using an un-weighted sliding average.

Fluctuations in Anadyr chum salmon abundance correlate with change in the temperature anomaly of the earth's average surface air temperature (Global dT). This is one of the basic climate indicators that characterizes long-period fluctuations in the earth's climate and has been correlated with changes in salmon productivity and productivity of other fish species (Klyashtorin and Lyubushin 2005). Within the long-period trend, there are short-term fluctuations in Anadyr chum salmon abundance caused by different local factors. For example, over the last 17 years of increasing chum salmon abundance there

have been 3- to 4-year short-term fluctuations in abundance. Local increases or decreases in abundance can be forecasted using data on chum salmon age structure. A low percentage of returning two-year old chum salmon in one year signals smaller runs the following year.

In odd-numbered years, pink salmon abundance and catch in Chukotka increases considerably, although it is difficult to estimate the total abundance of pink salmon returning. Despite the annual catch of pink salmon, the regular count of pink salmon catch has only been conducted in recent years. Aerial estimates of pink salmon abundance were conducted during special flights in 1985-1992. More recently, estimates were conducted by observers in the Mejnypilgynsky lake-river system and the Kajpylgin and Maynitz Lakes, where the largest pink salmon stocks exist and over half a million individuals were noted. In other lake systems draining to the Bering Sea, pink salmon abundance is less, and in the majority of these areas the number of fish does not exceed a thousand individuals. According to the aerial counts, pink salmon abundance in Chukotka was estimated at about seven hundred thousand. Recent results from counts in the Mejnypilgynsky lake-river system and other places suggested it was likely that pink salmon abundance in the beginning of 21st century was considerably higher than estimates obtained by observers on aircraft.

As clearly indicated by catches, Chukotka pink salmon abundance is dominated by runs in odd-numbered years. Pink salmon abundance in the last seven years is estimated at about 2-3 million fish, but this does not account for the abundance of fish escaping to spawning areas. There are three reasons for the lack of detailed information on pink salmon abundance in Chukotka. (1) There is an absence of reliable catch statistics in many rivers where indigenous people of Chukotka fish. In practice, fishing activities likely occur in almost all small watersheds. (2) There is a lack of commercial processing with the capability of handling large catches of pink salmon, and this leads to fishing that concentrates on higher-value species, i.e., sockeye and chum salmon. (3) Catch monitoring and research is nonexistent on many rivers where pink abundance is known to be high.

REFERENCES

Klyashtorin, L.B, and A.A. Lyubushin. 2007. Cyclic climate changes and fish productivity. VNIRO Publishing, Moscow. 224 pp.

Fluctuation of Japanese Chum Salmon Returning Rate Related to Sea Surface Temperatures Along the Spawning Migration Route

Toru Nagasawa¹ and Tomonori Azumaya²

¹*Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan*

²*Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
116 Katsurakoi, Kushiro 085-0802, Japan*

Keywords: chum salmon, adult return rate, sea surface temperature, migration

Asian chum salmon catches, including Japanese stocks, increased following the 1977 regime shift and have maintained a high level of catch since then. A large portion of Japanese chum salmon stocks originate in hatcheries, and the number of chum salmon smolt releases has been almost constant (1,817-2,094 million) since 1980. Although there has been a constant enhancement effort, the number of returning chum salmon has fluctuated (44-89 million) after 1990. Before 1993, the average release size of chum salmon from hatcheries in Hokkaido was positively related to the return rate of Hokkaido chum salmon. After 1994, when the average release size was over 1.0 g, sea surface temperatures (SSTs) along the migration route from the Bering Sea to natal rivers in Hokkaido during September have been negatively related to the return rate of chum salmon. Archival tag data indicated that maturing chum salmon avoid warm waters (higher than 16°C) in both their horizontal and vertical movements. We have supposed the survival rate during the early sea life period was connected to year-class strength and return rate of Japanese chum salmon. We propose the additional working hypothesis that water temperatures along the spawning migration route in the northwestern Pacific affects the number of returning Japanese chum salmon.

Recent Patterns in Return Rate of Chum Salmon to Different Regions of Hokkaido

Yasuyuki Miyakoshi and Mitsuhiro Nagata

Salmon and Freshwater Fisheries Research Institute,
 Hokkaido Research Organization, Eniwa, Hokkaido 061-1433, Japan

Key words: chum salmon, hatchery program, Hokkaido, return rate

Japanese chum salmon *Oncorhynchus keta* has contributed substantially to the recent high abundance of chum salmon in the North Pacific, representing more than 54-72 % of total commercial chum salmon catches during 2000-2009 (NPAFC, www.npafc.org/new/index.html). Hokkaido is the principal area of salmon production in Japan. Hokkaido chum hatchery production is intensive; currently an annual total of ~one billion hatchery-reared chum salmon juveniles are stocked in 140 rivers and 80 net-pen sites. The number of chum salmon returning to Hokkaido has been at historical high levels since the 1990s. Recent high returns have been attributed to favorable ocean conditions in the North Pacific (Kaeriyama et al. 2009) and to innovations in hatchery technology that improved release timing and fish quality by feeding fry at the hatchery (Kobayashi 1980; Kaeriyama 1999). Fry are reared for more than one month in hatcheries, making it possible to release them when the river and coastal environmental conditions are favorable.

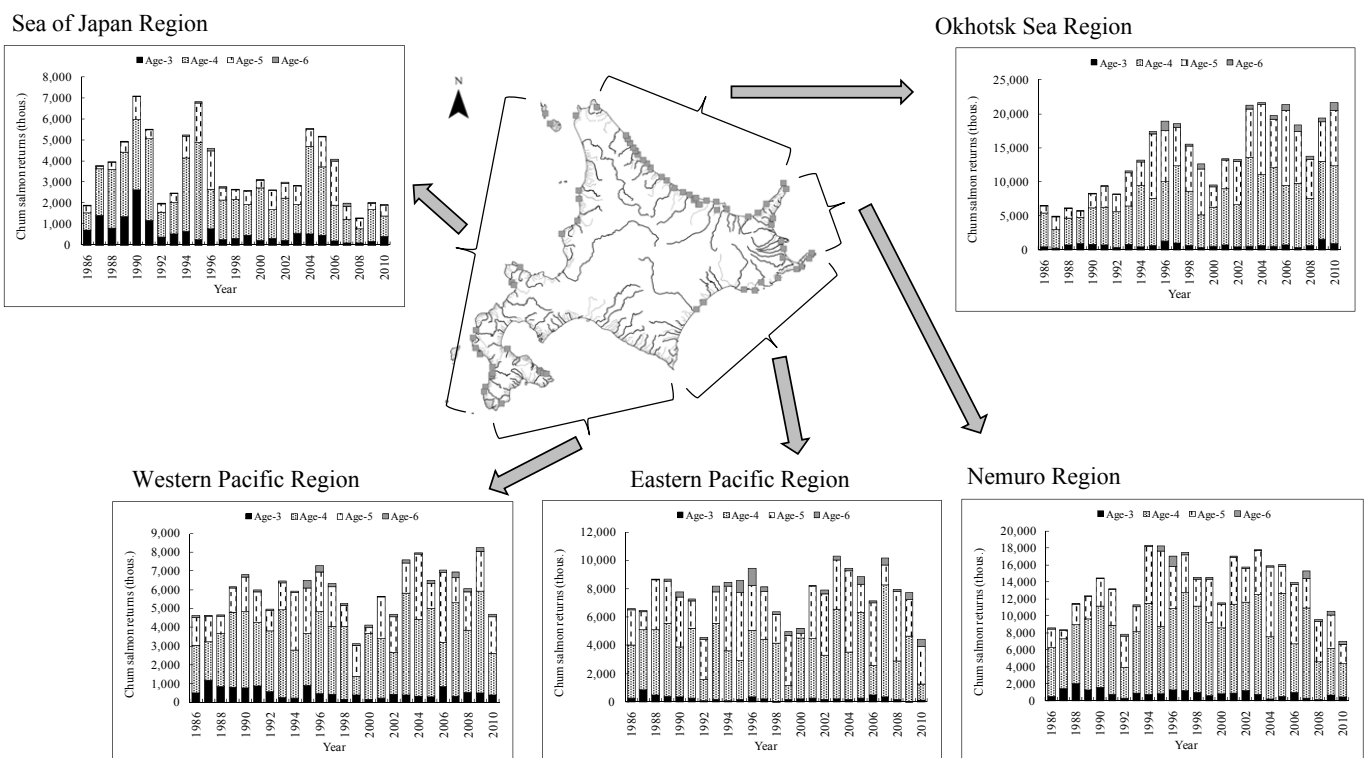


Fig. 1. Number of adult chum salmon returning to the Okhotsk Sea, Sea of Japan, and Pacific Ocean regions of Hokkaido stratified by age in thousands of fish, 1986-2020.

In its efforts to enhance commercial chum salmon stocks, the Hokkaido chum salmon hatchery program is considered successful. Nevertheless, many research areas require further investigation to continue making improvements to the program. Despite recent high return rates, since the late 2000s inter-annual fluctuations and large differences in return rates have been observed among regions in Hokkaido (Fig. 1). For example, return rates are historically high in the Okhotsk Sea region, relatively low in the Sea of Japan region, and highly variable in the Pacific Ocean region. Return of adults to

the Okhotsk Sea region has provided a substantial portion of total chum salmon return to Hokkaido in the last few years. Since 2000, return rates have varied significantly with distinct year-to-year variations in adult fish returning to the Nemuro Strait and Pacific Ocean regions (Fig. 2). In the last few years, there have been remarkable declines in returns to the Pacific Ocean and Nemuro Strait regions. Research has been conducted to clarify the causes of these fluctuations (e.g. Miyakoshi et al. 2007; Saito and Nagasawa 2009; Saito et al. 2011) and several investigators have focused on environmental factors in coastal waters during the residence of juvenile salmon (Nagata et al. 2007; Saito et al. 2009). It has been recommended that hatchery-reared juveniles should be released when coastal sea water temperatures range from 5° to 10°C (Kobayashi 1980). However, the timing when coastal sea water temperatures are within this range has been gradually changing.

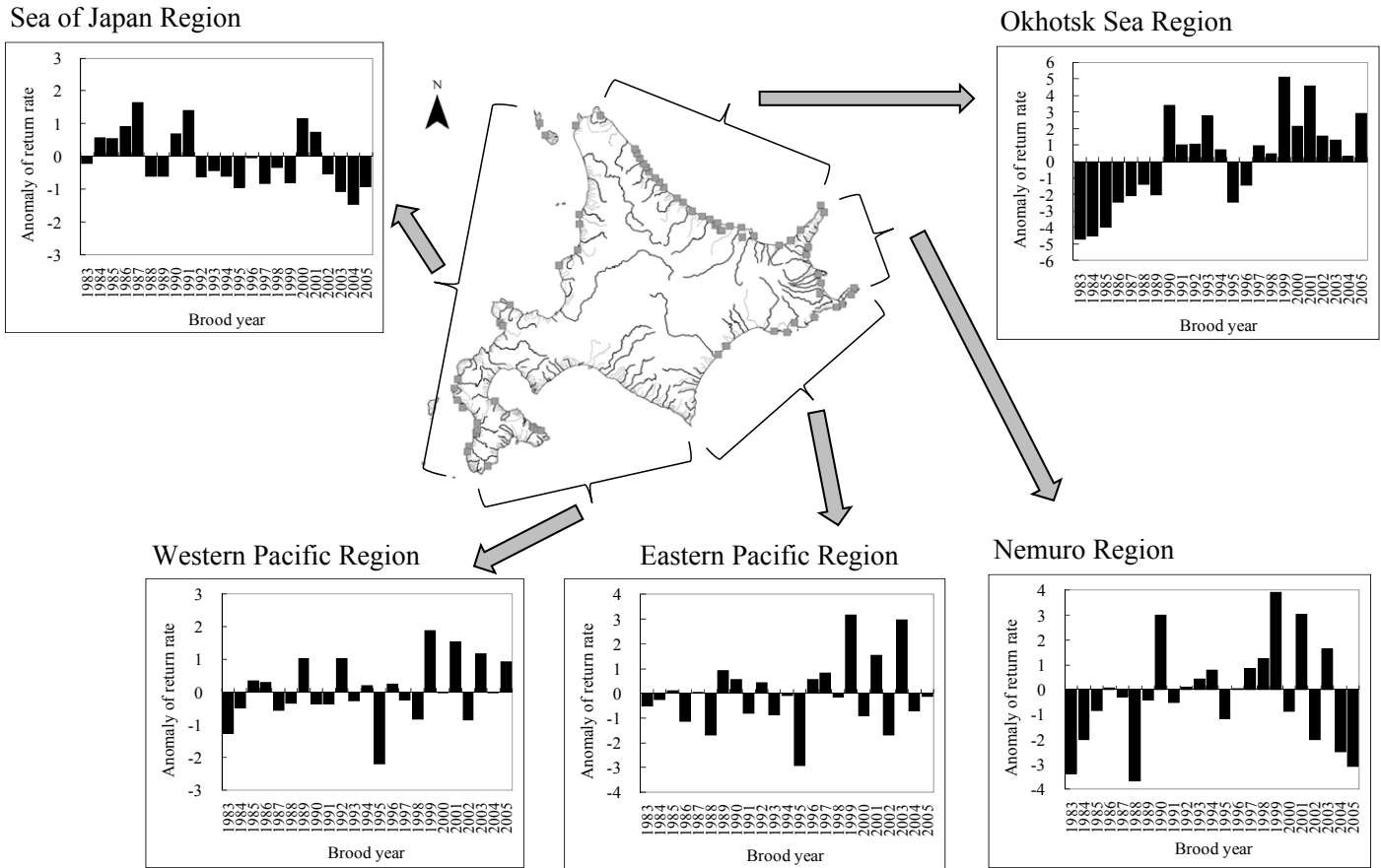


Fig. 2. Anomalies in the rate of return of adult chum salmon to the Okhotsk Sea, Sea of Japan, and Pacific Ocean regions of Hokkaido by brood year, 1983-2005.

Hokkaido hatchery practices continue to be modified and improved. Release size has been increased by improvement of rearing techniques and expansion of rearing facilities. The mean size of chum salmon fry was 0.8 g in 1987, exceeded 1.0 g in 1991, and attained 1.3 g in 2009. Although mean size has increased, release size differs among regions, and the effect of release size on return rate is highly variable in fish weighing over 1 g (Nagata and Kaeriyama 2004). Rearing density at hatcheries also differs greatly among regions, which may affect the quality of fish upon release. In the last decade, the proportion of hatchery-reared fish being released from net-pens increased, although the annual number of fish released has been constant. Contrasting hatchery stocking practices and differing regional coastal environments may affect the patterns in recent return rates of chum salmon to Hokkaido.

Although the hatchery program has been the major management tool for chum salmon in Hokkaido, assessment of naturally-spawning chum salmon has begun (Miyakoshi et al. 2012). Thus far, assessments have emphasized the distribution of naturally-spawning chum salmon. Results indicate that chum salmon spawn naturally in many rivers. A number of research areas have been identified for future examination including variation in run timing, quantitative estimation of run sizes, condition of spawning habitats, straying, and the genetic structure of naturally-spawning chum salmon (Miyakoshi et al. 2012).

In the future, Hokkaido's hatchery program will continue to be a major management tool for chum salmon and the program will continue to be evaluated scientifically and modified as necessary to adapt to climate change, conserve natural spawning populations, and support sustainable fisheries.

REFERENCES

- Kaeriyama, M. 1999. Hatchery programmes and stock management of salmonid populations in Japan. *In* Stock enhancement and sea ranching. *Edited by* B.R. Howell, E. Moksness, and T. Svåsand. Blackwell Science, Oxford. pp. 153-167.
- Kaeriyama, M., H. Seo, and H. Kudo. 2009. Trends in run size and carrying capacity of Pacific salmon in the North Pacific Ocean. *N. Pac. Anadr. Fish Comm. Bull.* 5: 293-302. (Available at www.npfc.org).
- Kobayashi, T. 1980. Salmon ranching in Japan. *In* Salmon ranching. *Edited by* J.E. Thorpe. Academic Press, London. pp. 91-107.
- Miyakoshi, Y., M. Nagata, and S. Saitoh. 2007. Sea surface temperature measured by satellite remote sensing and its effect on the return rate of chum salmon in the eastern region along the Okhotsk Sea. *Sci. Rep. Hokkaido Fish Hatchery* 61: 1-10. (In Japanese with English abstract).
- Miyakoshi, Y., H. Urabe, H. Saneyoshi, T. Aoyama, H. Sakamoto, D. Ando, K. Kasugai, Y. Mishima, M. Takada, M. Nagata. 2012. The occurrence and run timing of naturally spawning chum salmon in northern Japan. *Environ. Biol. Fish.* 94(1): 197-206. DOI: 10.1007/s10641-011-9872-5.
- Nagata, M., and M. Kaeriyama. 2004. Salmonid status and conservation in Japan. *In* Proceedings from the world summit on salmon. *Edited by* P. Gallagher, and L. Wood. Simon Fraser University, Vancouver. pp. 89-97.
- Nagata, M., Y. Miyakoshi, D. Ando, M. Fujiwara, M. Sawada, H. Shimada, and H. Asami. 2007. Influence of coastal seawater temperature on the distribution and growth of juvenile chum salmon, with recommendations for altered release strategies. *N. Pac. Anadr. Fish Comm. Bull.* 4: 223-235. (Available at www.npfc.org).
- Saito, T. and K. Nagasawa. 2009. Regional synchrony in return rates of chum salmon (*Oncorhynchus keta*) in Japan in relation to coastal temperature and size at release. *Fish. Res.* 95: 14-27.
- Saito, T., T. Kaga, E. Hasegawa, and K. Nagasawa. 2011. Effects of juvenile size at release and early marine growth on adult return rates for Hokkaido chum salmon (*Oncorhynchus keta*) in relation to sea surface temperature. *Fish. Oceanogr.* 20: 278-293.
- Saito, T., I. Shimizu, J. Seki, and K. Nagasawa. 2009. Relationship between zooplankton abundance and the early marine life history of juvenile chum salmon in eastern Hokkaido, Japan. *Fish. Sci.* 75: 303-316.

Relationship Between Environmental Variability and Chum Salmon Production at the Southern Limit of Distribution in Asia

Suam Kim¹, Hyunju Seo², and Sukyung Kang²

¹Department of Marine Biology, Pukyong National University,
 599-1 Daeyeon3-dong, Nam-gu, Busan 608-737, Korea.

²National Fisheries Research and Development Institute,
 Gijang-eup, Gijang-gun, Busan 619-705, Korea

Keywords: chum salmon, climate change, North Pacific, salmon production, Asian salmon fishery

Chum salmon (*Oncorhynchus keta*) are distributed mostly in the Okhotsk Sea, the Bering Sea, and North Pacific Subpolar Gyre System, and the larger portion of the total production is from the western side of Pacific Ocean. Catches from Japan, Russia, and Korea increased since the late 1970s and amounted to 250–300 thousand metric tones (MT) annually in the 2000s. Since the climate regime shift in 1976/77, ocean environments seem to be favorable for salmon stocks in the North Pacific Ocean (Beamish and Bouillon 1993). In addition, extensive chum salmon enhancement activities by NPAFC members have caused increases in chum salmon production in the 20th century (Kaeriyama 1998). Recently, chum salmon production in the North Pacific is at a record high, although the causes for the high abundance of chum salmon have not been clearly explained. Areas off the Korean Peninsula and the Japanese islands are considered the southernmost limit of chum salmon distribution in the northwestern Pacific Ocean (Kim et al. 2007). This study aims to investigate the relationship between chum salmon production in this region and environmental conditions, such as climate indices and SST in salmon habitats in the North Pacific, and to provide a basis for discussion of fishery management under conditions of changing environment.

Sea surface temperatures (SSTs) were obtained from SODA V2.2.4 during winter 1970–2008, and climate indices including Pacific Decadal Oscillation Index (PDOI), Arctic Oscillation Index (AOI), Southern Oscillation Index (SOI), and Aleutian Low Pressure Index (ALPI) were correlated with chum salmon catch. Fisheries information was collected from statistical books of NPAFC, Japan, and Korea. Some specific statistics data were obtained from hatcheries in Hokkaido (Japan) and Namdae (Korea). The cumulative sum (CuSum) and cross-correlation function (CCF) methods were used for statistical analysis of data sets.

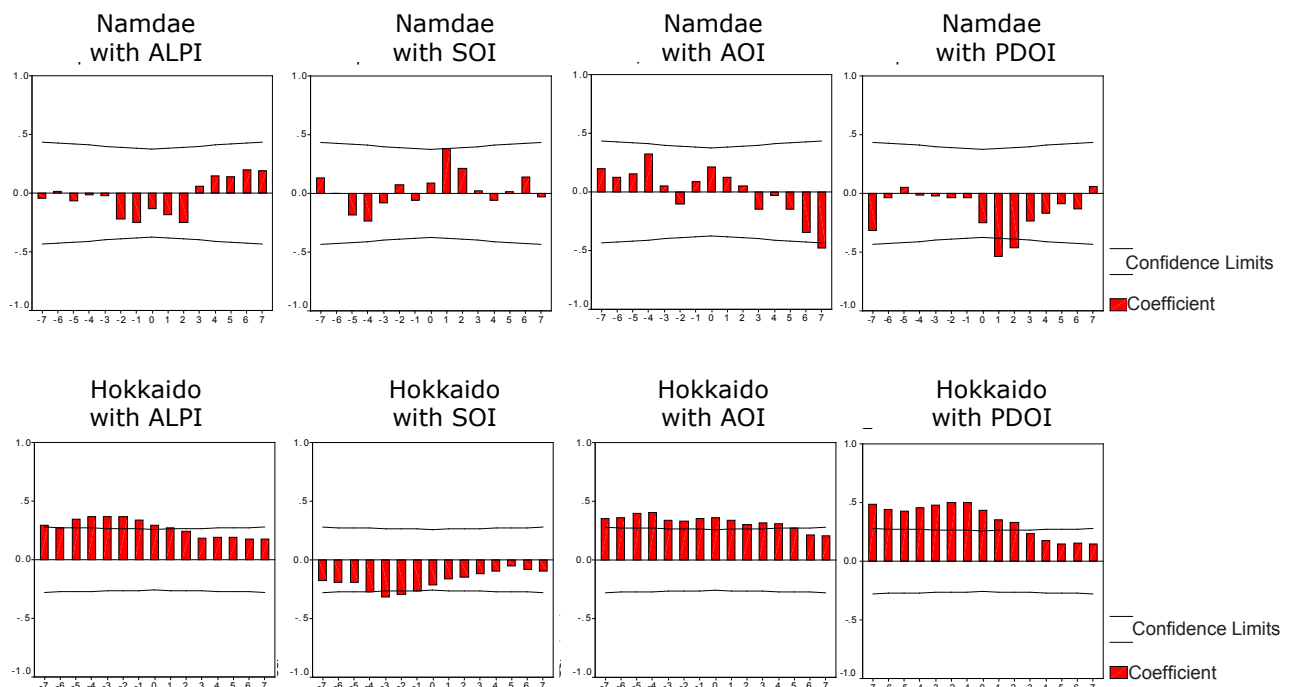


Fig. 1. Results of cross-correlation function (CCF) analysis of chum salmon catches and climate indices.

Chum salmon might be vulnerable to global warming at the southern limit of their distribution in Asia because the warming rate of winter SSTs has been conspicuously high, showing a 0.21 °C increase per decade in the northwestern Pacific during the last four decades (Kim et al. 2012). In contrast, the warming rate at the southern limit of chum salmon distribution in the eastern Pacific (i.e., off the coasts of British Columbia, Washington, and Oregon) has not been evident. The CuSum graph of climate indices showed a turning point in the mid 1970s and less conspicuous changes in the late 1980s and 1990s. Annual mean PDOI, SOI, and ALPI were strongly correlated, but AOI was not correlated with the other indices. Retrospective analysis was conducted using a time-series of climate indices with chum salmon catch. The results of CCF and CuSum analyses indicated that there was a major change in climate during the mid 1970s, and that chum salmon populations responded to this climate event with a time-lag. Hokkaido chum salmon catch and all the climate indices had the highest significant correlations with about a 2~4 year time-lag and that Namdae chum salmon catch did not show any significant correlations, possibly due small sample sizes (Fig. 1).

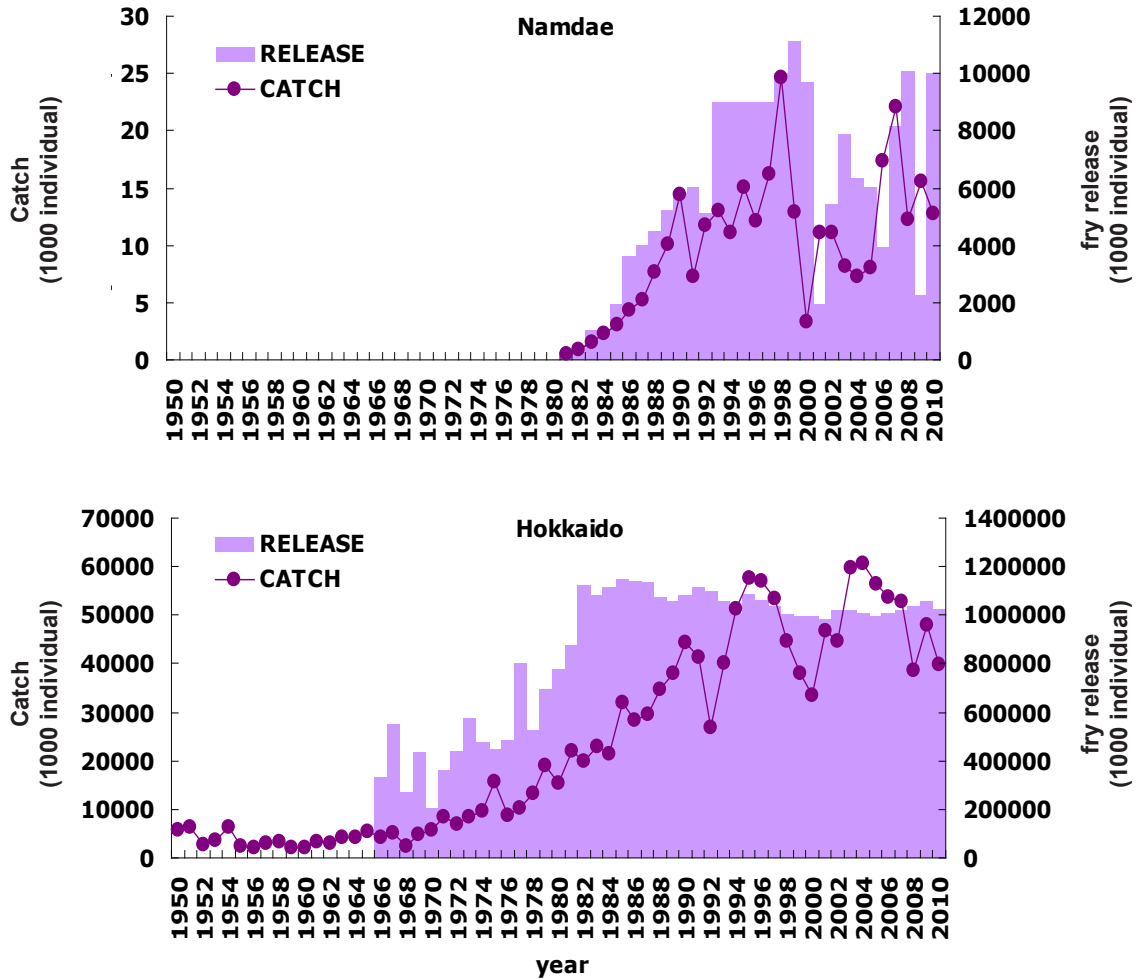


Fig. 2. Number of fry released and catch of returning adult chum salmon to Namdae (Korea) and Hokkaido (Japan).

Returns of chum salmon to Korea and Japan were significantly correlated ($r = 0.618, p < 0.01$), although Japanese catches were much higher than Korean catches. In the beginning of enhancement activities in Korea and Japan, catches of returning salmon were proportional to the number of fry released, but this was not always true due to high environmental variability, such as the 1997/98 El Nino (Fig. 2). We speculated that favorable environmental conditions during early ocean life seemed to be related to better growth and survival of young salmon in coastal areas. However, higher growth in Korean waters during early stages did not seem to relate to improved return rates of spawning adults. Rather, the growth in the Okhotsk Sea or the Bering Sea during the immature stage was significantly correlated with return rate.

Fish size-at-age varied inter-annually, but populations in Japan and Korea trended in similar ways. The body length of Korean female chum salmon decreased prior to the regime shift in 1988/89 and then stabilized at a lower level. The body

length of age-2 male chum salmon at spawning increased from 1984 to 1988, but the trend was negative in older males. The fork length of the Hokkaido population showed a decreasing trend from the late 1970s to the mid 1980s, and has leveled off to a smaller size since then.

In the coming years of the 21st century, it is anticipated that the warming trend in the northwestern Pacific (0.6 °C/decade) will be about 1.5 times higher than the trend in the northeastern Pacific (0.4 °C/decade; McFarlane et al. 2009). Future chum salmon production in Asia might be more seriously threatened by this warming rate than production in North America. Therefore, it is appropriate that fisheries management plans consider changes in climate and that policymakers and scientists begin discussion of strategies and policies by which to utilize and manage chum salmon resources under changing economic and environmental conditions in Asia.

REFERENCES

- Beamish, R.J., and D. Bouillon. 1993. Pacific salmon production trends in relation to climate. *Can. J. Fish. Aquat. Sci.* 50: 1002-1016
- Kaeriyama, M. 1998. Dynamics of chum salmon, *Oncorhynchus keta*, populations released from Hokkaido, Japan. *N. Pac. Anadr. Fish Comm. Bull* 1: 90-102. (Available at www.npafc.org).
- Kim, S., S. Kang, H. Seo, E. Kim, and M. Kang. 2007. Climate variability and chum salmon production in the North Pacific. *The Sea, J. Korean Soc. Oceanogr.* 12: 61-72.
- Kim, S., S. Kang, C.-I. Zhang, H. Seo, M. Kang, and J.J. Kim. 2012. Comparison of fisheries yield and oceanographic features at the southern boundaries of the western and eastern Subarctic Pacific Ocean. *ICES J. Mar. Sci.*, doi:10.1093/icesjms/fss054.
- McFarlane, G. A., C. I. Zhang, J.R. King, S. Kim, R.J. Beamish, and J.H. Oh. 2009. Contrast in life histories of exploited fishes and ecosystem structures in coastal waters off West Canada and East Korea. *Ocean Sci. J.* 44: 43-60.

An Assessment of the State of Chum Salmon Stocks From the East and West Coasts of Kamchatka

Lidia O. Zavarina

*Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO),
18, Naberezhnaya, Str., Petropavlovsk-Kamchatsky, 683600, Russia*

The contribution of Kamchatka chum salmon to the total catch of this species in Russia from 1934 to 2010 ranged from 8% (1995) to 55% (1986, 1990), and averaged 27%. In the recent decade, the catch of Kamchatka chum comprised 38% of the total catch of chum salmon in Russia. Kamchatka chum salmon stocks characteristically demonstrate extensive fluctuations. The catch of chum salmon in Kamchatka for the period 1934–2010 varied from 0.84 (1972) to 35.91 thousand tons (1946), and averaged 11.16 thousand tons. For 2001–2010 the catch of chum salmon along both coasts of Kamchatka increased three times compared to the decade before. Recently there has been an increasing trend. The maximal catch on the west coast of Kamchatka (13.61 thousand tons) was in 2010 and on the east coast (14.81 thousand tons) was in 2005.

An important component of chum salmon commercial stock assessment is the escapement of fish to the spawning grounds. From 1957 to present, the spawning escapement of Kamchatka chum salmon was higher on the east coast. In general the average escapement was about 1.65 million fishes, ranging from 0.39 (1973) to 6.64 million fishes (1959). Minimal average abundance of chum salmon on the spawning grounds of west (0.25 million fish) and east (0.49 million fish) coasts of Kamchatka was observed in 1971–1980. In the next decade, 1981–1990, escapement of chum salmon increased three times. The 1991–2000 decade demonstrated a decrease of chum salmon escapement to West Kamchatka and a two-fold decrease of escapement to East Kamchatka. For the last decade, 2001–2010, the escapement was higher on the west coast, perhaps due to underestimation of the escapement of chum salmon spawning in east coast rivers. From 2001, we observed an intentional increase in escapement and since 2008 chum salmon escapement has decreased.

The maximal and minimal values of brood year abundance can exhibit a 9- to 176-fold difference, depending on the commercial district. We observed an increase in the abundance of brood years 2001–2005 compared to brood years 1991–2000. Thus, the stock abundance and catches of Kamchatka chum salmon were increasing with an increase in escapement and an increase in the subsequent generations. The increase in abundance might arise from better conditions during the freshwater period of life, or from improved feeding conditions at sea.

Cyclic Fluctuations in Chum Salmon Abundance along the Pacific Coast of Hokkaido, Japan

Toshihiko Saito¹, Kyuji Watanabe¹, Kei Sasaki¹, Shigeto Kogarumai² and Shoko H. Morita¹

¹*Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
2-2 Nakanoshima, Toyohiraku, Sapporo, Hokkaido 062-0922, Japan*

²*Tokachi Salmon Field Station
444-55, Taishyo, Obihiro, Hokkaido 089-1242, Japan*

Keywords: chum salmon, pink salmon, coastal sea surface temperature, scale pattern analysis, odd- and even-year fluctuation

Some chum salmon stocks are known to exhibit a two-year cyclic variation in their biological parameters, such as age at maturity, size, marine survival, and abundance (Salo 1991). Previous studies suggest that this variation appears to be associated with pink salmon, which have a prominent two-year cyclic pattern of abundance (Salo 1991; Ruggerone and Nielsen 2004). On the Pacific coasts of Hokkaido (East Pacific, EP; West Pacific, WP) abundance of adult chum salmon, calculated on the basis of coastal and river catches, shows odd- and even-year fluctuations after the 1998 brood year. A similar fluctuation is also observed in chum salmon caught in the southern region of the Sea of Okhotsk, adjacent to the Nemuro Strait (Nemuro, NE). The objective of this study was to explain a possible mechanism causing the cyclic pattern of returning adult chum salmon.

Of 48 chum salmon river-stocks along the Sea of Okhotsk and Pacific coasts of Hokkaido, 11 stocks from the Pacific coast illustrate cyclic fluctuations in abundance for brood-years 1998-2004. Only one stock from the Sea of Okhotsk exhibit these cyclic fluctuations. Findings demonstrated that a few stocks from rivers on the Pacific coast cause the cyclic patterns in brood-year abundance in the NE, EP, and WP regions. In general, mass mortality of chum salmon occurs during early marine residence and frequently affects the brood-year abundance of returning adult salmon (Saito and Nagasawa 2009; Saito et al. 2011). The mass mortality is believed to be associated with biological interactions, like predation (Duffy and Beauchamp 2008), and oceanic conditions (Saito et al. 2011). In this study, effects of Asian pink salmon and sea surface temperature (SST) on brood-year abundance were tested to examine whether this could explain the cyclic fluctuations of these chum salmon stocks.

In Japan, spawning stocks of pink salmon are mainly distributed in rivers along the Sea of Okhotsk coast, and no abundant spawning stocks exist in rivers on the Pacific coast of Hokkaido. This suggests that chum salmon from the Pacific coast have no interaction with pink salmon during their freshwater and coastal residency. After leaving Japanese coastal waters, juvenile chum salmon migrate to the Sea of Okhotsk and remain there from August through November of their first ocean year (Urawa 2000; Urawa et al. 2004). During this period, Japanese juvenile chum salmon intermingle with Asian juvenile pink salmon originating in Japan and the Russian Far East (e.g., Ogura 1994; Nagasawa 2000). However, unlike chum from the Pacific coast, almost all Japanese chum salmon from rivers located on the Sea of Okhotsk coast do not show cyclic fluctuations in abundance. Juvenile chum salmon from both regions of Hokkaido co-mingle in the Sea of Okhotsk, so it was unexpected that fluctuations in brood-year abundance would occur only for stocks from the Pacific coast. Based on the distribution patterns of both chum and pink salmon, we hypothesized that juvenile chum salmon may overlap the distribution of maturing pink salmon on their homeward migration before both species enter the Sea of Okhotsk.

Of the 11 stocks showing cyclic fluctuations in abundance in brood-years 1998-2004 (the year of sea entry, 1999-2005), eight stocks were negatively correlated with catches of Asian pink salmon during 1999 to 2005. Adult chum salmon scales collected from age-0.3 adult fish in the Tokachi and Yurappu Rivers were measured to examine whether the growth during the first ocean year was affected by the presence of Asian pink salmon. These two stocks are representative of stocks from the Pacific coast. Circuli spacing on four areas of the scale (1-5th circulus, 5-10th circuli, 10-15th circuli, and 15th circulus-1st annulus) did not show cyclic growth fluctuations for either stock. This suggested there was no evidence that growth in the first ocean year was affected by the presence of pink salmon.

To detect if there was an effect of SST on chum salmon abundance, brood-years 1998-2004 from four of the most abundant stocks on the Pacific coast (Tokachi, Kushiro, Hiroo, and Yurappu) were compared to SST fluctuations. To clarify the spatial and temporal relationship between brood-year abundance and SSTs, the time series of chum salmon abundance was correlated with the corresponding average 10-day SST for a 1°X 1° grid from 40°N to 60°N and 140°E to 180°E during March of the year of sea entry and May of the second ocean year (i.e., from time of sea entry to the end of the first winter at sea). For comparison, the same analyses were repeated for brood-years 1991-1997, which did not show cyclic fluctuations in abundance.

The most remarkable difference between the two sets of data was found in the results for the coastal areas around Hokkaido. From March through July, the four stocks showed statistically positive correlations between brood-year abundance and SSTs in coastal waters for brood-years 1998-2004, but not for brood-years 1991-1997. These correlations indicate that coastal SSTs around Hokkaido fluctuated with the same cyclic pattern as chum salmon abundance during the spring-early summer of 1999 through 2005, and this pattern of SSTs may have affected the survival of juvenile chum salmon from the EP and WP regions.

When the time series was extended to brood-year 2006, the abundance of brood-years 1998-2006 was re-defined as the total number of returning adult salmon of age-0.1 to -0.3 fish in each brood year. The coastal SSTs no longer showed statistically significant correlations with abundance of either the EP or WP regions, although the catch of Asian pink salmon was still a valid variable to explain the cyclic fluctuation of brood-year abundance in the EP region. A comprehensive mechanism is not still clear, and does not yet explain how recent increases in Asian pink salmon production may negatively affect the survival of juvenile chum salmon originating on the Pacific coast of Hokkaido. We should consider two possibilities for future research: (1) a direct impact of pink salmon on chum salmon, and (2) a spurious interaction between pink and chum salmon. The former may include predation by adult pink salmon on juvenile chum salmon, and the latter indicates an unknown environmental factor that acts positively on the pink salmon abundance, but negatively on chum salmon abundance.

REFERENCES

- Duffy, E.J., and D.A. Beauchamp. 2008. Seasonal patterns of predation on juvenile Pacific salmon by anadromous cutthroat trout in Puget Sound. *Trans. Am. Fish. Soc.* 137: 165-181.
- Nagasawa, K. 2000. Long-term changes in the climate and ocean environment in the Okhotsk Sea and western North Pacific and abundance and body weight of East Sakhalin pink salmon (*Oncorhynchus gorbuscha*). *N. Pac. Anadr. Fish Comm. Bull.* 2: 203-211. (Available at www.npafc.org).
- Ogura, M. 1994. Migratory behavior of Pacific salmon (*Oncorhynchus* spp.) in the open sea. *Bull. Nat. Res. Inst. Far Seas Fish.* 31: 1-139. (In Japanese with English abstract).
- Ruggerone, G.T., and J.L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. *Rev. Fish Biol. Fish.* 14: 371-390.
- Saito, T., T. Kaga, E. Hasegawa, and K. Nagasawa. 2011. Effects of juvenile size at release and early marine growth on adult return rates for Hokkaido chum salmon (*Oncorhynchus keta*) in relation to sea surface temperature. *Fish. Oceanogr.* 20: 278-293.
- Saito, T., and K. Nagasawa. 2009. Regional synchrony in return rates of chum salmon (*Oncorhynchus keta*) in Japan in relation to coastal temperature and size at release. *Fish. Res.* 95: 14-27.
- Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). In *Pacific salmon life histories*. Edited by C. Groot, and L. Margolis. UBC Press, Vancouver. pp. 231-309.
- Urawa, S. 2000. Ocean migration route of Japanese chum salmon with a reference to future salmon research. *Nat. Salmon Res. Ctr. Newsletter* 5: 3-9. (In Japanese).
- Urawa, S., J. Seki, M. Kawana, P.A. Crane, L.W. Seeb, K. Gorbatenko, and M. Fukuwaka. 2004. Juvenile chum salmon in the Okhotsk Sea: their origins estimated by genetic and otolith marks. *N. Pac. Anadr. Fish Comm. Tech. Rep.* 5: 87-88. (Available at www.npafc.org).

Natural Reproduction of Pink Salmon (*Oncorhynchus gorbuscha*) on the Okhotsk coast of Hokkaido, Japan

Masaya Iida¹, Tsuyoshi Kato² and Hiroshi Tokuda²

¹Japan Sea National Fisheries Research Institute,
1-5939-22 Suido-cho, Chuo-ku, Niigata 951-8121, Japan

²Hokkaido National Fisheries Research Institute Nemuro Field Station
Nakashibetsu, Hokkaido 086-1109, Japan

Keywords: natural spawning, pink salmon, spawning redd, weir

The pink salmon population (*Oncorhynchus gorbuscha*) returning to Hokkaido, Japan, increased substantially from 1975 to 2000. Despite constant hatchery fry releases, the pink salmon catch exhibited a biennial oscillation indicating a fixed 2-year life cycle and a large addition of wild fish. Using a mathematical model, Morita et al. (2006) determined that the observed increases in the Japanese pink salmon catch could be explained primarily by climate change, and they attributed production to wild fish production because increasing hatchery releases had little effect on abundance of returning adults.

In Hokkaido, most major rivers have weirs completely blocking the upstream migration of fish in order to capture hatchery broodstock. Therefore, we assumed that rivers with weirs were unsuitable for natural spawning of pink salmon. To check this assumption and investigate the conditions of naturally spawning pink salmon in the Tokoro River, we conducted field surveys to visually inspect spawning streams for counts of pink salmon and redds.

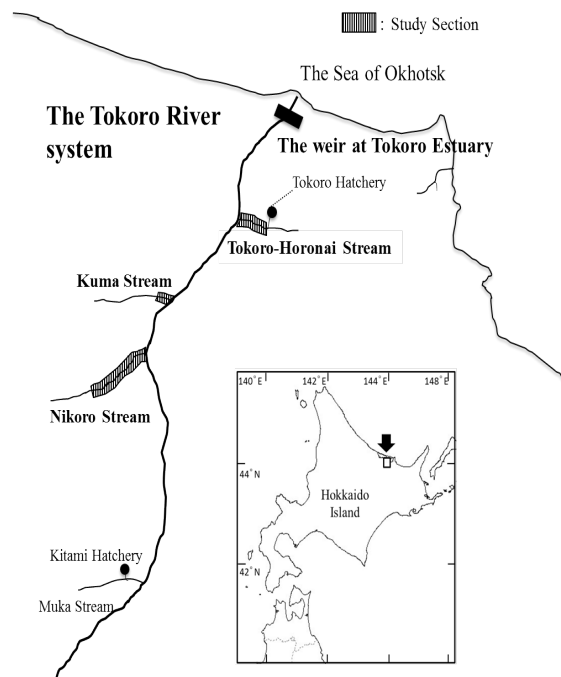


Fig. 1. Location of visual surveys conducted in three streams and the weir across the Tokoro River on the Okhotsk coast of Hokkaido.

We visually surveyed three tributaries: Tokoro-Horonai, Kuma, and Nikoro Streams (Fig. 1) with survey lengths (areas) of 821 m (3,454 m²), 317 m (998 m²), and 1,152 m (12,909 m²; Table 1), respectively. In 2010, we quantified the number of pink salmon and redds once every 10 days from the beginning of August until the beginning of October. We could not determine when the redds were made, but we confirmed there was superimposition of the redds by subsequent arrival of salmon on the spawning grounds. We counted all redds found daily during the investigation. Throughout the survey, the weir was not submerged and functioned normally.

Table 1. Description of the tributary streams of the Tokoro River, Hokkaido, Japan.

Stream	Length (m)	Width (m)	Area (m ²)
Tokoro-horonai	821	4.2±1.1	3,454
Kuma	317	3.1±0.4	998
Nikoro	2,290	10.6±2.5	12,909
Total	3,428		17,361

The data from the three streams followed similar trends. The number of naturally spawning pink salmon increased in early September, reached a maximum in mid September, and decreased in late September. In mid September, there were 1376, 20, and 360 spawning pink salmon in the Tokoro-Horonai, Kuma, and Nikoro Streams, respectively. The number of redds also increased in September. There were 1007, 165, and 773 redds in the Tokoro-Horonai, Kuma, and Nikoro Streams, respectively (Fig. 2). The Tokoro-Horonai Stream, which is located nearest to the Tokoro Estuary, had the highest redd density (Fig. 3).

We estimated the number of naturally-spawned eggs in the study areas. Pink salmon eggs are distributed in two or three, and sometimes four redds (Kaganovsky 1949; Soin 1954; Smirnov 1975). Most eggs are laid at low to moderate spawner densities. At high density, spawning is often interrupted and only some eggs are deposited (Semko 1954; Helle et al. 1964). Assuming that one redd contained half of the average female fecundity (approximately 1500 eggs), we estimated the total number of eggs in the study areas by multiplying the number of confirmed redds by half of the female average fecundity. The estimated number of eggs spawned was 755,000, 124,000, and 580,000 in the Tokoro-Horonai, Kuma, and Nikoro Streams, respectively (Table 2).

To collect newly emerged fry and determine the condition of the redds, we removed 0.39 m³ of gravel, (1.0 m X 1.3 m wide X 0.3 m deep) from the redds in the Tokoro-Horonai River on 28 February, 2011. A total of 491 pink salmon, 383 chum salmon (*Oncorhynchus keta*), 6 unknown fry, and approximately 500 dead eggs were collected from the gravel. We estimated 1,459,000 eggs were spawned in the 17,361 m² study area during the investigation, which suggests a very large total number of eggs were spawned over the entire 1,930 km² of the Tokoro River.

Although it appeared to be functioning normally, the weir did not block migration completely because many pink salmon migrated upstream over the weir. We assumed the weir contained some gaps through which pink salmon were able to pass. The gaps could have been formed by debris in the water or by water pressure.

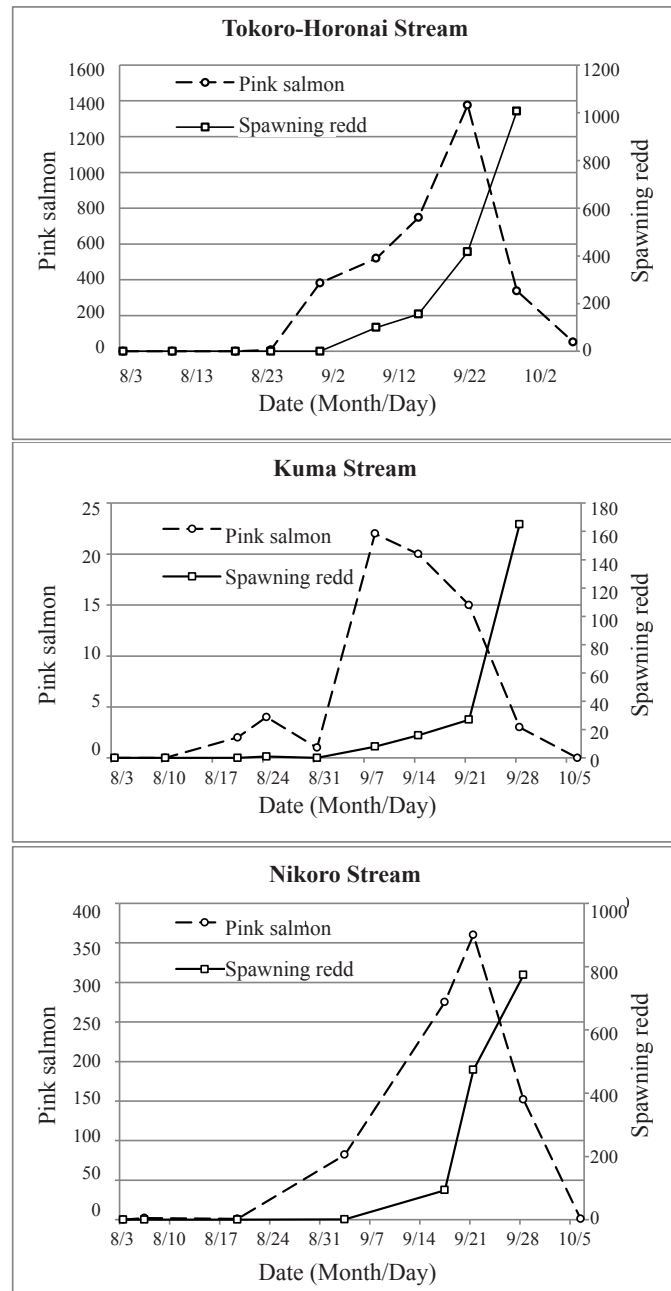


Fig. 2. Number of pink salmon and redds observed in three streams of the Tokoro River.

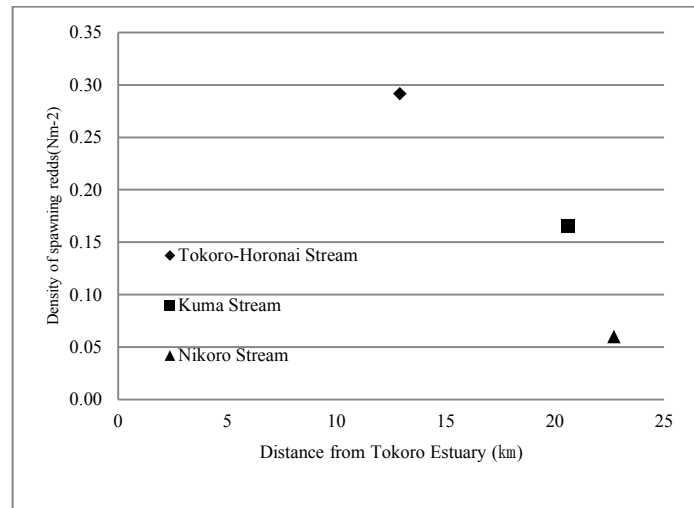


Fig. 3. Relationship between the density of redds in three streams of the Tokoro River and the distance from Tokoro Estuary (km).

Table 2. The number of redds and estimated number of naturally-spawned pink salmon eggs in the Tokoro-Horonai, Kuma, and Nikoro Streams.

Stream	Study area (m ²)	Redds	Number spawned eggs (thousands)
Tokoro-horonai	3,454	1,007	755
Kuma	998	165	124
Nikoro	12,909	773	580
Total	17,361	1,945	1,459

The assumption that the weir completely blocks the upstream migration of pink salmon was not correct, and we concluded that a substantial number of naturally-spawning pink salmon were able to move into the river and successfully spawn in the tributaries of the Tokoro River.

REFERENCES

- Helle, J.H, R.S. Williamson, and J.E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. US. Fish. Wild. Serv. Spec. Sci. Rep. Fish. 483: 26.
- Kaganovsky, A.G. 1949. Some problems of the biology and population dynamics of pink salmon. *Izv. TINRO* 31: 3–57. (In Russian).
- Morita, K., H.S. Morita, M. Fukuwaka. 2006. Population dynamics of Japanese pink salmon (*Oncorhynchus gorbuscha*): are recent increases explained by hatchery programs or climatic variations? *Can. J. Fish Aquat. Sci.* 63: 55–62.
- Semko, R.S. 1954. The stocks of west Kamchatka salmon and their commercial utilization. *Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr.* 41: 3–109. (In Russian).
- Smirnov, A.I. 1975. The biology, reproduction and development of the Pacific salmon. *Izdatelstvo Moskovskogo Universiteta, Moscow, USSR.* (In Russian).
- Soin, S.G. 1954. Pattern of development in summer chum, masu and pink salmon. *Tr. Soveshch. Ikhtiol. Kom. Akad. Nauk. SSSR.* 4: 144–155. (In Russian).

Trends in Harvest and Escapement for Southeast Alaska Pink and Chum Salmon Stocks

Andrew W. Piston and Steven C. Heintz

*Alaska Department of Fish and Game, Division of Commercial Fisheries,
2030 Sea Level Drive, Suite 205, Ketchikan, Alaska 99901, USA*

Keywords: pink salmon, chum salmon, harvest, escapement, Southeast Alaska, wild, hatchery

Annual commercial harvests of pink and chum salmon in Southeast Alaska increased dramatically in the 1980s and reached their highest levels in the 1990s. Pink salmon harvests averaged 49 million, and chum salmon harvests averaged 11 million, including peak harvests of 78 million pink salmon in 1999 and 16 million chum salmon in 1996. Nearly all of the pink salmon harvested in Southeast Alaska are of wild origin: hatchery-produced pink salmon contributed an average of only 3% of the annual harvest since the late 1970s. In contrast, the harvest of chum salmon has been comprised primarily of hatchery fish (average 73% over the last 10 years). Estimated harvests of wild chum salmon did not rebound to the same degree as pink salmon and have recently declined to levels similar to those of the 1970s. Annual pink salmon harvests have also declined over the most recent 10 years from an average of 49 million in the 1990s to an average of 40 million fish since 2001, but remain at historically high levels. The decline in overall pink salmon harvest during the past decade was due primarily to very poor even-year runs in 2006 and 2008 and a below average run in 2010. The Alaska Department of Fish and Game maintains escapement indices for aggregates of pink and chum salmon runs in three broad sub-regions in Southeast Alaska: Southern Southeast, Northern Southeast Inside, and Northern Southeast Outside. Escapement indices are based on peak aerial survey estimates and do not provide estimates of total escapement, but rather provide an index of abundance useful for assessing trends. Escapement indices for chum salmon increased in the late 1980s and 1990s and remained stable through the mid-2000s, but recently dropped to low levels similar to those of the 1970s. Pink salmon escapements in all three sub-regions increased dramatically from low levels in the 1960s and 1970s and have generally remained high since the mid-to-late 1980s. The notable exception was a very poor escapement to the Northern Southeast Inside subregion in 2008.

Salmon Culture Based on Preservation of Biological and Ecological Conditions of Aquatic Communities

Boris P. Safronenkov and Vladimir V. Volobuev

Magadan Research Institute of Fisheries and Oceanography (MagadanNIRO),
36/10 Portovaya Street, Magadan 685000, Russia,

Keywords: chum salmon, pink salmon, salmon hatchery, fall run, artificial population, naturalization, return of spawners, Magadan, Taiu Gulf, Sea of Okhotsk

Freshwater areas of the continental coast of the northern Sea of Okhotsk (within the Magadan region) provide spawning areas for the four main commercial species of Pacific salmon *Oncorhynchus* spp., including pink *O. gorbuscha*, chum *O. keta*, coho *O. kisutch*, and sockeye salmon *O. nerka*. In 1960-1970, increasing anthropogenic impacts in freshwater areas of the Magadan region, as well as intensive fishing of salmon at sea, resulted in decreased natural reproduction. In those years, the population of chum salmon decreased more than three times as compared to population levels in 1930-1940. In 1965-1973 pink salmon runs were at a minimum level (Volobuev et al. 2005). Decreased salmon catches provided the impetus to develop regional programs for replenishment of salmon populations by means of artificial reproduction.

In 1983 artificial salmon culture began in the Magadan region. Four federal salmon hatcheries were built with a total production capacity of 120 million downstream migrants per year. The hatcheries are located on large salmon rivers of the Taiu Gulf, including the Taiu, Yana, Arman, and Ola. Apart from salmon hatcheries, there are three major salmon nurseries also functioning on the northern coast of the Sea of Okhotsk. The research salmon culture facility "Kulkuty" was started in 1992 by the Research Institute for Fisheries (MagadanNIRO). Other salmon culture facilities, "Staraya Vesolaya" and a nursery at Glukhoe Lake, were built in 1996 and 2000, respectively. These facilities are a part of the organizational subdivision of the federal agency "Okhotskrybvod".

Chum salmon has a dominant role in salmon culture of the Magadan region and constitutes more than 71% of the total salmon hatchery production. Pink salmon is 24% of the total production of salmon released. Sockeye and coho salmon are of secondary consideration and constitute 1% and 4%, respectively, of hatchery releases. Lately, there has been an increase in the amount of juvenile pink and coho released and a decrease in the amount of chum salmon released in the Magadan region.

Salmon culture activities have been conducted for many years at salmon hatcheries located on major rivers of the Taiu Gulf (Taiu, Yana, Arman, and Ola), and this has resulted in formation of chum salmon populations characterized by different reproduction types and consisting of fishes of wild and artificial origin. At present, reproduction in these rivers of both wild and hatchery populations has not ensured stable catches of chum salmon in fisheries. It has been noted that chum salmon runs in rivers with salmon hatcheries decreased in recent years. At the same time, obtaining a sufficient supply of fertilized eggs became a serious problem (Safronenkov and Khovanskaya, 2004). Reduction in hatchery production was due to several factors, including a consistently insufficient number of adult salmon in major rivers due to natural causes and excessive fishing, and a low biological efficiency of outdated hatcheries that were built to meet the technological requirements of the 1980s. Hatchery reconstruction and introduction of modern biotechnologies have not yet been conducted. We assume that enhancement of the resource base for the salmon fishery of the Magadan region would be impossible without complex reorganization of the region's salmon culture facilities (Safronenkov et al. 2005).

Analysis of salmon culture activities in the region shows the necessity to change from conservative methods of culturing salmon only at fish hatcheries because this method has not increased productivity in the numerous minor coastal rivers of the northern Sea of Okhotsk. About 40% of the entire salmon stock originates from minor coastal rivers. These coastal rivers are not used for salmon culture, even though they sustain quite extensive fisheries.

MagadanNIRO has developed and is now testing a full-scale biotechnology-oriented program to create artificial populations of fall-run chum salmon in minor coastal rivers that previously produced only wild pink salmon. The technology does not provide for construction of a hatchery on each minor river. "In-hatchery" operations, such as incubation of eggs and rearing of alevins, are conducted at the nearest salmon hatchery, and "out-of-hatchery" operations, such as transportation, rearing, and release of fry, are carried out directly at the river. Creation of new chum populations in rivers typical of pink salmon production preserves the biological and ecological system of the river. Such a chum salmon population was formed in 1996 by MagadanNIRO at the Kulkuty River, located in Odyan Bay of the Taiu Gulf (Rogatnkykh et al. 1998). The Kulkuty River is only 19 km in length. Wild pink salmon inhabiting the Kulkuty River and the introduced fall-run chum salmon do not interact. Intensive spawning of pink salmon in rivers of the northern Sea of Okhotsk takes place in mid July and lasts until mid August. Fall-run chum salmon spawn in September (Fig. 1). Downstream migration of wild pink salmon

in the Kulkuty River occurs in May-June, and hatchery-raised chum salmon juveniles are released into the river in early or mid July. The difference in spawning and downstream migration timing between pink and chum salmon eliminates the risks of competition on the spawning grounds, inter-specific hybridization, destruction of existing redds, possible infections, food competition among fry in the river and coastal waters, and other risks.

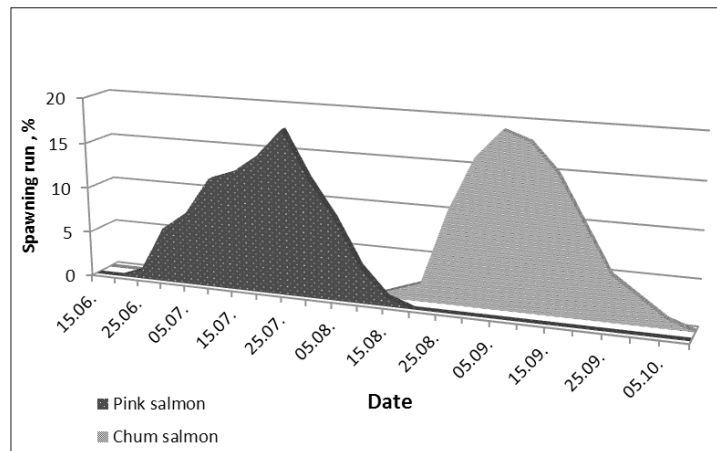


Fig. 1. Timing of the spawning run of wild pink salmon and hatchery-raised chum salmon in Kulkuty River. Date increments are at a 5-day interval.

There are no natural chum salmon populations in the rivers where hatchery-raised chum are introduced, and they exist in these rivers only by annual introductions. These introductions do not lead to eventual naturalization of the artificially-raised chum salmon in the river. All the adult chum salmon are caught, and natural spawning is prevented due to the unsuitable environment in small coastal rivers for natural spawning of chum salmon. As a rule, fall chum salmon spawn successfully in large rivers supplied with ground water discharge and where the water temperature does not go below 2-3 C° during winter and spring. Hydrological conditions on the spawning grounds of minor rivers do not facilitate survival of chum salmon progeny. In the Kulkuty River, for instance, the water temperature in the river channel is close to 0.2 C°, too cold for chum salmon embryos to survive, and the majority of them die. In the event that hatchery release operations end in minor rivers, the artificial fall chum salmon population will eventually disappear within several years due to the absence of adequate conditions to sustain successful reproduction.

Over 18 million chum salmon juveniles have been transported, raised, and released during the period of introductions to the Kulkuty River from 1993 to 2011. The number of juveniles released annually varied from 170 thousand up to 3.3 million individuals (average 0.99 million). Constant improvements have been observed in the size, weight, and biological parameters of chum salmon juveniles rearing in the Kulkuty River. Internal organ growth is characterized by proportional development. Over many years of study, average body weight of downstream migrants ranges from 406 to 840 mg (average 572.2 mg) and length varies from 37 to 47 mm (average 40.9 mm). Survival rates for juveniles tested for salt tolerance in sea water within 7 days approaches 100%.

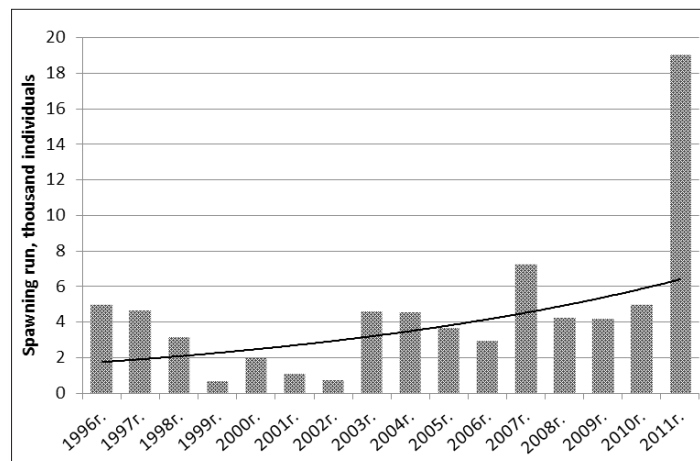


Fig. 2. Number of hatchery-raised chum salmon in the spawning run returning to the Kulkuty River, 1996-2011. Line indicates the long-term increase.

Adult chum salmon that were hatchery-raised and released as juveniles in the Kulkuty River began to return for spawning in 1996. Chum salmon runs varied from 0.7 to 19 thousand individuals (Fig. 2), and the maximum run was observed in 2011. During the whole period of operations (1996-2011), the total number of adults returning was more than 73 thousand (256 tons) from which more than 46 million fertilized eggs were obtained. The average rate of return was 0.7% (maximum – 1.87%) for recruits from the hatchery-raised population, which was estimated by taking into account generations that returned for spawning. This rate of return in salmon culture is considered to be quite successful, especially for areas with a climate as severe as that in the Magadan region. This means a biomass of 30 to 70 tons of chum salmon in the spawning run was obtained from release of 1 million juveniles into the feeding area of the river. Salmon returning to spawn can be used both for salmon culture and for fisheries.

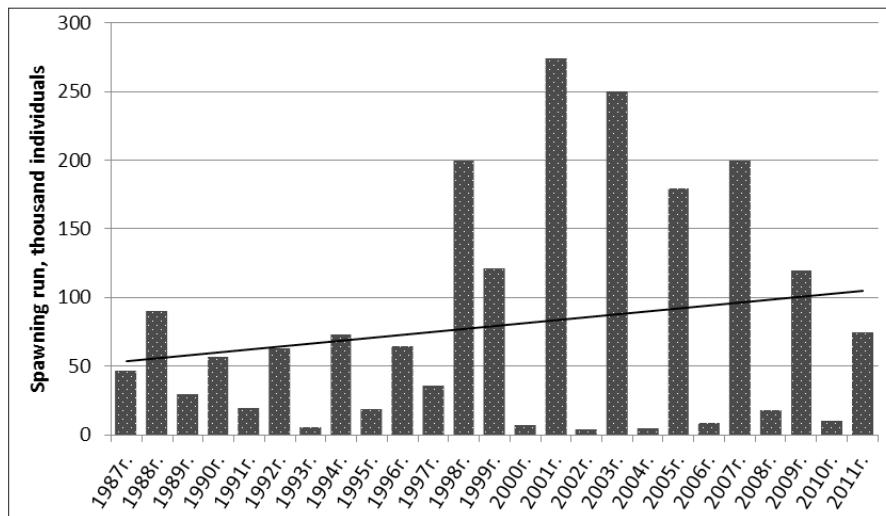


Fig. 3. Number of wild pink salmon returning to the Kulkuty River, 1987-2011. Line indicates the long-term increase.

Over the 1987-2011 period, the population of wild pink salmon in the Kulkuty River has remained at a stable high level. Spawning runs of wild pink salmon in odd-numbered (high-yield) years approached 270 thousand fish (Fig. 3). Where hatchery-raised fall-run chum salmon have been introduced, the abundance dynamics of wild pink salmon spawning runs comply with the general tendencies and common factors affecting the entire aggregate stock of pink salmon originating on the continental coast of the northern Sea of Okhotsk.



Fig. 4. Locations of small coastal rivers in the Odyan Gulf of the Magadan region that produce wild pink salmon and that are under consideration for future introductions of hatchery-raised chum salmon juveniles.

Formation of artificial populations of chum salmon in rivers typical of wild pink salmon production allows for significant increases in total salmon production capacity without causing damage to the biological and ecological conditions in rivers, providing that minimum inter-specific interaction is allowed. For example, in 1999-2011 the average cumulative wild pink salmon run for odd-numbered years in the Kulkuty River was 174 thousand individuals. The annual recommended commercial catch did not exceed 52,000 pink salmon, or 67 tons. Pink salmon are harvested from late June until late July. The spawning run of introduced fall chum salmon in the Kulkuty River begins in mid August. Run strength depends on the number of artificially-reared and released juveniles. The ecological capacity of the Kulkuty River is not less than 5 million chum salmon juveniles, given the density of fry on the feeding grounds is 0.4 thousand fish per m². Consequently, this number of juveniles can produce an adult return ranging from 40 to 90 thousand fish, from which approximately 8-10 thousand individuals are used for egg-taking, and another 32-80 thousand fish (120-290 tons) are available for commercial purposes. Given the above conditions, the potential production capacity of particular rivers can be increased 2 to 5 times, without causing any damage to the existing ecological structure and natural abundance dynamics of the wild salmon populations. By replicating this methodology in other minor coastal rivers of the northern Sea of Okhotsk, a whole network of environmentally-safe salmon populations can be created over time (Fig. 4). Provided that advanced technological principles of salmon culture are observed, such populations can produce an additional 1-1.5 thousand tons of salmon for fisheries. Formation of new salmon populations using biotechnology that is based on the peculiarities of the stock's temporal structure combined with both "in-hatchery" and "out-of-hatchery" culturing methods has proven in practice to be efficient and within the tolerance of natural river systems. The use of these methods on a large-scale basis will help resolve the problem of obtaining sufficient fertilized eggs for incubation at hatcheries and increase salmon harvest in the Magadan region.

REFERENCES

- Volobuev, V.V., I.A. Chereshev., and A.V. Shestakov. 2005. Peculiarities of biology and dynamics of anadromous and land-locked salmonids of rivers of the Tau Gulf of the Sea of Okhotsk. *Vestnik SVNTs DVO RAN*, No.2: 25-47. (In Russian).
- Rogatnykh, A. Yu., B.P. Safronenkov, and E.G. Akinicheva. 1998. Industrial population of chum of the northern Sea of Okhotsk. Collection of works "Condition of water ecosystems of Siberia", Tomsk. pp. 243-244. (In Russian).
- Safronenkov, B.P., and L.L. Khovanskaya. 2004. Contemporary condition of artificial reproduction of Pacific salmon in the Magadan region, 2003. Abstracts from Regional II Scientific Conference "The Russian North-East: Past, Present, Future" November 27-29, 2003. Volume II: 69-72. (In Russian).
- Safronenkov, B.P., L.L. Khovanskaya, and V.V. Volobuev. 2005. Condition of salmon culture in the northern Sea of Okhotsk and its short-term development trends. *Fisheries* 1: 43-47.

Genetic Variation Between Collections of Hatchery and Wild Masu Salmon Inferred From Mitochondrial and Microsatellite DNA Analyses

Jeong-Nam Yu^{1,2}, Noriko Azuma^{1,3} and Syuichi Abe¹

¹Division of Marine Biosciences, Faculty and Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1 Minato-cho, Hakodate, Hokkaido 041-8611, Japan

²National Institute of Bioresource Research, Environmental Research Complex, Gyeongseo-dong, Seo-gu, Incheon-si, 407-708, Korea

³Nodai Bioresource Institute, Tokyo University of Agriculture, 196 Yasaka, Abashiri 099-2493, Japan

Keywords: genetic diversity, *Oncorhynchus masou*, nucleotide sequence variation, allelic polymorphisms, wild and hatchery fish

There has been very little effort to understand genetic divergence between wild and hatchery masu salmon (*Oncorhynchus masou*) in Japan. Polymorphisms in the mitochondrial DNA (mtDNA) NADH dehydrogenase subunit 5 gene and six nuclear microsatellite loci (msDNA) were used to assess the genetic variation within and among wild and hatchery collections of masu salmon in Hokkaido. Both DNA markers suggested genetic differentiation between putative wild populations and hatchery brood stocks, primarily owing to decreased genetic diversity in the latter. We compared genetic variability in three hatchery brood stocks of masu salmon with the variability in eight putative wild masu populations sampled in five rivers including one known source river for the hatchery brood stocks in Hokkaido.

A total of 762 masu salmon was examined including 141 from the former Mori Research Branch of the Hokkaido Fish Hatchery and 621 categorized into eight separate collections representing five rivers in Hokkaido from 1997 to 2007 (Yu et al. 2010a, b). The rivers sampled included the Shiribetsu (SHI) and Teshio (TES) Rivers on the Sea of Japan coast, and the Tokushibetsu (TOK), Shari (SHA), and Ichani (ICH) Rivers on the Sea of Okhotsk coast (Fig. 1). The Shiribetsu River was the source river of the hatchery fish, and four annual collections in this river were obtained and analyzed to detect any change in genetic diversity over time.

Three different Mori Hatchery masu salmon collections were analyzed separately: (1) a captively bred (4-generation) line from the Shiribetsu River artificially selected for large size eggs since 1988 (hereafter referred to as Line 1), (2) a captively bred (5-generation) line from the Shiribetsu River without selection since 1987 (hereafter referred to as Line 2), and (3) 2nd generation fish derived from the wild fish of Line 3 (under selection for large body size and released at the 2nd generation after introduction) that originally homed to another adjacent river in 1989 (hereafter referred to as Line 3-RR).

Total genomic DNA was extracted from liver or fin samples from adult hatchery and wild fish using the Gentra Puregene Tissue Kit (QIAGEN). Nucleotide sequence variation in a PCR-amplified 561 bp fragment from the 5' end of mtDNA

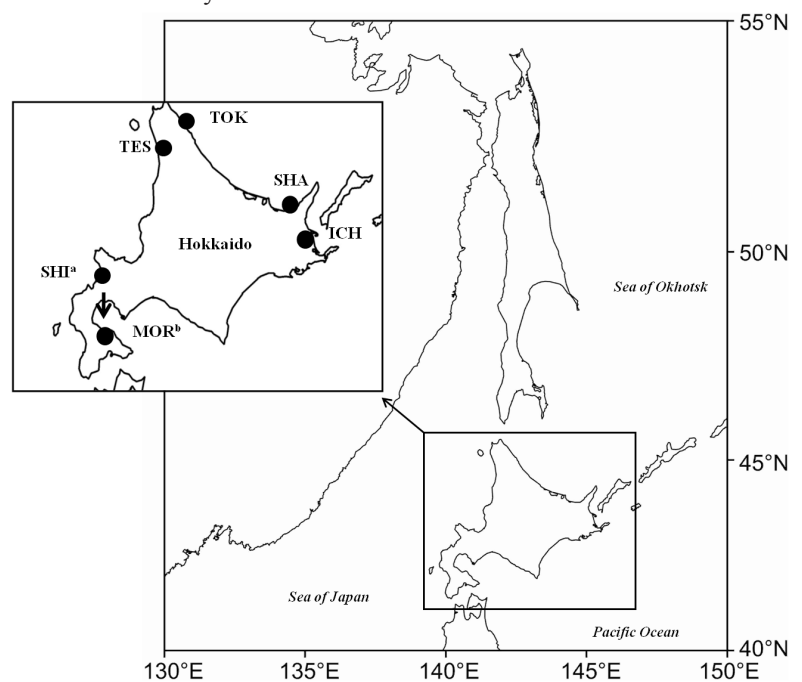


Fig. 1. Map showing the sampling sites for masu salmon in Hokkaido. The rivers sampled included the Shiribetsu (SHI^a: four annual collections, 1997-2000), Teshio (TES), Tokushibetsu (TOK), Shari (SHA), and Ichani (ICH). Samples were also obtained from the Mori Hatchery (MOR^b: three hatchery collections (Line 1, Line 2, and Line 3-RR)).

ND5 and allelic variation at six polymorphic msDNA loci were examined as previously described by Yu et al. (2010a). For genetic variability within and among collections, haplotype diversity (*h*) and nucleotide diversity (π) were calculated for *ND5*. Allelic richness (*Ar*), number of alleles per locus (*Na*), observed (*Ho*) and expected heterozygosity (*He*) per locus and sample collection, and mean heterozygosity within collections were computed, together with the departure from Hardy-Weinberg equilibrium (HWE) and linkage disequilibrium, for msDNA in ARLEQUIN version 3.1 (Excoffier et al. 2005). The population structure was estimated with pairwise F_{ST} and the hierarchical nesting of the genetic diversity among eight wild and three hatchery collections were analyzed using the analysis of molecular variance (AMOVA) in the ARLEQUIN program. The cluster of the collections was examined using the neighbor-joining (NJ) method (Saitou and Nei 1987) with NEIGHBOR in the PHYLIP program version 3.67 (Felsenstein 2004) based on the genetic distance of the Kimura-2-parameter method (Kimura 1980) for mtDNA and the Cavalli-Sforza and Edwards (1967) chord distances for msDNA. The bootstrapped consensus tree was generated with 1,000 replications using CONSENSUS in the PHYLIP program.

Average haplotype and nucleotide diversity were higher in the wild collections (*h*, 0.5577; π , 0.0016) than in the hatchery broodstocks (*h*, 0.457; π , 0.0011). The *He* and *Ho* for all collections ranged from 0.728 (Line 3-RR) to 0.817 (ICH) and 0.685 (Line 3-RR) to 0.817 (ICH), respectively, and no linkage disequilibrium was observed among all loci examined. Mean *He* was significantly greater in the wild (0.786) than in the hatchery (0.751) collections ($p = 0.02$), but there was no difference in the level of *Ho* ($p = 0.07$). Also, mean *Ar* was greater in the wild (11.27) than in the hatchery (9.47) collections ($p = 0.04$), suggesting a decreased genetic diversity in hatchery samples. Statistically significant deviation from HWE was observed in some wild and hatchery collections at some microsatellite loci.

Table 1. F_{ST} estimates of putative wild populations and hatchery brood stocks of masu salmon (mtDNA, above diagonal; msDNA, below diagonal). Statistical significance at $p < 0.005$ (*) and $p < 0.001$ (**) after sequential Bonferroni adjustments. No significant differences observed in the annual (1997-2000) collections of the SHI source population.

	TOK	SHA	ICH	TES	SHI97-00	Line 1	Line 2	Line 3-RR	
TOK		-0.007	0.079**	0.221**	0.161**	-0.224**	0.226**	0.173**	0.213**
SHA	0.023**		0.072**	0.236**	0.167**	-0.235**	0.241**	0.192**	0.232**
ICH	0.016**	0.026**		0.093**	0.033	-0.073**	0.080**	0.067**	0.097**
TES	0.044**	0.074**	0.052**		0.000	-0.021	0.080**	0.015	0.003
SHI97-00	0.027**	-0.052**	-0.029**	-0.006**			0.038*	-0.000	-0.000
	0.035**	0.064**	0.041**	0.015**			0.055*	0.027*	0.034*
Line 1	0.043**	0.062**	0.054**	0.045**	0.031**	-0.041**		0.085**	0.132**
Line 2	0.026**	0.051**	0.039**	0.032**	0.019**	-0.025**	0.042**		0.024*
Line 3-RR	0.029**	0.049**	0.038**	0.058**	0.037**	-0.048**	0.030**	0.044**	

Pairwise population F_{ST} estimates using both *ND5* and microsatellites suggest significant heterogeneity in the allele frequency distribution ($p < 0.001$) in almost all pairwise comparisons among collections, confirming their genetic divergence (Table 1). In the four annual SHI source river collections no significant differences were observed in both DNA markers, suggesting a common gene pool. The significant F_{ST} estimates with both DNA markers suggested genetic differentiation between the hatchery and the wild collections including those from the source population (Table 1). In addition, as shown in Table 2, AMOVAs revealed a small but significant genetic differentiation between all eight wild and three hatchery collections (*ND5*, 12.3%, $p < 0.001$; microsatellites, 2.31%, $p < 0.001$). Differentiation between all the SHI collections and all the hatchery collections was apparent with microsatellites but not with *ND5* (*ND5*, -0.70%, $p > 0.1$; microsatellites, 1.53%, $p < 0.05$). The three hatchery collections were distinctly separated from the wild collections (including the source river collections) on the NJ tree using both *ND5* and microsatellites (Fig. 2). The

Table 2. Analysis of molecular variance (AMOVA) based on mtDNA and msDNA data from putative wild populations and hatchery brood stocks of masu salmon. Analysis I: among stocks of the Sea of Okhotsk, Sea of Japan and Mori Hatchery. Analysis II: between stocks of the Shiribetsu River and Mori Hatchery.

Hierarchical structure	mtDNA			msDNA		
	%	Φ	<i>P</i>	%	Φ	<i>P</i>
Analysis I	12.3	0.120	0.000	2.31	0.023	0.000
Analysis II	-0.70	-0.006	0.828	1.53	0.016	0.027

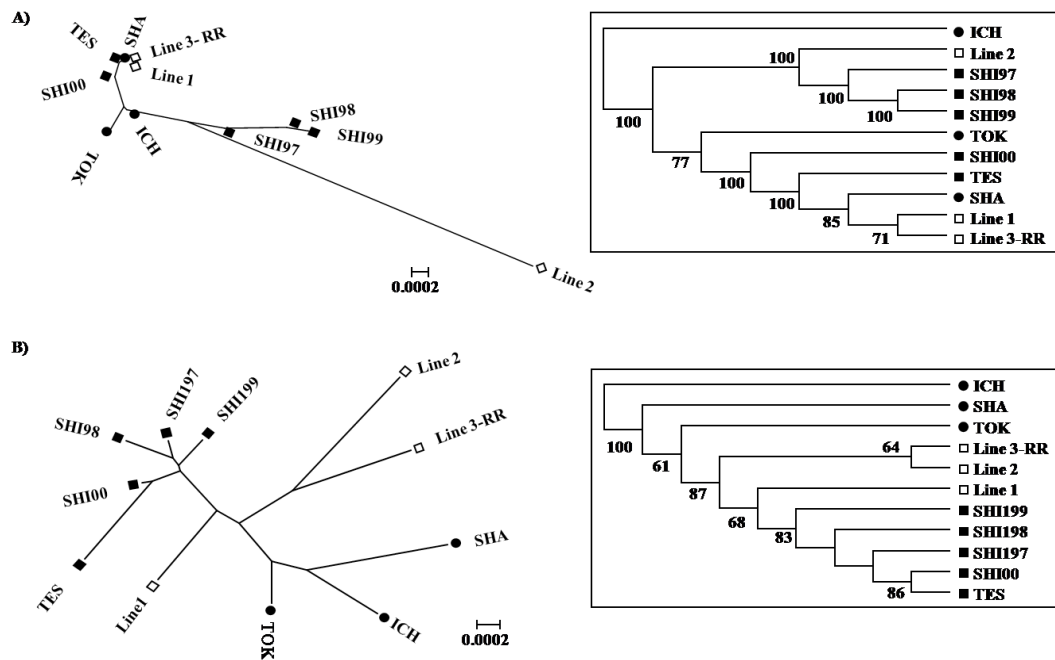


Fig. 2. Unrooted neighbor-joining tree showing genetic distance among collections based on mtDNA (A) and msDNA (B). Inset shows the topology of the consensus tree with nodal values for bootstrap support of over 50% of the 1000 replicated trees. Filled circle: samples from coastal rivers of the Sea of Okhotsk (Tokushibetsu, TOK; Shari, SHA; Ichani, ICH). Filled square: samples from coastal rivers of the Sea of Japan (Shiribetsu, SHI 1997-2000; Teshio, TES). Open square: Mori Hatchery samples (Line 1, Line 2, and Line 3-RR).

msDNA tree also suggested differentiation between masu salmon collections from the Sea of Okhotsk (TOK, SHA and ICH) and the Sea of Japan (SHI and TES), but the *ND5* tree failed to show a clear differentiation (Fig. 2).

The present results suggested that genetic diversity estimated with both DNA markers was low in three captive brood stocks relative to putative wild masu salmon populations. Such decrease in diversity occurred rapidly after introduction of wild masu salmon to the hatchery, i.e., within five generations, and caused genetic differentiation between the captive brood stocks and putative wild populations including the source population. These findings also suggest that careful hatchery operations are necessary for maintenance of genetic diversity in captive brood stocks and for safe-guarding against release of these fish that can potentially lower the fitness of wild masu salmon.

REFERENCES

- Cavalli-Sforza, L.L., and A.W.F. Edwards. 1967. Phylogenetic analysis: models and estimation procedures. *Am. J. Human Genet.* 19: 233-257.
- Excoffier, L., G. Laval, and S. Schneider. 2005. Arlequin ver. 3.0: An integrated software package for population genetics data analysis. *Evol. Bioinform. Online* 1: 47-50.
- Felsenstein, J. 2004. PHYLIP (Phylogeny Inference Package) version 3.6. Distributed by the author. Department of Genome Sciences, University of Washington, Seattle.
- Kimura, M. 1980. A simple method for estimating evolutionary rates of base substitutions through comparative studies of nucleotide sequences. *J. Mol. Evol.* 16: 111-120.
- Saitou, N., and M. Nei. 1987. The neighbor-joining method: A new method for reconstructing phylogenetic trees. *Mol. Biol. Ecol.* 4: 406-425.
- Yu J-N., N. Azuma, V. Brykov, S. Urawa, M. Nagata, D-H. Jin, and S. Abe. 2010a. Genetic population structure and phylogeography of masu salmon (*Oncorhynchus masou masou*) inferred from mitochondrial and microsatellite DNA analyses. *Zool. Sci.* 27: 375-385.
- Yu J-N., N. Azuma, V. Brykov, S. Urawa, K. Ohkuma, and S. Abe. 2010b. Genetic relationships between anadromous and non-anadromous masu salmon (*Oncorhynchus masou*) inferred from mitochondrial and microsatellite DNA variation. *Fish Genet. Breed. Sci.* 39: 75-85.

Improved Genetic Stock Identification of Chum Salmon Through the PacSNP Collaboration

**William D. Templin¹, Chris Habicht¹, Lisa W. Seeb², Shunpei Sato³, Syuiti Abe⁴,
Kenneth Warheit⁵, Jung Youn Park⁶, and James E. Seeb²**

¹*Gene Conservation Laboratory, Alaska Department of Fish and Game,
333 Raspberry Road, Anchorage, Alaska 99518, USA*

²*School of Aquatic and Fishery Sciences, University of Washington,
1122 NE Boat Street, Box 355020, Seattle, Washington 98195, USA*

³*Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan*

⁴*Division of Marine Biosciences, Graduate School of Fisheries Sciences, Hokkaido University,
3-1-1 Minato-cho, Hakodate 041-8611, Japan*

⁵*Washington Department of Fish and Wildlife, 600 Capitol Way N.,
Olympia, Washington 98501, USA*

⁶*Biotechnology Research Institute, National Fisheries Research and Development Institute,
408-1 Sirang-ri, Gijiang-eup, Gijang-gun, Busan 619-705, Korea*

Understanding the distributions of chum salmon in the oceanic and near-shore waters of the North Pacific Ocean and Bering Sea has become increasingly useful for studying the effects of climate change, large-scale hatchery production, and bycatch in offshore fisheries. For more than two decades, genetics data have been used as a key tool for studying the migratory routes of the species based on extensive sets of data from spawning populations originating from across the species' range. During this period the genetic markers applied continually improved with advances in technology. With the collaborative development of the PacSNP baseline among North American and Asian researchers, single nucleotide polymorphisms (SNPs) were demonstrated as particularly amenable for multinational applications because they are easily shared, require little inter-laboratory standardization, and can be assayed through increasingly efficient technologies. The PacSNP baseline is focused on the continued development of the database and applying it to problems of international interest. We present improvements to the PacSNP baseline to provide a more comprehensive representation of populations and greater resolution through the addition of more informative markers.

Stock-Specific Summertime Distribution of Immature Chum Salmon in the Bering Sea as Inferred from SNP Markers

Shunpei Sato¹, Masahiro Kato², Kentaro Morita¹, and Shigehiko Urawa¹

¹Salmon Resources Division, Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
 2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan

²Nijibetsu Field Station, Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
 728-1 Nijibetsu, Shibechea-cho 088-2462, Japan

Chum salmon (*Oncorhynchus keta*) is the most widely distributed salmon species of the North Pacific Rim. Populations of chum salmon from Asia and North America co-mingle in the North Pacific Ocean and Bering Sea. Estimation of stock origins and ocean distribution of chum salmon will provide valuable information to help clarify stock-specific patterns of ocean migration for stock assessment. Many salmon research cruises have been conducted in the summer in the Bering Sea because this area is a major feeding habitat for chum salmon during summer. However, the areas surveyed are limited to the central and southern Bering Sea (52°N to 59°N). Thus, distribution and stock-specific composition of chum salmon in the northern areas of Bering Sea and Arctic Ocean are unclear. In this study, we surveyed chum salmon distribution from the southern Bering Sea to the Arctic Ocean during summer 2009, and we estimated the stock-specific ocean distribution of chum salmon by genetic stock identification (GSI) using single nucleotide polymorphism (SNP) markers.

Cruises were conducted by the research vessel R/V *Hokko maru* in the Chukchi Sea (three stations, 67°53'N-70°05'N, 167°49'W-167°23'W), Bering Strait (two stations, 64°48'N-65°14'N, 169°36'W-168°40'W), northern Bering Sea (10 stations, 59°01'N-63°00'N, 177°28'E-170°05'W), and other areas of Bering Sea (17 stations, 52°30'N-58°23'N, 174°49'E-174°55'W) during July 15-24 and July 30-August 9, 2009. A mid-water trawl (MTN) and a surface trawl (STN) were used to catch fish during the cruises (Morita et al. 2009). The MTN was used in the northern Bering Sea, Bering Strait, and Chukchi Sea, and the STN was used in the other areas of Bering Sea. The MTN is smaller than the STN, and the catch by the STN was 2.7872 times higher than the catch by the MTN (Morita et al. 2009). The CPUE (catch per unit effort) and mean CPUE of chum salmon by MTN were standardized to the CPUE of the STN. Adipose fin samples (N=2,256) were collected and fixed in 100% ethanol. The DNA was extracted from the samples in the laboratory. Each sample was assayed for 32 SNP loci using TaqMan chemistry. The genotyping data were pooled from two or three nearby stations. Because most fish were immature (96%), maturing fish were excluded from the genetic analysis. Stock contributions (Japan, Russia, and North America) of immature fish were estimated using a Bayesian procedure and a SNP baseline dataset developed from 146 populations from the North Pacific Rim.

Table 1. Catch number and mean CPUE of chum salmon caught in four regions during the research cruise of the R/V *Hokko maru* in July-August 2009.

Region	Latitude	Number of stations	Catch No.	Mean CPUE
Chukchi Sea	67°N-70°N	3	4	3.716*
Bering Strait	64°N-65°N	2	3	4.181*
Northern Bering Sea	59°N-63°N	10	1,080	301.018*
Bering Sea (other areas)	52°N-58°N	17	2,817	165.706

*Mean CPUEs are standardized to the catch in a surface trawl.

The chum salmon catch in the northern Bering Sea and other areas of Bering Sea was 1,080 and 2,817, respectively (Table 1). Four chum salmon were caught in the Chukchi Sea and three were caught in the Bering Strait. Mean CPUE of chum salmon in the northern Bering Sea was higher than that in the Bering Strait and Chukchi Sea (Fig. 1). These results suggest that abundance of chum salmon in the northern Bering Sea was higher than in other survey areas. The estimated chum salmon stock composition was 49.2-58.4% Japanese and 27.6-47.0% Russian fish in the northern Bering Sea and 37.9-47.1% Japanese and 50.5-59.7% Russian in the central Bering Sea (56°N-58°N). The stock composition in the southern Bering Sea (52°N-55°N) was 5.3-37.1% Japanese and 55.8-86.9% Russian chum salmon. In the western Bering Sea (53°N-56°N, 175°E), the stock composition was estimated to be 6.3-14.7% Japanese and 84.0-88.9% Russian.

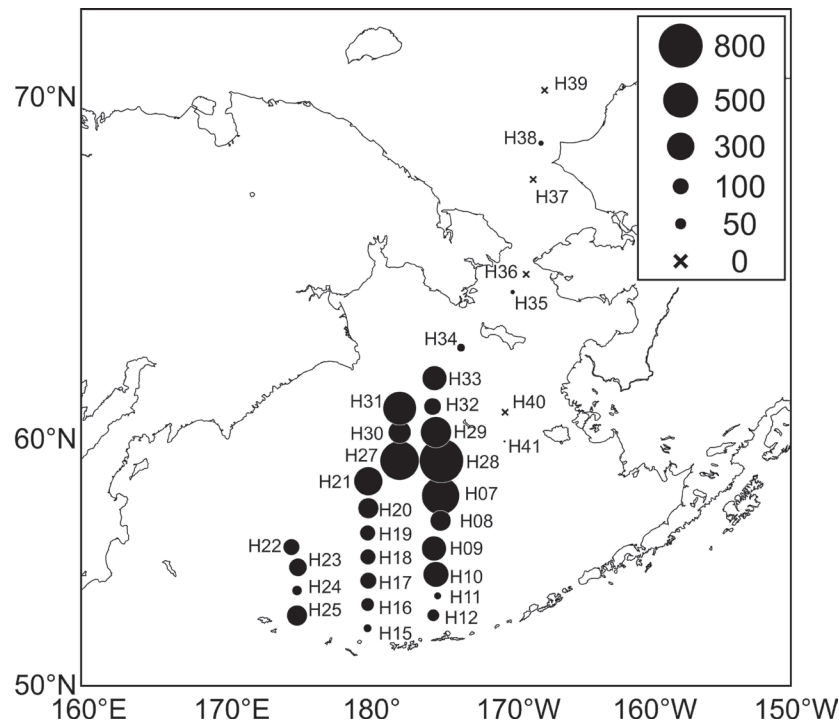


Fig.1. Distribution of chum salmon in the survey areas during summer 2009. Size of the circle indicates the abundance of fish by catch per unit of effort (CPUE). CPUEs are standardized to the catch in a surface trawl.

The percentages of North American stocks were 1.3-15.8% in the Bering Sea survey areas. The CPUEs weighted by GSI estimates indicated that abundance of Japanese stocks increased gradually from southern to northern areas of the Bering Sea, and they predominated in the central and northern Bering Sea. Russian stocks were highly abundant in the northern Bering Sea, and they predominated in the southern and western Bering Sea. North American stocks were less abundant than Asian stocks in the survey areas of the Bering Sea. Sato et al. (2009) and Urawa et al. (2009) indicated that Japanese immature chum salmon were widely distributed in the Bering Sea during summer and particularly predominant in the central Bering Sea. Our results are supported by their data, and our data also indicate that immature Japanese stocks migrate to northern areas ($> 60^{\circ}\text{N}$) in the Bering Sea during summer. Japanese chum salmon stocks may utilize wide regions of the Bering Sea, including northern waters, as a summer feeding area. A previous study showed that Russian immature chum salmon had a distribution similar to the Japanese stocks in the Bering Sea (Urawa et al. 2009). However, our results indicate that abundance of Russian stocks is higher than Japanese stocks in the southern and western Bering Sea. Recently, the commercial catch of Russian chum salmon has increased, while that of Japanese chum salmon has decreased. Perhaps our results reflect recent abundance trends of Asian chum salmon. We should continue monitoring the stock-specific ocean distribution patterns of Asian chum salmon to provide critical information for stock assessment.

REFERENCES

- Morita, K., S. Sato, M. Kato, and J. Yamamoto. 2009. The summer 2009 Japanese salmon research cruise of the R/V *Hokko maru*: exploration of the northern limit of offshore distribution and annual survey in the Bering sea. N. Pac. Anadr. Fish Comm. Doc. 1191. 12 pp. (Available at www.npafc.org).
- Sato, S., S. Moriya, T. Azumaya, H. Nagoya, S. Abe, and S. Urawa. 2009. Stock distribution patterns of chum salmon in the Bering Sea and North Pacific Ocean during the summer and fall of 2002–2004. N. Pac. Anadr. Fish Comm. Bull 5: 29–37. (Available at www.npafc.org).
- Urawa, S., S. Sato, P.A. Crane, B. Agler, R. Josephson, and T. Azumaya. 2009. Stock-specific ocean distribution and migration of chum salmon in the Bering Sea and North Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull. 5: 131-146. (Available at www.npafc.org).

Status of Hatchery-Origin Chum Salmon in the Bering Sea Deduced From Otolith Mark Recoveries

Shigehiko Urawa, Shunpei Sato, Masaya Takahashi, and Toshihiko Saito

Salmon Resources Division, Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan

Keywords: chum salmon, Bering Sea, otolith mark, distribution, run forecast

Otolith marking is an effective tool for determining the hatchery origin of individual salmon in both high seas and coastal waters. Otolith-marked salmon are annually released from hatcheries in Canada, Japan, Korea, Russia, and the United States under the coordination of the North Pacific Anadromous Fish Commission (NPAFC). The total number of otolith-marked chum salmon released in 2003-2009 was approximately 4.8 billion juveniles (23% of the total hatchery releases in North Pacific Rim countries).

Otolith samples were collected from chum salmon caught in the central North Pacific and Bering Sea by researchers aboard Japanese research vessels (*Wakatake maru* and *Hokko maru*) in the summer of 2006-2010. The samples (n=13,279) were examined to detect otolith marks, and hatchery origins were determined by referring to the NPAFC database of otolith mark releases, which is available at <http://npafc.taglab.org>.

A total of 372 otolith-marked chum salmon was found in the Bering Sea, of which 352 (94.6%) fish were released from 11 hatcheries in northern Japan. The Japanese marked fish showed no hatchery-specific distribution, and most fish were distributed north of 55°N in the Bering Sea during July and early August (Fig. 1). Distribution patterns were slightly different between young fish (ocean age-1) and older fish and between immature and maturing fish that may reflect their specific migration routes (Urawa et al. 2009).

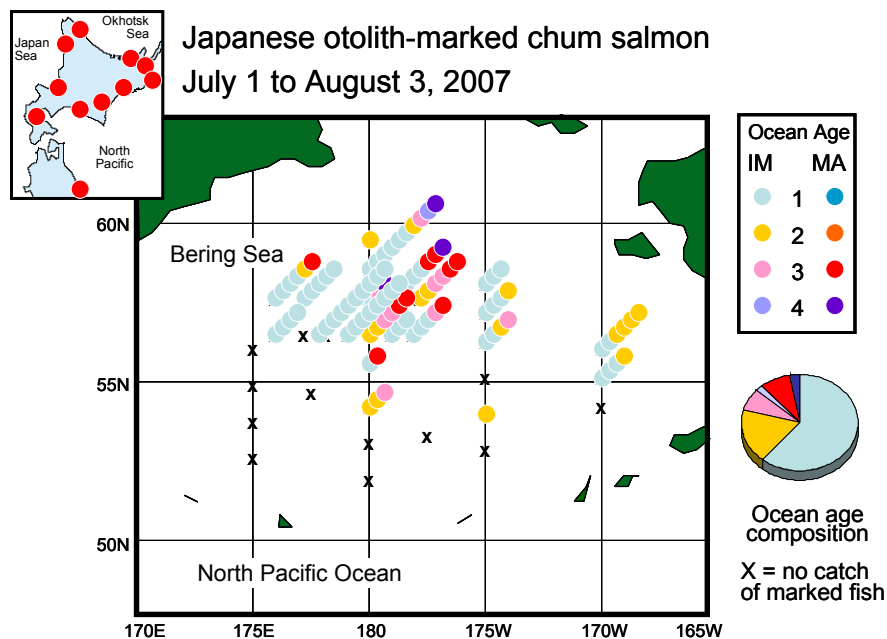


Fig. 1. Ocean distribution of otolith-marked chum salmon released from 11 hatcheries in northern Japan (map, upper left corner). The trawl surveys were conducted from July 1 to August 3, 2007. IM, immature fish; MA, maturing fish.

Alaskan marked chum salmon (n = 7) were found widely distributed in the Bering Sea, and all of them were released from Southeast Alaska and Prince Williams Sound. Russian marked fish (n=5) were recovered in the central Bering Sea, and they originated from the Ketkinsky and Paratunsky Hatcheries located in Eastern Kamchatka. One Korean marked chum salmon released from the Yangyang Hatchery was found in the western area (56°30'N, 176°E) in July 2007, as already reported by Sato et al. (2009).

Can high-seas otolith-mark recovery data be used for the forecast of hatchery chum salmon runs? To test this possibility, the recovery rate of chum salmon otolith marks in the Bering Sea (Bering Sea Catch Index, BSCI) during 2006-2010 surveys and the return rate of adults to the natal river were compared for the 2004-2006 brood years.

$$\text{BSCI} = \text{number of marked fish recovered in the Bering Sea} / \text{number of marked fish released in the river}$$
$$\text{Return rate (\%)} = \text{number of adults caught in the river} / \text{number of fry released in the river}$$

Results differed among regional populations. In rivers on the Okhotsk Sea coast, a high BSCI was followed by a high return rate of chum salmon. By contrast, in rivers on the Japan Sea coast, a low BSCI was followed by a low return rate. There was a positive linear relation between BSCI and return rate for brood year 2004 ($R^2 = 0.803$, $p = 0.001$), 2005 ($R^2 = 0.664$, $p = 0.004$), and 2006 ($R^2 = 0.934$, $p < 0.001$). These results suggest the possibility that high-seas otolith-mark recovery data are useful for forecast of chum salmon runs in specific populations.

We thank the crew and researchers on board the R/V *Wakatake maru* and R/V *Hokko maru* for their devotion to collection of otolith samples. We also express our gratitude to Dr. Beverly Agler and her staff at the Alaska Department of Fish and Game for reconfirming high-seas otolith marks.

REFERENCES

- Sato, S., M. Takahashi, N. Watanabe, S. Kitatsuji, D. Takasaki, T. Chiba, S. Imai, Y. Goda, M. Watanabe, M. Fukuwaka, B.A. Agler, and S. Urawa. 2009. Preliminary records of otolith-marked chum salmon found the Bering Sea and North Pacific Ocean in 2006 and 2007. *N. Pac. Anadr. Fish Comm. Bull.* 5: 99-104. (Available at www.npafc.org).
- Urawa, S., S. Sato, P.A. Crane, B. Agler, R. Josephson, and T. Azumaya. 2009. Stock-specific ocean distribution and migration of chum salmon in the Bering Sea and North Pacific Ocean. *N. Pac. Anadr. Fish Comm. Bull.* 5: 131-146. (Available at www.npafc.org).

Early Marine Residence of Juvenile Pink and Chum Salmon in the Northern California Current: Life at the Southern End of the Range

Laurie A. Weitkamp¹, Elizabeth A. Daly², and Joseph P. Fisher³

¹Newport Research Station, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2032 SE Marine Sciences Drive, Newport, OR 97365, USA

²Cooperative Institute for Marine Resources Studies, Oregon State University, Hatfield Marine Science Center, 2030 Marine Science Drive, Newport, OR 97365, USA

³Cooperative Institute for Marine Resources Studies, Oregon State University, 104 COAS Administration Bldg., Corvallis, Oregon 97331, USA

Keywords: northern California Current, juvenile pink salmon, juvenile chum salmon, distribution, abundance, size, growth

Juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon have been regularly captured in the northern California Current (NCC) off of Washington and Oregon in ecological studies focused on the dominant salmon species in the region, juvenile Chinook (*O. tshawytscha*) and coho (*O. kisutch*) salmon. The NCC area represents the southern end of the species range for pink and chum salmon in North America, which occurs on the central Oregon Coast (45°N) for chum salmon (Salo 1991; ODFW 2005), and in Puget Sound (47°N) for pink salmon (Heard 1991). Here, we provide an overview of the marine ecology of juvenile pink and chum salmon in the NCC: their seasonal, interannual, and latitudinal distributions and abundances, and their seasonal size and growth. Our results come from two studies spanning three decades (1981-2011), a period characterized by variable ocean productivity.

The first study was conducted by Oregon State University (OSU) during 1981-1985 (hereafter referred to as the “1980s”; see Percy and Fisher 1990, Percy 1992), and the second was initiated by NOAA Fisheries and OSU in 1998 and continues to the present (referred to as the “2000s”; see Fisher et al. 2007). Both studies sampled common east-west transects from Cape Flattery, Washington (48°N), to Newport, Oregon (45°N; Fig. 1), during three months (May, June, September) following a similar methodology. However, the studies used fundamentally different types of nets (purse seine vs. rope trawl) to collect juvenile salmon. Because these nets undoubtedly had different (but unknown) efficiencies for catching juvenile salmon, we compared patterns of abundance rather than actual abundances. To explore latitudinal variation in distributions, we also used additional sampling south to Cape Blanco, Oregon (43°N), in the 1980s (Percy and Fisher 1990) and to the Oregon/California border (42°N) during two years in the 2000s (Pool et al. 2011).

Juvenile pink and chum salmon were minor members of the juvenile salmon communities during both time periods, contributing an average relative abundance of 4% and 8%, respectively (Table 1). Although there was considerable variation in this community between the two periods (more coho salmon in the 1980s and more Chinook salmon in the 2000s), neither pink nor chum salmon ever became as abundant as the two dominant species.

Perhaps the most striking difference between pink and chum salmon in the NCC was their spatial and temporal distributions, which were generally consistent between the two time periods. On a seasonal basis, very few pink salmon were caught in

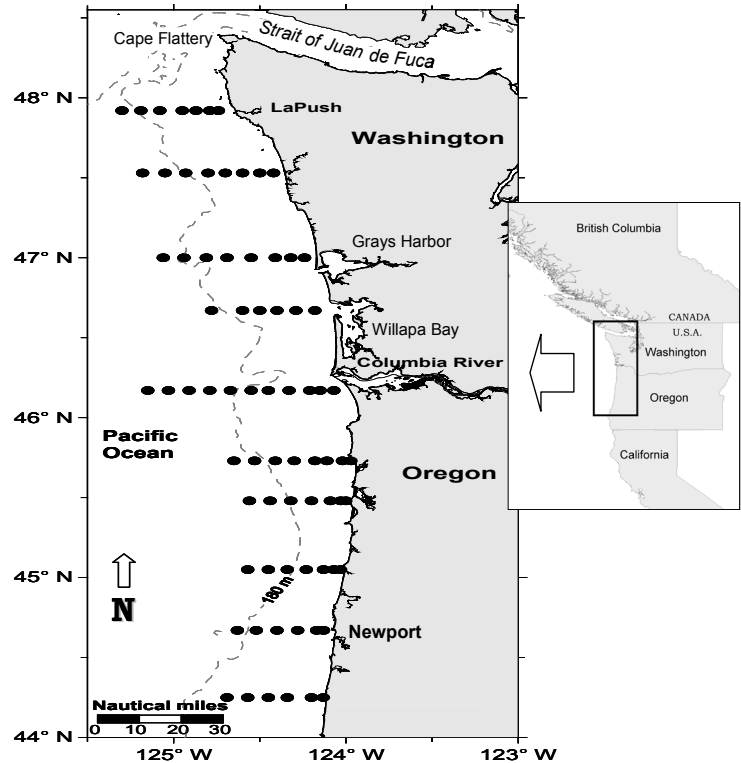


Fig. 1. Location of sampling transects and stations used in the 2000s by the Columbia River Plume Study. Most transects were also used during the 1980s by the Oregon State University Study.

Table 1. Relative abundance (%) of juvenile salmon species caught in the northern California Current (NCC) by month and study period. The 1980s refer to the study by Oregon State University conducted during 1981-1985 and the 2000s refer to the Columbia River Plume Study conducted during 1998-2011.

Species	1980s			2000s		
	May	June	September	May	June	September
Chum	4.6	3.8	9.9	9.3	18.6	2.8
Pink	<0.1	<0.1	10.5	<0.1	<0.1	12.4
Chinook	27.2	19.3	22.7	35.4	35.7	74.3
Coho	62.4	74.0	56.8	43.6	42.2	10.5
Sockeye	3.3	0.9	0.1	4.1	2.8	<0.1
Steelhead	2.5	2.0	0	7.4	0.2	<0.1

either May or June, and abundances were high in September (Fig. 2). By contrast, chum had relatively high abundances in May and June, which either remained high in September (1980s) or decreased to low levels (2000s). Latitudinal variation in catches was equally distinct (Fig. 2): in May and June chum salmon were distributed across four degrees of latitude (44-48°N), with higher abundances north of the Columbia River (46°N) at a time when pink salmon were largely absent. By September, however, both pink and chum salmon were restricted to the northern portion of the study area (47-48°N; Fig. 2). Taken together, these patterns likely reflect geographic differences in source populations and migratory behavior. Chum salmon populations exist in most river basins along the Washington and northern Oregon coasts (Phinney and Bucknell 1975, ODWF 2005), and juveniles appear to occupy coastal marine habitats early in the summer, but have largely dispersed or moved northwards by late summer. By contrast, there are no known pink salmon populations on the Washington and Oregon coasts, although large populations (millions of spawners) exist in Puget Sound and the Strait of Georgia, including the Fraser River (PFMC 2011, PSC 2011). Juvenile pink salmon in our study likely originated from these large populations and were caught as they exited the Strait of Juan de Fuca.

There was also large interannual variation in the abundances of both pink and chum salmon, with annual monthly abundances varying by an order of magnitude among years (Fig. 3). In the 2000s chum salmon catches in May and June were particularly high (> 3 fish/km²) in 2001, 2003 and 2006-2009, and were unusually high in September 2006. There were large peaks in the abundance of pink salmon in 2006 and 2008. However, these abundance peaks had little correspondence with adult abundances in likely source populations (i.e., Willapa Bay and Grays Harbor for chum salmon [PSC 2011, WDFW 2011], Fraser River for pink salmon [PFMC 2011]) in either the previous year (the parent generation) or 1 year (pink) or 2-4 years (chum) later when juveniles would return as adults. Lack of correspondence in pink salmon abundance is likely due to essentially random movement of fish into the study area from the Strait of Juan de Fuca. Lack of consistency between chum salmon juvenile and adult abundances is less clear; better information on actual source populations, eggs to smolt survival rates, and adult age structure would help resolve this issue.

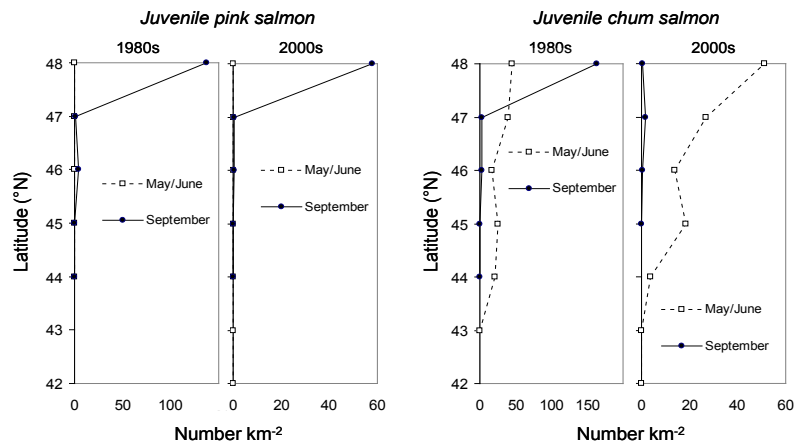


Fig. 2. Juvenile salmon densities by latitude for pink salmon (left) and chum salmon (right) in the 1980s and 2000s by month (May/June, September).

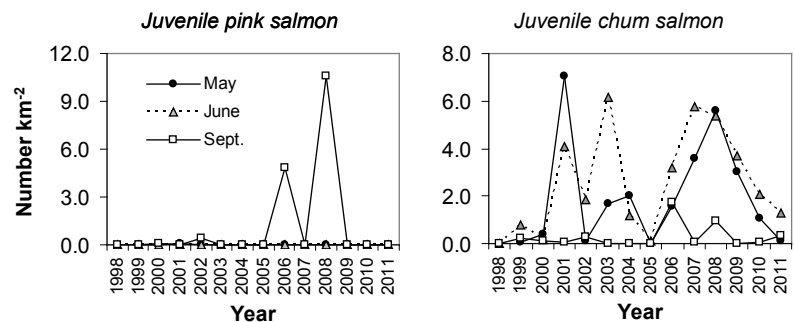


Fig. 3. Mean density of juvenile pink (left) and chum (right) salmon by month and year during the 2000s.

While seasonal and latitudinal abundance patterns were consistent over the three-decade time span, the size of fish was not. Chum salmon in both time periods rapidly increased in size over the summer, however, in the 1980s juvenile pink and chum salmon were 14-19% longer than fish caught in the 2000s (Fig. 4). These differences were statistically significant ($p < 0.05$), except for chum salmon caught in September. Furthermore, visual (but not statistical) comparisons of the size of juvenile pink and chum salmon caught in regions where they are abundant, such as Southeast Alaska and Strait of

Georgia, suggest that NCC pink salmon caught in September in the 2000s were somewhat smaller than in these other regions, and NCC chum salmon caught in the 1980s appear to be larger than in these other regions (Fig. 4). The reason(s) for these size differences, if they truly exist, is presently unknown.

Juvenile pink and chum salmon at the southern end of the species range in North America experience marine conditions that are quite different from those experienced by fish in northern British Columbia or Alaska. Compared to these regions, pink and chum salmon in the NCC experience warmer and more saline waters, and they are a minor—rather than major—component of the epipelagic fish community (Fisher et al. 2007, Orsi et al. 2007b). Given recent concerns about the competitive interactions between juvenile pink salmon and other salmon species (Ruggerone and Nielsen 2004, Beamish et al. 2010), the NCC provides a unique opportunity to study chum salmon for much of the summer in the absence of pink salmon. Further understanding of the ocean ecology of juvenile pink and chum salmon in the NCC and comparisons to the same species in northern regions should yield valuable information about the ability of these species to adapt to diverse environments; how these environments, in turn, influence survival; and the factors that limit their southern distribution.

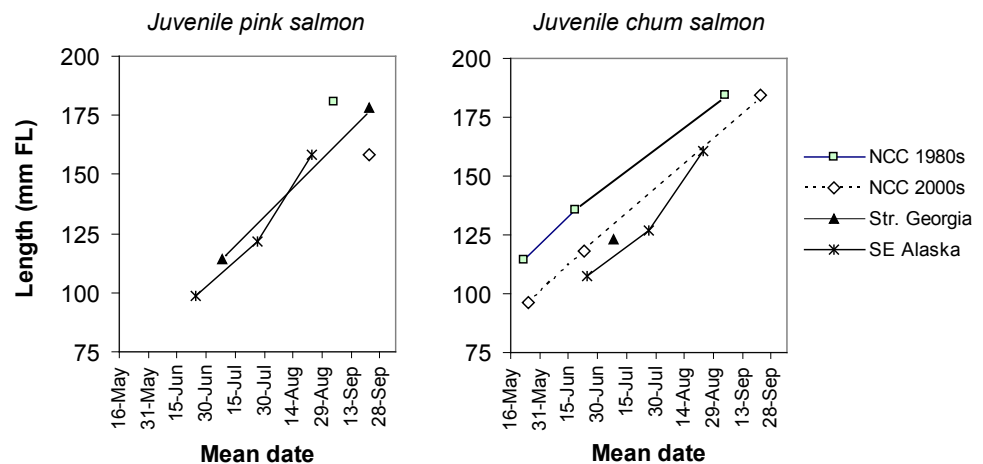


Fig. 4. Mean length (mm FL) of juvenile pink (left) and chum salmon (right) by mean date of capture in the northern California Current (NCC) during 1980s and 2000s compared to the mean size of juvenile pink and chum salmon reported from the Strait of Georgia and Southeast Alaska. (Strait of Georgia data source: Sweeting et al. 2004, Beamish et al. 2010; Southeast Alaska data source: Orsi et al. 2005, 2006, 2007a, 2008, 2009, 2010.)

REFERENCES

- Beamish, R.J., R.M. Sweeting, C.M. Neville, and K.L. Lange. 2010. Competitive interactions between pink salmon and other juvenile Pacific salmon in the Strait of Georgia. N. Pac. Anadr. Fish Comm. Doc. 1284. 26 pp. (Available at www.npafc.org).
- Fisher, J., M. Trudel, A. Ammann, J.A. Orsi, J. Piccolo, C. Bucher, E. Casillas, J.A. Harding, B. MacFarlane, R.D. Brodeur, J.F. Morris, and D.W. Welch. 2007. Comparisons of the coastal distributions and abundances of juvenile Pacific salmon from Central California to the Northern Gulf of Alaska. Am. Fish. Soc. Symp. 57: 31-80.
- Heard, W.R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). In Pacific salmon life histories. Edited by C. Groot and L. Margolis. UBC Press, Vancouver. pp. 119-230.
- Oregon Department of Fish and Wildlife (ODFW). 2005. 2005 Oregon native fish status report, volume II: Assessment methods and population results. ODFW, Fish Division, Salem, Oregon. (Available at www.dfw.state.or.us/fish/ONFSR/docs/final).
- Orsi, J.A., E.A. Fergusson, M.V. Sturdevant, B.L. Wing, A.C. Wertheimer, and W.R. Heard. 2005. Survey of juvenile salmon and associated epipelagic ichthyofauna in the marine waters of southeastern Alaska, May-August 2004. N. Pac. Anadr. Fish Comm. Doc. 871. 61 pp. (Available at www.npafc.org).
- Orsi, J.A., E.A. Fergusson, M.V. Sturdevant, B.L. Wing, A.C. Wertheimer, and W.R. Heard. 2006. Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of southeastern Alaska, May-August 2005. N. Pac. Anadr. Fish Comm. Doc. 955. 108 pp. (Available at www.npafc.org).
- Orsi, J.A., E.A. Fergusson, M.V. Sturdevant, B.L. Wing, A.C. Wertheimer, and W.R. Heard. 2007a. Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of southeastern Alaska, May-August 2006. N. Pac. Anadr. Fish Comm. Doc. 1057. 72 pp. (Available at www.npafc.org).

- Orsi, J.A., J.A. Harding, S.S. Pool, R.D. Brodeur, L.J. Haldorson, J.M. Murphy, J.H. Moss, E.V. Farley, R.M. Sweeting, J.F. Morris, M. Trudel, R.J. Beamish, R.L. Emmett, and E.A. Fergusson. 2007b. Epipelagic fish assemblages associated with juvenile Pacific salmon in neritic waters of the California Current and the Alaska Current. *Am. Fish. Soc. Symp.* 57: 105-156.
- Orsi, J.A., E.A. Fergusson, M.V. Sturdevant, B.L. Wing, A.C. Wertheimer, and W.R. Heard. 2008. Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of southeastern Alaska, May-August 2007. *N. Pac. Anadr. Fish Comm. Doc.* 1110. 82 pp. (Available at www.npafc.org).
- Orsi, J.A., E.A. Fergusson, M.V. Sturdevant, B.L. Wing, A.C. Wertheimer, and W.R. Heard. 2009. Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of southeastern Alaska, May-August 2008. *N. Pac. Anadr. Fish Comm. Doc.* 1181. 72 pp. (Available at www.npafc.org).
- Orsi, J. A., E.A. Fergusson, M.V. Sturdevant, B.L. Wing, and W.R. Heard. 2010. Annual survey of juvenile salmon and ecologically-related species and environmental factors in the marine waters of southeastern Alaska, May-August 2009. *N. Pac. Anadr. Fish Comm. Doc.* 1280. 83 pp. (Available at www.npafc.org).
- Pacific Fishery Management Council (PFMC). 2011. Preseason Report I: Stock abundance analysis and environmental assessment Part I for 2011 ocean salmon fishery regulations. PFMC, Portland, Oregon. (Available at www.pfcouncil.org).
- Pacific Salmon Commission (PSC). 2011. Joint chum technical committee 2009 post season summary report. Report TCCHUM (11)-1. (Available at www.psc.org).
- Pearcy, W.G. 1992. Ocean ecology of North Pacific salmonids. Washington Sea Grant, Seattle. 179 pp.
- Pearcy, W.G., and J.P. Fisher. 1990. Distribution and abundance of juvenile salmonids off Oregon and Washington, 1981-1985. U.S. Dept. Comm., NOAA Tech. Rep. NMFS 93. 83 pp.
- Phinney, L. A., and P. Bucknell. 1975. A catalog of Washington streams and salmon utilization. Volume 2: Coastal region. Washington Dept. Fisheries, Olympia, WA. Unnumbered.
- Pool, S. S., D.C. Reese, and R.D. Brodeur. 2011. Defining marine habitat of juvenile Chinook salmon, *Oncorhynchus tshawytscha*, and coho salmon, *O. kisutch*, in the northern California Current System. *Environ. Biol. Fish.* DOI 10.1007/s10641-011-9909-9.
- Ruggerone, G. T., and J. L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. *Rev. Fish Biol. Fish.* 14:371-390.
- Salo, E. O. 1991. Life history of chum salmon (*Oncorhynchus keta*). In *Pacific salmon life histories*. Edited by C. Groot and L. Margolis. UBC Press, Vancouver. pp. 231-309.
- Sweeting, R. M., R.J. Beamish, and C. M. Neville. 2004. The continuation of the productive regime in the Strait of Georgia. *N. Pac. Anadr. Fish Comm. Doc.* 818. 24 pp. (Available at www.npafc.org).
- Washington Department of Fisheries and Wildlife (WDFW). 2011. Run size data for Washington Coast and Columbia chum salmon populations. (Available at wdfw.wa.gov/fish/chum/index.htm).

Distribution and Abundance of Juvenile Chum Salmon (*Oncorhynchus keta*) in Nemuro Bay, Eastern Hokkaido, Japan

Kiyoshi Kasugai¹, Mitsuru Torao¹, Hiroshi Kakizaki², Hiroshi Adachi³, Hiromi Shinhama³,
Yutaka Ogasawara⁴, Shinji Kawahara⁴, Tsutomu Arauchi⁵ and Mitsuhiro Nagata⁶

¹*Doto Research Branch, Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, Nakashibetsu, Hokkaido 086-1164, Japan*

²*Nemuro Salmon Enhancement Programs Association, Shibetsu, Hokkaido 086-1634, Japan*

³*Notsuke Fisheries Cooperative Association, Betsukai, Hokkaido 086-1643, Japan*

⁴*Betsukai Fisheries Cooperative Association, Betsukai, Hokkaido 086-0522, Japan*

⁵*Nemuro Field Station, National Salmon Resources Center, Fisheries Research Agency, Nakashibetsu, Hokkaido 086-1109, Japan; Present address: Miyako Station, Tohoku National Fisheries Research Institute, Miyako, Iwate 027-0052, Japan*

⁶*Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, Eniwa, Hokkaido 061-1433*

Keywords: juvenile chum salmon, Nemuro Bay, littoral zone, nearshore area, sea surface temperature, release date, survival

Catches of chum salmon in Hokkaido increased after the 1970s and have remained over 30 million since the 1990s (Mayama and Ishida 2003). However, there are large differences in the amount of chum salmon catch among regions of Hokkaido (Saito and Nagasawa 2009; Nagata et al. 2012a, b). In the Nemuro region, catches of chum salmon constitute about 30% of the total catch in Hokkaido, however, the catches in the northern and southern areas differ (Fig. 1). Although the number of juvenile chum salmon released in both areas is almost the same, the catch in the southern area is about one-third the catch in the northern area.

Mortality of juvenile chum salmon in coastal waters just after entering the sea is thought to be higher than during other periods of their life history (Parker 1968; Healey 1982; Bax 1983; Fukuwaka and Suzuki 2002; Saito et al. 2011). Therefore, one of the ways to obtain higher survival would be to decrease mortality of juveniles in coastal waters. Coastal environments influencing mortality and distribution of juvenile chum salmon might differ and be specific to each region (Mueter et al. 2002). Juvenile chum salmon should be released from the hatchery at a time when coastal environments are suitable for their survival because release timing affects return of adult fish (Seki and Shimizu 1996).

We hypothesized that lower return of adult chum salmon to the southern Nemuro area may be caused by a mismatch between release timing and conditions suitable for survival in the coastal environment. For this investigation, we released juvenile chum salmon marked with alizarine-complexone at various times (late March–early May) and surveyed their distribution and abundance in coastal waters between late April and mid July 2007–2010. We investigated the suitability of coastal environments in the southern Nemuro area for survival of juvenile chum salmon. Furthermore, we proposed a release time for hatchery-reared fish to achieve better adult returns.

Table 1. Date and duration of time when specific sea surface temperature (SST) conditions existed at Betsukai Station (ST) in Nemuro Bay, Eastern Hokkaido, 2007-2010.

Year	SST > 6°C (date)	SST > 8°C (date)	SST > 13°C (date)	SST 8°–13°C (period)	SST 8°–13°C (number of days)
2007	6 May	29 May	16 June	late May to mid June	19
2008	7 May	5 June	12 July	early June to mid July	38
2009	4 May	13 May	26 June	mid May to late June	45
2010	6 May	10 June	21 June	early June to late June	12

At the Betsukai Station (ST), the dates when sea surface temperatures (SSTs) exceeded 8°C varied from year to year; the earliest and latest dates were in 2009 and 2010, respectively (Table 1; Fig. 1). The earliest date when SSTs exceeded 13°C was during 2007 and latest date was during 2008. The number of days when SSTs ranged between 8°C and 13°C was 12 to 45 days.

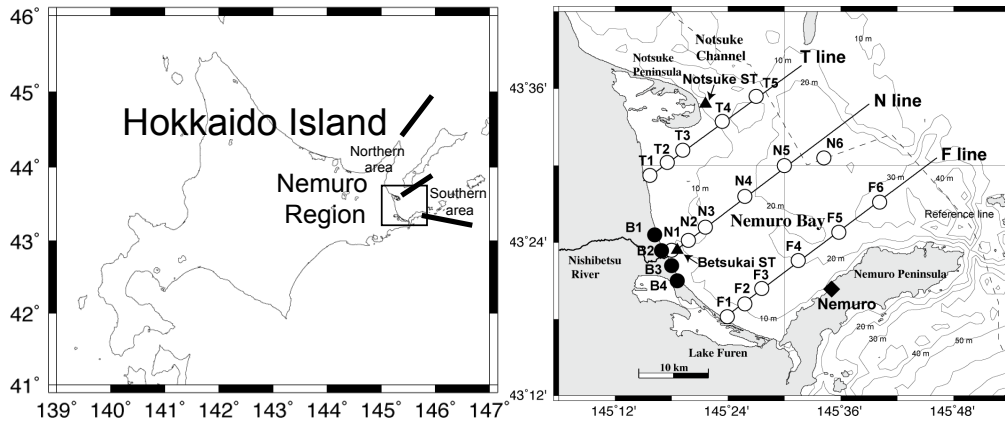


Fig. 1. Study area in the Nemuro region of eastern Hokkaido and positions of sampling stations in the littoral zone (B1-B4) and nearshore area (T1-T3, N1-N3, and F1-F3).

In the littoral zone (B1-B4; Fig. 1), catch per unit effort (CPUE) exceeding 100 fish/net was observed at SSTs between 5°-14°C, and the frequency of high CPUEs was greater when SSTs were between 7°-9°C. In nearshore areas (T1-T3, N1-N3, F1-F3), CPUEs over 100 fish/km were observed at SSTs between 6°-16°C, and the frequency of high CPUEs was greater when SSTs were between 7°-14°C. The upper limit of SST experienced by juvenile salmon was lower in the littoral zone than in nearshore areas because fish migrated to the nearshore area as SSTs increased. The SSTs in nearshore areas where large numbers of juvenile chum salmon were caught was between 8°-13°C, which is consistent with previous reports (Pearcy et al. 1989; Kaeriyama 1986; Irie 1990; Seki 2005; Nagata et al. 2007).

Annual mean CPUE in the littoral zone was relatively low in 2007 and 2009 and relatively high in 2008 and 2010 (Fig. 2), however, no significant difference was observed. The number of days from 1 May until SSTs exceeded 8°C at Betsukai ST was relatively high in 2008 and 2010 and relatively low in 2007 and 2009 (Fig. 2). The high annual mean CPUE in the

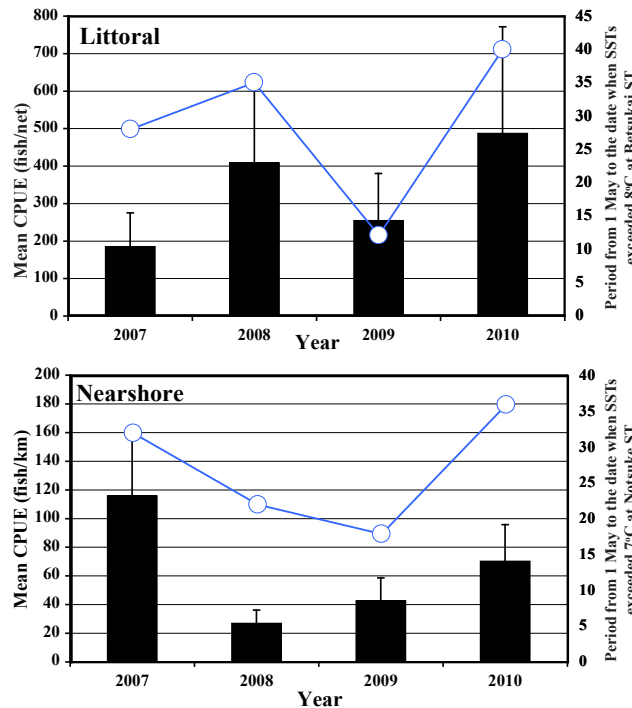


Fig. 2. Abundance of juvenile chum salmon and sea water temperature (SST) conditions in the littoral and nearshore areas in Nemuro Bay, eastern Hokkaido, 2007-2010. Upper panel: annual mean catch per unit effort (CPUE) of chum salmon in the littoral zone (black column and standard error) and number of days from 1 May to the date when SSTs exceeded 8°C (line) at Betsukai Station. Lower panel: annual mean catch per unit effort (CPUE) of chum salmon in the nearshore area (black column and standard error) and number of days from 1 May to the date when SSTs exceeded 7°C (line) at Notsuke Station.

littoral zone may be attributed to delayed SST increase at Betsukai ST because juvenile chum salmon cannot migrate to nearshore areas when SSTs are too low (Nagata et al. 2007).

Mean CPUE in nearshore areas when juvenile salmon were most abundant ranged from 681.75 fish/km in 2007 to 125.22 fish/km in 2008. The annual mean CPUE in nearshore areas was considerably higher in 2007 than in other years (Fig. 2). The amount of time that SSTs ranged between 8°-13°C at Betsukai ST was relatively short in 2007 and 2010. In contrast, the time period when SSTs exceeded 7°C at Notsuke ST, which is located outside Nemuro Bay, was longer in 2007 and 2010. The earlier timing for rising SSTs at Notsuke ST may spread the distribution of juvenile chum salmon out of Nemuro Bay, and thereby decrease the annual mean CPUEs in nearshore areas of the Nemuro region.

In the littoral zone and nearshore area, the date when the maximum number of marked chum salmon was recaptured varied from year to year. However, recapture of marked fish coincided with peaks in mean CPUE in the littoral zone and nearshore areas and did not coincide with release dates.

Stepwise multiple regression analyses were conducted to determine the relationships between number of recaptured marked fish and environmental variables. The number of days from 25 March to the release date (RELEASE), number of days from release date to the date when SSTs at Betsukai ST exceeded 8°C (DAYS1), number of days when SSTs at Betsukai ST were 8°-13°C (DAYS2), and number of days from 1 May to the date when SSTs at Notsuke ST exceeded 7°C (DAYS3) were used as predictors and the log-transformed number of marked fish recaptured in the littoral zone or nearshore areas was used as the dependent variable. Analysis of the littoral zone data showed RELEASE was significantly correlated with the quantity of recaptured marked fish ($p < 0.01$; Fig. 3). The later the release date the more recaptured marked fish were caught. In contrast, analysis of the nearshore samples showed RELEASE, DAYS1, and DAYS2 were significantly negatively correlated with the number of recaptured marked fish ($p < 0.05$). The absolute value of the adjusted regression coefficient was the highest for DAYS1, indicating that DAYS1 strongly influenced the number of marked fish recaptured in nearshore areas (Fig. 4). The number of marked fish recaptured in nearshore areas increased as time between the release date and the date when SSTs at Betsukai ST exceeded 8°C decreased. These results suggest that high mortality may occur in the river and/or littoral zone before juvenile chum salmon migrate to nearshore areas.

Analysis of the nearshore data showed the intercepts of the growth curves were significantly different ($p < 0.01$; 2008 = 2009 > 2007 = 2010) among the groups released in mid April, although specific growth rates (SGRs; slopes) were not different. The SGRs and intercept of the growth curves were not significantly different among the groups released after mid April in 2007, 2008, and 2010. Environmental variability in coastal areas during spring may influence the growth of marked fish released in mid April more strongly than those released after mid April.

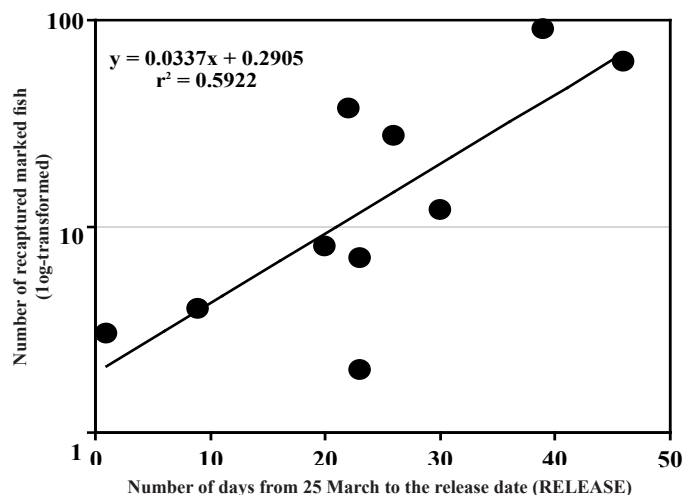


Fig. 3. Relationship between the number of days from 25 March to the juvenile chum salmon release date and the log-transformed number of marked fish recaptured in the littoral zone of Nemuro Bay, 2007-2010.

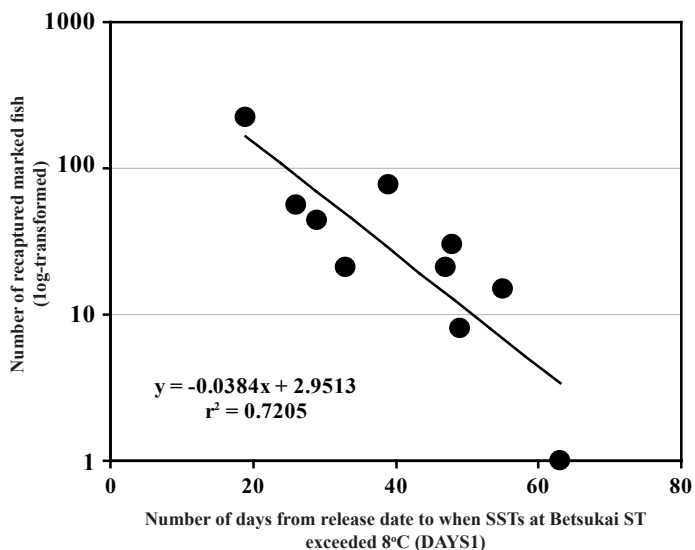


Fig. 4. Relationship between the number of days from the juvenile chum salmon release date to the date when sea surface temperatures exceeded 8°C at Betsukai Station and the log-transformed number of marked fish recaptured in nearshore areas of Nemuro Bay, 2007-2010.

In conclusion, the SSTs in nearshore areas strongly influenced the distribution and abundance of juvenile chum salmon in Nemuro Bay. Delayed migration to nearshore areas from the river or littoral zone due to low SSTs may result in high mortality. Therefore, release timing of juvenile chum salmon in Nemuro Bay should be shifted from late March-late May to late April-mid May to increase juvenile chum salmon survival.

REFERENCES

- Bax, N.J. 1983. Early marine mortality of marked juvenile chum salmon (*Oncorhynchus keta*) released into Hood Canal, Puget Sound, Washington, in 1980. *Can. J. Fish. Aquat. Sci.* 40: 426-435.
- Fukuwaka, M. and T. Suzuki. 2002. Early sea mortality of mark-recaptured juvenile chum salmon in open coastal waters. *J. Fish Biol.* 60: 3-12.
- Healey, M.C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. *Can. J. Fish. Aquat. Sci.* 39: 952-957.
- Irie, T. 1990. Ecological studies on the migration of juvenile chum salmon, *Oncorhynchus keta*, during early ocean life. *Bull. Seikai Nat. Fish. Res. Inst.* 68: 1-142. (In Japanese with English abstract).
- Kaeriyama, M. 1986. Ecological study on early life of the chum salmon, *Oncorhynchus keta* (Walbaum). *Sci. Rep. Hokkaido Salmon Hatchery* 40: 31-92. (In Japanese with English abstract).
- Mayama, H. and Y. Ishida. 2003. Japanese studies on the early ocean life of juvenile salmon. *N. Pac. Anadr. Fish Comm. Bull.* 3: 41-68. (Available at www.npafc.org).
- Mueter, F.J., R.M. Peterman, and B.J. Pyper. 2002. Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (*Oncorhynchus* spp.) in northern and southern areas. *Can. J. Fish. Aquat. Sci.* 59: 456-463.
- Nagata, M., Y. Miyakoshi, D. Ando, M. Fujiwara, M. Sawada, H. Shimada, and H. Asami. 2007. Influence of coastal seawater temperature on the distribution and growth of juvenile chum salmon, with recommendations for altered release strategies. *N. Pac. Anadr. Fish Comm. Bull.* 4: 223-235. (Available at www.npafc.org).
- Nagata, M., Y. Miyakoshi, H. Urabe, M. Fujiwara, Y. Sasaki, K. Kasugai, M. Torao, D. Ando, and M. Kaeriyama. 2012a. An overview of salmon enhancement and the need to manage and monitor natural spawning in Hokkaido, Japan. *Environ. Biol. Fish.* 94(1): 311-323. DOI 10.1007/s10641-011-9882-3.
- Nagata, M., Y. Miyakoshi, H. Urabe, M. Fujiwara, Y. Sasaki, K. Kasugai, M. Torao, D. Ando, and M. Kaeriyama. 2012b. Erratum to: An overview of salmon enhancement and the need to manage and monitor natural spawning in Hokkaido, Japan. *Environ. Biol. Fish.* 94(1): 359-361. DOI 10.1007/s10641-011-9945-5.
- Parker, R.R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. *J. Fish. Res. Board Can.* 25: 757-794.
- Pearcy, W.G., C.D. Wilson, A.W. Chung, and J.W. Chapman. 1989. Residence times, distribution, and production of juvenile chum salmon, *Oncorhynchus keta*, in Netarts Bay, Oregon. *Fish. Bull.* 87: 553-568.
- Saito, T., and K. Nagasawa. 2009. Regional synchrony in return rates of chum salmon (*Oncorhynchus keta*) in Japan in relation to coastal temperature and size at release. *Fish. Res.* 95: 14-27.
- Saito, T., T. Kaga, E. Hasegawa, and K. Nagasawa. 2011. Effects of juvenile size at release and early marine growth on adult return rates for Hokkaido chum salmon (*Oncorhynchus keta*) in relation to sea surface temperature. *Fish. Oceanogr.* 20: 278-293.
- Seki, J. 2005. Study of characteristic of feeding habitat of juvenile chum salmon and their food environment in the Pacific coastal waters, central part of Hokkaido. *Bull. Nat. Salmon Resources Center* 7: 1-104. (In Japanese with English abstract).
- Seki, J., and I. Shimizu. 1996. Effect time of larval release on return rate in chum salmon (*Oncorhynchus keta*) in the Hiroo River, Hokkaido, Japan. *Bull. Japan. Soc. Fish. Oceanogr.* 60: 339-347. (In Japanese with English abstract).

Polymorphism of Mitochondrial DNA (mtDNA) of the Cytb/D-loop Region in Pink Salmon Populations

Nina Yu. Shpigalskaya, Vladimir A. Brykov, Andrey D. Kukhlevsky, and Anna A. Chetvertak

*Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO),
 18, Naberezhnaya Str., Petropavlovsk-Kamchatsky 683600, Russia*

Keywords: pink salmon, mitochondrial DNA, haplotypes, genetic differentiation

Pink salmon is the most abundant Pacific salmon species in the North Pacific Ocean, and its commercial role in salmon fisheries of the Russian Far East is paramount. The principal stocks supporting commercial salmon fisheries originate from local populations in Kamchatka, Sakhalin, Kuril Islands and the Amur River basin. The purpose of our research was to determine the level of pink salmon mtDNA polymorphism as a marker to identify the regional origin of pink salmon in mixed-stock marine aggregations. We analyzed the population and regional level genetic variation on the basis of polymorphism of mtDNA Cytb/D-loop region using the following restriction enzymes: *Dde* I, *Hin6* I, *Hinf* I, *Msp* I, *Rsa* I, *Sfr*13 I.

We analyzed 32 samples of pink salmon returning to spawn in even-numbered years (25 populations, 1612 fishes) and 17 samples of pink salmon returning in odd-numbered years (16 populations, 805 fishes) from the rivers of West and East Kamchatka, Sakhalin, Amur River, continental shore of the Okhotsk Sea and Primorye. As a result of restriction fragment length polymorphism (RFLP) analysis, 59 unique Cytb/D-loop haplotypes were found in the 2417 individuals. Analysis of even-year pink salmon revealed 39 haplotype variants, and 34 haplotypes were found in the odd-year samples. Fourteen composite haplotypes were found in common between the odd- and even-year brood lines. Only three haplotypes were detected in all 49 samples analyzed. Most of the haplotypes (39) were rare and detected once in one of the samples.

Based on the variation of composite haplotype frequencies, we confirmed the difference between even- and odd-year brood lines in Asian pink salmon, and we obtained data indicating the heterogeneity of even- and odd-year generations of pink salmon. Pair-wise comparison of all samples indicated significant differences in 55.1% of the comparisons. Analysis of samples from even-year brood lines revealed significant differences in 33.7% of the pair-wise comparisons, and analysis of samples from the odd-year brood line indicated significant differences in 33.8% of the comparisons.

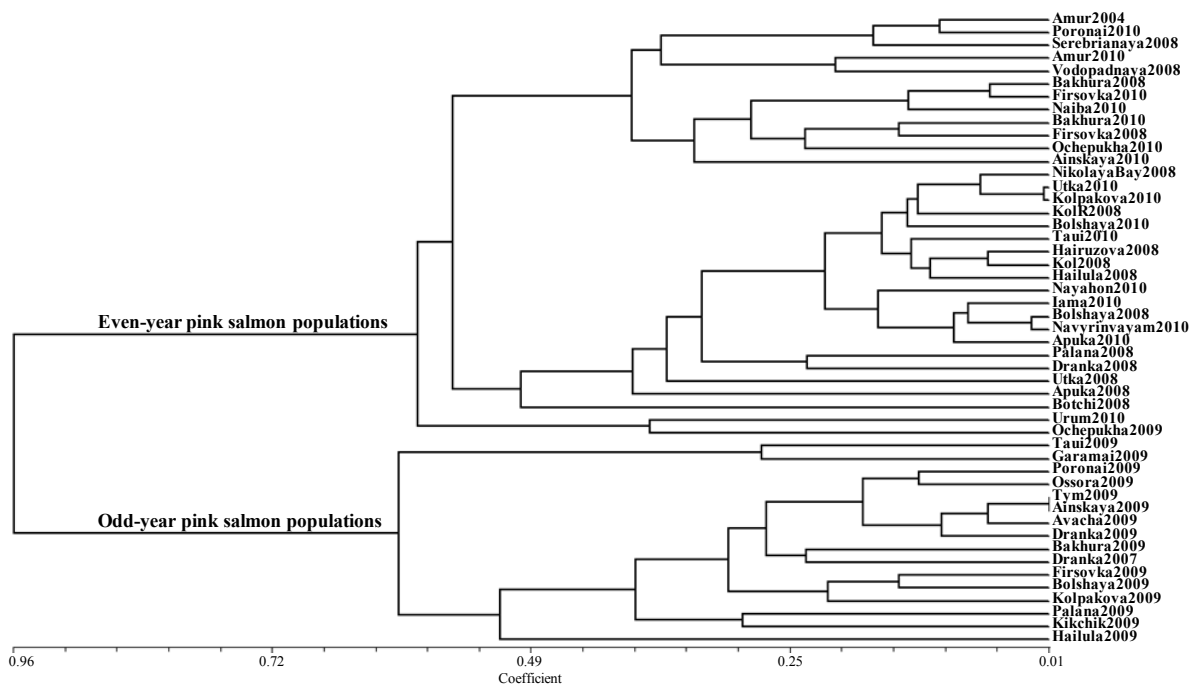


Fig. 1. The unweighted pair-group method with arithmetic mean (UPGMA) dendrogram created using genetic chord distances and based on the frequencies of composite haplotypes of even- and odd-year Asian pink salmon.

The genetic chord distances, calculated from the frequencies of the composite haplotypes, were analyzed using cluster analysis and multidimensional scaling (Figs. 1 and 2). The samples formed two significant divergent clusters, one each for the even- and odd-year brood line. Samples from even-year brood lines clearly expressed a regional division into northern and southern groups of populations. Samples from odd-year brood lines did not demonstrate any regional groups or other clusters.

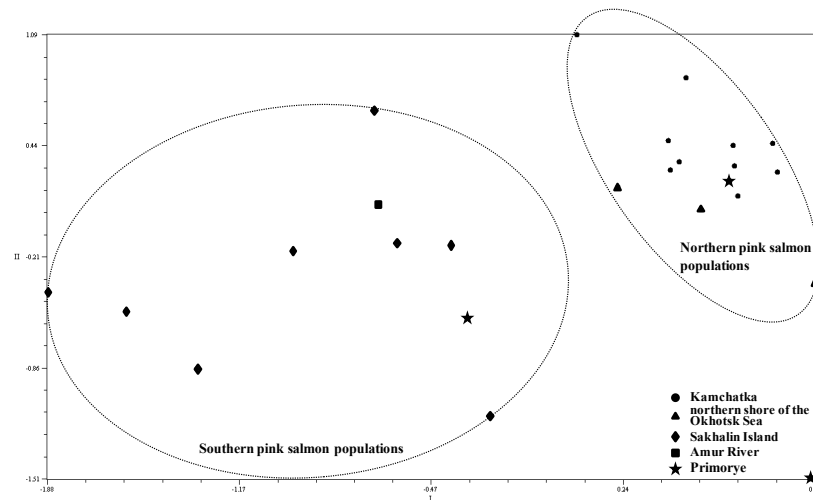


Fig. 2. Multidimensional scaling analysis of genetic distances calculated from composite haplotype frequencies of even-year Asian pink salmon populations.

Table 1. The relative (%) genetic variation among and within populations and regional groups that was observed in even-year Asian pink salmon populations. Variation estimated by hierarchical analysis of molecular variation (AMOVA).

Analyzed pool	Source of variation	Percentage of variation
All samples	Among populations	1.88
	Within populations	98.12
5 regional groups of populations: Kamchatka, Sakhalin, Amur R., Primorye, northern shore of the Okhotsk Sea	Among groups	2.10
	Among populations within groups	0.30
	Within populations	97.60

Within regional groups of populations, hierarchical analysis of molecular variation (AMOVA) of samples collected from even-year brood lines indicated a visibly higher inter-regional variation than inter-population variation (Table 1). Analysis of samples from odd-year brood lines demonstrated higher differentiation at the population level than the even-year brood line. Variation between populations was substantially higher than between regions in samples collected from odd-year brood lines (Table 2).

Table 2. The relative (%) genetic variation among and within populations and regional groups that was observed in odd-year Asian pink salmon populations. Variation estimated by hierarchical analysis of molecular variation (AMOVA).

Analyzed pool	Source of variation	Percentage of variation
All samples	Among populations	3.10
	Within populations	96.90
3 regional groups of populations: Kamchatka, Sakhalin, northern shore of the Okhotsk Sea	Among groups	1.00
	Among populations within groups	2.69
	Within populations	96.31

Judging from these results, we have no doubt there is regional divergence in the even-year brood line of Asian pink salmon. Determination of intra-regional divergence will require additional analysis using a larger number of samples from major spawning rivers. However, the use of mtDNA polymorphism of the Cytb/D-loop region as a regional marker looks promising for analysis of mixed-stock catches of even-year pink salmon.

Identification of Pink Salmon Mixed-Stock Aggregations on the Basis of Mitochondrial DNA Polymorphism

Nina Yu. Shpigalskaya, Vladimir A. Brykov, Andrey D. Kukhlevsky, and Evgeny A. Shevlyakov

*Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO),
 18, Naberezhnaya Str., Petropavlovsk-Kamchatsky 683600, Russia*

Keywords: pink salmon, mitochondrial DNA, haplotypes, genetic stock identification

The ability to identify contributing regional stock complexes and major pink salmon populations in marine aggregations will help to increase accuracy in forecasting pink salmon abundance. Pink salmon are the most abundant species of Pacific salmon in the Russian Far East. To determine the level of population and regional genetic variation, we analyzed the Cytb/D-loop region of mtDNA polymorphism in populations contributing to mixed-stock marine aggregations. We used the following restriction enzymes our analysis: *Dde* I, *Hin6* I, *Hinf* I, *Msp* I, *Rsa* I, *Sfr*13 I.

Variations in the frequency of composite haplotypes of pink salmon returning to spawn in even-numbered years were investigated for populations from East and West Kamchatka, Sakhalin, rivers of the northern coast of the Okhotsk Sea, Primorye, and the Amur River. Maximum likelihood was used to estimate identification accuracy in the baseline stocks. The accuracy for Kamchatka was not high and was determined to be in range of 42.9-68.8%. Identification accuracy for Sakhalin populations was lower, from 40.8% to 83.2%. Amur River pink salmon were identified with 66.1% accuracy, and stocks from Primorye and the north coast of the Okhotsk Sea were identified with 40.7–78.3% accuracy.

Simulations using a 100% composition of each stock at the five-region level indicated high accuracies at the regional level, which averaged 94.2% for Kamchatka pink salmon and 84.7% for Sakhalin pink salmon (II analysis; Table 1). Separation of West and East Kamchatka in a six-way analysis decreased accuracy to 74.7% and 68.0%, respectively (III analysis; Table 1).

Table 1. Average percent (and standard deviation) correct and incorrect allocations (read vertically) by region for simulated mixtures based on the number of even-year pink salmon regional groups. Expected value for estimates shown in bold is 100%.

		I analysis					
№	Region	1				2	
1	Northern populations	93.6 _(6.3)				12.8	
2	Southern populations	6.0				86.8 _(7.3)	
	Unknown	0.4				0.4	
		II analysis					
№	Region	1	2	3	4	5	
1	Sakhalin Island	84.7 _(9.8)	19.3	12.0	14.2	2.3	
2	Amur River	2.2	66.1 _(14.1)	0.1	0.4	0.1	
3	Northern shore of the Okhotsk Sea	2.8	2.3	52.0 _(16.7)	3.7	2.6	
4	Primorye	2.7	2.4	2.8	64.5 _(14.2)	0.4	
5	Kamchatka	7.5	8.8	32.4	16.1	94.2 _(6.2)	
	Unknown	0.1	1.1	0.7	1.1	0.4	
		III analysis					
№	Region	1	2	3	4	5	6
1	Sakhalin Island	84.7 _(9.8)	19.3	12.0	14.2	2.4	2.1
2	Amur River	2.2	66.1 _(14.1)	0.1	0.4	0.0	0.1
3	Northern shore of the Okhotsk Sea	2.8	2.3	52.0 _(16.7)	3.7	3.5	5.6
4	Primorye	2.7	2.4	2.8	64.5 _(14.2)	0.3	0.4
5	West Kamchatka	4.9	2.5	11.5	11.6	74.7 _(14.3)	23.6
6	East Kamchatka	2.6	6.3	20.9	4.5	18.6	68.0 _(17.3)
	Unknown	0.1	1.1	0.7	1.1	0.5	0.2

We provided proof that pink salmon mtDNA haplotype variations can be used for identification of mixed-stock marine aggregations. Samples from 595 juvenile pink salmon were obtained from the autumn trawl survey of the R/V *Professor Kaganovsky* in 2009. The baseline data we used were the haplotype frequencies in samples of adult even-year pink salmon from nine rivers of Kamchatka and eight sites in Sakhalin and the Amur River (980 individuals in total). Analysis showed the stock composition of the juvenile pink salmon was mostly West Kamchatka (52.4%), followed by Sakhalin (27.1%), Amur River (11.9%), East Kamchatka (7.2%), and other (unknown; 1.4%).

Assuming the mortality rate is equal for the contributing stocks in the mixture of juveniles, we hypothesized that the regional stock proportions would be approximately the same for adults returning of following year. A comparison of the stock proportions in the juvenile pink salmon mixture from our analysis of 2009 samples with the proportions observed in the regional catch and escapement of adult pink salmon runs in 2010 showed there was a high degree of similarity (Fig. 1).

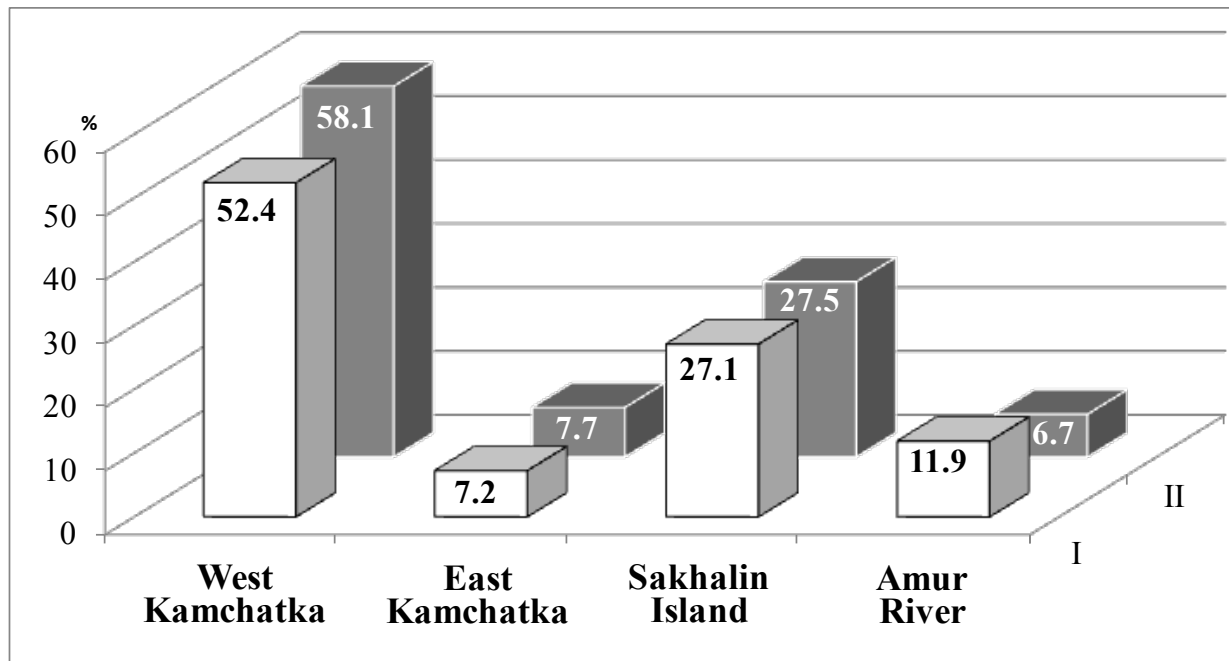


Fig. 1. Comparison of proportional estimates of pink salmon based on genetic analysis of juveniles in marine feeding aggregations in fall 2009 (row I) and regional catch and escapement of adults in 2010 (row II).

Comparison of Even- and Odd-Year Broodlines of Pink Salmon Using Genotyping by Sequencing

Lisa W. Seeb, Ryan K. Waples, and James E. Seeb

*School of Aquatic and Fishery Sciences, University of Washington,
1122 NE Boat Street, Box 355020, Seattle, Washington 98195, USA*

Keywords: pink salmon, genetics, genotyping, adaptation, Norton Sound, Prince William Sound, Puget Sound

Pink salmon represent a critically important component of the North Pacific and Bering Sea ecosystem. They are the most numerous salmon species in the North Pacific Ocean and Bering Sea and are unique among Pacific salmon with an obligate two-year life history resulting in two genetically distinct lineages (even- or odd-year) that largely overlap in range. In North America, odd-year broods predominate in the south, with even-year pink salmon predominating in more northerly latitudes. In many streams, even- and odd-year lineages occupy the same habitat, but experience no gene flow providing for a naturally-occurring replicate experiment to test for genomic signals of adaptation. We present next-generation sequence results using restriction site associated DNA (RAD tags) to compare three paired populations of even- and odd-year pink salmon. Our population pairs originate from widely-separated locations in North America and include Norton Sound in Northwest Alaska, Prince William Sound in Southcentral Alaska, and Puget Sound in Washington State. We compare sequence divergence and identify outlier loci between population pairs, as well as within and between the lineages, and test for signals of neutral and adaptive markers across the genomes.

Differentiation of Local Pink Salmon Stocks on the Basis of Variations in Their Scale Structure

Vladimir A. Savin, Roman A. Shaporev, Ekaterina V. Savenkova, and Natalya V. Varnavskaya

*Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO),
18, Naberezhnaya Str., Petropavlovsk–Kamchatsky 683602, Russia*

Key words: pink salmon, local stocks, differentiation, scale structure, scale pattern analysis

One of the challenges facing Pacific salmon fisheries management is the differentiation of local populations in mixtures of prespawning or feeding aggregations. The problem of differentiating stocks is especially urgent for pink salmon, the most abundant species of Pacific salmon in Asia. One method for stock identification is based on scale pattern analysis. Investigations in recent decades have demonstrated that pink salmon scales, particularly the first-year zone, can be an informative marker to differentiate populations at the level of major regional groups (e.g., Grachev 1983; Temnykh 1998; Antonov et al. 2005). A general characteristic trait for pink salmon returning to spawn in even- or odd-numbered years is the capacity for significant phenotypic separation using scales collected from local stocks in the southern and northern portions of pink salmon distribution in Asia. The difference in the scale structure has been described by several fish biologists in earlier works. Moreover, some regional complexes can be identified within local stocks in the southern and northern groups.

We expanded the baseline and have improved on procedures of scale pattern analysis since an earlier study by Shaporev et al. (2007). In this project our objective was to use Asian pink salmon scale samples from known populations to explore inter-population differences for fish that returned as adults in 2007-2009. Samples used for this investigation included adult pink salmon scales collected from 34 local areas of Hokkaido, Sakhalin, the Amur River system, continental shore of the Okhotsk Sea, and West and East Kamchatka (Fig. 1). The samples consisted of 8,777 individual adult pink salmon originating from 67 stocks. Scales were scanned at 10-fold magnification and scanned images included the whole scale. From one to five scales were examined from each pink salmon, and the analysis was based on averaged scale variables.

To discover the extent of characteristics differentiating the stocks, we computed the Mahalanobis distance between population centroids using multidimensional scaling. The resolving ability of the data was analyzed using the maximum likelihood estimation procedure available in the computer program SPAM (Statistics Program for Analyzing Mixtures; Masuda et al. 1991; Pella et al. 1996).

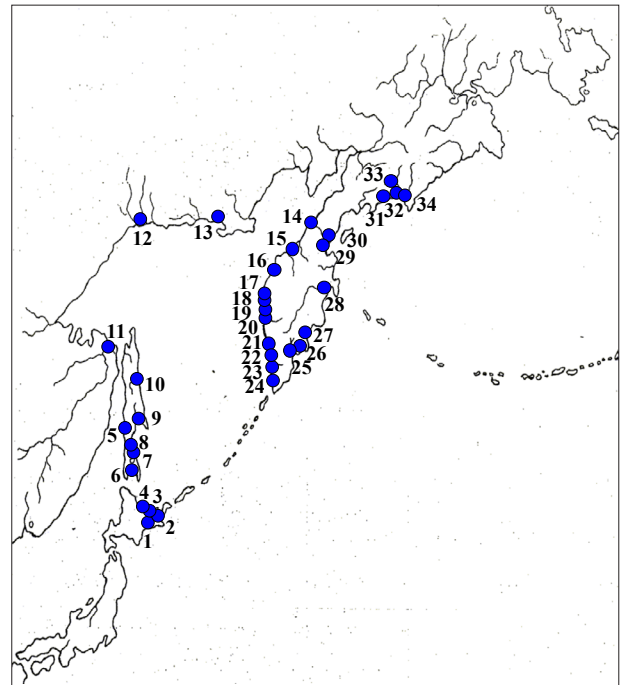


Fig. 1. Location of individual pink salmon populations sampled from adults returning in 2004-2009. Populations were located in the following areas: Hokkaido (1-4), Sakhalin (5-10), Amur River (11), coast of Okhotsk Sea (12-13), Western Kamchatka (14-24), and Eastern Kamchatka (25-34).

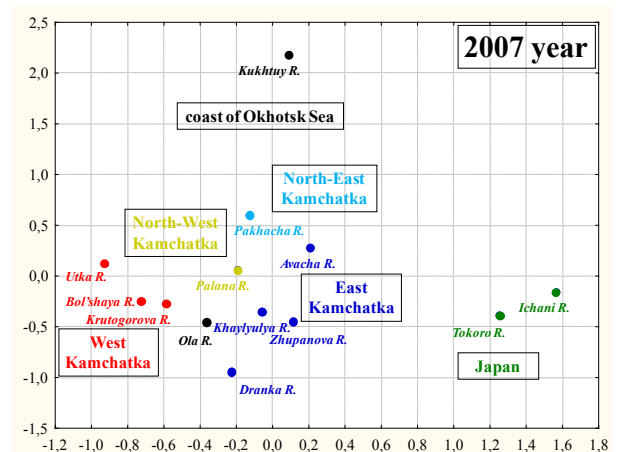


Fig. 2. Separation of populations and regional clusters of Asian pink salmon collected in 2007 based on scale patterns. Multidimensional scaling was used to differentiate among populations.

Multidimensional scaling of the 2007 samples showed two complexes of pink salmon local stocks, one from the western coast and a second from the eastern coast of Kamchatka (Fig. 2). The scale patterns of pink salmon originating in the Pakhacha (Olutorsky Gulf), Palana (Northwest Kamchatka) and Ola (continental shore of the Okhotsk Sea) Rivers were intermediate between the West and East Kamchatka groups of pink salmon. Pink salmon from the Kukhtuy River on the continental shore of the Okhotsk Sea was widely separated from the other groups.

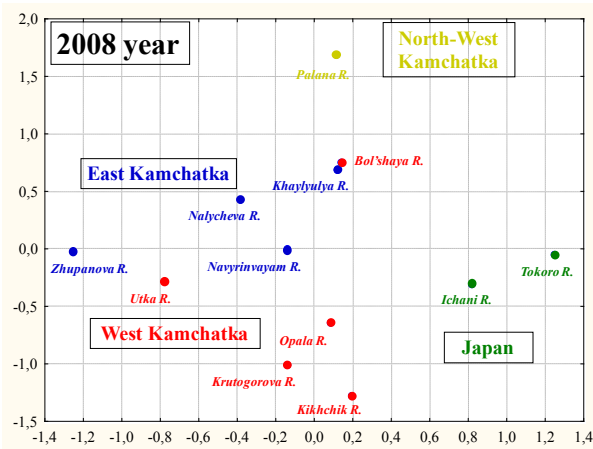


Fig. 3. Separation of populations and regional clusters of Asian pink salmon collected in 2008 based on scale patterns. Multidimensional scaling was used to differentiate among populations.

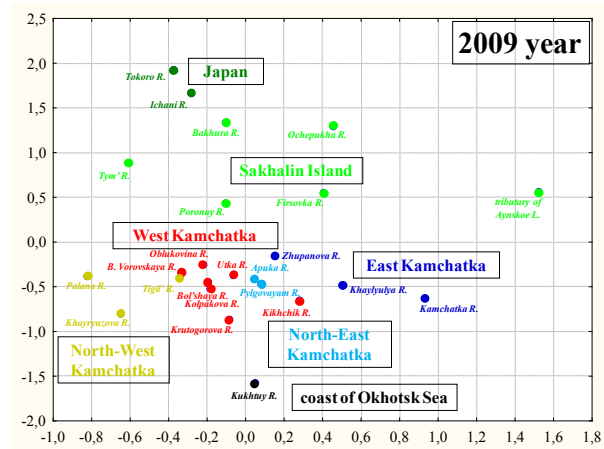


Fig. 4. Separation of populations and regional clusters of Asian pink salmon collected in 2009 based on scale patterns. Multidimensional scaling was used to differentiate among populations.

With the exception of the Bolshaya River, there were no overlapping clusters in the 2008 samples, which indicated that the West and East Kamchatkan regional complexes of pink salmon could be differentiated (Fig. 3). The Palana River (Northwest Kamchatka) sample was widely separated from the other groups.

Analysis of samples collected in 2009 clearly showed that the portion of the scale formed in the estuary can help to characterize stocks originating from Japan and Sakhalin (Fig. 4). Within the northern group, two non-overlapping clusters separated East and Northwest Kamchatka. Scales from the Olutorsky Gulf were similar to the West Kamchatkan populations, and the Kukhtuy River was widely separated from the other samples of the northern group.

Table 1. Maximum likelihood estimates developed from apportionment of scales from a baseline of Asian pink salmon collected from adults returning in 2007. Shaded boxes indicate the correct allocation based on a simulated proportion of 1.00 to the correct region. Misallocations are read across.

Population	Japan	Coast of Okhotsk Sea	West Kamchatka	East Kamchatka	SD	CI ± 90%	
Ichani R.	0.902	0.013	0.038	0.048	0.028	0.851	0.943
Tokoro R.	0.872	0.018	0.034	0.077	0.032	0.822	0.921
Kukhtuy R.	0.010	0.791	0.084	0.115	0.049	0.711	0.874
Ola R.	0.008	0.614	0.302	0.076	0.033	0.558	0.669
Palana R.	0.029	0.209	0.627	0.136	0.072	0.505	0.747
Krutogorova R.	0.000	0.282	0.617	0.101	0.078	0.489	0.743
Utkha R.	0.003	0.198	0.733	0.066	0.081	0.589	0.867
Bol'shaya R.	0.044	0.222	0.661	0.074	0.075	0.533	0.779
Avacha R.	0.042	0.068	0.173	0.718	0.074	0.589	0.841
Zhupanova R.	0.124	0.066	0.310	0.500	0.075	0.370	0.629
Khaylyulya R.	0.059	0.223	0.240	0.478	0.074	0.355	0.601
Dranka R.	0.028	0.193	0.241	0.539	0.141	0.301	0.768
Pakhacha R.	0.012	0.108	0.219	0.661	0.090	0.508	0.807

Assessment of the likelihood of accurate regional separation of pink salmon varied from year to year. For samples of fish returning in 2007, the estimated correct allocation to groups included Japan 87-90%, continental shore of the Okhotsk Sea 61-79%, West Kamchatka 62-73%, and East Kamchatka 48-72% (Table 1). The maximum likelihood estimates of correct

allocation for samples collected in 2008 included Japan 78-84%, West Kamchatka 66-87%, and East Kamchatka 52-91% (Table 2). Estimated correct allocation for samples in the 2009 baseline included Japan 75-76%, Sakhalin 63-91%, continental shore of the Okhotsk Sea 76%, West Kamchatka 53-86%, and East Kamchatka 16-68% (Table 3).

Table 2. Maximum likelihood estimates developed from apportionment of scales from a baseline of Asian pink salmon collected from adults returning in 2008. Shaded boxes indicate the correct allocation based on a simulated proportion of 1.00 to the correct region. Misallocations are read across.

Population	Japan	West Kamchatka	East Kamchatka	SD	CI ± 90%	
Ichani R.	0.778	0.089	0.133	0.037	0.715	0.835
Tokoro R.	0.835	0.078	0.087	0.036	0.777	0.892
Palana R.	0.008	0.853	0.139	0.054	0.761	0.936
Krutogorova R.	0.074	0.748	0.178	0.067	0.632	0.846
Kikhchik R.	0.048	0.782	0.170	0.058	0.683	0.879
Utka R.	0.014	0.663	0.323	0.050	0.582	0.747
Bol'shaya R.	0.007	0.886	0.106	0.045	0.807	0.955
Opala R.	0.030	0.828	0.143	0.052	0.734	0.907
Nalycheva R.	0.160	0.323	0.517	0.067	0.400	0.626
Zhupanova R.	0.034	0.057	0.908	0.031	0.853	0.956
Khaylyulya R.	0.011	0.362	0.628	0.085	0.493	0.768
Navyrinvyayam R.	0.021	0.262	0.717	0.056	0.622	0.805

Table 3. Maximum likelihood estimates developed from apportionment of scales from a baseline of Asian pink salmon collected from adults returning in 2009. Shaded boxes indicate the correct allocation based on a simulated proportion of 1.00 to the correct region. Misallocations are read across.

Population	Japan	Sakhalin	Coast of Okhotsk Sea	West Kamchatka	East Kamchatka	SD	CI ± 90%	
Ichani R.	0.764	0.194	0.000	0.012	0.031	0.045	0.686	0.840
Tokoro R.	0.745	0.225	0.000	0.005	0.025	0.043	0.676	0.817
tributary of Aynskoe L.	0.012	0.905	0.010	0.072	0.001	0.046	0.826	0.980
Ochepukha R.	0.089	0.797	0.000	0.021	0.094	0.070	0.675	0.912
Bakhura R.	0.156	0.774	0.000	0.027	0.043	0.065	0.660	0.874
Firsovka R.	0.024	0.628	0.002	0.213	0.134	0.082	0.488	0.759
Poronay R.	0.015	0.738	0.000	0.139	0.108	0.073	0.607	0.853
Tym' R.	0.025	0.878	0.000	0.097	0.000	0.059	0.775	0.970
Kukhtuy R.	0.000	0.019	0.756	0.158	0.067	0.054	0.663	0.846
Palana R.	0.008	0.131	0.073	0.716	0.072	0.043	0.644	0.786
Tigil' R.	0.009	0.080	0.112	0.772	0.028	0.053	0.683	0.858
Khayryuzova R.	0.029	0.205	0.148	0.553	0.065	0.056	0.457	0.645
Oblukovina R.	0.000	0.115	0.004	0.858	0.023	0.052	0.775	0.940
Krutogorova R.	0.000	0.029	0.286	0.654	0.031	0.060	0.555	0.761
Kolpakova R.	0.000	0.085	0.118	0.777	0.019	0.051	0.694	0.857
B. Vorovskaya R.	0.008	0.143	0.097	0.740	0.012	0.042	0.667	0.810
Kikhchik R.	0.014	0.136	0.094	0.655	0.101	0.048	0.575	0.734
Utka R.	0.033	0.081	0.102	0.688	0.096	0.047	0.606	0.771
Bol'shaya R.	0.059	0.205	0.141	0.529	0.065	0.051	0.447	0.615
Zhupanova R.	0.017	0.208	0.056	0.414	0.306	0.047	0.230	0.387
Kamchatka R.	0.000	0.053	0.089	0.174	0.684	0.048	0.612	0.770
Khaylyulya R.	0.020	0.075	0.142	0.269	0.494	0.048	0.418	0.574
Pylgovayam R.	0.017	0.105	0.182	0.405	0.292	0.071	0.172	0.415
Apuka R.	0.006	0.288	0.111	0.433	0.162	0.039	0.096	0.226

One of the problems identified during the course of the investigation was the lack of satisfactory sample size of scales from all principle spawning regions of pink salmon. This was the reason why we were not able to estimate the extent of separation of Amur River pink salmon returns in odd-numbered years, or to separate the local stocks from rivers in Sakhalin and the continental shore of the Okhotsk Sea returning in even-numbered years.

In general the estimated accuracy of the samples suggests to us that the baselines have the capability for rather high resolution. However, in order to test the capability of the baseline and be confident in future scale pattern analyses, we want to examine scale samples from the maximum number of populations available from all principle regions of pink salmon production in Asia.

REFERENCES

- Antonov, N.P., Zh.Kh. Zorbidi, and E.S. Baluyeva. 2005. Scale structure comparative analysis of pink salmon *Oncorhynchus gorbuscha* (Walb.) and coho *O. kisutch* (Walb.) intraspecific variations in the north-west part of Pacific Ocean. Popular biology, genetics, and taxonomy of hydrobionts. KamchatNIRO Publishing, Petropavlovsk-Kamchatsky. 1160–1167 pp. (In Russian).
- Grachev, L.E. 1983. Differentiation of Asian pink salmon stocks. Biological grounds of salmon fisheries in the watersheds of the USSR. M. Nauka. 84–97 pp. (In Russian).
- Pella, J.J., M. Masuda, and S. Nelson. 1996. Search algorithms for computing stock composition of a mixture from traits of individuals by maximum likelihood. NOAA Tech. Memo. NMFS-AFSC-61. 68 pp.
- Masuda, M., S. Nelson, and J. Pella. 1991. The computer programs for computing conditional maximum likelihood estimates of stock composition from discrete characters. USA-Doc-NOAA NMFS, Auke Bay Laboratory, Juneau, AK.
- Shaporev, R.A., N.V. Varnavskaya, V.A. Savin, V.G. Stepanov, and A.G. Bazhin. 2007. Method of complex analyzing of variations of Pacific salmon's stratified scale structures: Kamchatka River chum salmon example. Investigations of aquatic biological resources of Kamchatka and of the Northwestern Pacific. KamchatNIRO Publishing, Petropavlovsk-Kamchatsky. 9: 131–142. (In Russian).
- Temnykh, O.S. 1998. Regional variations of Asian pink salmon scale scleritograms. Izv. TINRO 124: 375–390. (In Russian).

Assessing the Use of Otolith Microstructure for Identification of Regional Stock Complexes of Juvenile Chum Salmon

Alexandra I. Chistyakova, Roman A. Shaporev, and Natalya V. Varnavskaya

*Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO),
18, Naberezhnaya Str., Petropavlovsk-Kamchatsky 683602, Russia*

Key words: chum salmon, otolith microstructure, differentiation, regional stock complexes, wavelet spectral analysis, Kamchatka, Sea of Okhotsk

The ability to differentiate the stocks of juvenile salmon that are in mixed aggregations at sea is vital for forecasting salmon returns. Research in this field indicates that stock differentiation based on morphological variability of otolith structure is promising. Otoliths have been of great interest to fish biologists as structures that record physiological and ontogenetic transformations of fish, and environmental changes of fish habitat. Otolith microstructure of populations should reflect the genetic specifics of the population and environmental conditions of juvenile development. As a rule, individuals from different populations demonstrate differences in otolith microstructure and in the relative size of otoliths. Variability in otolith microstructure has been used to differentiate populations of White Sea and Barents Sea herring (Svetocheva and Stasenkova 2003), Asian and American populations of Dolly Varden (Radtke et al. 1996) Norwegian coastal cod populations (Otterlei et al. 2000), and summer/winter and wild/hatchery stocks of steelhead (McKern et al. 1974). Different chum salmon temporal groups and the varied hydrological conditions on the spawning grounds can be fixed in the otolith microstructure of ecological morphs (Akinicheva and Izergin 2004). As a rule, morphological classification of the otoliths is subjective and can be used only for identification of certain ecological morphs within a single watershed. The question of how to characterize and estimate differences between chum salmon at a regional or population level based on otolith microstructure was the problem we sought to answer.

The purpose of this our work was to estimate intra- and inter-population variation in otolith microstructure of juvenile chum salmon as a possible tool to differentiate populations in mixed-stock aggregations during the first year of ocean residence. Otolith samples of juveniles from eight rivers in Kamchatka and five rivers from the northern coast of the Okhotsk Sea were collected in May and June 2008-2009. In addition, chum salmon were collected from hatcheries in the Magadan region (Armansky, Tauysky and Yansky hatcheries) and in Kamchatka (Paratunsky and Ketkinsky hatcheries). To estimate the character and degree of microstructure variability, we used wavelet analysis, which is a modification of classical spectral analysis. Readings from the wavelet transformation scalegram (Morlet wavelet transform) were used as criteria for differentiation (Fig 1). We used scalegrams of the diapason with scaling coefficients from 1 to 7 and a 0.3 step. Statistical processing was made using STATISTICA 6.0 and Microsoft Excel. To estimate the resolution of the method, we used the maximum likelihood estimation (MLE) procedure available in the computer program SPAM.

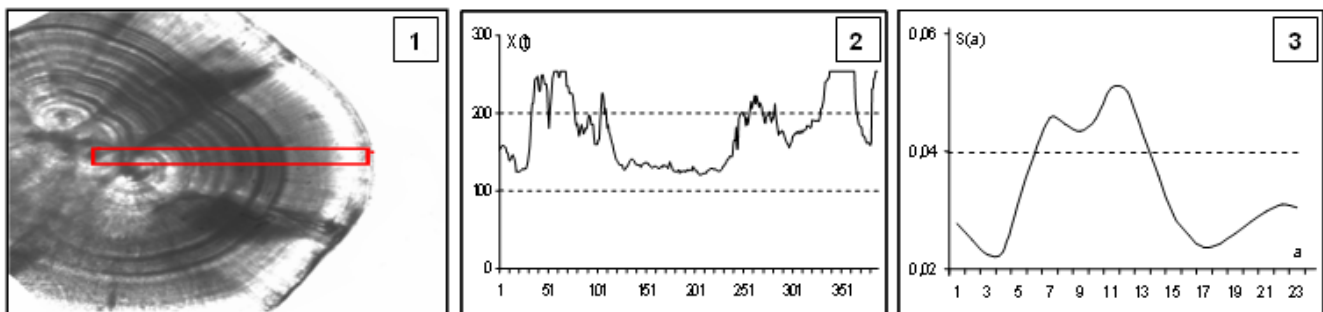


Fig. 1. Photo of a juvenile chum salmon otolith and the portion in the red box that was analyzed by wavelet spectral analysis (1, left panel); example of the signal values of the otolith scan (2, center panel); scheme of the wavelet transformation of the signal (3, right panel).

Discriminate analysis of intra-population variability of juvenile chum salmon within populations of the Bolshaya River did not reveal any differences between temporally distant samples ($p > 0.05$). Similarly, examination of the otolith microstructure of juvenile chum salmon from the Palana River did not show differences between samples collected from different periods of downstream migration ($p > 0.05$).

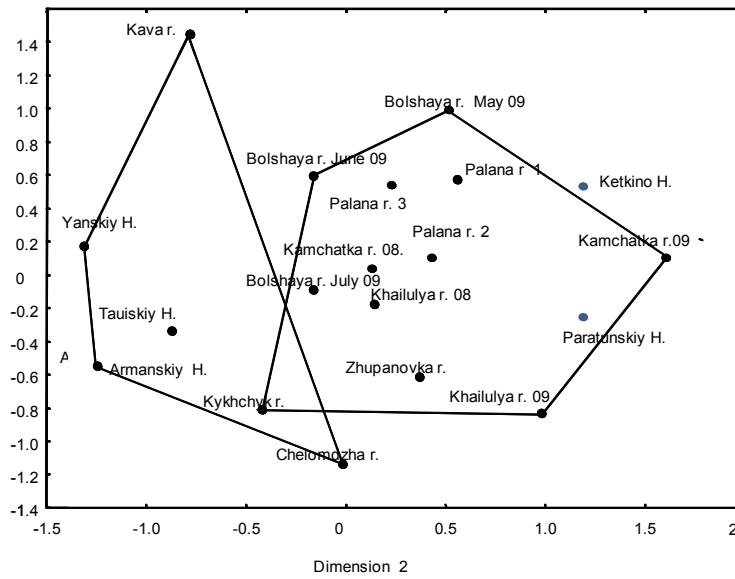


Fig. 2. Diagram of similarities using multidimensional scaling of samples from populations of juvenile chum salmon collected from rivers in Kamchatka and the northern coast of the Sea of Okhotsk.

Discriminate analysis of inter-population variability indicated the Mahalanobis distance between the centroids of the northern Okhotsk Sea and Kamchatkan regional groups of chum salmon was highly significant ($2.79, p < 0.001$; Fig. 2). The high heterogeneity within the hatchery samples from the Magadan hatcheries (Arman, Tauy and Yana) produced a non-significance result ($p > 0.05$). However, these samples were highly significantly different from the groups of Kamchatka populations ($3.86, p < 0.001$) and from the Chelomdzha River (wild population on the north shore of the Okhotsk Sea; $3.58, p < 0.001$). An explanation may be that when hatchery chum salmon alevins shift to exogenous feeding the regular feeding schedule produces stable daily growth on the otoliths that is different from the pattern on wild fish otoliths (Zhang and Beamish 1994). Otoliths of hatchery-raised Pacific salmon record hatchery “release marks” depicting wide uniform increments when the fish rears in the hatchery and then showing irregular and narrow increments after the fish is released from the hatchery (Brothers 1981; Zhang et al 1995; Fukuwaka 1998).

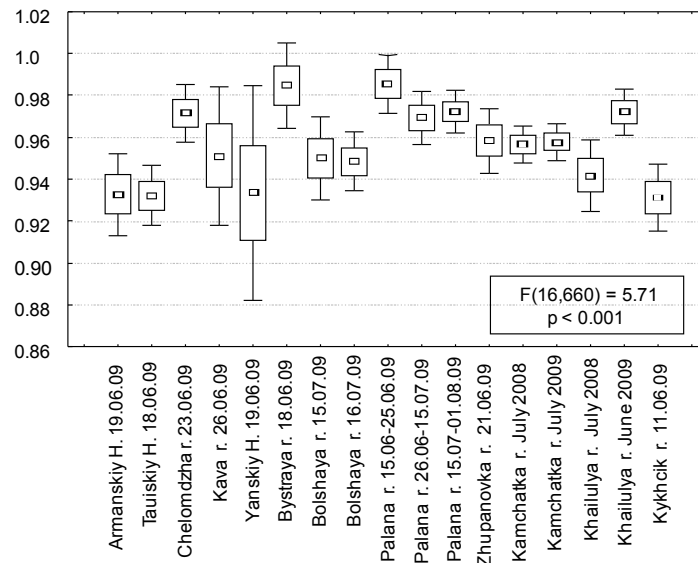


Fig. 3. Group statistical indicators of the first scaling coefficient that characterizes otolith microstructure of juvenile chum salmon collected from rivers in Kamchatka and the northern coast of the Sea of Okhotsk.

Statistical characteristics of the populations based on the first scaling coefficient are shown in Fig. 3. Minimal differentiating characteristics were demonstrated by Arman, Tauy and Yana hatchery fish and Kikhchik River chum salmon. This may result from minimal or complete lack of daily temperature fluctuations, which causes the formation of evenly-spaced growth increments on the otoliths. Assessment of the baseline resolution by MLE indicated the level of accuracy in differentiating regions ranged from 62% to 93%.

We conclude there is likely to be enough variability in otolith microstructure in these regional stock complexes to differentiate mixed-stock samples of chum salmon at the regional level.

REFERENCES

- Akinicheva, E.G., and I.L. Izergin. 2004. Analysis of otolith microstructure in the Tauy River (the North Okhotsk Sea shore). State of fisheries researches in the Northern Okhotsk Sea. MagadanNIRO Publishing, Magadan. 2: 375-381. (In Russian).
- Svetocheva, O. N., and N.I. Stasenkova. 2003. About otolith structure of White Sea herring (*Clupea pallasii suworovi Rabinerson, 1927*) in the Barents Sea and its application as a marker. Presentation at the meeting of SevPINRO about results of researches in 2001-2002. SevPINRO Publishing, Arkhangelsk. pp. 174-188. (In Russian).
- Brothers, E.B. 1981. What can otolith microstructure tell us about daily and sub-daily events in the early life history of fish? Rapp. P.v. Reun. Cons. Int. Explor. Mer. 178: 393-394.
- Fukuwaka, M. 1998. Scale and otolith pattern prove growth history of Pacific salmon. N. Pac. Anadr. Fish Comm. Bull. 1: 190-198. (Available at www.npafc.org).
- McKern, J.L., H.F. Horton, and K.V. Koski. 1974. Development of steelhead trout (*Salmo gairdneri*) otoliths and their use for age analysis and for separating summer from winter races and wild from hatchery stocks. J. Fish. Res. Board Can. 31: 1420-1426.
- Otterlei, E., A. Folkvord, and G. Nyhammer. 2000. Temperature- and size-dependent growth of larval and early juvenile Atlantic cod (*Gadus morhua*). University of Bergen, Bergen, Norway. 29 pp.
- Radtke, R.L., D.P. Fey, A.F. DeCicco, and A. Montgomery. 1996. Otolith microstructure in young-of-the-year Dolly Varden, *Salvelinus malma*, from American and Asian populations: resolution of comparative life history characteristics. Arctic 49(2): 162-169.
- Zhang, Z., and R.J. Beamish. 1994. Use of otolith microstructure to identify hatchery-reared and wild Pacific salmon. N. Pac. Anadr. Fish Comm. Doc. 90. 27 pp. (Available at www.npafc.org).
- Zhang, Z., R.J. Beamish, and B.E. Riddell. 1995. Differences in otolith microstructure between hatchery-reared and wild Chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 52: 344-352.

Thermal Habitats of Pacific Salmon: Does Climate Change Benefit Pink and Chum Salmon?

Kentaro Morita

Hokkaido National Fisheries Research Institute, Fisheries Research Agency
2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan

Because most physiological processes of ectotherms are controlled by temperature, climate warming could affect a variety of population processes in Pacific salmon. In the ocean, Pacific salmon actively move to preferred thermal habitats by migration. Generally, Pacific salmon migrate northward during summer and southward during winter (e.g., Yatsu and Kaeriyama 2005). For example, Japanese chum salmon move to the Bering Sea during the summer (sea surface temperature, ~6–11°C), and then move to the eastern North Pacific during winter (sea surface temperature, ~5–7°C; Fukuwaka et al. 2007). In addition, chum salmon control their body temperature using vertical migrations across the thermocline during summer in the Bering Sea (Azumaya and Ishida 2005; Morita 2011). Active migrations throughout their ocean lifespan allow salmon to narrow their habitat choices to their preferred temperatures. By contrast, Pacific salmon spend their juvenile and spawning stages in freshwater, where they are passively affected by ambient temperature. For example, river water temperatures in Hokkaido, Japan, vary from ~0–2°C during winter to over 20°C during summer; thus juvenile masu salmon, which spend more than one year in freshwater before seaward migration, have to adapt to this broad temperature range (Morita and Nagasawa 2010; Morita et al. 2011). Therefore, active control of thermal habitat mitigates the impact of seasonal and annual change in temperature during the ocean life stage, whereas passive control of thermal habitat operates during the freshwater life stage. These observed behavioral patterns lead to the hypothesis that climate warming would have a severe negative effect on species with long freshwater stages (e.g., masu, coho, Chinook, and sockeye salmon) and populations originating from southern populations, in particular. Moreover, preferred temperature ranges differ by species and age (body size) because older, larger fishes generally inhabit deeper and colder waters than younger, smaller fishes (Bergmann's rule). Similarly, pink salmon and small chum salmon tend to inhabit warmer waters than sockeye and large chum salmon (Morita et al. 2010a). Therefore, fish with a smaller body size (e.g., pink salmon) or shorter freshwater life (e.g., pink and chum salmon) may experience reduced or even beneficial effects from climate warming. In addition, rising temperatures involve reductions in the body size of many organisms (Gardner et al. 2011). The negative effect of rising temperature on growth is hypothesized to be more severe for large chum than for small chum salmon (Fig. 1; Morita et al. 2010b).

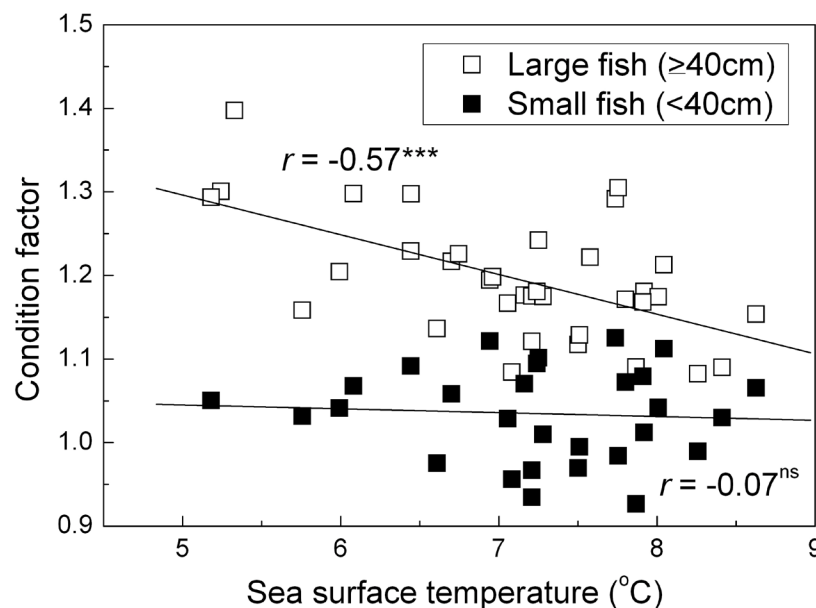


Fig. 1. Condition factor of large chum salmon is significantly and negatively related to sea surface temperature in the Bering Sea (1973-2008), even after accounting for annual trends and chum salmon CPUE (from Morita et al. 2010b).

REFERENCES

- Azumaya, T., and Y. Ishida. 2005. Mechanism of body cavity temperature regulation of chum salmon (*Oncorhynchus keta*) during homing migration in the North Pacific Ocean. *Fish. Oceanogr.* 14: 81-96.
- Fukuwaka, M., S. Sato, S. Takahashi, T. Onuma, O. Sakai, N. Tanimata, K. Makino, N.D. Davis, A.F. Volkov, K.B. Seong, and J.H. Moss. 2007. Winter distribution of chum salmon related to environmental variables in the North Pacific. *N. Pac. Anadr. Fish Comm. Tech. Rep.* 7: 29–30. (Available at www.npafc.org).
- Gardner, J.L., A. Peters, M.R. Kearney, L. Joseph, and R. Heinsohn. 2011. Declining body size: a third universal response to warming? *Trends Ecol. Evol.* 26: 285-291.
- Morita, K. 2011. Body size trends along vertical and thermal gradients of chum salmon in the Bering Sea during summer. *Fish. Oceanogr.* 20: 258-262.
- Morita, K., and T. Nagasawa. 2010. Latitudinal variation in the growth and maturation of masu salmon (*Oncorhynchus masou*) parr. *Can. J. Fish. Aquat. Sci.* 67: 955-965.
- Morita, K., M. Fukuwaka, and N. Tanimata. 2010a. Age-related thermal habitat use by Pacific salmon *Oncorhynchus* spp. *J. Fish. Biol.* 77: 1265-1272.
- Morita, K., M. Fukuwaka, N. Tanimata, and O. Yamamura. 2010b. Size-dependent thermal preferences in a pelagic fish. *Oikos* 119: 1265-1272.
- Morita, K., S.H. Morita, and T. Nagasawa. 2011. Seasonal changes in stream salmonid population densities in two tributaries of a boreal river in northern Japan. *Ichthyol. Res.* 58: 134-142.
- Yatsu, A., and M. Kaeriyama. 2005. Linkages between coastal and open-ocean habitats and dynamics of Japanese stocks of chum salmon and Japanese sardine. *Deep-Sea Res. II* 52: 727-737.

Changes in Size, Age, and Intra-Annual Growth of Anadyr Chum Salmon (*Oncorhynchus keta*) from 1962 to 2010

Alexander V. Zavolokin¹, Vladimir V. Kulik¹, and Yury N. Khokhlov²

¹Pacific Scientific Research Fisheries Center (TINRO-center), 4, Shevchenko Alley, Vladivostok 690091, Russia

²Chukotka Branch, Pacific Scientific Research Fisheries Center, 56, Otko St., Anadyr 689000, Russia

Keywords: chum salmon, body length, age, growth, Anadyr River, scale pattern analysis, climate indices

Many researchers have reported that increases in Pacific salmon abundance in the North Pacific accompanied decreases of age-specific body length, weight, and growth after the first year of life of chum salmon (Ishida et al. 1993; Bigler et al. 1996; Kaeriyama 1998; Volobuev 2000; Kaev 2003; Helle et al. 2007). This has led to conclusions about shortages of food resources and overpopulation of the North Pacific by Pacific salmon (Ishida et al. 1993; Welch and Morris 1994; Bigler et al. 1996; Klovach 2003). Over the past decade, total abundance of Pacific salmon has continued to rise (Irvine and Fukuwaka 2011). This means that density-dependent interactions may be more intensive now than in earlier decades. We studied changes in body size, age, and growth of Anadyr chum salmon from samples collected over the last 50 years and discussed possible factors affecting chum salmon growth.

Adult chum salmon were sampled annually from 1962 to 2010. Fish samples were collected in the Anadyrskiy estuary using a trap net and on the spawning grounds. We analyzed scales of age-0.3 and -0.4 chum salmon. A total of 2,506 chum salmon was sampled (for details on methods, see Zavolokin et al. 2011, 2012).

Results showed body size of Anadyr chum salmon significantly decreased from the 1960s to 2000s (Fig. 1). In 1962–1980, mean fork length was 67 cm for age-0.3 and 71 cm for age-0.4 chum salmon. In 1990–2010, chum salmon mean fork length decreased to 61 cm for age-0.3 and decreased to 64 cm for age-0.4 chum salmon. From the 1960s to 1990s, the mean age of Anadyr chum salmon increased. During 1968-1990, the mean age was 3.2 yr, and in the 1990s it rose to 3.4 yr. In the 2000s, the mean age of chum salmon decreased to 3.3 yr.

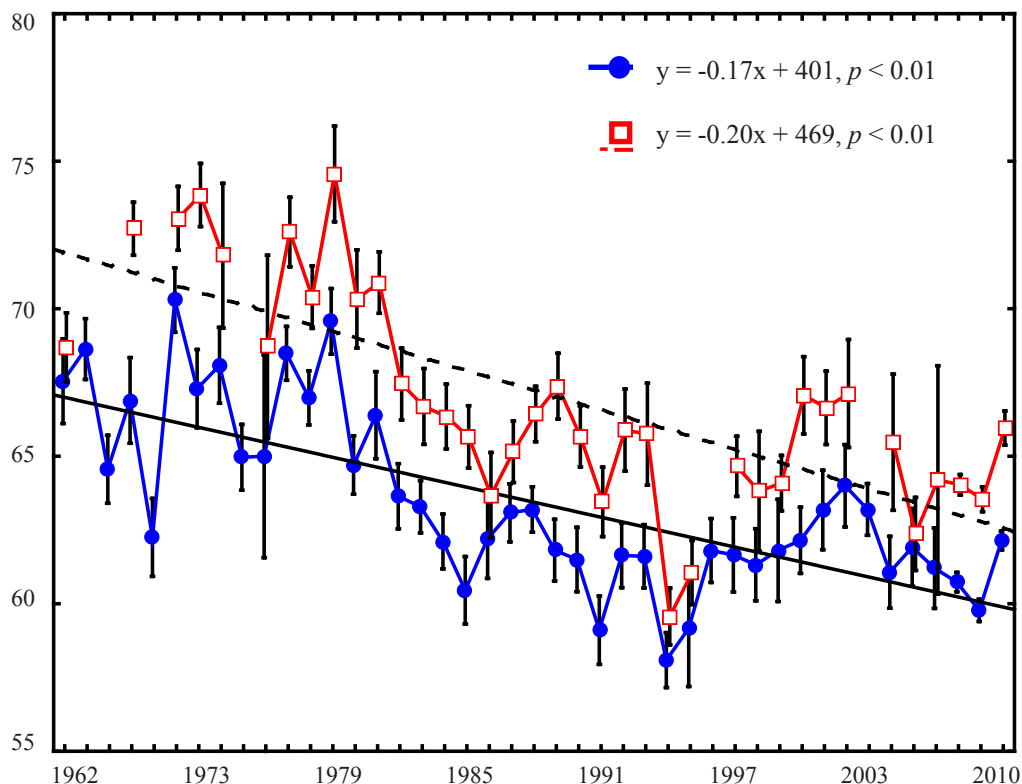


Fig. 1. Changes in mean fork length (cm) of Anadyr chum salmon (● – age-0.3, □ – age-0.4) from 1962 to 2010. Bars – 95% confidence interval.

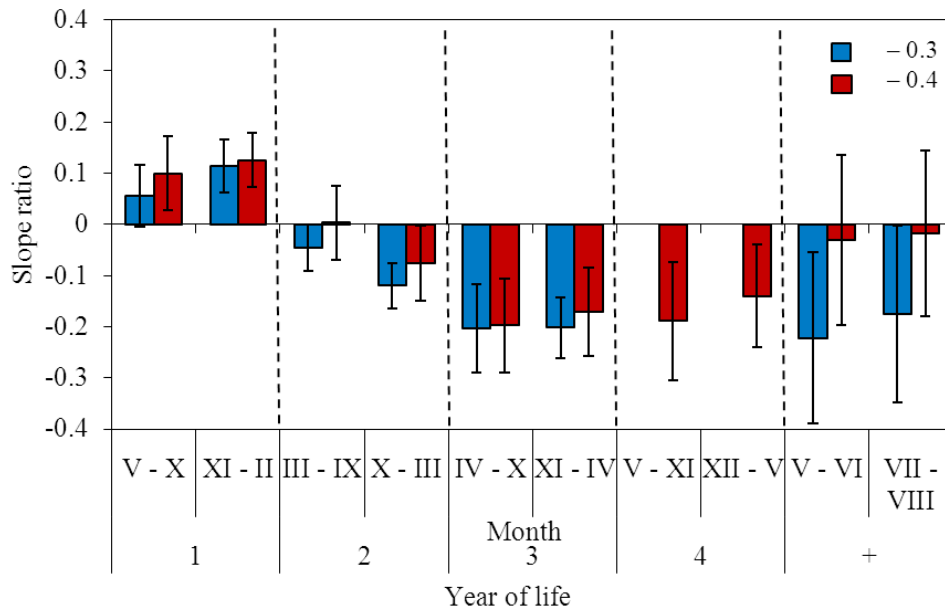


Fig. 2. Slope ratio (a) from the linear regression $y = ax + b$, where the independent variable (x) is return year (1962-2007) and the dependent variable (y) is the inter-circuli distances in that year. Bars – 95% confidence interval. Data collected from scale analysis of age-0.3 and -0.4 Anadyr River chum salmon.

Inter-annual trends in chum salmon growth were evaluated by simple linear regression analysis: $y = ax + b$. Figure 2 shows the slope ratio (parameter a) that describes changes in chum salmon growth from the 1960s to 2000s. First year growth of Anadyr chum salmon was enhanced (Figs. 2 and 3). And the best growth enhancement occurred during the second half of the first year during late fall and winter. After the first year at sea, the trend in chum salmon growth changed. From March through August, growth was relatively stable. After the first half of the second year, growth was reduced. The greatest reduction occurred throughout the third and fourth years of life and was the most conspicuous in summer and fall when the fish foraged in the Bering Sea.

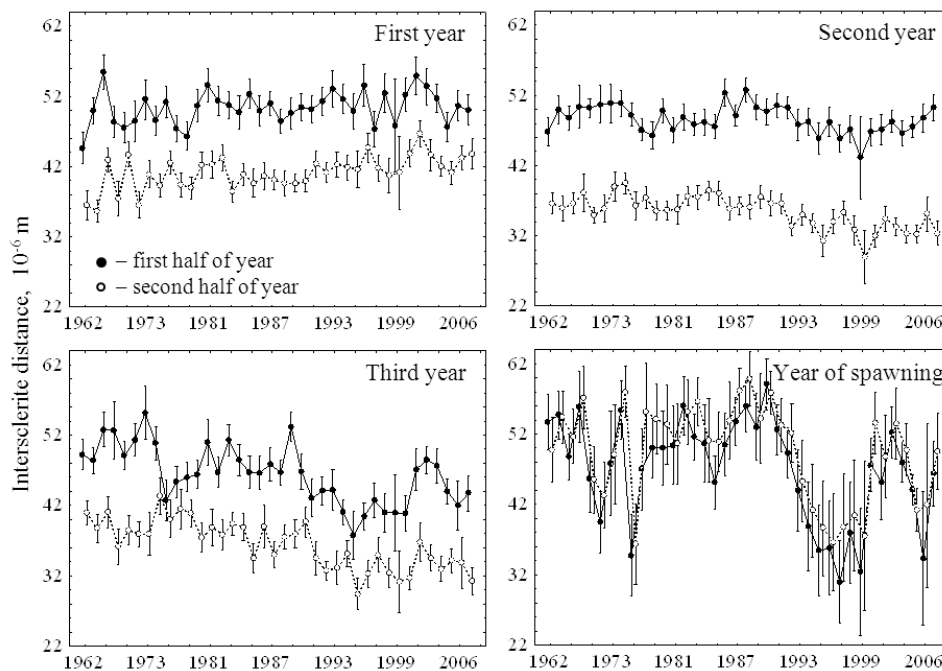


Fig. 3. Changes in mean intercirculus distances of age-0.3 Anadyr chum salmon from 1962 to 2007. Bars – 95% confidence interval.

Changes in Body Size and Growth of Pacific Salmon

Our study and those of other researchers show that growth trends of many chum salmon stocks from several widely separated regions illustrate the same growth pattern. Chum salmon growth patterns that we observed were similar to those of some Russian, Japanese and Korean stocks; the first year growth was enhanced, and the third and fourth year growth was reduced in samples collected over the last several decades (Ishida et al. 1993; Kaev 2003; Kaeriyama et al. 2007; Seo et al. 2009).

Body size trends since the 1960s of chum salmon stocks show similar patterns from areas in Japan, Korea, and North America (Ishida et al. 1993; Bigler et al. 1996; Kaeriyama 1998; Volobuev 2000; Kaev 2003; Seo et al. 2009; Helle et al. 2007). There are significant positive correlations in body weight of chum salmon from several large Russian rivers in samples collected in 1960-2009 (Temnykh et al. 2012). Inter-annual changes in body size of other salmon species usually differed from those of chum salmon, but growth of some populations of pink, sockeye, and Chinook salmon also had common features during this time period (Temnykh 1999; Ruggerone et al. 2007, 2009; Martinson et al. 2008). Like Anadyr chum salmon, these species showed increasing first year marine growth and decreasing third year marine growth that suggests there are common large-scale factors affecting these species in the same way.

Potential Factors Affecting Salmon Growth

Fish growth is a complex process that results from a combination of many factors. Growth reflects internal and external influences on metabolism, physiological functions, food consumption, and excretion. As we have suggested, the factor (factors) leading to Anadyr chum salmon growth reduction was likely operating at the large-scale because it affected several widely separated salmon populations. Therefore, internal factors could not be the main cause of observed growth changes because it is unlikely these could synchronously affect several salmon species and take place over a vast area.

Table 1. Pearson correlation coefficients relating mean intercirculus distances of Anadyr chum salmon (age 0.3) to some climatic indices (see data sources below). * – $p < 0.05$

Index	Year of life			
	1	2	3	+
HC PO	0.55*	-0.57*	-0.52*	-0.49*
	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.05$
HC NP	0.59*	-0.64*	-0.56*	-0.42*
	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.05$
GLB.Ts + dSST	0.45*	-0.64*	-0.48*	-0.23
	$p < 0.05$	$p < 0.01$	$p < 0.05$	$p = 0.27$
N.HEMI	0.43*	-0.64*	-0.49*	-0.30
	$p < 0.05$	$p < 0.01$	$p < 0.05$	$p = 0.14$
NP	-0.07	0.29	0.25	-0.01
	$p = 0.74$	$p = 0.16$	$p = 0.21$	$p = 0.94$
ALPI	0.19	-0.32	-0.13	0.10
	$p = 0.34$	$p = 0.11$	$p = 0.54$	$p = 0.61$
AFI	0.27	-0.17	-0.10	0.14
	$p = 0.19$	$p = 0.40$	$p = 0.64$	$p = 0.50$
PDO	0.09	-0.03	-0.14	0.16
	$p = 0.67$	$p = 0.87$	$p = 0.49$	$p = 0.42$

Aleutian Low Pressure Index (ALPI). 2010.

URL: <http://www.pac.dfo-mpo.gc.ca/science/species-especes/climatology-ie/cori-irco/indices/alpi.txt>

Atmospheric Forcing Index (AFI). 2010.

URL: <http://www.pac.dfo-mpo.gc.ca/science/species-especes/climatology-ie/cori-irco/indices/afi.txt>

Global Land-Ocean Temperature Index in 0.01 degrees Celsius. 2011. URL: <http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts+dSST.txt>

Global Ocean Heat Content. 2011.

URL: ftp://ftp.nodc.noaa.gov/pub/data.nodc/woa/DATA_ANALYSIS/3M_HEAT_CONTENT/DATA/basin/yearly/h22-p0-700m.dat

N.HEMI Temperature Anomalies in 0.01 degrees Celsius. 2011. URL: <http://data.giss.nasa.gov/gistemp/tabledata/NH.Ts.txt>

NCAR Climate Analysis Section. 2011. URL: <http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html#npmon>

PDO INDEX. 2011. URL: <http://jisao.washington.edu/pdo/PDO.latest>

The main external influences on Pacific salmon productivity are likely to be climatic and density-dependent factors. Our analysis of Anadyr chum salmon growth reduction in both the foraging and over-wintering areas does not corroborate the definitive importance of density-dependent factors affecting chum salmon productivity. In view of published data on forage resources, it seems unlikely that a long-term decrease in salmon food supply could cause a long-term decrease in fish size and synchronously occur in large areas of the Bering Sea and North Pacific. Furthermore, it seems incredible that chum salmon have been experiencing insufficient feeding conditions both in the Bering Sea and North Pacific. In the western Bering Sea, which is an important foraging area for Pacific salmon, macrozooplankton biomass has increased from the 1980s to 2000s (Shuntov et al. 2010). Based on the abundant plankton resources available in the forage base in comparison to the low percentage of prey resources consumed by Pacific salmon (Naydenko 2007), there is no reason to suggest there are strong competitive interactions between and among salmon species in the western Bering Sea. Negative correlations between total salmon abundance and chum salmon body size were evident only in our data from the 1980-1990s. After the mid-1990s, there was no such relationship. After 1997, growth of Anadyr chum salmon increased and average age decreased. Even with increasing abundance of Pacific salmon, production characteristics of Anadyr chum salmon have improved. Therefore, it is possible that density-dependent interactions are not the only determining factor of chum salmon productivity.

Over the last 50 years, there have been three universally recognized regime shifts in the North Pacific (1977, 1989, and 1998; Hare and Mantua 2000; Overland et al. 2008). We compared scale increments in each climatic period to estimate if these regime shifts influenced Anadyr chum salmon growth. We found that growth of adult chum salmon differed significantly between most periods. Therefore, changes in the ocean environment arising from regime shifts may affect Anadyr chum salmon growth. Table 1 shows correlations between Anadyr chum salmon growth and some climatic indices that reflect climatic changes in the North Pacific. The first year of growth of Anadyr chum salmon was positively correlated with temperature indices, such as heat content of the Pacific Ocean (HC PO), heat content of the North Pacific (HC NP), global temperature anomalies (GLB.Ts+dSST), and northern hemisphere temperature anomalies (N.HEMI). In contrast, the second and third year of growth was negatively correlated with these indices. Negative correlations between temperature indices and the second and third year of growth of Anadyr chum salmon suggest that warming of the North Pacific may have an adverse impact on their growth after the first year of life. Thus, chum salmon growth reduction after the early marine period may be caused by a combination of increasing abundance of Pacific salmon and a warming ocean.

REFERENCES

- Bigler, B.S., D.W. Welch, and J.H. Helle. 1996. A review of size trends among North Pacific salmon *Oncorhynchus spp.* Can. J. Fish. Aquat. Sci. 53: 455–465.
- Hare, S.R., and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47(2-4): 103-145.
- Helle, J.H., E.C. Martinson, D.M. Eggers, and O. Gritsenko. 2007. Influence of salmon abundance and ocean conditions on body size of Pacific salmon. N. Pac. Anadr. Fish Comm. Bull. 4: 289–298. (Available at www.npafc.org).
- Irvine, J.R., and M. Fukuwaka. 2011. Pacific salmon abundance trends and climate change. ICES J. Mar. Sci. 68: 1122–1130. (Available at icesjms.oxfordjournals.org/content/early/2011/03/02/icesjms.fsq199.full).
- Ishida Y., S. Ito, M. Kaeriyama, S. McKinnell, and K. Nagasawa. 1993. Recent changes in age and size of chum salmon (*Oncorhynchus keta*) in the North Pacific Ocean and possible causes. Can. J. Fish. Aquat. Sci. 50: 290–295.
- Kaeriyama, M. 1998. Dynamics of chum salmon, *Oncorhynchus keta*, populations released from Hokkaido, Japan. N. Pac. Anadr. Fish Comm. Bull. 1: 90–102. (Available at www.npafc.org).
- Kaeriyama, M., A. Yatsu, M. Noto, and S. Saitoh. 2007. Spatial and temporal changes in the growth patterns and survival of Hokkaido chum salmon populations in 1970–2001. N. Pac. Anadr. Fish Comm. Bull. 4: 251–256. (Available at www.npafc.org).
- Kaev, A.M. 2003. Chum salmon reproduction in relation to their size-age structure. SakhNIRO, Yuzhno-Sakhalinsk. 288 pp. (In Russian).
- Klovach, N.V. 2003. Ecological consequences of large-scale artificial reproduction of chum salmon. VNIRO, Publ., Moscow. 164 pp. (In Russian).
- Martinson E.C., J.H. Helle, D.L. Scarnecchia, and H.H. Stokes. 2008. Density-dependent growth of Alaska sockeye salmon in relation to climate-oceanic regimes, population abundance, and body size, 1925 to 1998. Mar. Ecol. Prog. Ser. 370: 1–18.
- Naydenko, S.V. 2007. Role of Pacific salmon at the trophic structure of the epipelagical in the western Bering Sea in summer–fall 2002–2006. Izv. TINRO 151: 214–239. (In Russian with English abstract).
- Overland, J., S. Rodionov, S. Minobe, N. Bond. 2008. North Pacific regime shifts: Definitions, issues and recent transitions. Progr. Oceanogr. 77: 92-102.

- Peterson, T. C., R.S. Vose. 1997. An overview of the global historical climatology network temperature database. *Bull. Am. Meteorol. Soc.* 78: 2837-2849.
- Ruggerone, G.T., J.L. Nielsen, J. Bumgarner. 2007. Linkages between Alaskan sockeye salmon abundance, growth at sea, and climate, 1955–2002. *Deep-Sea Res. II.* 54: 2776–2793.
- Ruggerone, G.T., J.L. Nielsen, B.A. Agler. 2009. Climate, growth and population dynamics of Yukon River Chinook salmon. *N. Pac. Anadr. Fish Comm. Bull.* 5: 279–285. (Available at www.npafc.org).
- Seo, H., H. Kudo, M. Kaeriyama. 2009. Spatiotemporal change in growth of two populations of Asian chum salmon in relation to intraspecific interaction. *Fish. Sci.* 75: 957–966.
- Shuntov, V.P., A.F. Volkov, N.T. Dolganova, A.V. Zavolokin, O.S. Temnykh, S.V. Naydenko, I.V. Volvenko. 2010. To the substantiation of carrying capacity of Far-Eastern Seas and Subarctic Pacific for Pacific salmon hatchery. 2. Composition, stock and dynamic of zooplankton and nekton — forage base of Pacific salmon. *Izv. TINRO.* 160: 185-208. (In Russian with English abstract).
- Temnykh, O.S. 1999. Growth of pink salmon of Primorye during period of it high and low abundance. *J. Ichthyol.* 39(2): 219-223.
- Temnykh, O.S., A.V. Zavolokin, E.A. Shevlyakov, L.O. Zavarina, V.V. Volobuev, S.L. Marchenko, S.F. Zolotukhin, N.F. Kaplanova, E.V. Podorozhnik, A.A. Goryainov, A.V. Lisenko, A.M. Kaev, Yu.I. Ignatyev, E.V. Denisenko, Yu.N. Khokhlov, O.A. Rassadnikov. 2012. Peculiarities of interannual changes in size and age composition of Russian chum salmon. *Bull. Pac. Salmon Stud. Far East* 6: 226-239. (In Russian).
- Volobuev, V.V. 2000. Long-term changes in the biological parameters of chum salmon of the Okhotsk Sea. *N. Pac. Anadr. Fish Comm. Bull.* 2: 175–180. (Available at www.npafc.org).
- Welch, D.W., and J.F.T. Morris. 1994. Evidence for density-dependent marine growth in British Columbia pink salmon population. *N. Pac. Anadr. Fish Comm. Doc.* 97. Dept. Fish. and Oceans, Nanaimo. 33 p. (Available at www.npafc.org).
- Zavolokin, A.V., V.V. Kulik, Y.N. Khokhlov. 2011. Changes in size, age, and intra-annual growth of Anadyr chum salmon (*Oncorhynchus keta*) from 1962-2010. *N. Pac. Anadr. Fish Comm. Doc.* 1330. 11 pp. (Available at www.npafc.org).
- Zavolokin, A.V., V.V. Kulik, I.I. Glebov, E.N. Dubovets, Yu.N. Khokhlov. 2012. Dynamics of body size, age, and annual growth rate of Anadyr chum salmon *Oncorhynchus keta* in 1962-2010. *J. Ichthyol.* 52(3): 207-225.

Body Size Variation of Juvenile Chum Salmon Collected From Three Coastal Areas of Hokkaido, Northern Japan

Koh Hasegawa, Tomoki Sato, and Kei Sasaki

Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
2-2 Nakanoshima, Toyohira-ku, Sapporo, Hokkaido 062-0922, Japan

Keywords: chum salmon, growth, migration, otolith analysis

For Pacific salmon *Oncorhynchus* spp., growth during coastal residency (the first few weeks after juvenile salmon enter the sea) is a critical factor for juvenile survival (Bradford 1995). Thus, many researchers have studied the growth of juveniles. Although individual growth rates can be estimated using scale and otolith analyses, body size is often used as a simple index of growth rate (e.g. LaCroix et al. 2009; Duffy and Beauchamp 2011). In some instances, such as when using historical data, the only available measure of growth may be body size. However, the size of juvenile salmon in a given area may not accurately reflect the growth rate because individuals that originate from rivers outside the area may migrate into it and be captured. Juvenile chum salmon *O. keta* increase in size throughout their oceanic migration (Mayama and Ishida 2003). Therefore, individuals growing outside an area and that had a longer coastal residency can immigrate into the area and cause an overestimation of chum salmon growth rate.

To evaluate the relationship between juvenile chum salmon body size and the river of origin, we compared the size of fish in samples collected from three areas off the coast of Hokkaido, northern Japan. We analyzed data from surface trawl surveys of chum salmon conducted in three coastal areas (Atsuta, Konbumori and Shari) from late March to mid-July, 1999-2010. Results showed the sizes of juveniles in the Konbumori area (annual mean fork length ranged 8-12 cm) were larger than fish collected in the Atsuta and Shari areas (annual mean fork length ranged 5-6 cm). Otolith analysis suggested that the large size of juveniles in Konbumori was due to immigration of large individuals originating from rivers located outside the area. Our results highlight the need to consider the migratory behaviour of individuals when considering the cause of body size variation in juvenile chum salmon.

REFERENCES

- Bradford, M. J. 1995. Comparative review of Pacific salmon survival rates. *Can. J. Fish. Aquat. Sci.* 52: 1327–1338.
- Duffy, E. J., and D.A. Beauchamp. 2011. Rapid growth in the early marine period improves the marine survival of Chinook salmon (*Oncorhynchus tshawytscha*) in Puget Sound, Washington. *Can. J. Fish. Aquat. Sci.* 68: 232–240.
- LaCroix, J. J., A.C. Wertheimer, J.A. Orsi, M.V. Sturdevant, E.A. Fergusson, and N.A. Bond. 2009. A top-down survival mechanism during early residency explains coho salmon year-class strength in southeast Alaska. *Deep-Sea Res. II* 56: 2560–2569.
- Mayama, H., and Y. Ishida. 2003. Japanese studies on the early ocean life of juvenile salmon. *N. Pac. Anadr. Fish Comm. Bull.* 3: 41–67.

Feeding Strategies and Trends of Pink and Chum Salmon Growth in the Marine Waters of Kamchatka

Vladimir I. Karpenko and Maxim V. Koval

*Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO)
18, Naberezhnaya Str., Petropavlovsk-Kamchatsky 683602, Russia*

Keywords: pink salmon, chum salmon, feeding, ration, body weight, temperature, growth, productivity, West and East Kamchatka

This study is based on long-term data of feeding of Pacific salmon in the marine waters of Kamchatka and biological parameters of spawners returning to the Kamchatka coast. Trophological data were collected by researchers of the Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO) on marine expeditions in three main regions: northwestern Pacific Ocean, Okhotsk Sea, and Bering Sea. At various times since 1952, several methods were used to catch salmon including drift-nets, purse and beach seines, and pelagic trawl.

In total, 24,112 pink and chum salmon stomachs (13,322 juveniles and 10,790 adult fish) were analyzed for this study. Laboratory analysis of salmon feeding habits since 1952 has employed one standardized method at KamchatNIRO, which is the same method that has been standardized across Russian laboratories (Anonymous 1974). Thus, we hope that we have managed to avoid the problem of data comparability for different periods of observation. For analysis of changes in growth of salmon populations, we used annual commercial catch statistics and the average weight of salmon in West and East Kamchatka from 1971 to 2010.

It is well known that most of the growth of the individual and the formation of total production of the population occurs during the marine period of life. Figure 1 shows the generalized growth of Kamchatka pink and chum salmon for the first year at sea. This figure illustrates differences in growth rate between these species over the seasonal feeding periods. In the early period of marine life, pink and chum salmon growth rates are similar. Differences become apparent in winter months, and by the end of the over-wintering period pink salmon average weight is twice as large as that of chum salmon. This difference in weight is maintained until the following year.

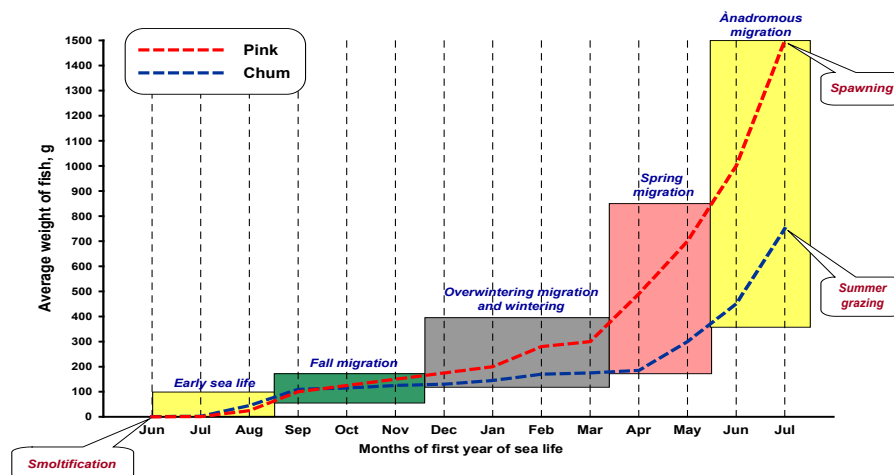


Fig. 1. Generalized growth trajectory of Kamchatka pink and chum salmon throughout the first year at sea.

Most fish biologists agree that growth rate of salmonids is driven by three basic factors: ration, body size, and temperature (e.g., Stauffer 1973; Elliot 1975; Hoar et al. 1979; Shulman and Love 1999). Ration is the locomotive power of the organism; temperature controls the metabolic process; and body weight is the scaling factor modifying the metabolic process according to body size of the growing fish.

Analysis of the food composition of different salmon species shows that while in rivers, estuaries, and in littoral zones, juvenile pink and chum salmon consume similar food. Well-marked differences in diet begin to appear in Kamchatka coastal waters. During fall migrations, differences in diet decrease somewhat and wintering pink and chum salmon consume similar

food items. However, during the spring-summer period differences in pink and chum salmon food composition increase (Koval 2007). Therefore, feeding habits of pink and chum salmon during the seasonal marine feeding periods account for some of the differences in growth rates of these species.

It is known that salmon can be divided into two main groups—plankton-eaters and predators. The first group (pink, chum, and sockeye salmon) generally consume zooplankton. The second group (coho and Chinook salmon) generally consume nekton. Among the plankton-eaters, pink salmon has the highest feeding rate and sockeye salmon has the lowest. In this group, chum salmon feeding rates are intermediate.

Feeding strategies of different salmon species are associated with morphological and physiological characteristics (Koval 2007). For example, chum digestive system morphology and internal organs differ considerably from other Pacific salmon species (Azuma 1992; Klovach 2003). Total calorie content of adult chum salmon food is appreciably lower than the food of pink salmon (Fig. 2).

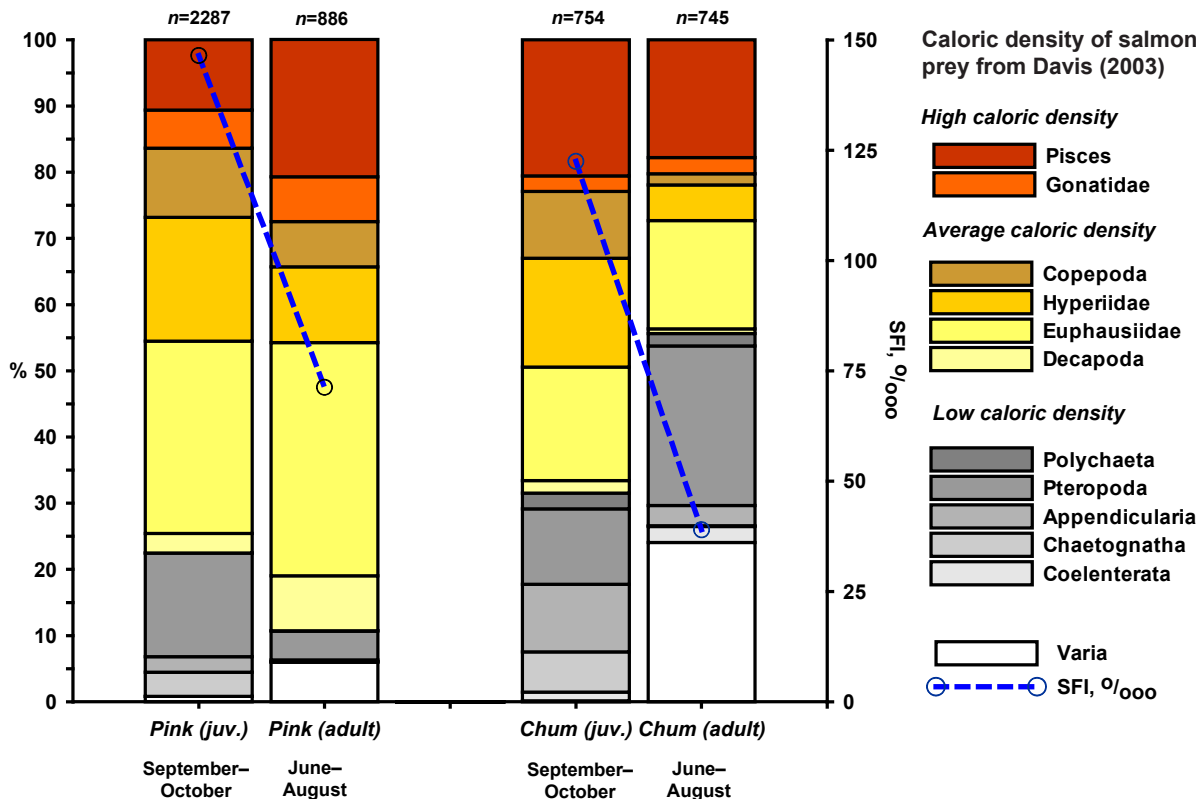


Fig. 2. Composition of basic prey items (% of food weight) and intensity of feeding (stomach fullness index (SFI)) of juvenile and adult pink and chum salmon in Kamchatkan waters of the Bering Sea, 1965–2005. (Values for caloric density from Davis 2003.)

Pink salmon prey consumption rates are less than that of chum salmon, but the nutritional value of pink salmon food is higher than the food of chum salmon. These factors determine the growth rate of pink salmon, which is able to prepare the fish for spawning in one year. Chum salmon also feed actively at sea, but low-caloric animals prevail in the ration. Nevertheless, the large size of the stomach and rapid digestion rate provide chum salmon with energy essential for vital functions, growth, and maturation. Perhaps, these are an adaptive mechanism allowing chum salmon to avoid food competition with other salmon species in common feeding areas. However, chum salmon are obliged to “pay” for consumption of low-caloric prey with reduced growth rates, as they are not able to attain spawning size in one year (Fig. 1).

During recent decades, increasing abundance has been observed for West and East Kamchatka pink, chum, and sockeye salmon. With gradual increasing abundance of pink salmon, average weight has also increased. However, in years of maximum abundance, average weight can be significantly lower than the long-term average (Fig. 3). Over the same period, the linear trend of chum and sockeye average weight has declined, particularly for chum salmon.

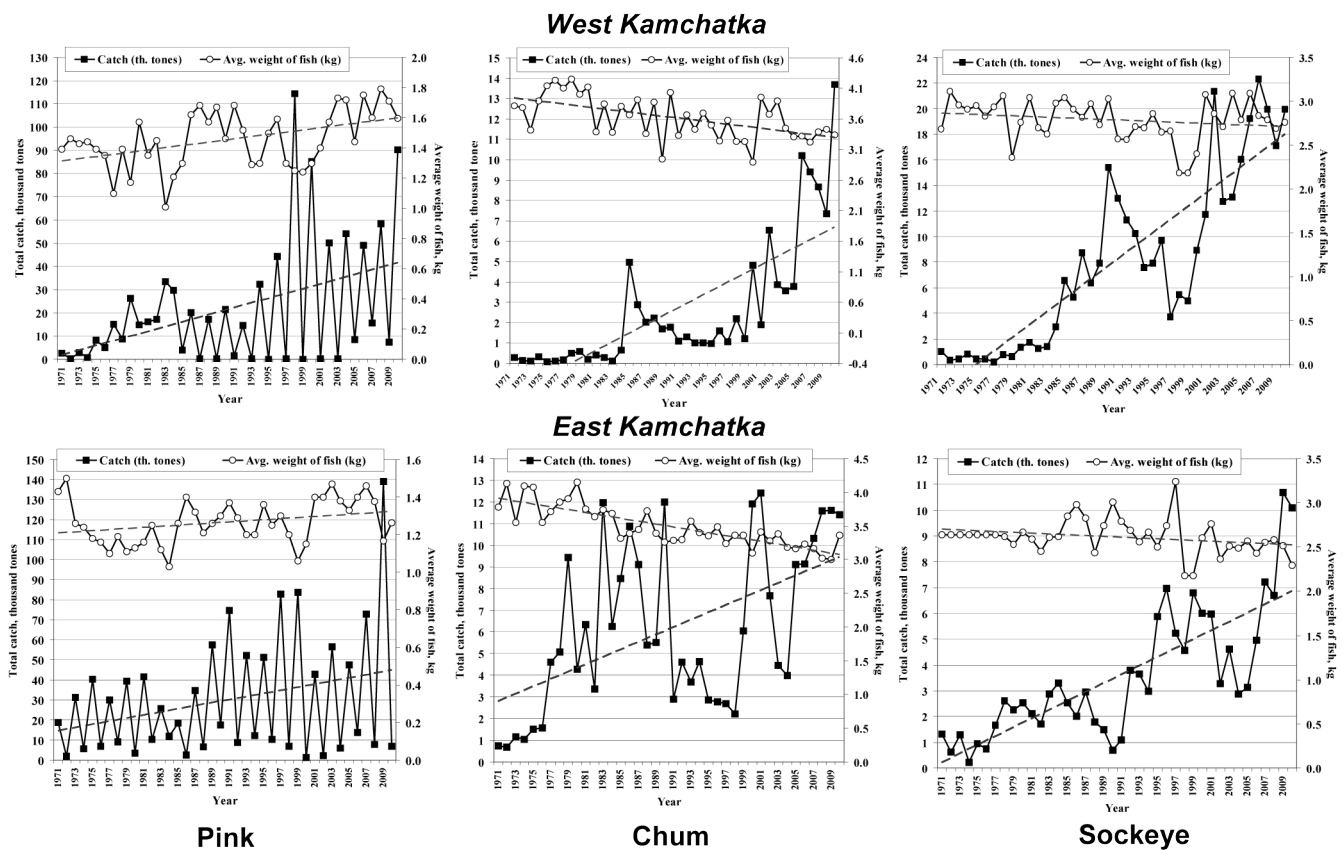


Fig. 3. Total commercial catch (thousand tonnes) and average body weight (kg) of pink, chum, and sockeye salmon in West and East Kamchatka, 1971–2010.

Decreasing chum salmon average weight has been observed not only in Kamchatka, but practically everywhere for Asian populations with the exception of the Primorye region (Table 1). At the same time, decrease in average weight has been less considerable in chum salmon originating from areas where chum salmon populations are less abundant (e.g., East and Southwest Sakhalin, North coast of the Sea of Okhotsk, and the Bering Sea). In the opinion of Bugaev et al. (2007), a large population of pink salmon causes changes of sockeye salmon body size in stocks from both Kamchatkan coasts. This phenomenon is observed under the influence of both West and East Kamchatka pink salmon. The influence of pink salmon abundance on the size characteristics of Alaskan sockeye salmon has been observed by scientists (Ruggerone et al. 2003; Ruggerone and Nielsen 2004; Ruggerone et al. 2005, 2007), and a number of researchers note increasing average age composition of sockeye and chum salmon in fish returning to regions of the western North Pacific.

Table 1. Average body weight (kg) and percent change in average body weight of pink, chum, and sockeye salmon in different regions of the North Pacific from the 1970s to 2000s.

Region	Pink		Chum		Sockeye	
	kg	%	kg	%	kg	%
<i>West Kamchatka</i>	1.44	16.8	3.64	-12.1	2.78	-1.1
<i>East Kamchatka</i>	1.26	13.8	3.53	-19.0	2.62	-5.0
<i>Kuril Islands</i>	1.32	10.2	3.78	-8.4	—	—
<i>East Sakhalin</i>	1.24	8.2	3.58	-25.6	—	—
<i>North coast of the Okhotsk Sea</i>	1.27	5.6	3.78	-7.0	2.59	-2.0
<i>North part of the Bering Sea</i>	1.35	1.4	3.58	-7.2	3.33	1.2
<i>West Sakhalin</i>	1.24	-7.9	3.61	-7.0	—	—
<i>Primorye region</i>	1.48	-11.0	3.57	3.8	—	—

Over several decades, Russian trophologist L.D. Andrievskaya noted repeatedly that during periods of extremely high abundance of pink salmon in Kamchatkan waters the number of prey items consumed by pink and chum salmon increased, but the average weight of fish decreased (Andrievskaya 1966, 1975, 1998). She considered this observation was related to large aggregations of salmon at sea that could lead to salmon accidentally consuming low-calorie prey items.

Analysis of our long-term trophological data showed that in recent decades the portion of low-calorie prey items in juvenile pink and chum salmon diets in the Okhotsk Sea has increased considerably. At the same time, there was a considerable expansion in the number of prey items in their diet. In recent years we noted an increase in the total number of prey items of juvenile salmon in the southwestern part of the Bering Sea. However, there was no distinct change in caloric content of food in this area, as there was in samples collected in the Sea of Okhotsk. According to our data, conditions for salmon feeding in Kamchatkan waters of the Bering Sea are always less stable than feeding conditions in the Sea of Okhotsk. This is associated with lower productivity of the forage base and the smaller area for salmon feeding in the Bering Sea. As a result, the food spectrum of Pacific salmon in the Bering Sea is always wider than in the Sea of Okhotsk.

We have a longer series of observations of adult salmon feeding in the northwestern part of the Pacific Ocean. Unfortunately, this series has some missing years, but if we consider it as a whole, there are some time periods when the food spectrum of salmon expands or contracts. When comparing data collected from salmon during the same period in other areas (Okhotsk and Bering Seas from 1965 to 2005) we observed expansion of the food spectrum for adult salmon. Chum salmon showed these changes to a greater degree. Almost without exception, the portion of low-calorie food was more than 50% in adult chum salmon diets in this area. From the 1950s to the 1970s zooplankton dominated in pink salmon diets. In the subsequent period, the portion of young fish and squids in the diet increased, and the calorie content of the diets increased.

We have discussed two of the main factors of salmon growth, ration and body weight, and that leaves the third important factor, temperature. In our opinion, temperature was the main factor contributing to the record increase of pink salmon productivity observed in recent decades in Kamchatka. Pink salmon is one of the most thermophilic species of Pacific salmon, so increased temperatures (within limits) is particularly favorable for pink salmon growth. Perhaps total temperature increases in the North Pacific (including coastal waters of Kamchatka) were favorable for survival of the abundant species of Kamchatka salmon (pink, chum, and sockeye salmon). Continuing increased environmental temperature might contribute to better growth of pink salmon at sea. This hypothesis requires further study.

The abundance of pink salmon is influenced not only by its biological characteristics, but also by the biology of other salmon, like chum and sockeye salmon that have a similar feeding ecology. For example, in the mid 1990s, chum salmon fed on gelatinous animals to a great extent, which lead to muscle structural changes expressed as flabbiness (Klovach 2003). Chum salmon feeding habits could be associated not only with high abundance of pink salmon at sea, but also to the large number of young chum salmon released from hatcheries in Japan, USA, Russia, and Canada (Klovach 2003). The decrease of chum salmon average body weight in recent decades could be linked to limited forage resources in the North Pacific and the diverse prey composition of chum salmon (e.g., Birman 1985; Ishida et al. 2001; Davis et al. 2005; Karpenko et al. 2007). In our opinion, chum salmon is at some disadvantage in competition with other more favorably adapted salmon species.

REFERENCES

- Anonymous. 1974. Methodical edition for study for fishes feeding and feeding interactions in the natural habitat. Moscow. Nauka Publ. 254 pp. (In Russian).
- Andrievskaya, L.D. 1966. Feeding interactions of Pacific salmon at sea. *Vopr. Ichthyologii* 6: 84–90. (In Russian).
- Andrievskaya, L.D. 1975. The feeding of Pacific salmon during marine period of life. Ph.D. Dissertation. Vladivostok. TINRO. 175 pp. (In Russian).
- Andrievskaya, L.D. 1998. The forming conditions of productivity of pink salmon *Oncorhynchus gorbuscha* (Walbaum) (Salmonidae) generations in the south–west part of Bering Sea. Research of water biological resources of Kamchatka and of the northwest part of Pacific Ocean: Selected Papers. Vol. 4: 94–97. Petropavlovsk–Kamchatsky, KamchatNIRO Publ. (In Russian with English summary).
- Azuma, T. 1992. Diel feeding habits of sockeye and chum salmon in the Bering Sea during the summer. *Nippon Suisan Gakkaishi* 58: 2019–2025.
- Birman, I.B. 1985. Marine period of life and matters of stock dynamics of Pacific Salmon. Agropromizdat Publ., Moscow. 208 pp. (In Russian).
- Bugaev, V.F., B.B. Vronsky, L.O. Zavarina, Z.K. Zorbidi, A.G. Ostroumov, and I.V. Tiller. 2007. Fishes of Kamchatka River. Petropavlovsk–Kamchatsky. KamchatNIRO Publ. 458 pp. (In Russian).
- Davis N. 2003. Feeding ecology of Pacific salmon (*Oncorhynchus spp.*) in the central North Pacific Ocean and central Bering sea, 1991–2000. Ph.D. Dissertation. Hokkaido Univ., Hakodate, Japan. 190 pp.

- Davis N., M. Fukuwaka, J.L. Armstrong, and K.W. Myers. 2005. Salmon food habits studies in the Bering Sea, 1960 to present. N. Pac. Anadr. Fish Comm. Tech. Rep. 6: 24-28. (Available at www.npafc.org).
- Elliot, J. 1975. The growth rate of brown trout (*Salmo trutta*), fed on maximum rations. J. Anim. Ecol. 44: 805–821.
- Hoar, W.S., D.J. Randall, and J.R. Brett. 1979. Bioenergetics and growth. Fish Physiol. Vol. VIII. Academic Press, New York. 786 p.
- Ishida, Y., T. Azumaya, M. Fukuwaka, and N. Davis. 2001. Interannual variability in stock abundance and body size of Pacific salmon in the central Bering Sea. N. Pac. Anadr. Fish Comm. Doc. 549. 12 pp. (Available at www.npafc.org).
- Karpenko, V.I., A.F. Volkov, M.V. Koval. 2007. Diets of Pacific salmon in the Sea of Okhotsk, Bering Sea, and Northwest Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull. 4: 105–116. (Available at www.npafc.org).
- Klovach, N.V. 2003. Ecological consequences of massive hatchery of chum salmon. Moscow. VNIRO Publ. 164 pp. (In Russian).
- Koval, M.V. 2007. Forage base and feeding particulars of Pacific salmon in Kamchatkan waters of the Okhotsk and Bering seas and in the northern part of Pacific Ocean. Ph.D. Dissertation. Kamchatka Technical Univ. Petropavlovsk–Kamchatsky. 262 pp. (In Russian).
- Ruggerone, G.T., M. Zimmerman, K.W. Myers, J.L. Nielsen, and D.E. Rogers. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. Fish. Oceanogr. 12: 209-219.
- Ruggerone, G.T. and J.L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. Rev. Fish Biol. Fish. 14: 371-390.
- Ruggerone, G.T., E.V. Farley, J. Nielsen, and P. Hagen. 2005. Seasonal marine growth of Bristol Bay sockeye salmon (*Oncorhynchus nerka*) in relation to competition with Asian pink salmon (*O. gorbuscha*) and the 1977 ocean regime. Fish. Bull. 103: 355-370.
- Ruggerone, G.T., J.L. Nielsen, and J. Bumgarner. 2007. Linkages between Alaskan sockeye salmon abundance, growth at sea, and climate, 1955–2002. Deep Sea Res. II. 54: 2776–2793.
- Shulman, G.E. and R.M. Love. 1999. The biochemical ecology of marine fishes. Adv. Mar. Biol. 36. 351 pp.
- Stauffer, G.D. 1973. A growth model for salmonids reared in hatchery environments. Ph.D. Thesis. Univ. Washington, Seattle. 212 pp.

Lipid Content of Immature Chum Salmon (*Oncorhynchus keta*) Affected by Pink Salmon (*O. gorbuscha*) Abundance in the Central Bering Sea

Toshiki Kaga¹, Shunpei Sato², Tomonori Azumaya¹, Nancy D. Davis³, and Masa-aki Fukuwaka¹

¹Hokkaido National Fisheries Research Institute (HNFRI), Fisheries Research Agency,
116 Katsurakoi, Kushiro 0850802, Japan

²HNFRI, 2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan.

³School of Aquatic and Fishery Sciences, University of Washington,
Box 355020, Seattle, WA 98195-5020, USA

Present address: North Pacific Anadromous Fish Commission,
Suite 502, 889 West Pender Street, Vancouver, BC V6C 3B2, Canada

Keywords: lipid contents, chum salmon, pink salmon, central Bering Sea

Lipid is the principal energy storage constituent in salmonids, including chum salmon. Chum salmon migrate in the Bering Sea for foraging during the summer, and immature fish begin moving southward for overwintering in autumn. Variability of lipid content in fish can depend on foraging conditions during the growing season; therefore, lipid content during the summer can be regarded as a reliable marker for chum salmon body condition. We analyzed the lipid contents of 461 immature chum salmon collected in the central Bering Sea from 2002 to 2007. Individual variation of log-transformed lipid content was tested using generalized linear models and biological and environmental variables. A model that included fish size and pink salmon CPUE was the most effective at describing variation of lipid content in immature chum salmon. Lipid content of immature chum salmon decreased as pink salmon CPUE increased. The negative correlation between chum salmon lipid contents and pink salmon CPUE is consistent with the hypothesis of inter-specific exploitative competition for food items. The main prey of chum salmon is gelatinous plankton in odd-numbered years and crustaceans in even-numbered years. Lipid composition of gelatinous plankton is substantially lower than that of crustaceans. Results suggest the nutritional condition of immature chum salmon may be related to the shift of prey items through inter-specific interactions, which might occur during occupation of the surface layer by large numbers of pink salmon.

Spatial Variability in Lipid Content and Fatty Acid Profiles of Macrozooplankton From Coastal British Columbia, Canada

Daniel P. Bevan¹, John F. Dower^{1,2}, Marc Trudel³, and Asit Mazumder¹

¹ Department of Biology, University of Victoria, PO Box 3020 STN CSC, Victoria, BC V8W 3N5, Canada

² School of Earth and Ocean Sciences, University of Victoria, PO Box 3065, STN CSC, Victoria, BC V8W 3V6, Canada

³ Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo, BC V9T 6N7, Canada

Keywords: zooplankton, fatty acids, lipid content, coastal British Columbia

This study explores the relationship between food quality and Pacific salmon production through impacts on the growth and overwinter survival of juvenile salmon during their first year at sea. Recent development in the use of fatty acids as bioindicators has drawn attention to the importance of food quality and nutritional value in the productivity of marine ecosystems and that prey quality may be as important as prey abundance in transferring energy through food webs. The concentrations of polyunsaturated fatty acids, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) within an organism, have become popular proxies for estimating food quality. Here we examine spatial variability in fatty acid profiles, key fatty acid ratios, and overall lipid content across a range of zooplankton species commonly found in coastal British Columbia, Canada. Selection of target species, which included copepods, amphipods and euphausiids, was motivated by their prevalence across a wide area, ease of capture, and importance in the diet of juvenile salmon. Samples were collected from bongo tows at more than 100 locations in the waters surrounding Vancouver Island and in more northern coastal areas between May and September 2010. Sampling allowed for intraspecies comparisons over multiple spatial scales. These results explore how variability in the presence of critical fatty acids can potentially alter the efficiency of energy transfer to juvenile salmon across ecosystems.

Food Supply of Pacific Salmon During Their Marine Period of Life in the North Pacific in 1980–2011

Svetlana Naydenko

*Pacific Research Fisheries Center (TINRO-center),
 4, Shevchenko Alley, Vladivostok 690091, Russia*

Keywords: Pacific salmon, food supply, macroplankton, nekton, consumption, forage resources, North Pacific

This study focused on estimates of food supply for salmon and other nektonic species in the epipelagic layer of regions of the subarctic Northwest Pacific (except estuarine and coastal areas). For this purpose, a long-term data series (1980–2011) was analyzed that was developed from integrated Russian research surveys in the pelagic zone of Russian Far East seas and the northwestern Pacific Ocean. Information gained from these surveys includes total quantitative estimates of nekton biomass, stock of forage resources (macroplankton and small nekton), and Pacific salmon and nekton feeding.

Estimates summarizing the dynamics of forage resources were presented by Shuntov (2001), Dulepova (2002), Shuntov and Temnykh (2007), and Volkov et al. (2007). Based on their reports, the total estimated stock of zooplankton in the epipelagic layer of the subarctic Northwest Pacific, including the Okhotsk and Bering Seas, decreased from 722.5 million tons in 1980 to 587.8 million tons in 2000 (decreased approximately 20%). However, the large-sized fraction of zooplankton, which is the basis of feeding for nektonic planktivores, slightly decreased from 1980 to the early 1990s (8%) and there was a slight increase in succeeding years to 520.1 million tons. These dynamics illustrate some specific provincial features. Generally, in spite of a definite decrease in total abundance of macroplankton, the biomass is still rather high (Shuntov 2001; Dulepova 2002; Shuntov and Temnykh 2007).

Abundance of the dominant pelagic nekton species had a clear decrease in the late 1980s to early 1990s, when the walleye pollock stock decreased and Japanese sardines stopped its mass migration to subarctic waters. Later, this reduction was partially compensated for by increasing populations of herring, saury, Japanese anchovy, capelin, several species of squids, and Pacific salmon. Recently, from 1996 to 2011 pelagic nekton resources have remained at a level that is lower than the 1980s, but higher than it was in the early 1990s (Shuntov et al. 1997; Shuntov and Temnykh 2004).

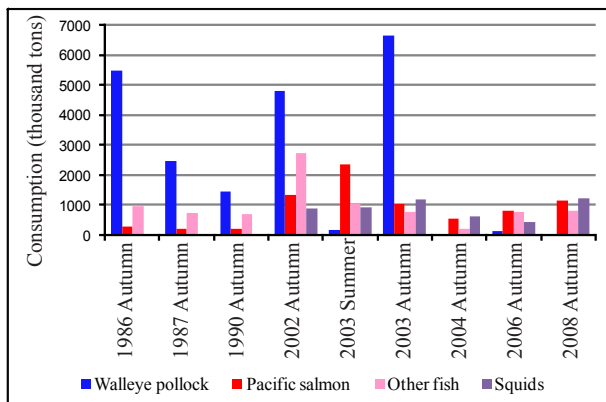


Fig. 1. The total consumption (thousand tons) of forage resources by nekton and Pacific salmon in the upper epipelagic layer in the western Bering Sea during summer 2003 and autumn 1986–2008.

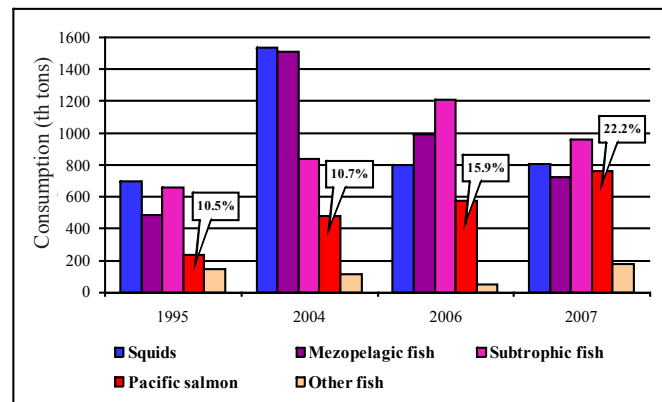


Fig. 2. The total consumption (thousand tons) of forage resources by nekton and Pacific salmon in the upper epipelagic layer of the Pacific waters of Kuril Islands during summer (from Naydenko 2010).

In comparison, Pacific salmon biomass has increased 2- to 4-fold since the 1980s. However, the role of salmon in the trophic structure of the upper pelagic layer is still not as important as that of pollock or sardine in years when these species are highly abundant (Figs. 1 and 2). Salmon consume a lower quantity of the forage resources than species of the low boreal-subtropical complex, or even of mesopelagic fishes and squids, during periods when these species are highly abundant (Naydenko 2002, 2009, 2010; Naydenko et al., 2010a, b).

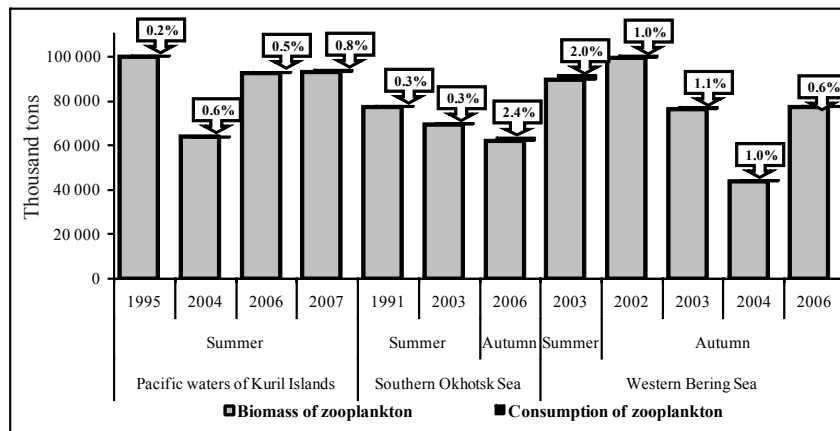


Fig. 3. The biomass of zooplankton (thousand tons, grey columns) and its consumption by Pacific salmon (arrows indicate %) in the upper epipelagic layer of different regions of the northwestern North Pacific, Okhotsk Sea and Bering Sea (data from Naydenko 2009, 2010).

Only during short periods of the pre-anadromous adult salmon migrations (e.g., in the western Bering Sea) beginning before the mass arrival of migrants from the south (e.g., Pacific waters of Kuril Islands), and during the period of post-catadromous juvenile migrations (e.g., October-December in the southern Okhotsk Sea) does salmon become the most important consumer of zooplankton resources, at least when there is a relatively low abundance of mesopelagic fish. In general, salmon (Fig. 3) and all nekton (Fig. 4) consume only a small portion of the total amount of zooplankton that is available.

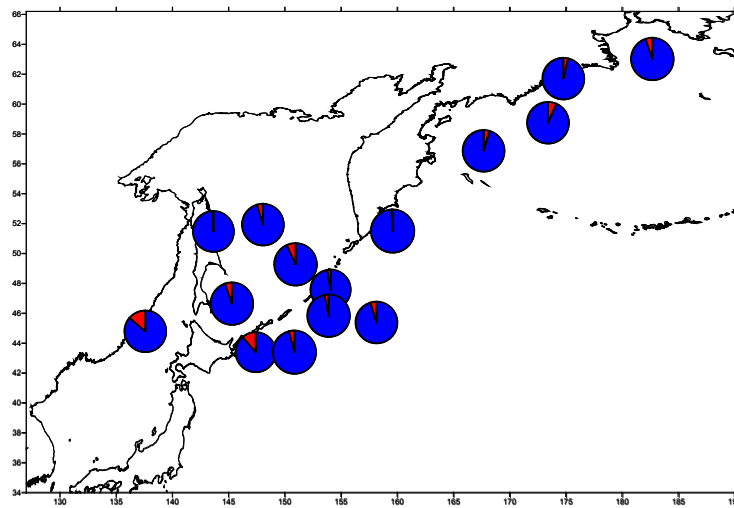


Fig. 4. The zooplankton stock (blue portion of the circle, %) and its consumption by nekton (red portion of the circle, %) in the upper epipelagic layer of different regions in summer.

Separation in space and time of salmon feeding from other consumers are important factors for preventing competition for food with other zooplankton consumers. In certain areas, some competition for food is possible where the feeding grounds overlap, but this is mitigated by plasticity and electivity of prey selection by salmon, as well as abundant forage reserves. A satisfactory food supply for salmon is provided by the stable and high value of their daily ration, which exists against a background of considerable fluctuations in plankton and nekton abundance. Salmon diet composition consistently show their preference to consume hyperiids, pteropods, and euphausiids. Examples of the diet composition (%) of pink and chum salmon in the Northwest Pacific in 1990s and 2000s are shown in Figs. 5 and 6.

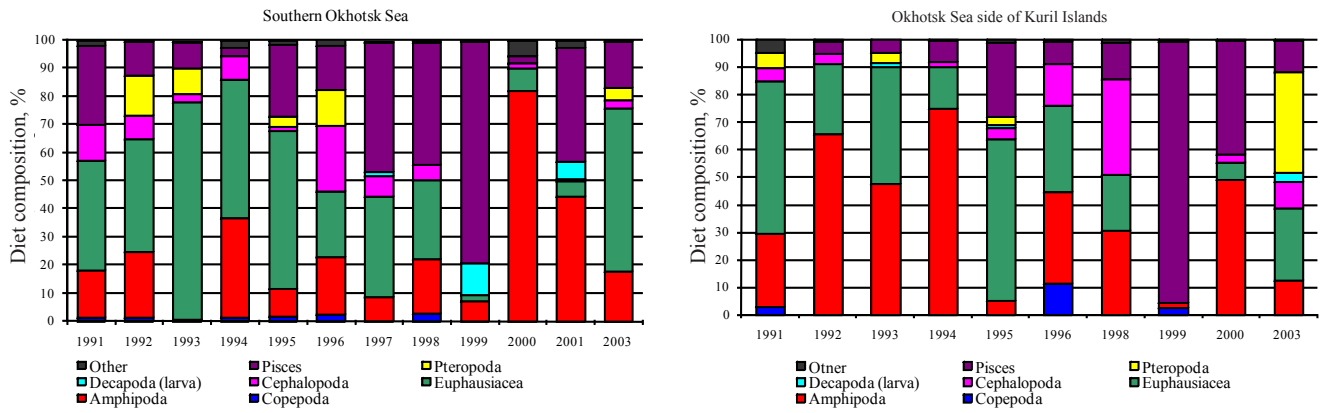


Fig. 5. The diet composition (%) of pink salmon in the Okhotsk Sea in summer, 1991-2003. The 2000s is a period of high pink and chum salmon abundance.

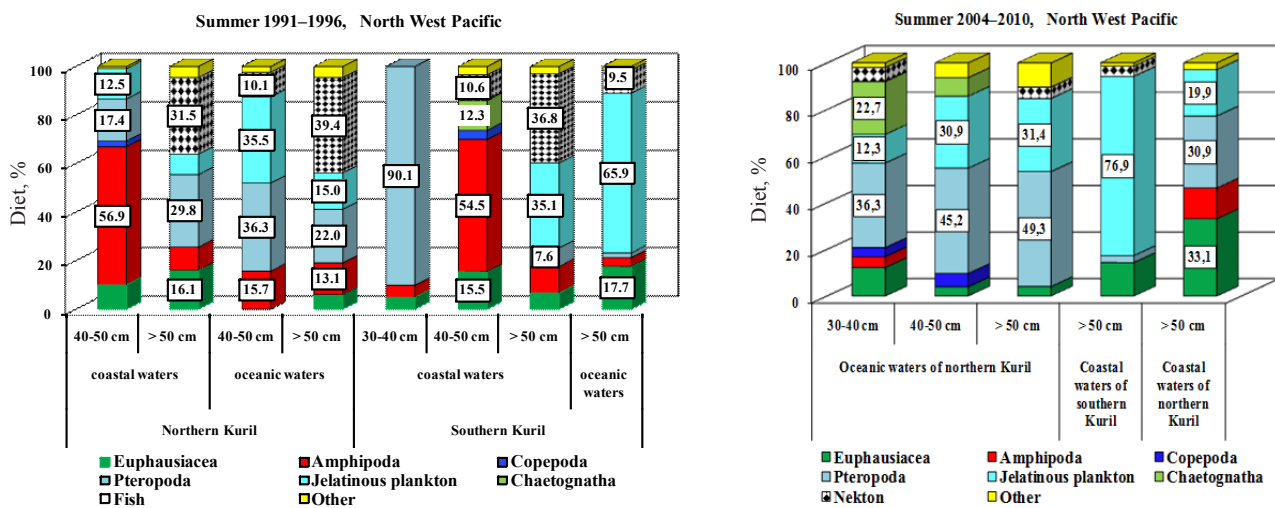


Fig. 6. The diet composition (%) of chum salmon in the Northwest Pacific in summer, 1991–1996 and 2004–2010. The 2000s is a period of high pink and chum salmon abundance.

Research surveys in the central and western North Pacific Ocean that were conducted by TINRO-Center during winter-spring 2009-2011 have provided valuable information on the food supply of salmon during that seasonal period. Plankton studies from the winter-spring cruises do not confirm the conclusions of previous research (Nagasawa 1999, 2000) about a considerable decrease in zooplankton biomass in winter. The biomass reported earlier indicated that mean monthly zooplankton biomasses in winter did not exceed 21.5-46.1 mg/m³ (northern Pacific), 29.0-34.6 mg/m³ (western Pacific) and 19.7-52.3 mg/m³ (central Pacific) and concluded that poor food conditions exist in winter for salmon (Nagasawa 1999, 2000). Results from the TINRO cruises indicated that zooplankton biomass in the pelagic layer during the winter-spring period varied widely, and was higher than levels reported earlier (Fig. 7). The mean zooplankton biomass in the pelagic layer

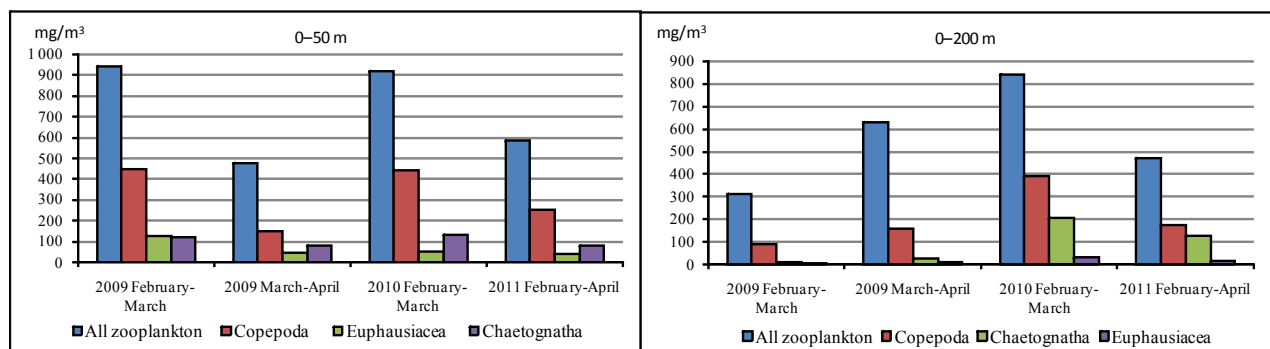


Fig. 7. The plankton composition and biomass (mg/m³) in the pelagic layer (0–50 and 0–200 m) in the subarctic frontal zone in the North Pacific in February-April 2009-2011 (data from Naydenko et al. 2010 a, b; Kuznetsova and Efimkin 2010; Glebov et al. 2011).

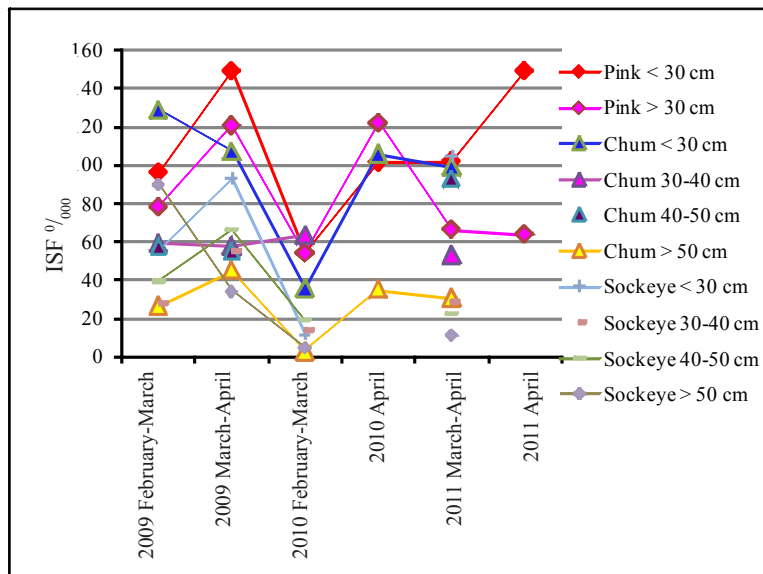


Fig. 8. The feeding intensity (ISF, ‰) of Pacific salmon in the subarctic frontal zone in the North Pacific in February-April 2009–2011 (data from Naydenko et al. 2010b; Kuznetsova 2010).

(0-200 m) was estimated at 313 and 631 mg/m³ (2009), 839 mg/m³ (2010), and 470 mg/m³ (2011), and that the biomass in the 0–50 m layer was higher than in the 0-200 m water column (Naydenko et al. 2010a, b; Kuznetsova and Efimkin 2010; Glebov et al. 2011). In winter-spring 2009–2011 the feeding intensity of salmon varied largely depending on fish size and time and location where fish were caught. The index of stomach fullness (ISF) of immature small-sized fish was higher than for large-sized fish (Fig. 8). Although the mean index of stomach fullness in winter-spring samples was lower than in summer-fall samples, the majority of fishes were observed to have a high feeding activity, suggesting the winter-spring is not period of fasting when food resources are scarce. Hyperiid, copepods, euphausiids and pteropods predominated in salmon diets during all research periods (Fig. 9). These results indicate there was sufficient and stable forage reserves for salmon during all seasons of the year.

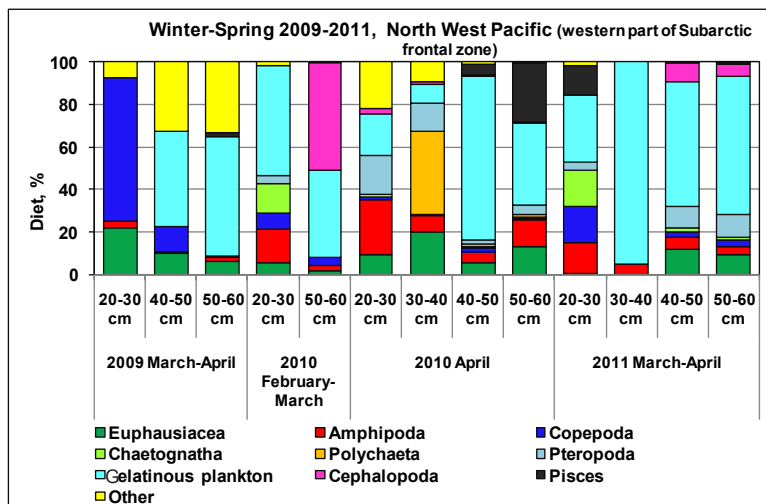


Fig. 9. The diet composition (%) of chum salmon in the subarctic frontal zone in the North Pacific in February-April 2009–2011 (data from Naydenko et al. 2010b; Kuznetsova 2010).

Conclusions based on these long-term data indicate that stable dependence of Pacific salmon abundance and marine survival on zooplankton abundance has not been observed. The feeding intensity of Pacific salmon is high despite substantial year-to-year variability of salmon abundance and zooplankton biomass. Selective and stable feeding on some prey items (hyperiid, pteropods, and some species of euphausiids and copepods) by the most abundant planktivorous salmon species (pink, chum, and sockeye) was observed in different seasons and years, and in different areas of the Russian Far Eastern seas and the northwestern Pacific Ocean. These conditions indicate sufficient food resources for salmon. At the same time, it is necessary to mention that there are certain regions where some competition for food is possible in the local foraging

environment. Competition for food is also possible in estuarine and coastal or shelf environments, but these areas were not considered in this research.

On the whole, the portion of forage resources consumed by salmon is insignificant, and the recent rise in salmon abundance scarcely causes serious restructuring of the trophic structure of the upper pelagic layer of the Russian Far East seas and Northwest Pacific. Indeed, population fluctuations of the dominant consumers lead to changes in the trophic structure. However, even if there are multiple shifts in the biomass of those species characterized by large fluctuations, such as pollock, herring, capelin, sardine, scomber, anchovy, and Japanese flying squid, the result is merely the fitting and adjustment of trophic relations and energy transfer that does not cause crises in the pelagic community.

REFERENCES

- Dulepova, E.P. 2002. Comparative bioproductivity of Far East Seas macroecosystems. Vladivostok, TINRO-Center. 273 pp. (In Russian).
- Glebov, I.I., S.V. Naydenko, N.A. Kuznetsova, E.V. Kurenkova, A.A. Khoruzhiy, R.G. Ovsvyanikov, K.V. Padchenko, and S.P. Dudkov. 2011. Composition and structure of epipelagic nekton and plankton communities in the western parts of subarctic frontal zone in winter-spring 2011 (Result of 2011 research cruise of R/V *TINRO*). N. Pac. Anadr. Fish Comm. Doc. 1331 (Rev. 1). 28 pp. (Available at www.npafc.org).
- Kuznetsova, N.A. 2010. Feeding of Pacific salmon in the north-western part of North Pacific in winter and spring 2010. Implementation of “Strategic plan for far eastern basin-scale Pacific salmon research program for 2006–2010 period”. TINRO-Centre, Vladivostok. Bull. 5: 146–152. (In Russian).
- Kuznetsova, N.A., and A.Y. Efimkin. 2010. The composition of plankton communities in the western part of North Pacific in winter and spring 2010. Implementation of “Strategic plan for far eastern basin-scale Pacific salmon research program for 2006–2010 period”. TINRO-Centre, Vladivostok. Bull. 5: 164–177. (In Russian).
- Nagasawa, K. 1999. Is there abundant zooplankton prey for salmon in the subarctic North Pacific in winter? Bull. Nat. Res. Inst. Far Seas Fish. 36: 69-75.
- Nagasawa, K. 2000. Winter zooplankton biomass in the Subarctic North Pacific, with a discussion on the overwintering survival strategy of Pacific salmon (*Oncorhynchus* spp.). N. Pac. Anadr. Fish Comm. Bull. 2: 21-32. (Available at www.npafc.org).
- Naydenko, S.V. 2002. Trophic structure of nekton in the epipelagic of the South Kuril region in summer, 1991–1995. Izv. TINRO 130 (2): 618–652. (In Russian with English abstract).
- Naydenko, S.V. 2009. The role of Pacific salmon in trophic structure of the upper epipelagic layer in the western Bering Sea during summer-autumn 2002–2006. N. Pac. Anadr. Fish Comm. Bull. 5: 231–241. (Available at www.npafc.org).
- Naydenko, S.V. 2010. Feeding habits of the Pacific salmon, their trophic status and role in North Pacific marine ecosystem. In *Salmon: biology, nutrition and consumption*. Series: Fish, fishing and fisheries. Edited by P. Lacopo and M. Riemma. (ebook). pp. 61-111.
- Naydenko, S.V., A.Ya. Efimkin, K.K. Karyakin, A.A. Balanov, N.A. Kuznetsova, A.L. Figurkin, R.G. Ovsvyanikov, S.S. Ponomarev, A.V. Klimov, I.Y. Spirin, and A.V. Kojevnikov. 2010a. Result of research survey by R/V *TINRO* in winter-spring 2010 in subarctic frontal zone. N. Pac. Anadr. Fish Comm. Doc. 1272 (Rev. 1). 13 pp. (Available at www.npafc.org).
- Naydenko, S.V., A.N. Starovoytov, E.V. Kurenkova, V.I. Chuchukalo, and R.G. Ovsvyanikov. 2010b. Feeding of Pacific salmon in the subarctic frontal zone in winter and spring. Izv. TINRO. 161: 142–161. (In Russian with English abstract).
- Shuntov, V.P. 2001. Biology of the Russian Far Eastern Seas. Vladivostok, TINRO-Centre. Vol. 1. 580 pp. (In Russian).
- Shuntov, V.P., and O.S. Temnykh. 2004. Is the North Pacific carrying capacity over in connection with salmon high abundance: myths and reality. Izv. TINRO 138: 19–36. (In Russian with English abstract).
- Shuntov, V.P., and O.S. Temnykh. 2007. Total estimation of forage resources (macroplankton and small nekton) for Pacific salmon in the Far East Seas and adjacent ocean waters of the north-western Pacific Ocean. Implementation of Strategic plan for Far Eastern basin-scale Pacific salmon research program for 2006–2010 period. Vladivostok, TINRO-Center: Bull. 2: 260–266. (In Russian).
- Shuntov, V.P. and O.S. Temnykh. 2008. Pacific Salmon in marine and ocean ecosystems. Vladivostok, TINRO-Center. Vol. 1. 461 pp. (In Russian).
- Shuntov, V.P., V.I. Radchenko, E.P. Dulepova, and O.S. Temnykh. 1997. Biological resources of the Russian Far Eastern Economic Zone: structure of pelagic and benthic communities, contemporary status, long-term dynamics trends. Izv. TINRO 122: 3–15. (In Russian with English abstract).
- Volkov, A.F., A.Ya. Efimkin, and N.A. Kuznetsova. 2007. Results of the BASIS studies on Pacific salmon feeding habits in 2002–2006. Izv. TINRO 151: 365–402. (In Russian with English abstract).

Evidence for Bottom-Up Effects on Pink and Chum Salmon Abundance and the Consequences for Other Salmon Species

Gregory T. Ruggerone¹, Katherine W. Myers², Beverly A. Agler³, and Jennifer L. Nielsen⁴

¹Natural Resources Consultants, Inc., 4039 21st Ave W, Suite 404, Seattle, WA 98199 USA

²School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195-5020, USA

³Alaska Department of Fish and Game, Mark, Tag, and Age Laboratory, Division of Commercial Fisheries,
10107 Bentwood Place, Juneau, AK 99801, USA

⁴The Evergreen State College, 2700 Evergreen Parkway NW, Olympia, WA 98505, USA

Keywords: pink salmon, sockeye salmon, density dependence, competition, growth, survival, Fraser River, Bristol Bay

Total abundances of adult pink, chum, and sockeye salmon returning from the North Pacific Ocean have been at a high level since the ocean regime shift in 1976-77, but increasing abundances were not synchronous among all species and regions (Ruggerone et al. 2010). The large increase in total chum salmon abundance was due to significant increases in hatchery production that offset stable or declining regional abundances of wild chum salmon. Total abundance of hatchery chum salmon began to exceed total abundance of wild chum salmon in the mid-1980s. Regions where hatchery pink and/or chum salmon abundances significantly exceeded wild salmon abundance include Japan, Prince William Sound, and Southeast Alaska. Increased marking and monitoring of hatchery salmon by management agencies would allow more accurate measures of abundance and productivity of wild salmon.

Abundance of wild pink salmon has been exceptional, averaging approximately 4.2 to 5.6 times more adult fish than wild sockeye and chum salmon, respectively (Ruggerone et al. 2010). Pink salmon represent nearly 70%, on average, of all wild adult salmon returning from the ocean. The exceptional abundance of pink salmon appears to be related to their unique life history, which seems to be especially suited to ocean conditions since the 1976/77 regime shift. Pink salmon fry spend little time in freshwater after emergence from redds, and they migrate quickly through the estuary; therefore, juvenile pink salmon may experience less impact relative to other salmonids in estuarine habitats degraded by human activities. The early entry of pink salmon fry into coastal marine waters relative to most other salmon species may be conducive to growth and survival during the recent period when ocean temperature and productivity tended to be higher and earlier relative to that prior to the mid-1970s (Brodeur and Ware 1992; Ruggerone and Goetz 2004).

Rapid growth is important for pink salmon, which have the highest early marine growth rates of salmon (Ricker 1976; Brett 1979). Rapid growth of pink salmon is accomplished by continuous feeding at rates that maintain a full stomach at high prey densities (Godin 1981). Moss et al. (2005), using stock-specific scale growth from immature pink salmon captured at sea versus scale growth of these returning adults, demonstrated that larger and faster-growing pink salmon experienced higher survival.

Few long time series of salmon growth at sea exist, especially for pink salmon. However, early marine scale growth of Alaska sockeye salmon was consistently above average following the mid-1970s ocean regime shift (Ruggerone et al. 2007), suggesting rapid early marine growth of sockeye salmon (and presumably pink salmon) contributed to greater survival and abundance after the regime shift. Total abundance of Alaska sockeye salmon since 1955 was positively correlated with their scale growth during the first two years at sea. Given that the diet of sockeye and pink salmon overlap considerably in the ocean (Davis et al. 2005; Myers et al. 2009), it is likely that pink salmon growth also increased after the mid-1970s regime shift (Walker et al. 1998). Evidence suggests that bottom-up (growth-related) processes associated with ocean regime shifts and seasonal ocean conditions strongly influence wild salmon abundance. However, greater abundance of salmon has led to density-dependent growth, which is more apparent and detectable during late life stages when growth-related mortality is less (Ruggerone et al. 2007).

Salmon Interactions at Sea

Although productivity of the ocean is a primary driver of salmon survival and abundance, evidence indicates salmon interactions at sea can be significant. Salmon migrate long distances at sea and interact with other salmon originating from distant regions; therefore, high regional abundances of salmon may have adverse impacts on salmon from other regions. These interactions are difficult to evaluate because there are numerous potentially confounding factors (see below). Nevertheless, the interaction between Bristol Bay sockeye salmon and Asian pink salmon is one example of this previously unknown interaction (Ruggerone et al. 2003). Additionally, recent evidence suggests that the high abundance of Asian chum

salmon, which originate primarily from hatcheries, adversely affects the survival, age-at-maturation, and adult length-at-age of chum salmon from Norton Sound in northern Alaska (Ruggerone et al. 2011). Although abundance of Norton Sound chum salmon is low, these salmon are highly important to people for subsistence.

Pink Salmon Effects on Fraser Sockeye Salmon

The great abundance of pink salmon has consequences for other species of salmon (Ruggerone and Nielsen 2004, 2009) as well as marine birds (Toge et al. 2011). Using sockeye salmon data provided by the Pacific Salmon Commission, we found that high abundances of pink salmon adversely influenced the growth, age-at-maturation, and survival of Fraser River, British Columbia, sockeye salmon.

The mean productivity of 16 Fraser River sockeye salmon populations during brood years 1961 to 2005 was inversely correlated with abundance of North American pink salmon ($r = -0.60$; Fig. 1). Productivity was defined as the residual from the stock-specific Ricker recruitment curve (Peterman et al. 1998). The relationship shows two modest outliers corresponding with brood years 2003 and 2005, i.e., adult returns in 2007 and 2009. The unusually low 2009 sockeye salmon return surprised managers and led to ongoing investigations (Peterman et al. 2010; www.cohencommission.ca/en/). The low returns in 2007 and 2009 were consistent with alternating-year abundances of pink salmon, but the relationship (Fig. 1) suggests that other factor(s) also contributed to these low sockeye returns. In 2010, sockeye salmon abundance was high, as expected from the alternating-year pattern of pink salmon abundance, but stock-specific productivity of the 2010 return has yet to be reported by the Pacific Salmon Commission. Since 1979, sockeye salmon productivity from odd-numbered brood years has been significantly lower than productivity from even-numbered years. Most sockeye salmon produced by odd-numbered broods mature four years later in odd-numbered years. The unusual sockeye returns in recent years are consistent with interactions with pink salmon, although some other factor(s) also affected survival.

Evidence indicates that growth of Fraser River sockeye was a key factor influencing their survival in relation to pink salmon. Adult length-at-age of Fraser sockeye salmon was significantly smaller during odd-year returns. Adult length-at-age was inversely related to abundance of adult sockeye and pink salmon.

Growth at sea also affected age-at-maturation of Fraser River sockeye salmon, which was delayed among odd-year broods compared with even-year broods. Age-at-maturation was positively correlated with abundance of pink salmon in North America ($r = 0.69$, Fig. 2a), suggesting that higher abundance of pink salmon led to reduced sockeye growth and delayed maturation. Productivity of Fraser River sockeye salmon (mean of 16 populations) was inversely correlated with age-at-maturation of the broods since 1961

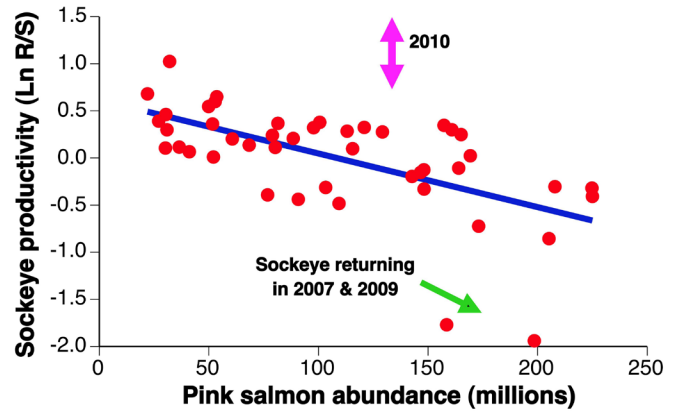


Fig. 1. Relationship between mean productivity of 16 Fraser River sockeye stocks (brood years 1961-2005) and abundance of pink salmon returning to North America (southern British Columbia, Southeast Alaska, Prince William Sound, Kodiak stocks) during the year of adult sockeye return, i.e., brood year plus four years. Productivity of the 2003 and 2005 broods was consistent with the pink salmon hypothesis, but other factors impacted these broods. The vertical arrow indicates the likely range in productivity of the 2006 brood year that produced an abundant sockeye return in 2010 following apparently favorable ocean conditions. Productivity is the residual from the stock-specific Ricker recruitment curve. Sockeye salmon data provided by the Pacific Salmon Commission.

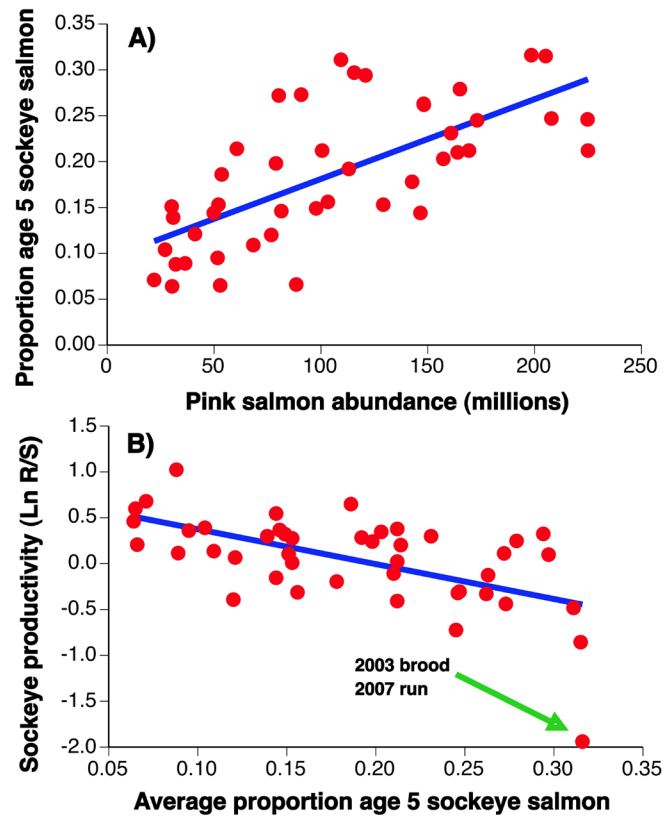


Fig. 2. Relationship between the mean proportion of age-5 Fraser River, British Columbia, sockeye salmon in the brood year return (mean of 16 stocks) and the abundance of North American pink salmon (A), and the relationship between Fraser River sockeye salmon productivity and the mean proportion of age-5 Fraser sockeye salmon in the adult brood year return (B).

($r = -0.58$; Fig. 2b). These findings suggest that growth of sockeye salmon was reduced by high pink salmon abundance, and high pink salmon abundance contributed to delayed maturation and lower survival of Fraser River sockeye salmon. Delayed maturation is an important mechanism in which reduced growth can contribute to lower survival of salmon. This analysis indicates mortality can be high during late marine life in addition to high mortality during early marine life. The growing evidence for bottom-up control of salmon survival and abundance and for competition over prey highlights the need to better understand interactions between and among species of salmon at sea. Additional effort is needed to identify the time period(s) of species interaction (Beamish et al. 2010).

Pink Salmon Effects on Bristol Bay Sockeye Salmon

Evidence based on Alaskan sockeye salmon smolt survival, adult returns, and ocean growth indicates there is competition with abundant Asian pink salmon stocks (Ruggerone et al. 2003, 2005). Information was reported at the 2011 NPAFC workshop (Wertheimer and Farley, this report) that suggested smolt-to-adult survival of Bristol Bay sockeye salmon was not inversely correlated with abundance of Asian pink salmon. While preparing the 2003 manuscript, we also found no strong correlation between smolt-to-adult survival of Bristol Bay sockeye salmon and Asian pink salmon abundance, but we also recognized there were multiple reasons why correlation analysis failed to document a relationship. Therefore, Ruggerone et al. (2003) and subsequent manuscripts used several more robust approaches to test the pink salmon hypothesis as further discussed below.

We identified six reasons why correlation analyses did not detect a negative relationship between survival of Bristol Bay sockeye salmon and Asian pink salmon abundance:

- (1) Ocean productivity is a major factor driving pink and sockeye salmon production and both Asian pink and Bristol Bay sockeye salmon responded similarly to ocean conditions in recent decades (Ruggerone et al. 2010);
- (2) The interaction between Bristol Bay sockeye salmon and Asian pink salmon begins during the second year at sea (Ruggerone et al. 2003, 2005). Time of this interaction is important because significant and highly variable mortality of salmon occurs during the first year at sea and, therefore, prior to the pink salmon interaction. We do not consider pink salmon interaction to be the primary factor driving sockeye salmon survival, but there is considerable evidence that this interaction is an important factor;
- (3) There is undoubtedly significant measurement error in Bristol Bay smolt-to-adult survival rates and error in total pink salmon abundance estimates and inconsistent error from year to year would weaken a correlation;
- (4) Pink and sockeye salmon distribution at sea varies from year to year, and this influences the degree of interaction independent of total abundance;
- (5) Analyzing relationships involving only the total abundance of Asian pink salmon may not reveal correlations because there are year-to-year stock-specific migration patterns and abundances of pink and sockeye salmon. As indicated by overlap in known ocean ranges from high seas tagging experiments (Myers et al. 1996), the primary Asian pink salmon stock that interacts with Bristol Bay sockeye salmon is that from Eastern Kamchatka, but pink salmon from other regions of Asia and North America are also abundant and could interact with Bristol Bay sockeye salmon. It is noteworthy that the dominant odd-year line of pink salmon returning to western Kamchatka switched to even-year dominance (most apparent beginning in 1994) following the tremendous spawning escapement in 1983 (Bugaev 2002; Ruggerone and Nielsen 2009). Year-to-year variation in stock-specific abundances and the degree of overlap in ocean distribution with Bristol Bay sockeye salmon would inhibit correlation;
- (6) Cyclic abundances of pink salmon may create annual cycles in abundances of their prey, which in turn influence the feeding rate of sockeye and pink salmon (Ruggerone et al. 2005).

According to Farley et al. (2011), Bristol Bay post-smolts during 2002-2007 had higher energy density in even-numbered years and this likely contributed to somewhat higher adult returns and survival from even-year smolt migrations rather than lower survival, which is expected when post-smolt sockeye interact with abundant pink salmon during the following odd-numbered year. Higher energy density in even-numbered years corresponded with lower abundance of post-smolt sockeye salmon, leading Farley et al. (2011) to suggest that energy content of sockeye salmon was density-dependent. Therefore, in relation to Asian pink salmon, high energy density of sockeye salmon near the end of the first growing season of even-numbered years may have offset negative effects that could have occurred during subsequent years when they began to overlap with pink salmon. Farley et al. (2011) also produced confidence intervals for their post-smolt abundance and survival estimates, indicating high uncertainty in the estimates in some years. Uncertainty was higher in even-numbered years, e.g., the 95% CI for abundance and survival in 2006 was 27.2-139.5 million post-smolts and 9.6-95.9% survival, respectively. Correlation between post-smolt abundance near the end of the first year at sea and the corresponding adult return was weak ($r = 0.14$) and non-significant ($p = 0.79$).

Therefore, rather than comparing sockeye survival directly with pink salmon abundance trends, Ruggerone et al. (2003) examined the effects of pink salmon on survival and abundance of Bristol Bay sockeye salmon using two approaches: (1)

comparison of smolt survival rates by odd- versus even-years of smolt migration, and (2) stock-specific adult returns by odd- versus even-years of smolt migration across a 21-year time period. These two independent approaches are more robust to assumptions required by correlation analysis and are consistent with the fact that pink salmon are approximately 39 times more abundant in the central Bering Sea during July of odd- versus even-numbered years based on sampling at sea (Davis et al. 2005; Myers et al. 2009). Sockeye salmon smolts migrating in even-numbered years averaged 46% to 26% lower survival, depending on smolt age, than odd-year migrants. Scale growth analyses demonstrated that even-year migrants were influenced by abundant odd-year pink salmon immediately after peak growth in spring of their second year at sea (Ruggerone et al. 2005). Furthermore, 22% fewer adult salmon returned from even-year smolt migrations during 1977-1997, based on age-specific returns to each Bristol Bay watershed (Ruggerone et al. 2003; Ruggerone and Nielsen 2004, 2009).

Finally, it is important to note that adult length-at-age and annual scale growth of Bristol Bay sockeye salmon were negatively correlated with Asian and/or eastern Kamchatka pink salmon abundance since the 1950s (Ruggerone et al. 2003, 2007; Ruggerone and Nielsen 2004). Total prey consumption and quality of prey declined more in sockeye than pink salmon during odd- versus even-numbered years (Davis et al. 2005). The density-dependent growth relationships and diet analyses were consistent with alternating-year patterns of sockeye smolt survival and adult abundance and the fact that salmon survival is strongly influenced by growth at sea (Moss et al. 2005). Mean salmon size measurements provide more robust values compared with survival estimates and size measurements are less prone to measurement error.

In summary, we are not surprised by a lack of correlation between survival of Bristol Bay sockeye salmon and abundance of Asian pink salmon. This relationship can be confounded by numerous factors. Nevertheless, multiple lines of evidence indicate that pink salmon affect the growth and abundance of Bristol Bay sockeye salmon, and new analyses indicate pink salmon also affect growth, age-at-maturation, and abundance of Fraser River sockeye salmon.

REFERENCES

- Beamish, R.J., R.M. Sweeting, C.M. Neville, and K.L. Lange. 2010. Competitive interactions between pink salmon and other juvenile Pacific salmon in the Strait of Georgia. N. Pac. Anadr. Fish Comm. Doc. 1284. 26 pp. (Available at www.npafc.org).
- Brett, J.R. 1979. Energetic factors and growth. In *Fish Physiology*, volume 8. Edited by W.S. Hoar, D.J. Randall, and J.R. Brett. Academic Press, New York. pp. 599-675.
- Brodeur, R.D., and D.M. Ware. 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. *Fish. Oceanogr.* 1: 32-38.
- Bugaev, V.F. 2002. On pink salmon (*Oncorhynchus gorbuscha*) abundance influence on Asian sockeye salmon (*Oncorhynchus nerka*) abundance. N. Pac. Anadr. Fish Comm. Doc. 628. 11 pp. (Available at www.npafc.org).
- Davis, N.D., M. Fukuwaka, J.L. Armstrong, and K.W. Myers. 2005. Salmon food habits studies in the Bering Sea, 1960 to present. N. Pac. Anadr. Fish Comm. Tech. Rep. 6: 24-28. (Available at www.npafc.org).
- Farley, E.V., A. Starovoytov, S. Naydenko, R. Heintz, M. Trudel, C.M. Guthrie, L. Eisner, and J.R. Guyon. 2011. Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. *ICES J. Mar. Sci.* 68: 1138-1146.
- Godin, J.-G.J. 1981. Effect of hunger on the daily pattern of feeding rates in juvenile pink salmon, *Oncorhynchus gorbuscha* Walbaum. *J. Fish Biol.* 19: 63-71.
- Moss, J.H., D.A. Beauchamp, A.D. Cross, K.W. Myers, E.V. Farley Jr., J.M. Murphy, and J.H. Helle. 2005. Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. *Trans. Am. Fish. Soc.* 134: 1313-1322.
- Myers, K.W., K.Y. Aydin, R.V. Walker, S. Fowler, and M.L. Dahlberg. 1996. Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956-1995. N. Pac. Anadr. Fish Comm. Doc. 192. 227 pp. (Available at www.npafc.org).
- Myers, K.W., R.V. Walker, N.D. Davis, J.L. Armstrong, and M. Kaeriyama. 2009. High seas distribution, biology, and ecology of Arctic-Yukon-Kuskokwim salmon: direct information from high seas tagging experiments, 1954-2006. *Am. Fish. Soc. Symp.* 70: 201-239.
- Peterman, R.M., B.J. Pyper, M.F. Lapointe, M.D. Adkison, and C.J. Walters. 1998. Patterns of covariation in survival rates of British Columbian and Alaskan sockeye salmon stocks. *Can. J. Fish. Aquat. Sci.* 55: 2503-2517.
- Peterman, R.M., D. Marmorek, B. Beckman, M. Bradford, N. Mantua, B.E. Riddell, M. Scheuerell, M. Staley, K. Wieckowski, J.R. Winton, C.C. Wood. 2010. Synthesis of evidence from a workshop on the decline of Fraser River sockeye. June 15-17, 2010. A Report to the Pacific Salmon Commission, Vancouver, B.C.
- Ricker, W.E. 1976. Review of rate of growth and mortality of Pacific salmon in saltwater, and non-catch mortality caused by fishing. *J. Fish. Res. Board Can.* 33: 1483-1524.
- Ruggerone, G.T., and F. Goetz. 2004. Survival of Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) in response to

- climate-induced competition with pink salmon (*O. gorbuscha*). *Can. J. Fish. Aquat. Sci.* 61: 1756-1770.
- Ruggerone, G.T., and J.L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. *Rev. Fish Biol. Fish.* 14: 371-390.
- Ruggerone, G.T., and J.L. Nielsen. 2009. A review of growth and survival of salmon at sea in response to competition and climate change. *Am. Fish. Soc. Symp.* 70: 241-266.
- Ruggerone, G.T., M. Zimmermann, K.W. Myers, J.L. Nielsen, and D.E. Rogers. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. *Fish. Oceanogr.* 12: 209-219.
- Ruggerone, G.T., E. Farley, J. Nielsen, and P. Hagen. 2005. Seasonal marine growth of Bristol Bay sockeye salmon (*Oncorhynchus nerka*) in relation to competition with Asian pink salmon (*O. gorbuscha*) and the 1977 ocean regime shift. *Fish. Bull.* 103: 355-370.
- Ruggerone, G.T., J.L. Nielsen, and J. Bumgarner. 2007. Linkages between Alaskan sockeye salmon abundance, growth at sea, and climate, 1955-2002. *Deep Sea Res. II.* 54: 2776-2793.
- Ruggerone, G.T., R.M. Peterman, B. Dorner, and K.W. Myers. 2010. Magnitude and trends in abundance of hatchery and wild pink, chum, and sockeye salmon in the North Pacific Ocean. *Mar. Coast. Fish. Dynam. Manage. Ecosys. Sci.* 2: 306-328. (Available at afs-journals.org/doi/pdf/10.1577/C09-054.1).
- Ruggerone, G.T., B.A. Agler, and J.L. Nielsen. 2011. Evidence for competition at sea between Norton Sound chum salmon and Asian hatchery chum salmon. *Environ. Biol. Fish.* In press. (Available online: DOI 10.1007/s10641-011-9856-5).
- Toge, K., R. Yamashita, K. Kazama, M. Fukuwaka, O. Yamamura, and Y. Watanuki. 2011. The relationship between pink salmon biomass and the body condition of shorttailed shearwaters in the Bering Sea: can fish compete with seabirds? *Proc. Royal Soc.* 278(1718): 2584-2590. doi: 10.1098/rspb.2010.2345.
- Walker, R.V., K.W. Myers, and S. Ito. 1998. Growth studies from 1956-95 collections of pink and chum salmon scales in the central North Pacific Ocean. *N. Pac. Anadr. Fish Comm. Bull.* 1: 54-65. (Available at www.npafc.org).

The Need for International Cooperation to Reduce Competition Among Salmon for a Common Pool of Prey Resources in the North Pacific Ocean

Randall M. Peterman¹, Carrie A. Holt^{1,2}, and Murray R. Rutherford¹

¹*School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC V5A 1S6, Canada*

²*Present address: Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Rd., Nanaimo, BC V9T 6N7, Canada*

Keywords: Pacific salmon, density-dependent competition, common-pool resource, international agreements

In recent decades, many populations of Pacific salmon (*Oncorhynchus* spp.) have shown long-term decreases in age-specific body size, which reduce the economic value of catches and fecundity of spawners. Several hypotheses have been proposed to explain these trends, including deteriorating environmental conditions, size-selective fishing, and density-dependent growth associated with the large increases in pink (*O. gorbuscha*), chum (*O. keta*), and sockeye salmon (*O. nerka*) abundances in the North Pacific Ocean (Ricker 1981; Peterman 1984a; Ishida et al. 1993; Ruggerone et al. 2003). The density-dependent hypothesis, which is based on competition among salmon for limited food, has the greatest support. That evidence is based on overlapping geographic distributions of pink, chum, and sockeye salmon populations, their stomach contents, and analyses of scale-growth patterns as well as abundances. Some sockeye populations have also suffered reduced productivity (adult recruits produced per spawner) in addition to reduced growth when present with high abundances of competitors, particularly pink salmon populations that vary dramatically in abundance between even and odd years (Ruggerone et al. 2003).

This evidence of density-dependent growth and survival rate among salmon in the North Pacific Ocean raises a concern about the detrimental effects of hatchery-released Pacific salmon. Hatchery-released pink and chum salmon constitute a substantial and growing portion of total wild plus enhanced salmon in the North Pacific Ocean, and plans exist to expand hatchery releases in the future, especially in Alaska and Russia (Ruggerone et al. 2010). Such plans are worrisome, given the magnitude of density-dependent processes on the high seas that reduce body size, and in some cases productivity, of both hatchery-origin and wild salmon. Smaller increments in net benefits (i.e., total benefits minus costs) as abundance increases mean that additional social and economic net benefits from incremental investments in hatcheries may decrease with increasing hatchery releases of salmon (Fig. 1A; Peterman 1991). However, if density-dependence in mortality rates is severe enough, further increasing hatchery abundances could potentially also decrease the total benefits derived from all production of hatchery and wild salmon (Fig. 1B; Peterman 1991).

Therefore, it is important that salmon-producing nations begin serious discussions on how to deal with this problem caused by competition for prey of salmon in the North Pacific. This situation of potential overuse of a limited

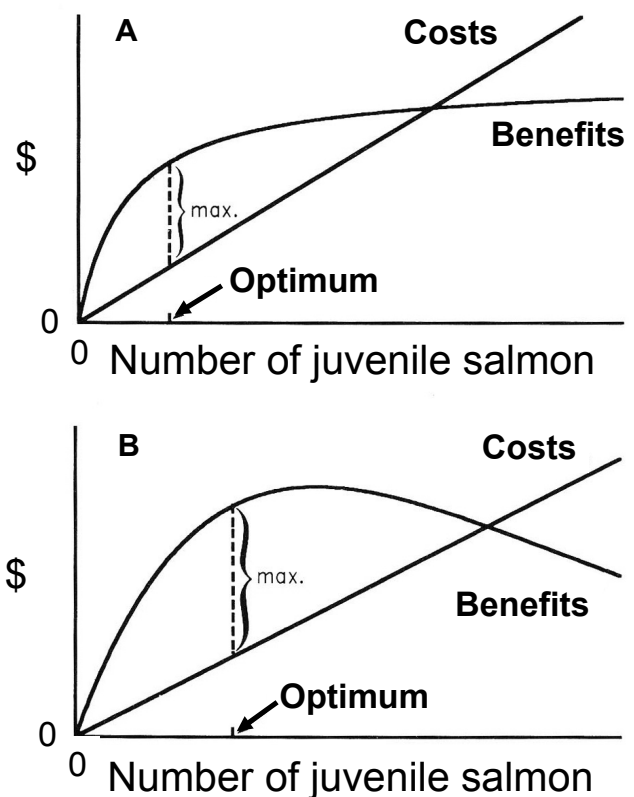


Fig. 1. Two possible situations relating total benefits (total dollar value of biomass yield from harvesting Pacific salmon populations) and costs of generating those benefits to the number of juveniles produced (from wild and artificially enhanced populations, including those from hatcheries). Adapted from Peterman (1991). A: Additional net benefits from each increment in hatchery investments may decrease with increasing salmon hatchery releases of juvenile salmon. B: If density-dependent mortality is severe, further increasing hatchery production could decrease benefits from all production of hatchery and wild salmon.

food resource is an example of the classic “common-pool resource” issue in economics where shared resources, such as pastures and water, benefit multiple users, each user reduces the available resource, and no one is excluded from using the resource (Ostrom et al. 1994). However, in many cases, such users may have little immediate indication of the effect of their use of the resource on reducing the value of the resource to other users. If users do not cooperate to restrict their use of the common-pool resource, a frequent outcome is depletion of the resource to the point where all users’ benefits are drastically reduced (e.g., overgrazed public pastures), often called the “Tragedy of the Commons” (Hardin 1968; Ostrom et al. 1999).

We therefore recommend that discussions about controlling competition among salmon be initiated by the North Pacific Anadromous Fish Commission (NPAFC) after appropriate amendments are made to its mandate. The objective for such discussions would be to identify and implement collective actions to prevent further increases in competition among salmon from different nations or even reduce it (Peterman 1984b; Heard 1998; Holt et al. 2008). Action on this problem of multi-national grazing of salmon food is long overdue. In an analogous situation over 20 years ago, the NPAFC reduced exploitation of salmon in the North Pacific Ocean by banning directed fishing on salmon in waters beyond territorial limits. However, there are currently no analogous regulations to deal with the next lower trophic level, i.e., to restrict the “harvest” of a common pool of North Pacific prey by salmon populations that come from different nations. Many precedents exist worldwide for creating appropriate incentives to sustainably use such limited common-pool resources. One of the more successful agreements has been the North Pacific Fur Seal Treaty of 1911 among Russia and the United States of America (on whose islands fur seals breed) and Japan plus Canada (which harvested fur seals in international waters at the time). That Treaty eliminated harvesting of fur seals on the high seas and restricted it to the breeding grounds. It also created incentives for long-term cooperation through sharing of benefits from harvested pelts among all four nations and making side-payments from the U.S.A. to Japan and Canada (represented by Britain) to change the incentive structure (Barrett 2003).

Over 900 international environmental treaties have come into force since 1970 (Anonymous 2011), so there is considerable experience in developing such accords and learning which processes work best for coming to agreement and generating effective implementation. Some of the lessons are to have: (1) clearly stated goals and objectives, as well as measurable indicators to assess progress toward meeting them, (2) flexibility to adapt to changing situations, (3) formal processes for taking new information into account, (4) robust implementation and enforcement, and (5) ongoing updates on the effectiveness of the agreement (Anonymous 2011). Multi-national discussions to develop an agreement should be based on principles such as (1) respecting sovereignty issues, (2) ensuring fairness and equity among all parties, (3) aiming to increase the benefits of all parties above what they would obtain if they did not cooperate in an agreement, (4) being open to considering “side payments” to achieve such added benefits (FAO 2002), and (5) developing an action plan over time. Key features of such sustainable-use systems have been identified from extensive experience (Ostrom 2009).

Although some may argue that in the case of Pacific salmon the incremental benefits are too small to justify acting now to limit the number of hatchery salmon, the history of fisheries management has numerous examples of cases where meaningful action was delayed until situations were in a crisis. In such cases, it has been much more difficult to resolve long-standing historical access issues and still meet long-term management objectives. Furthermore, if the productivity of the North Pacific Ocean should return to lower levels like those seen prior to the mid-1970s, and/or if future climatic changes lead to less suitable habitat for Pacific salmon, then pressures will be intense to increase hatchery releases, rather than reduce them to be more commensurate with reduced habitat quality. We therefore urge initiation of discussions now among the nations of the North Pacific Rim that produce wild and artificially-enhanced salmon (through hatcheries, lake enrichment, spawning channels, and other methods of increasing survival rate at early life stages).

The NPAFC is uniquely positioned to become a leader in resolving this environmental issue. For decades, it has performed a key role in management of Pacific salmon around the North Pacific Rim through data collection, monitoring, and enforcement. The good will and international collaborations among the member nations has already created a solid foundation for moving into this new realm of cooperation. Thus, the NPAFC has an excellent opportunity to begin discussions, which will not be easy, but which should ultimately lead to benefits for all member nations over and above the current situation.

REFERENCES

- Anonymous. 2011. Rio+20 policy brief: transforming governance and institutions for a planet under pressure. 8 pp. Available at www.icsu.org/rio20/policy-briefs/InstFrameLowRes.pdf. (Accessed 28 October 2011.)
- Barrett, S. 2003. *Environment and statecraft: the strategy of environmental treaty-making*. Oxford University Press, Oxford, U.K. 437 pp.
- FAO (Food and Agriculture Organization of the United Nations). 2002. Report of the Norway-FAO expert consultation on the management of shared fish stocks. FAO Fish. Rep. 695: FIPP/R695 (En). 34 pp.
- Hardin, G. 1968. The tragedy of the commons. *Science* 162 (3859): 1243-1248.

- Heard, W.R. 1998. Do hatchery salmon affect the North Pacific Ocean ecosystem? N. Pac. Anadr. Fish Comm. Bull. 1: 405-411.
- Holt, C.A., M.B. Rutherford, and R.M. Peterman. 2008. International cooperation among nation-states of the North Pacific Ocean on the problem of competition among salmon for a common pool of prey resources. Mar. Policy 32(4): 607-617.
- Ishida, Y.I. Soto-o, M. Kaeriyama, S. McKinnell, and K. Nagasawa. 1993. Recent changes in age and size of chum salmon (*Oncorhynchus keta*) in the North Pacific Ocean and possible causes. Can. J. Fish. Aquat. Sci. 50: 290-295.
- Ostrom, E. 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325 (5939): 419-422.
- Ostrom, E., J. Burger, C.B. Field, R.B. Norgaard, and D. Policansky. 1999. Revisiting the commons: local lessons, global challenges. Science 284: 278-282.
- Ostrom, E., R. Gardner, and J. Walker. 1994. Rules, games, and common-pool resources. University of Michigan Press, Ann Arbor. 392 pp.
- Peterman, R.M. 1984a. Density-dependent growth in early ocean life of sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 41: 1825-1829.
- Peterman, R.M. 1984b. Effects of Gulf of Alaska sockeye salmon (*Oncorhynchus nerka*) abundance on survival, body size, growth rate and age at maturity of British Columbia and Bristol Bay, Alaska, sockeye populations. Can. Tech. Rep. Fish. Aquat. Sci. No. 1302, iv + 87 pp.
- Peterman, R.M. 1991. Density-dependent marine processes in North Pacific salmonids: lessons for experimental design of large-scale manipulations of fish stocks. ICES Mar. Sci. Symp. 192: 69-77.
- Ricker, W.E. 1981. Changes in the average size and average age of Pacific salmon. Can. J. Fish. Aquat. Sci. 38: 1636-1656.
- Ruggerone, G.T., M. Zimmerman, K.W. Myers, J.L. Nielsen, and D.E. Rogers. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. Fish. Oceanogr. 12: 209-219.
- Ruggerone, G.T., R.M. Peterman, B. Dorner, K.W. Myers. 2010. Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean. Mar. Coast. Fish. Dynam. Manag. Ecosys. Sci. 2: 306-328.

Do Asian Pink Salmon Affect the Survival of Bristol Bay Sockeye Salmon?

Alex Wertheimer¹ and Edward V. Farley, Jr.²

¹*Fishheads Technical Services, 17200 Andeanoff Drive, Juneau, AK 99801, USA*

²*Ted Stevens Marine Research Institute, Alaska Fisheries Science Center, NOAA Fisheries, 17109 Point Lena Loop Road, Juneau, AK 99801, USA*

Keywords: pink salmon, sockeye salmon, density dependence, Bristol Bay

The abundance of pink salmon and chum salmon in the subarctic North Pacific Ocean are at historically high levels (Eggers 2009; Irvine et al. 2009; Ruggerone et al. 2010a). This increased abundance has raised concerns that density dependent interactions in the ocean may reduce growth and survival of conspecifics and associated salmon species (Ruggerone and Neilson 2004; Helle et al. 2007; Ruggerone et al. 2010a). Ruggerone et al. (2003) found that competition between Asian pink salmon and Bristol Bay sockeye salmon reduced the growth of sockeye salmon. They suggested average sockeye smolt-to-adult survival rates for three large stocks (Kvichak, Egegik, and Ugashik) outmigrating in 1977-1997 were significantly lower for smolts entering the ocean during even-numbered years and interacting with abundant odd-year Asian pink salmon than for smolts entering the ocean during odd-numbered years (Fig. 1). However, their analysis did not link smolt survival directly to the highly variable annual abundance of Asian pink salmon. If the large variation in average odd- and even-year smolt survival was caused by the differences in average odd- and even-year pink salmon abundances, we would expect the actual annual abundance of pink salmon to have a significant and measurable impact on annual variation in smolt survival.

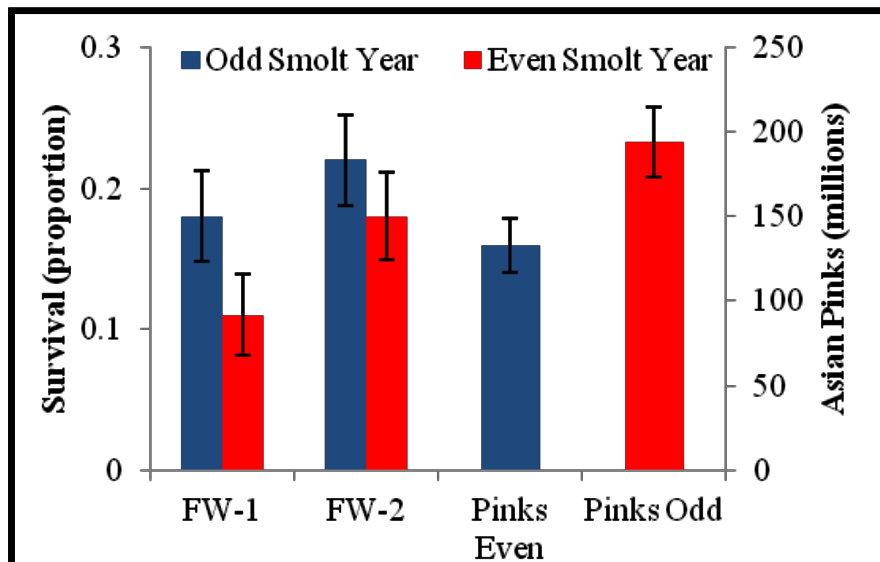


Fig. 1. Average smolt-to-adult survival for three Bristol Bay sockeye salmon stocks (Kvichak, Egegik, and Ugashik) for the smolt years 1977-1997 and corresponding adult Asian pink salmon abundance. Error bars are SE of means.

The objectives of this paper were to (1) revisit the 1977-1997 smolt data to evaluate the effect of Asian pink salmon abundance on Bristol Bay sockeye salmon smolt survival and (2) use juvenile salmon data from the Bering-Aleutian Salmon International Survey (BASIS) and corresponding adult returns to examine the effects of Asian pink salmon abundance on survival and returns of Bristol Bay sockeye salmon for the smolt years 2002-2007 (the smolt year is when smolts out-migrate to the ocean).

Sockeye Salmon Smolt Years 1977-1997

To evaluate 1977-1997 sockeye salmon smolt survival, we used the same data sets as Ruggerone et al. (2003). Sockeye salmon smolt numbers and corresponding adult returns were provided by the Alaska Department of Fish and Game (ADFG; personal communication, Lowell Fair, 333 Raspberry Road, Anchorage, AK 99518) for the Kvichak River (smolt years 1977-1997); Egegik River (smolt years 1982-1997); and Ugashik River (smolt years 1983-1997). Asian pink salmon abundance data were from Rogers (2001). We compared four models to examine if pink abundance affects sockeye salmon survival by stock and smolt age and for the three stock average: simple regression (no temporal trend in survival); autoregressive 1 (AR(1) annual trend in survival); autoregressive 2 (AR(2) biennial trend in survival); and autoregressive 1,2 (AR(1,2), accounting for both annual and biennial trends in survival). We transformed survival data for the analysis using the arcsine square root and used the corrected Akaike Information Criterion (AIC_c ; Shono 2000) to compare alternate models.

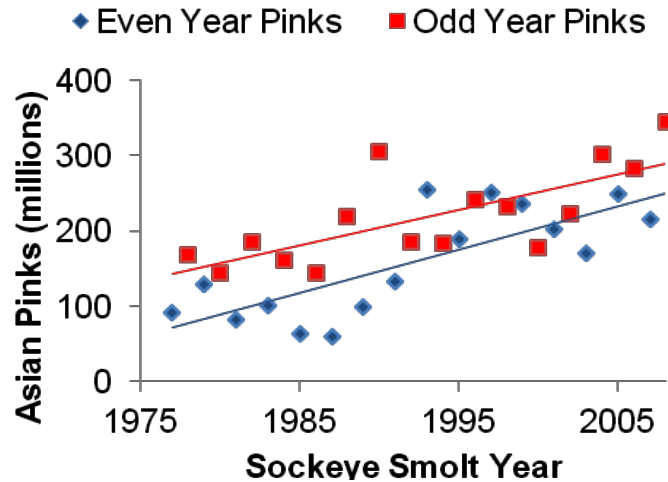


Fig. 2. Abundance of odd- and even-year Asian pink salmon compared with abundance of sockeye salmon for the smolt years 1997-2008.

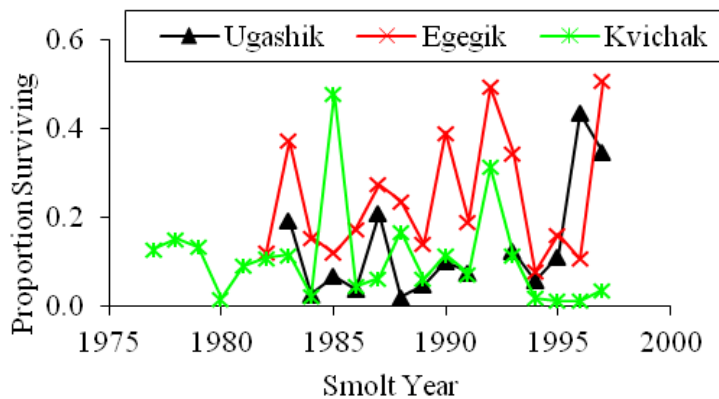


Fig. 3. Smolt-to-adult survival for three Bristol Bay sockeye salmon stocks for the smolt years 1977-1997.

During the smolt years 1977-1997, Asian pink salmon increased in abundance over time for both the odd and even lines (Fig. 2), but there was no consistent trend in the survival of the three sockeye salmon stocks (Fig. 3). Survival was not significantly ($p > 0.1$) correlated between stocks; survival was positively correlated with time for the Egegik and Ugashik stocks and negatively correlated with time for the Kvichak stock (Table 1). Temporal correlations were significant only for Ugashik sockeye survival ($p = 0.06$) and pink salmon abundance ($p < 0.01$). The AIC_c comparisons indicated that the AR models fit survival data better than the simple regression model and that the AR(1,2) model did not improve the fit (Table 2).

The AR(1) and AR(2) models had virtually identical AIC_c values for all stock/age combinations (differences < 0.5), except for Egegik age-1 smolts for which the AIC_c value of the AR(1) was more than 3 points lower (Table 2). For both the AR(1) and AR(2) models, the coefficients for pink salmon abundance (indicating effect of pinks) were negative for the Kvichak stock, positive for the Egegik and Ugashik stocks, and positive for the three stock average; significance levels are shown in Fig. 4.

Table 1. Cross-correlation matrix of correlation coefficients (r) for Bristol Bay sockeye smolt survival, Asian pink abundance, and time for the smolt years 1977-1997.

	Year	Kvichak	Egegik	Ugashik
Kvichak	-0.19			
Egegik	0.22	0.17		
Ugashik	0.51 ¹	-0.25	0.34	
Pinks	0.57 ²	-0.23	0.34	0.27

¹*p* = 0.06 ²*p* < 0.01

Table 2. Akiake information criterion (AIC_c) values (corrected for small sample sizes) for simple regression (Regr) and autoregressive models (AR(1), AR(2), and AR(1,2)) of sockeye smolt-to-adult survival as a function of Asian pink abundance. Sockeye salmon survival stratified by stock and smolt age and the three-stock average. Lowest values within 0.5 of each other are shown in the grey area for each stock/age group.

Stock/Age	Regr.	AR(1)	AR(2)	AR(1,2)
Kvichak-1	-10.4	-32.5	-32.1	-29.1
Kvichak-2	-11.3	-32.3	-32.3	-32.3
Egegik-1	-1.2	-26.1	-29.5	-27.8
Egegik-2	-0.7	-35.1	-35.3	-32.9
Ugashik-1	-8.0	-27.1	-27.0	-23.6
Ugashik-2	-4.7	-27.6	-26.8	-24.3
3-stock average	-32.6	-45.0	-44.6	-44.5

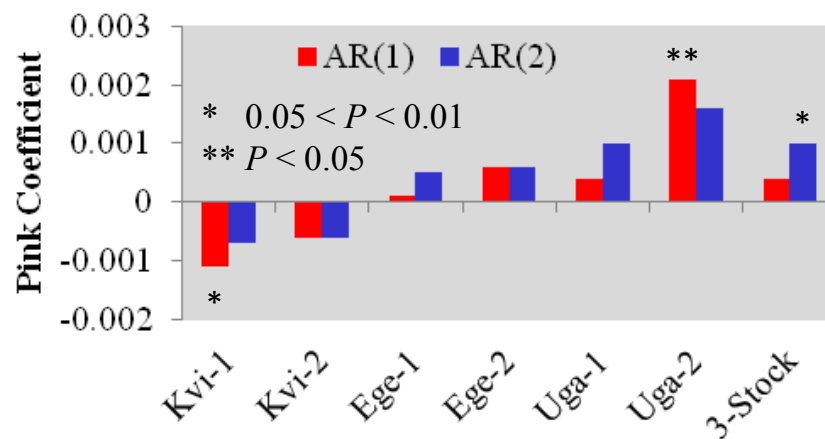


Fig. 4. Coefficients for the effect of Asian pink salmon abundance on survival of sockeye salmon by stock and smolt age for AR(1) and AR(2) time-series models.

In all cases, the autoregressive coefficients for the models were not significant ($p > 0.1$), which suggests the regression (no trends) model may be more appropriate even with higher AIC_c values. The results for the pink salmon coefficient were the same for the regression model as for the autoregressive models (for both smolt ages, Kvichak negative, Egegik and Ugashik positive; positive for the three-stock average), but none of the coefficients for pink abundance were significant ($p > 0.1$).

Our results show no consistent response of smolt survival among the three Bristol Bay sockeye stocks in relation to Asian pink salmon abundance. This could be caused by actual stock-specific differences in response to Asian pink salmon. Seeb et al. (2010) have shown differences in ocean distributions of Bristol Bay sockeye salmon, so the stocks could have differential overlap with, and response to, Asian pink salmon. The negative response of the Kvichak stock could be driven by density-dependent growth consistent with Ruggerone et al. (2003). The positive response of the other stocks could be a compensatory effect of predator sheltering by the more abundant pink salmon that results in increased survival of Egegik and Ugashik sockeye salmon. A more simplistic explanation is that the relationships between sockeye survival and pink abundance are artifacts of increasing pink numbers and stock-specific survival patterns driven by other factors. Regardless of

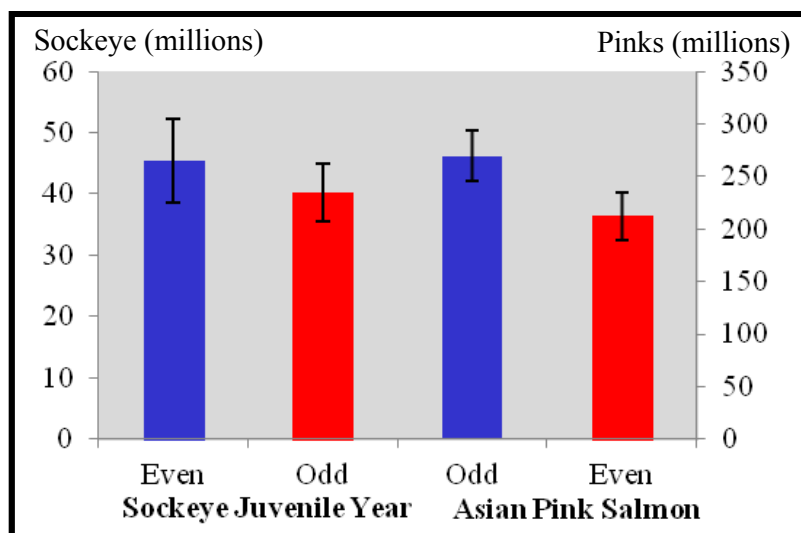


Fig. 5. Average Bristol Bay adult sockeye returns and Asian adult pink salmon abundances in odd and even years for the smolt years 2002-2007. Error bars are SE of means.

the mechanism, our results for the smolt years 1977-1997 show no net reduction in sockeye smolt survival due to Asian pink salmon abundance.

Sockeye Salmon Smolt Years 2002-2007

Estimates of juvenile Bristol Bay sockeye salmon abundance in the Bering Sea were available for the smolt years 2002-2007 (Farley et al. 2009). Corresponding adult return data were provided by ADFG. An index of sockeye salmon marine survival from juvenile-to-adult was calculated by dividing the estimate of juvenile abundance by the number of adults returning. Asian pink salmon data were extended to this time period using the data and methods of Ruggerone et al. (2010b).

Average Bristol Bay sockeye salmon adult returns for this time period were higher for even-year smolts, even though the odd-year pink salmon they encountered in the first ocean winter were also more abundant (Fig. 5). The index of juvenile sockeye salmon survival was higher for even-year juveniles during 2002-2007, and the survival index was positively correlated with pink salmon abundance (Fig. 6). These results are contradictory to the hypothesis that even-year sockeye smolts encountering more abundant odd-year pink salmon will have reduced survival due to density-dependent interactions.

We conclude, based on our results from both time periods, there is no discernable negative impact of Asian pink salmon on smolt-to-adult survival of Bristol Bay sockeye salmon.

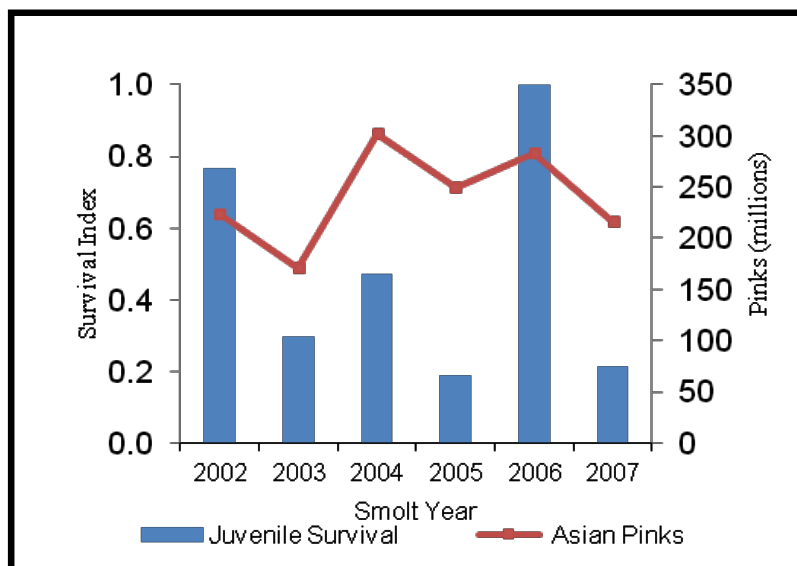


Fig. 6. Comparison of the Bristol Bay juvenile sockeye survival index and Asian pink salmon abundance for the smolt years 2002-2007.

The conclusion that there is no discernable negative impact of Asian pink salmon on ocean survival of Bristol Bay sockeye salmon is challenged by Ruggerone et al. (this report) by their questioning the validity of our correlation analyses (and by extension, our regression and time-series analyses) and asserting that comparison of odd- and even- year smolt survival of Bristol Bay sockeye salmon (Ruggerone et al. 2003) is a more robust approach to analyzing these data. We disagree that our use of data is inappropriate or that our analytical approach is less robust than odd-/even-year averaging of smolt survival.

Ruggerone et al. (this report) state that our correlation analyses are confounded because environmental conditions influence the degree to which Asian pink salmon interact or affect Bristol Bay sockeye salmon and because of measurement error in the time series of Asian pink salmon abundance and Bristol Bay sockeye salmon. Concerns for environmental noise and measurement error affecting the power of correlation analyses are certainly valid. However, Ruggerone et al. (2003) used correlation analysis to establish a statistical connection between Bristol Bay sockeye salmon scale growth and Asian pink salmon abundance. The use of correlation analysis for similar time series with unknown measurement errors is ubiquitous in Ruggerone et al. (this report) to support the concept of density-dependence. Ruggerone et al. (2003) also used the Bristol Bay smolt data in an analysis of variance to statistically evaluate the average survival of odd- and even- year smolts, without concern for measurement error. Our application of statistical analyses to these data is consistent with and as credible as those of Ruggerone et al.

Our time series approach is a much better approach for determining if the abundance of Asian pink salmon affects Bristol Bay sockeye salmon smolt survival than the odd-/even-year averaging approach used by Ruggerone et al. (2003). Both pink salmon abundance and sockeye smolt survival have varied considerably over time (Figs. 2 and 3). Our time series analysis examines both for trends in survival and the effect of abundance on survival, with the explicit hypothesis that abundance in a given year has some effect on survival in that year. Environmental factors can certainly influence the relationship, but over time, if the large effects of pink salmon abundance asserted by Ruggerone et al. (2003) are occurring, we should be able to detect the abundance effect. The odd-/even-year averaging approach, in contrast, unlinks the actual abundance of pink salmon from the response variable, smolt survival. The same criticism, that environmental factors can influence the degree to which pink salmon abundance affects survival, applies to this approach. But in this case, very high or very low survival rates have a large weighting affect on the analysis, regardless of the magnitude of pink salmon abundance in the year in which survival anomalies occur.

In closing, we stand by our analyses, results, and conclusions. Our use of the data series is consistent with what has been established in the scientific literature by Ruggerone et al. (2003), and our analytical approach is an improvement in evaluating the impact of Asian pink salmon on Bristol Bay sockeye salmon smolt-to-adult survival.

REFERENCES

- Eggers, D.M. 2009. Historical biomass of pink, chum, and sockeye salmon in the North Pacific Ocean. *Am. Fish. Soc. Symp.* 70: 267-305.
- Farley, E.V., J. Murphy, J. Moss, A. Feldmann, and L. Eisner. 2009. Marine ecology of western Alaska juvenile salmon. *Am. Fish. Soc. Symp.* 70: 307-329.
- Helle, J.H., E.C. Martinson, D.M. Eggers, and O. Gritsenko. 2007. Influence of salmon abundance and ocean conditions on body size of Pacific salmon. *N. Pac. Anadr. Fish Comm. Bull.* 4: 289-298. (Available at www.npafc.org).
- Irvine, J.R., M. Fukuwaka, T. Kaga, J.H. Park, K.B. Seong, S. Kang, V. Karpenko, N. Klovach, H. Bartlett, and E. Volk. 2009. Pacific salmon status and abundance trends. *N. Pac. Anadr. Fish Comm. Doc.* 1199, Rev. 1. 153 pp. (Available at www.npafc.org).
- Rogers, D.E. 2001. Estimates of annual salmon runs from the North Pacific, 1951-2001. Univ. Washington, School of Aquatic Sciences, SAFS-UW-0115, Seattle. 11 pp. (Available at <https://digital.lib.washington.edu/researchworks/handle/1773/3783>).
- Ruggerone, G.T., and J.L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. *Rev. Fish Biol. Fish.* 14: 371-390.
- Ruggerone, G.T., M. Zimmermann, K.W. Myers, J.L. Nielsen, and D.E. Rogers. 2003. Competition between Asian pink salmon and Alaskan sockeye salmon in the North Pacific Ocean. *Fish. Oceanogr.* 3: 209-219.
- Ruggerone, G.T., R.M. Peterman, B. Dorner, and K.W. Myers. 2010a. Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean. *Mar. Coast. Fish. Dynam. Manage. Ecosys. Sci.* 2: 306-328.
- Ruggerone, G.T., R.M. Peterman, B. Dorner, K.W. Myers, and N.J. Mantua. 2010b. Abundance of adult hatchery and wild salmon by region of the North Pacific. Univ. Washington, School of Aquatic and Fishery Sciences, SAFS-UW 1001, Seattle. (Available at <https://digital.lib.washington.edu/researchworks/handle/1773/3783>).
- Seeb, L.W., J.E. Seeb, C. Habicht, E.V. Farley, and F.M. Utter. 2010. Single-nucleotide polymorphic genotypes reveal patterns of early juvenile migration of sockeye salmon in the eastern Bering Sea. *Trans. Am. Fish. Soc.* 140(3): 734-738.
- Shono, H. 2000. Efficiency of the finite correction of Akaike's information criteria. *Fish. Sci.* 66: 608-610.

Historical Scale Growth of Bristol Bay and Yukon River, Alaska, Chum Salmon (*Oncorhynchus keta*) in Relationship to Climate and Inter- and Intra-Specific Competition

Beverly A. Agler¹, Gregory T. Ruggerone², and Lorna I. Wilson¹

¹Alaska Department of Fish and Game, Mark, Tag, and Age Laboratory, Division of Commercial Fisheries, 10107 Bentwood Place, Juneau, AK 99801, USA

²Natural Resources Consultants, Inc., 4039 21st Ave West, Suite 404, Seattle, WA 98199, USA

Keywords: growth, chum salmon, climate change, surface temperature, scale pattern analysis, Yukon River, Alaska

Growth is a key factor affecting survival of Pacific salmon (e.g. Healey 1986; Ruggerone et al. 2007; Martinson et al. 2008). Faster growing salmon are able to avoid predators and survive when prey availability is low (Beamish and Mahnken 2001). Salmon growth has been shown to co-vary with climate (Ruggerone et al. 2005, 2007; Farley et al. 2007), and the North Pacific Ocean has experienced climate shifts during this study (Mantua et al. 1997; Hare and Mantua 2000). Another factor affecting growth and productivity of salmon may be interactions with pink salmon (*Oncorhynchus gorbuscha*), which are abundant (Ruggerone et al. 2010). Intraspecific competition may lead to density-dependent growth (Ishida et al. 1993; Peterman et al. 1998; Ruggerone et al. 2003), and increased hatchery chum (*O. keta*) production possibly caused reduction in growth of Asian chum salmon (Ishida et al. 1993; Kaeriyama et al. 2007).

We used salmon scales to determine whether marine growth of chum salmon varied with climate and interspecific competition. We examined annual growth using scales collected from Bristol Bay (age-0.3, 1965-2006; age-0.4 1966-2006) and Yukon River (age-0.3, 1965-2006; age-0.4, 1967-2006) chum salmon (Fig. 1). We compared the growth data with climate indices, abundance of Asian chum salmon, and the odd- and even-year abundance pattern of pink salmon.

Generalized least squares regression was used to compare relationships among environmental variables, Asian pink and chum salmon abundance, and growth of western Alaska salmon because analyses indicated there was autocorrelation among residuals. The number of model parameters was reduced by stepwise regression, and the Akaike Information Criterion (AIC) was used to determine the best model.

Full model - First year at sea (SW1): age-0.3 and -0.4 fish

$$SWI\ growth = \alpha + \beta_1(local\ SST_t) + \beta_2(ALPI_t) + \beta_3(NPI_t) + \beta_4(May\ Mix_t) + \beta_5(Ice\ Cover_t) + \beta_6(local\ Air\ Temp_t) + \varepsilon_t \quad (1)$$

where local SST_t is the local sea surface temperature (SST), $ALPI_t$ is the Aleutian Low Pressure Index, NPI_t is the North Pacific Index, $May\ Mix_t$ is the wind mixing index from St. Paul Island, Alaska, $Ice\ Cover_t$ is the ice cover index from the northern Bering Sea, and $local\ Air\ Temp_t$ is air temperature at Nome or King Salmon, Alaska.

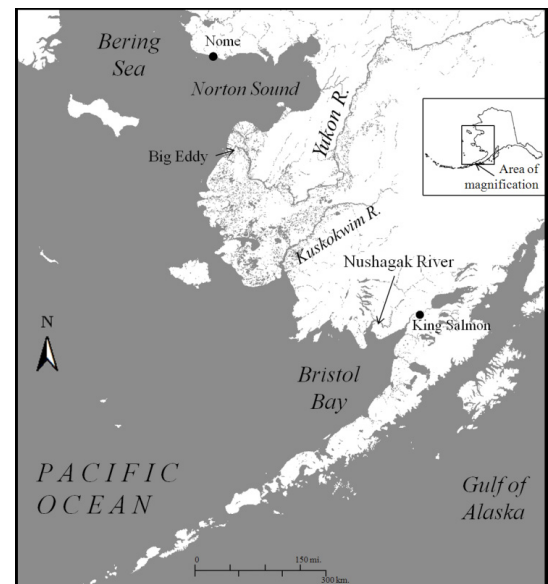


Fig. 1. Location in western Alaska where chum salmon scale samples were collected annually in Bristol Bay and the Yukon River, 1965-2006. Scales were collected during commercial chum salmon fisheries in the Nushagak District, which were conducted at the mouth of the Nushagak River. Yukon River chum salmon scales were collected at the river mouth during commercial and test fisheries at Flat Island and Big Eddy.

Full model - Third year at sea (SW3): age-0.3 and -0.4 fish

$$SW3\ growth = \alpha + \beta_1(Pinks_t) + \beta_2(Asian\ Chums_t) + \beta_3(GOA\ Annual\ SST_k) + \beta_4(NPI_k) + \beta_5(Pinks_t * Asian\ Chums_t) + Gender + \epsilon_t \quad (2)$$

where $Pinks_t$ represents total abundance of Russian pink salmon, $Asian\ chums_t$ is a four-year moving average of Asian chum abundance (Ruggerone et al. 2010), and $GOA\ Annual\ SST_t$ represents annual average SST of the Gulf of Alaska.

Normalized plots of Bristol Bay SW1 and SW3 age-0.4 growth by year provide an example of the data and the lack of visible odd- and even-year pattern related to the abundance of Asian pink salmon (Fig. 2). Plots showed changes in growth around 1976/77, or the regime shift associated with the Pacific Decadal Oscillation (PDO) and changes in SST.

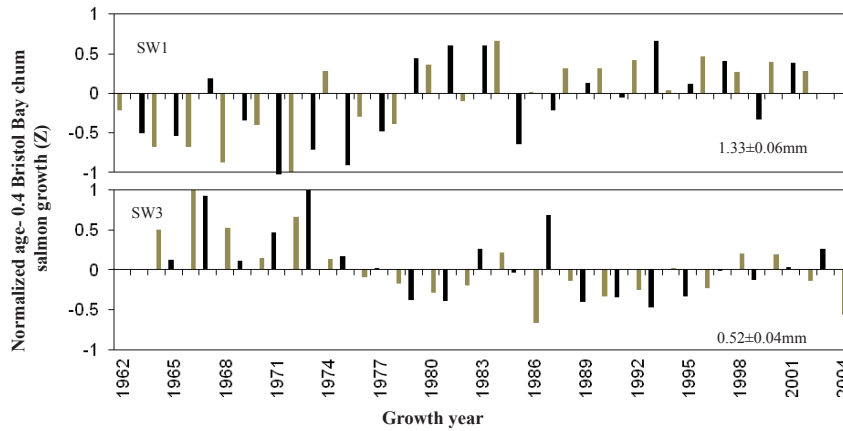


Fig. 2. Mean annual growth of age-0.4 Bristol Bay chum salmon during their first (SW1) and third (SW3) year at sea is plotted against time, 1961-2006. Un-weighted mean ± 1 SD during each life stage is shown.

Bristol Bay first-year growth: For age 0.3 chum salmon, local SST and ice cover showed a significant positive relationship with first year growth (Table 1). For age 0.4 fish, the local SST and NPI showed a significant positive relationship with first year growth, and the ALPI, May mixing index, and ice cover showed a detectable negative relationship with first year growth.

Table 1. Generalized least squares models (GLS) comparing growth during the first (SW1) and third (SW3) year at sea for age-0.3 (1965-2006) and age-0.4 chum (1966-2006) salmon caught in commercial fisheries at the mouth of the Nushagak River in Bristol Bay. AIC=Akaike Information Criterion; AR = autocorrelation function; Int = intercept.

Model variables	AIC	AR	Int	Model coefficients					
				V1	V2	V3	V4	V5	
SW1 growth									
Age-0.3									
SST + Ice Cover	-120.3	3	1.349	0.075	0.016				
				<0.001	0.070				
Age-0.4									
SST + ALPI + NPI + May Mix + Ice Cover	-128.1	0	0.541	0.200	-0.017	0.033	-0.770	-0.024	
				<0.001	0.022	0.055	0.005	0.032	
SW3 growth									
Age-0.3									
Pinks + Asian chums + Pinks*Asian chums + Gender	-236.4	1	0.629	2.3E-4	-0.071	2.7E-4	-0.050		
				0.040	0.002	0.027	<0.001		
Age-0.4									
Pinks + GOA SST + Gender	-239.2	4	0.641	2.4E-4	-0.012	0.051			
				0.024	0.037	0.028			

Bristol Bay third-year growth: For age 0.3 chum salmon, Asian chum salmon abundance showed significant negative effects on third year growth; whereas, pink salmon abundance and the interaction term (Pinks*Asian chums) showed a significant positive relationship with third-year growth (Table 1). For age 0.4 chum salmon, GOA SST showed significant negative effects, and pink salmon abundance had a significant positive relationship with third year growth. For both ages, females showed significantly less third-year growth than males.

Yukon River first-year growth: For age 0.3 chum salmon, first-year growth was significantly negatively correlated with the May mixing index, and positively correlated with Nome annual air temperature (Table 2). For age 0.4 chum salmon, the best model indicated that there was a significant positive relationship of local sea surface temperature, ALPI, and the May mixing index with first-year growth.

Yukon River third-year growth: For both ages of chum salmon, Asian chum salmon abundance and GOA SST showed a significant negative relationship with third-year growth; whereas, pink salmon abundance and the interaction term (Pinks*Asian chums) showed a significant positive relationship with third-year growth (Table 2). Females grew significantly less in the third year than males.

Table 2. Generalized least squares models (GLS) comparing growth during the first (SW1) and third (SW3) full year of growth at sea for age-0.3 (1965-2006) and age-0.4 (1967-2006) chum salmon caught in commercial and test fisheries at the mouth of the Yukon River. AIC=Akaike Information Criterion; AR = autocorrelation function; Int = intercept.

Model variables	AIC	AR	Int	Model coefficients					
				V1	V2	V3	V4	V5	
SW1 growth									
Age-0.3									
MayMix + local Air Temp	-131.8	4	1.071	-1.131	0.010				
				0.061	<0.001				
Age-0.4									
SST + ALPI + May Mixing	-126.8	4	1.289	0.021	0.016	0.014			
				0.002	0.022	0.053			
SW3 growth									
Age-0.3									
Pinks + Asian chums + GOA SST + Pinks*Asian chums + Gender	-246.9	1	0.604	2.6E-4	-0.060	-0.015	2.5E-4	-0.060	
				0.020	0.005	0.047	0.027	<0.001	
Age-0.4									
Pinks + Asian chums + GOA SST + Pinks*Asian chums + Gender	-263.3	1	0.469	2.5E-4	-0.053	-0.019	2.4E-4	-0.034	
				0.016	0.004	0.002	0.016	0.008	

Overall, we found that warmer regional temperatures, NPI, and less ice cover significantly enhanced the first-year growth of chum salmon in Bristol Bay and Yukon River. We also found that third-year growth was significantly affected by Asian chum salmon abundance for all but Bristol Bay age 0.4 fish. In contrast to our hypothesis that cooler temperatures in the Gulf of Alaska would have inhibited growth, we found that warmer large-scale SSTs from the Gulf of Alaska were associated with reduced growth in the third year at sea.

We hypothesized that cooler temperatures in the Gulf of Alaska would inhibit the marine growth of western Alaska chum salmon and that Gulf of Alaska temperatures would significantly affect marine growth of both ages of Bristol Bay and Yukon River chum salmon, but the model coefficients were negative. Thus, we found opposite effects, contradicting our hypothesis. Although this appears counterintuitive, Ruggerone et al. (2011) found that adult length-at-age was negatively correlated with sea surface temperature, rather than positively correlated as they had hypothesized. They suggested that this unexpected result was due to density-dependent effects involving abundance of hatchery chum salmon. Perhaps the abundance of hatchery chum salmon overwhelmed the favourable growing conditions associated with warm SSTs.

Pink salmon abundance appeared to inhibit growth of western Alaska chum salmon during the third year of growth, but the effect was much less than that observed for Asian chum salmon abundance. Researchers suggested that chum salmon change their spatial distribution in years when pink salmon abundance was high (Azumaya and Ishida 2000). If pink salmon abundance increased, and chum salmon moved into the Gulf of Alaska where sea surface temperatures were also warmer, it is possible that growing conditions were good for both species. Thus, improved SST might explain improved growth of pink

and chum salmon in recent years. Chum salmon have unique gut architecture, allowing them to “prey switch” and forage on lower quality prey (Davis et al. 2004). This ability to survive on a variety of prey species perhaps allowed chum salmon to increase in abundance if prey productivity was high even though pink salmon abundance was also high.

The abundance of Asian chum salmon negatively affected the growth of both ages of Yukon River and age-0.3 Bristol Bay chum salmon. Age-0.3 is the predominant age group of Asian chum salmon, thus it is possible Yukon River and Bristol Bay age-0.3 chum salmon would be affected to a larger degree by increased abundance of Asian chum salmon because competition for prey among conspecifics would likely be greater among fish of the same age group.

The North Pacific Ocean is part of a dynamic ecosystem, and many of the explanatory variables in the models overlap, or are autocorrelated. Thus, we found the complexity of the ecosystem created problems in our analysis as noted by the importance of the multiplicative effects in the models. Do these multiplicative effects create spurious results, or do they indicate important interactions among the components of a complex ecosystem? Overall, it appears that several factors, notably, sea surface temperature, abundance of pink salmon, and abundance of Asian chum influence growth of Bristol Bay and Yukon River chum salmon during their first and third year at sea.

REFERENCES

- Azumaya, T., and Y. Ishida. 2000. Density interactions between pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) and their possible effects on distribution and growth in the North Pacific Ocean and Bering Sea. N. Pac. Anadr. Fish Comm. Bull. 2: 165-174. (Available at www.npafc.org).
- Beamish, R.J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Prog. Oceanogr. 49: 423-437.
- Davis, N.D., J.L. Armstrong, and K.W. Myers. 2004. Bering Sea salmon diet overlap in fall 2002 and the potential for interactions among salmon. N. Pac. Anadr. Fish Comm. Doc. 779. Sch. Aquat. Fish. Sci., Univ. Washington, Seattle. 30 pp.
- Farley, Jr., E.V., J.H. Moss, and R.J. Beamish. 2007. A review of the critical size, critical period hypothesis for juvenile Pacific salmon. N. Pac. Anadr. Fish Comm. Bull. 4: 311-317.
- Hare, S.R., and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47: 103-145.
- Healey, M.C. 1986. Optimum size and age at maturity in Pacific salmon and effects of size-selective fisheries. Can. Sp. Pub. Fish. Aquat. Sci. No. 89. pp. 39-52.
- Ishida, Y., S. Ito, M. Kaeriyama, S. McKinnell, and K. Nagasawa. 1993. Recent changes in age and size of chum salmon (*Oncorhynchus keta*) in the North Pacific Ocean and possible causes. Can. J. Fish. Aquat. Sci. 50: 290-295.
- Kaeriyama, M., A. Yatsu, H. Kudo, and S. Saitoh. 2007. Where, when, and how does mortality occur for juvenile chum salmon *Oncorhynchus keta* in their first ocean year? N. Pac. Anadr. Fish Comm. Tech. Rep. 7: 52-55. (Available at www.npafc.org).
- Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteorol. Soc. 78(6): 1069-1079.
- Martinson, E.C., J.H. Helle, D.L. Scarnecchia, and H.H. Stokes. 2008. Density-dependent growth of Alaska sockeye salmon in relation to climate-oceanic regimes, population abundance, and body size, 1925 to 1998. Mar. Ecol. Prog. Ser. 370: 1-18.
- Peterman, R.M., B.J. Pyper, M.F. Lapointe, M.D. Adkison, and C.J. Walters. 1998. Patterns of covariation in survival rates of British Columbian and Alaskan sockeye salmon (*Oncorhynchus nerka*) stocks. Can. J. Fish. Aquat. Sci. 55: 2503-2517.
- Ruggerone, G.T., M. Zimmermann, K.W. Myers, J.L. Nielsen, and D.E. Rogers. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. Fish. Oceanogr. 12 (3): 209-219.
- Ruggerone, G.T., E.V. Farley, J. Nielsen, and P. Hagen. 2005. Seasonal marine growth of Bristol Bay sockeye salmon (*Oncorhynchus nerka*) in relation to competition with Asian pink salmon (*O. gorbuscha*) and the 1977 ocean regime shift. Fish. Bull. 103(2): 355-370.
- Ruggerone, G.T., J.L. Nielsen, and J. Bumgarner. 2007. Linkages between Alaskan sockeye salmon abundance, growth at sea, and climate, 1955-2002. Deep-Sea Res. II. 54: 2776-2793.
- Ruggerone, G.T., R.M. Peterman, B. Dorner, and K.W. Myers. 2010. Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean. Mar. Coast. Fish. Dynam. Manage. Ecosys. Sci. 2: 306-328. (Available at afs-journals.org/doi/pdf/10.1577/C09-054.1).
- Ruggerone, G.T., B.A. Agler, and J.L. Nielsen. 2011. Evidence for competition at sea between Norton Sound chum salmon and Asian hatchery chum salmon. Environ. Biol. Fish. In press. (Available online: DOI 10.1007/s10641-011-9856-5).

Density-dependent Growth of Salmon in the North Pacific Ocean: Implications of a Limited, Climatically Varying Carrying Capacity for Fisheries Management and International Governance

Gladys Oka, Carrie Holt, James R. Irvine, and Marc Trudel

*Pacific Biological Station, Fisheries and Oceans Canada,
3190 Hammond Bay Road, Nanaimo, BC V9T 6N7, Canada*

Keywords: density-dependent growth, chum salmon, hatchery, wild, marine growth, scale pattern analysis

Recent evidence has revealed that hatchery-origin salmon compete with wild salmon for a common pool of prey resources in the North Pacific Ocean. Density-dependent effects on growth of chum salmon are of special concern because of large increases in hatchery production of this species (and pink salmon) in Asia and evidence for both intra- and inter-specific competition for limited prey. Age-specific body size-at-return of chum salmon has declined over the last 3-4 decades in Japan, Korea, Alaska, Washington, and BC, and these declines have been explained by competition with abundant hatchery-produced chum salmon from Asia, although spatial overlap of distribution remains uncertain. This has led to international interest on potential effects of hatchery production on wild stocks in Asia and North America. In order to investigate the relative contribution of density-dependent growth arising from a limited carrying capacity and climatically varying oceanographic drivers, in this pilot project we investigated the marine growth of one population of chum salmon from BC (Big Qualicum, Vancouver Island, 1968-2005). Salmon marine growth was determined by analysing scales from fish captured on the spawning grounds at ages three (3_1) and four (4_1). Preliminary results indicated that return year had a significant effect on the growth rate of most chum salmon in both age groups. Specifically, scale growth (and presumably fish length) was greatest in the first marine year and declined incrementally in subsequent years. The growth rate of 3_1 chum salmon in all years was higher than 4_1 chum salmon. The effect of sex on scale growth was less conclusive, with male growth rates being higher than female growth rates in some years. Correlation analysis revealed a negative correlation between the first and second year of growth for both 3_1 and 4_1 chum salmon, suggesting that chum salmon may have an optimal size at the end of their second year. Growth was also correlated by ocean entry year, and as different ages of fish presumably occupy different areas in the ocean, this demonstrates the importance of large-scale climatic factors in determining chum salmon growth. Proposed future work includes comparisons of marine growth among pink, chum, and sockeye salmon from neighbouring and spatially diverse populations across British Columbia.

Recent Production Trends of Chum Salmon *Oncorhynchus keta* Under Conditions of Warming Climate

Yuxue Qin¹ and Masahide Kaeriyama²

¹Graduate School of Fisheries Science, Hokkaido University,
 3-1-1 Minato, Hakodate, Hokkaido 041-8611, Japan

²Faculty of Fisheries Sciences, Hokkaido University,
 3-1-1 Minato, Hakodate, Hokkaido 041-8611, Japan

Keywords: chum salmon, production trend, global warming, hatchery-program effect

Pacific salmon (*Oncorhynchus* spp.) play an important role as a keystone species and in ecosystem services in the subarctic North Pacific. Planktivorous pink (*O. gorbuscha*) and chum salmon (*O. keta*) abundance has increased since the 1975/76 regime-shift until the present, but their abundances have shown stable or declining trends in Canada, Japan, and USA since the 1990s, even though Russian chum and pink salmon abundance have been increasing (Fig. 1). Run size of Japanese chum salmon showed a decreasing trend in Honshu Island since the late 1990s and in Hokkaido Island since the early 2000s (Fig. 2). The carrying capacity of sockeye (*O. nerka*), chum, and pink salmon has changed to a downward trend since the early 2000s (Kaeriyama et al. 2011).

Abundance of wild chum salmon in the 1990s decreased to 50% below that of the 1930s, while there have been significant increases in hatchery populations (Kaeriyama et al. 2009). Hatchery-derived salmon genetically disturb native-wild Pacific salmon. Araki and Schmid (2010) examined 266 peer-reviewed papers on effects of hatchery fish stocking on wild stocks and the consequences for stock enhancement. They concluded that negative effects of hatchery rearing on a variety of fish species are common and there are few indications of successful stocking. Hatchery-derived chum salmon have lower genetic diversity than wild salmon (Okazaki 1982). Yokotani et al. (2009) surveyed the population structure in the Yurappu River using mitochondrial DNA (mtDNA) analysis. Yurappu River chum salmon showed eight haplotypes (Ht1-Ht8) in the 481 bp 5' variable portion of the mtDNA control region (Fig. 3). Pairwise population F_{ST} estimates showed that the December-run population (YPD) differed significantly from the October-run population (YPO) in the Yurappu River. The YPO population was closely related to others, such as the Chitose, Tokachi, and Nishibetsu river-populations (Table 1). These results suggest that Yurappu River chum salmon are genetically different and perhaps reproductively isolated by run-timing. It is thought that the native population persists as the late-run timing component, and that the early-run

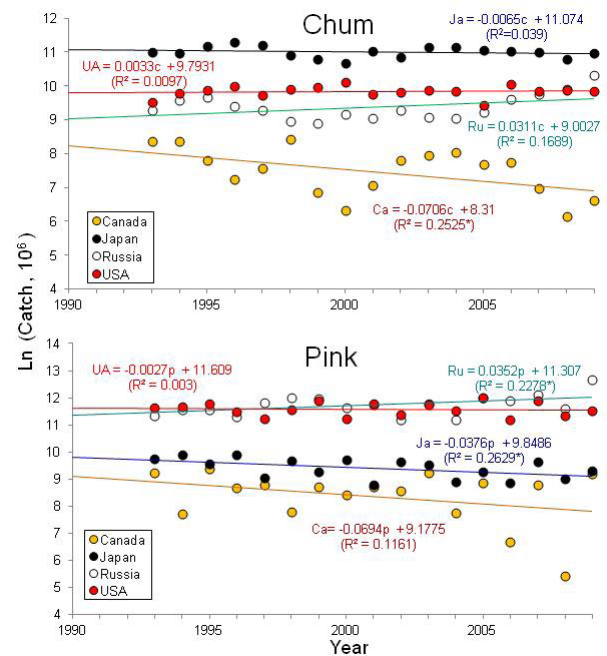


Fig. 1. Annual changes in catch of chum and pink salmon in the North Pacific Ocean since 1990. Catch data are based on NPAFC Statistical Yearbooks (www.npafc.org/new/pub_statistics.html). Ca: Canada, Ja: Japan, Ru: Russia, UA: USA.

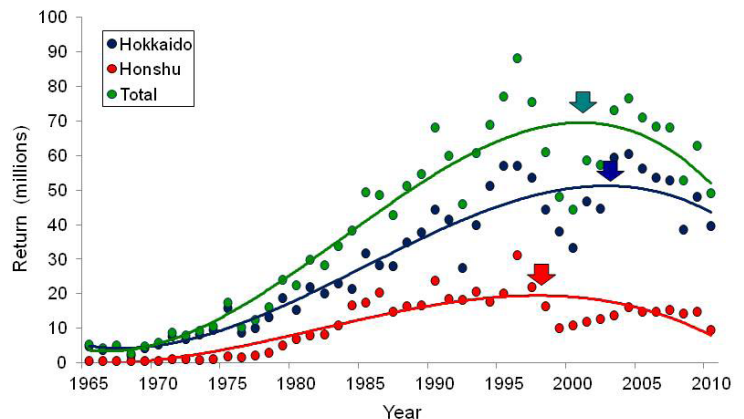


Fig. 2. Annual change in return of chum salmon to Japan during 1965-2010. Arrows indicate estimated time when the number of returning chum salmon started to decrease.

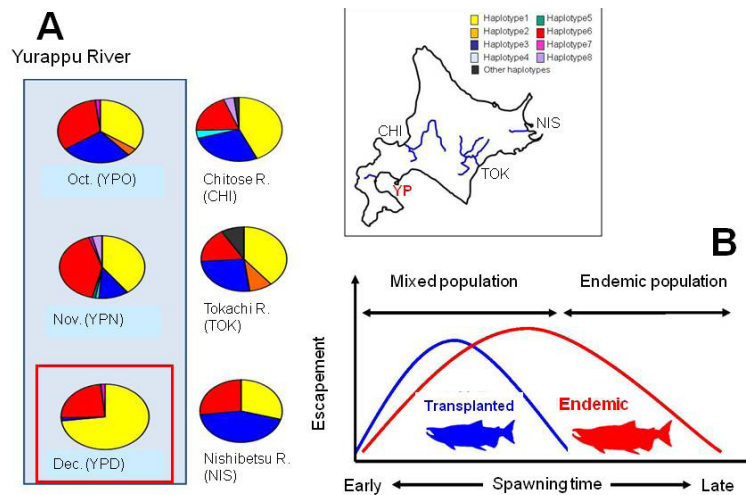


Fig. 3. Genetic population structure of chum salmon in the Yurappu (October: YPO, November: YPN, December: YPD), Chitose (CHI), Tokachi (TOK), and Nishibetsu (NIS) Rivers using mitochondrial DNA (mtDNA) analysis based on variable nucleotide sites in the 481 bp 5' portion of mtDNA control region. A: haplotype distribution of populations. B: genetic population structure of Yurappu River chum salmon. (Modified from Yokotani et al. 2009.)

timing component represents an introgressed population consisting of the native strain and out-of-basin transplants. This phenomenon could be observed in almost all populations of Hokkaido chum salmon because of the strong hatchery program. Hatchery programs lead to drastic declines in the genetic variability of wild Pacific salmon populations (Edpalina et al. 2004; Araki et al. 2007). This information suggests that ecological and genetic interactions between wild- and hatchery-derived salmon populations should be elucidated because wild salmon have greater ability to adapt to new environmental conditions (Kaeriyama et al. 2011).

Table 1. Pairwise population F_{ST} estimated between chum salmon populations in Hokkaido. Chum salmon populations include October-run (YPO), November-run (YPN), December-run (YPD) from the Yurappu, Chitose (CHI), Tokachi (TOK), and Nishibetsu (NIS) Rivers (from Yokotani et al. 2009).

	CHI	TOK	NIS	YPO	YPN	YPD
CHI	0.000					
TOK	0.000	0.000				
NIS	0.013	0.034	0.000			
YPO	0.000	0.000	0.030	0.000		
YPN	0.039	0.027	0.145*	0.013	0.000	
YPD	0.211**	0.160**	0.486**	0.168**	0.059**	0.000

Kaeriyama et al. (2011) advised that since the late 1980s global warming is positively affecting Hokkaido chum salmon by providing environmental conditions supporting increased growth for age-1 fish and survival. They predicted that global warming will affect all populations of chum salmon through mechanisms that will (1) decrease carrying capacity by reducing the area of distribution in the Bering Sea, (2) move fish to northern areas (e.g., the Chukchi Sea), (3) induce a strong density-dependent effect, (4) change the fish's wintering area from the Gulf of Alaska to the western Subarctic Gyre, (5) cause the loss of migration routes of juvenile Hokkaido chum salmon to the Okhotsk Sea, and (6) cause a crash in population abundance in the future.

In the Japan Sea, the Tsushima Warm Current flows northwards. Since the early 1990s, the current has been influenced by the warming climate (Fig. 4A). Abundance of early-run chum salmon returning to Hokkaido's Japan Sea coast in years when the current was strong was significantly lower than when the current was weak (ANOVA $p < 0.05$; Fig. 4B). In turn, the escapement pattern of Hokkaido chum salmon has changed dramatically. Where there were two populations of Hokkaido chum salmon in the 1980s, the late-run populations disappeared during the 1990s-early 2000s due to selection in the hatchery program favoring the salmon fisheries industry. Since 2006 early-run populations have decreased slightly from global warming effects (Fig. 5). The early-run population has a low adaptability because it has been mixed and artificially-disturbed by unregulated transplantation of hatchery stocks. On the other hand, the late-run population may have had higher adaptability because it is a wild population that spawned naturally. Therefore, the remnant wild late-run population of Hokkaido chum salmon is an important genetic resource that should be preserved for the future.

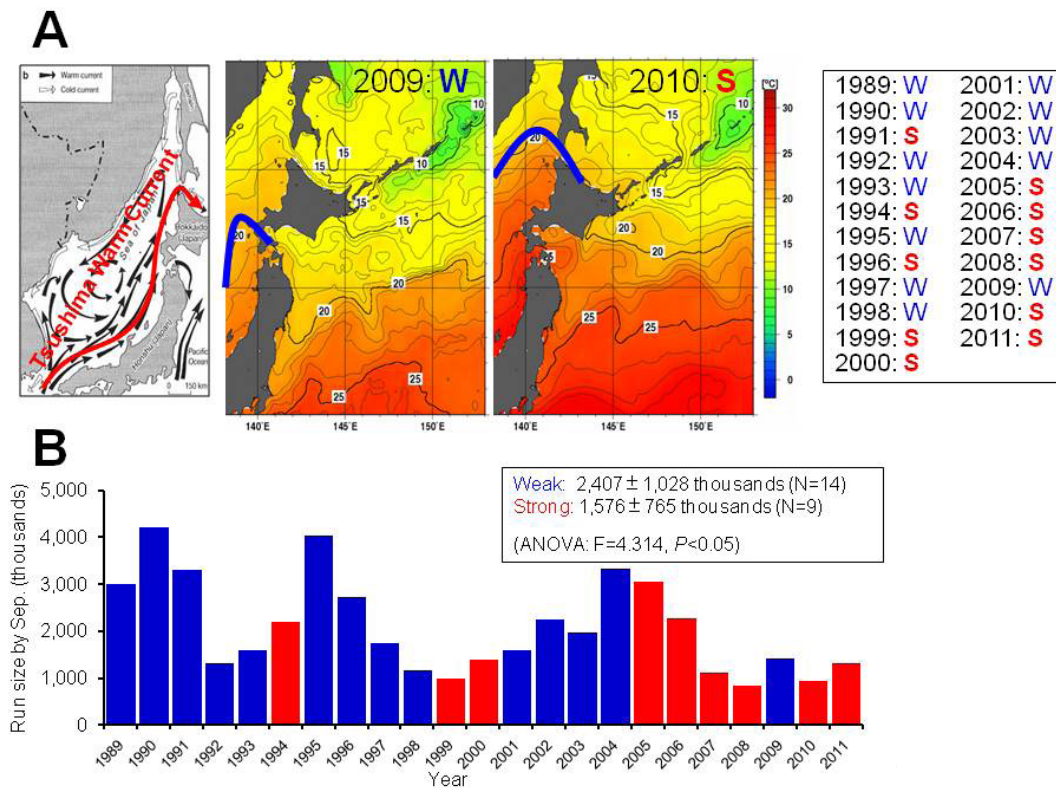


Fig. 4. Fluctuation in the strength of Tsushima Warm Current compared to the run size of early-population chum salmon returning to the Japan Sea coast of Hokkaido. A: mean SST isothermal diagrams around Japan in September of 2009 (typical of a weak Tsushima Warm Current) and 2010 (typical of a strong Tsushima Warm Current). B: annual change in the run size of early-population chum salmon returning to the Japan Sea coast in Hokkaido. W and S: weak and strong years of the Tsushima Warm Current, respectively. Mean SST isothermal diagrams from the Japan Meteorological Agency (www.data.kishou.go.jp/kaiyou/db/hakodate/monthly/sst_h.html).

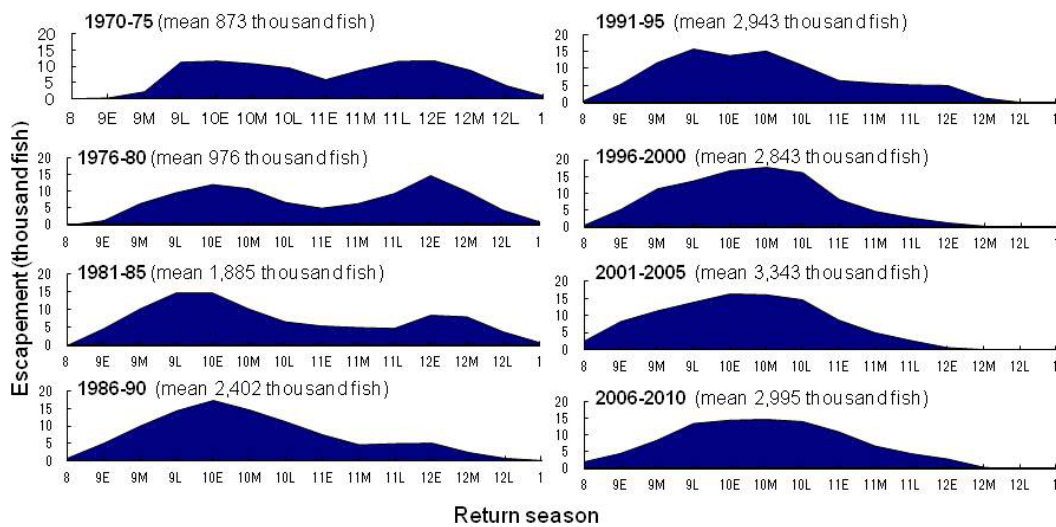


Fig. 5. Long-term change in the escapement data of Hokkaido chum salmon (data from Y. Miyakoshi, miyakoshi-yasuyuki@hro.or.jp, personal communication). E: early, M: middle, L: late portion of the population.

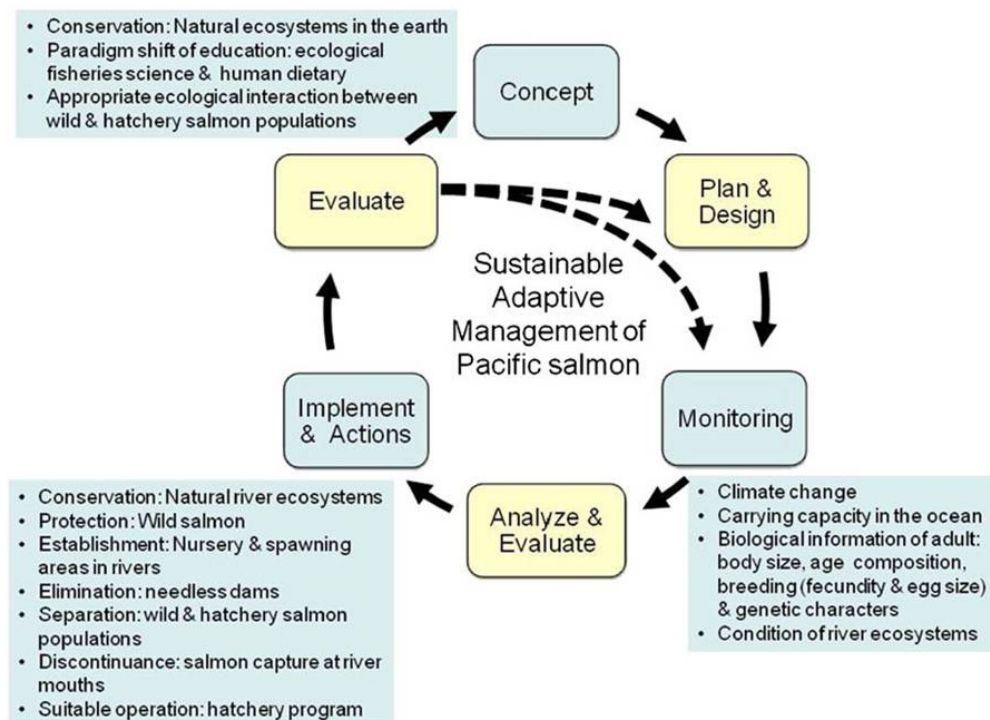


Fig. 6. Conceptual diagram showing components of a plan for sustainable adaptive management of Pacific salmon (from Kaeriyama et al. 2011).

We should recognize *ex dono* ecosystem services and understand the threats to these services. In the North Pacific Ocean, the carrying capacity of Pacific salmon is limited and fluctuates in synchrony with long-term climate change. As issues on sustainability and conservation of Pacific salmon in North Pacific develop, it is imperative that we establish sustainable adaptive management of the fisheries and hatchery programs (Fig. 6). Feedback control based on monitoring and modeling is critically important for adaptive management. The NPAFC should move quickly to establish a framework and methodology for conservation of Pacific salmon.

REFERENCE

- Araki, H., and C. Schmid. 2010. Is hatchery stocking a help or harm? Evidence, limitations and future directions in ecological and genetic surveys. *Aquaculture* 308: S2-S11.
- Araki, H., B. Cooper, and M.S. Blouin. 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. *Science* 318: 100-103.
- Edpalina, R.R., M. Yoon, S. Urawa, S. Kusuda, A. Urano, and S. Abe. 2004. Genetic variation in wild and hatchery populations of masu salmon (*Oncorhynchus masou*) inferred from mitochondrial DNA sequence analysis. *Fish Genet. Breed. Sci.* 34: 37-44.
- Kaeriyama, M., H. Seo, and H. Kudo. 2009. Trends in run size and carrying capacity of Pacific salmon in the North Pacific Ocean. *N. Pac. Anadr. Fish Comm. Bull.* 5: 293-302. (Available at www.npafc.org).
- Kaeriyama, M., H. Seo, H. Kudo, and M. Nagata. 2011. Perspectives on wild and hatchery salmon interactions at sea, potential climate effects on Japanese chum salmon, and the need for sustainable salmon fishery management reform in Japan. *Environ. Biol. Fish.* 94(1): 165-177. DOI 10.1007/s10641-011-9930-z.
- Okazaki, T. 1982. Genetic study on population structure in chum salmon (*Oncorhynchus keta*). *Bull. Far Seas Fish. Res. Lab.* 19: 25-116.
- Yokotani, R., N. Azuma, H. Kudo, S. Abe, and M. Kaeriyama. 2009. Genetic differentiation between early- and late-run populations of chum salmon (*Oncorhynchus keta*) naturally spawned in the Yurappu River inferred from mitochondrial DNA. *Fish Genet. Breed. Sci.* 39: 9-16.

Ecosystem Approach for Management of Artificial Release of Chum Salmon from Japan Based on a Bioenergetic Model Coupled with NEMURO

Michio J. Kishi^{1,2}, Kenta Awa¹, Takeshi Miwa¹, Hiromichi Ueno^{1,2}, and Toru Nagasawa³

¹Graduate School of Environmental Science, Hokkaido University,
N10W5 Kita-ku, Sapporo, 060-0810, Japan

²Faculty of Fisheries Sciences, Hokkaido University, Japan

³National Salmon Resources Center, Fisheries Research Agency,
2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan

Keywords: NEMURO, artificial release, chum salmon, model, ecosystem approach

Our goal is to estimate the optimum amount of artificial releases of chum salmon to maximize the income of chum salmon fishermen in Hokkaido, Japan, under the restriction of the carrying capacity of ocean habitat.

Income of fishermen

Income of fishermen can be calculated by multiplying total catch by unit price. The number of adult chum salmon that returned is calculated by multiplying the released number by the return ratio. The return ratio of released chum salmon from Hokkaido is between 2% and 6% (National Salmon Resources Center, NSRC). The number of released salmon is 3 billion (Okamoto 2009) and the mortality ratio is supposed to be constant, so in our model, the return ratio is fixed at 4%. Almost 90% of returning salmon is caught by set nets (NSRC). The total number of set nets is 886 in Hokkaido in 2008 (Statistics by Ministry of Agriculture, Forestry and Fisheries, Japan; available at www.maff.go.jp/j/tokei/kouhyou/kaimen_gyosei/). Consequently, the total catch by one set net (N) is calculated as follows:

$$N = 3 \times 10^9 \times 0.04 \times 0.9 / 886 \quad (1)$$

The time-dependent features of a year class of Hokkaido chum salmon caught by set net is shown on the NSRC homepage (available at salmon.fra.affrc.go.jp/zousyoku/H22salmon/h22salmon.htm#4). In our model, the return ratio and year-class ratio is fixed. Averaging the year-class return ratio for ocean age-3 and -4 chum salmon leads to the ratio of 62.9 : 37.1 for age-3 and -4, which means $N \times 0.629$ is the number of age-3 fish and $N \times 0.371$ is the number of age-4 chum salmon returning to Hokkaido.

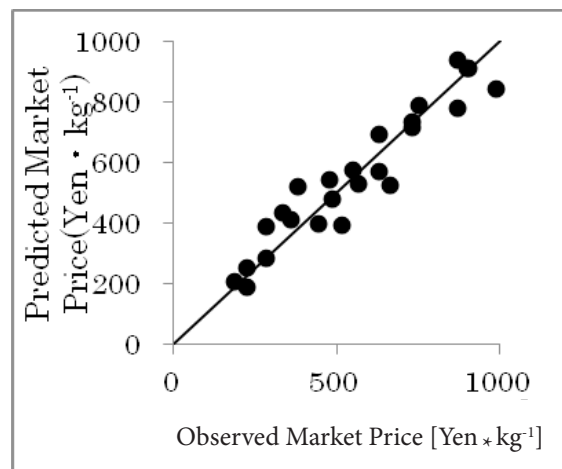


Fig. 1. Comparison between predicted and observed market price.

We can calculate the unit price of fish in the market (y) using multiple regression of the wet weight of ocean age-4 (x₁) salmon and the return number (x₂), as is shown in Figure 1 (r=0.92).

$$y = 0.499x_1 - 0.530x_2 \quad (2)$$

The total income (IC) is calculated as follows:

$$IC = ((N \cdot 0.629 \cdot \text{wet weight of age-3 chum salmon}) + (N \cdot 0.371 \cdot \text{wet weight of age-4 chum salmon})) \cdot y \quad (3)$$

According to data of the Japan Fisheries Research Agency, in 2006 the number of set nets in Hokkaido was 886. Consequently, the income per one set net is represented as IC/886.

Wet weight of chum salmon

Kishi et al. (2010) developed a bioenergetics model for chum salmon coupled with the results from a lower trophic ecosystem model embedded into a three-dimensional global model. In the bioenergetics model, respiration and consumption terms are assumed to be functions of water temperature and forage (zooplankton) density, which are the determining factors of body size. The detailed descriptions are provided in Kishi et al. (2010). Urawa (2000) suggested that inter-annual variations in wet weight of chum salmon can be observed after they migrate into the western North Pacific from the Okhotsk Sea. In our analysis, we excluded the juvenile period spent in the Okhotsk Sea and begin the simulation at age 404 days when the fish are in the western North Pacific. We used the daily averaged output (from Aita-Noguchi et al. 2003) for the upper 20 m of the water column and also averaged spatially within each box. In the Gulf of Alaska, chum salmon prefer jellyfish rather than copepods (Kaeriyama et al. 2004), and we assumed predatory zooplankton (ZP) to be the prey of chum salmon. In the NEMURO model, ZP includes jellyfish, salps, and/or krill (Kishi et al. 2007). The NEMURO describes zooplankton density as nitrogen density (mol N l⁻¹) that we converted into wet weight following Megrey et al. (2002). Chum salmon in the present model changes its prey based on Kishi et al. (2010). The NEMURO compartments of prey density ZP and ZL (non-predatory zooplankton) decrease by fish grazing. Chum salmon in the present model migrate from the northwestern Pacific to the Bering Sea and Gulf of Alaska following Kishi et al. (2010). The physical forcing of the NEMURO box model is given in the same way as Kishi et al. (2010).

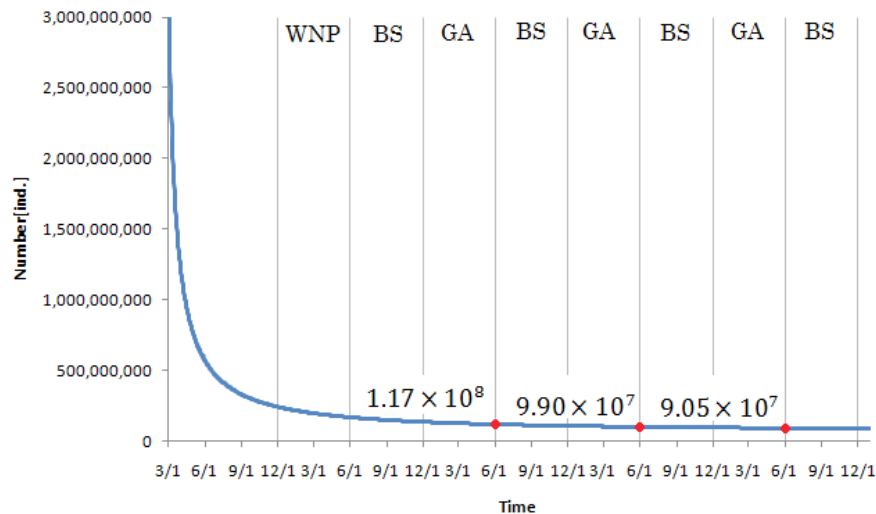


Fig. 2. The number of chum salmon through time when 3 billion fry are released. WNP: western North Pacific; BS: Bering Sea; GA: Gulf of Alaska.

Results in Figure 2 show the estimated number of chum salmon through time when 3 billion fry are released. The spatial volume where chum salmon live is estimated to be 4000 km³ (200 km * 200 km * 100 m) for each area. Although this value is arbitrary, it is necessary for converting the number of salmon per m³ that NEMURO requires for a predator. Figure 3 shows the time-dependent value of the calculated wet weight of Hokkaido chum salmon when 500 million, 1.0 billion and 1.5 billion fry are released (total number of chum salmon released in the North Pacific is 2, 3, and 4 billion, respectively). Differences in growth appears in ocean age-3 and -4. Body weight shrinks due to competition for food when the number released is 1 billion. Figure 4 shows the income of fishermen (per one set net) calculated by Eq. 2 and 3 and IC/886. The horizontal axis is the number of chum salmon released from Hokkaido. In 2007, the number released was 1 billion and Figure 4 suggests that the present number of releases brings about the maximum income to fishermen.

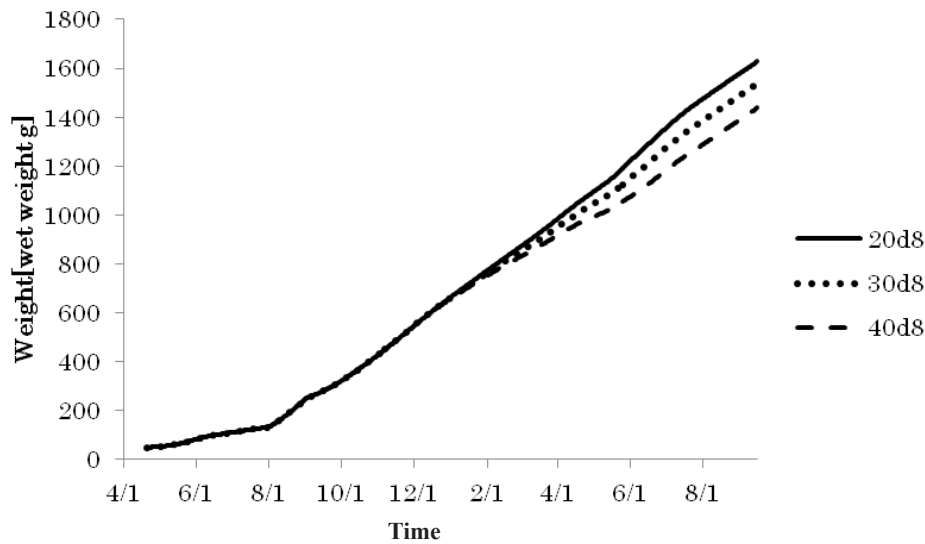


Fig. 3. Time-dependent value of calculated wet weight of Hokkaido chum salmon when 0.5 billion (black line), 1.0 billion (dotted line) and 1.5 billion (dashed line) fry are released (total number of chum salmon released in the North Pacific is 2 billion, 3 billion, and 4 billion, respectively).

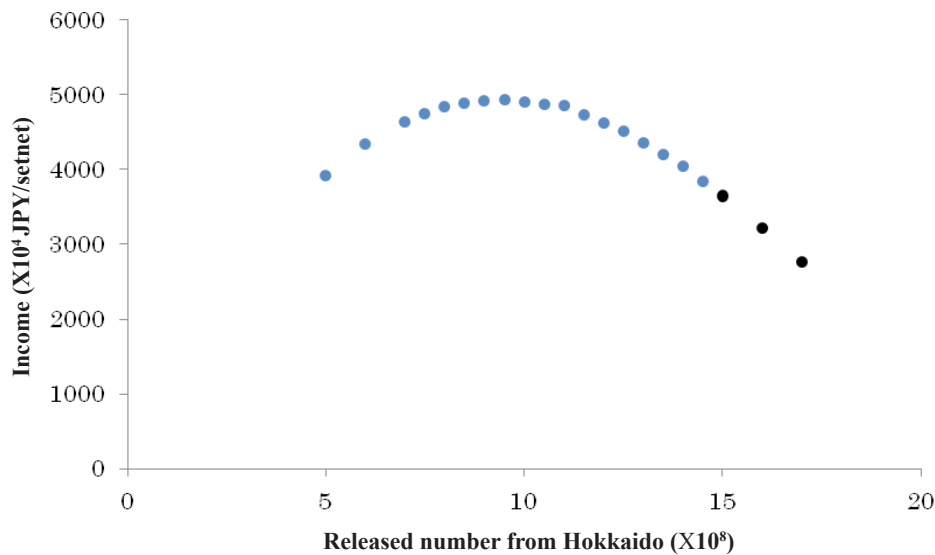


Fig. 4. Income to fishermen per one set net related to the number of Hokkaido chum salmon released.

In summary, the suitable release number of Hokkaido chum salmon was calculated based on an “ecosystem approach”. The constraining condition is the carrying capacity of North Pacific Ocean, which is calculated by a two-way version of NEMURO, and the cost function, which is total income to fishermen. The unit price of chum salmon, which is used to calculate a cost function, is determined by empirical data as a function of return ratio. NEMURO, which is a lower trophic model of the North Pacific, coupled with a physical model was used to calculate prey density and to predict wet weight of salmon. Observations indicate a decline in the number of salmon. Results indicate that the present release number under current conditions brings about the maximum income to fishermen. The present model is based on the assumption that the return ratio is constant (4%), however, it must be related to the physical environment and release number. Competition for food among chum salmon and the other species is also not considered in the present model. We should include these aspects in future considerations.

REFERENCES

- Aita-Noguchi, M., Y. Yamanaka, and M. J. Kishi. 2003. Effect of ontogenetic vertical migration of zooplankton on the results of NEMURO embedded in a general circulation model. *Fish. Oceanogr.* 12: 284-290.
- Kaeriyama, M., M. Nakamura, R. Edpalina, J.R. Bower, H. Yamaguchi, R.V. Walker, and K.W. Myers. 2004. Change in feeding ecology and trophic dynamics of Pacific salmon (*Oncorhynchus* spp.) in the central Gulf of Alaska in relation to climate events. *Fish. Oceanogr.* 13: 197-207.
- Kishi, M.J., D.L. Eslinger, M. Kashiwai, B.A. Megrey, D.M. Ware, F.E. Werner, M.N. Aita, T. Azumaya, M. Fujii, S. Hashimoto, D. Huang, H. Iizumi, Y. Ishida, S. Kang, G.A. Kantakov, H. Kiml, K. Komatsu, V.V. Navrotsky, S.L. Smith, K. Tadokoro, A. Tsuda, O. Yamamura, Y. Yamanaka, K. Yokouchi, N. Yoshie, J. Zhang, Y.I. Zuenko, and V.I. Zvansky. 2007. NEMURO - a lower trophic level model for the North Pacific marine ecosystem. *Ecol. Mod.* 202: 12-25.
- Kishi, M.J., M. Kaeriyama, H. Ueno, and Y. Kamezawa. 2010. The effect of climate change on the growth of Japanese chum salmon (*Oncorhynchus keta*) using a bioenergetics model coupled with a three-dimensional lower tropic ecosystem model (NEMURO). *Deep-Sea Res. II* 57: 1257-1265.
- Megrey, B.A., K. Rose, F.E. Werner, R.A. Klumb, and D. Hay. 2002. A generalized fish bioenergetics/biomass model with an application to Pacific herring. *PICES Sci. Rep.* 20: 4-12.
- Okamoto, Y. 2009. Resource and propagation of Salmoniformes in Northern Pacific and Japan. *Fish. Res. Agency Salmon Res. Rep.* 3: 24-25. (In Japanese).
- Urawa, S. 2000. Future task on migration route of Japanese salmon. *Nat. Salmon Resources Center Newsletter* 5: 3-9. (In Japanese)

Forecast and Production Dynamics of the Pink Salmon of Kamchatka

Evgeny A. Shevlyakov and Maxim V. Koval

*Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO)
18, Naberezhnaya Str., Petropavlovsk–Kamchatsky 683602, Russia*

Keywords: pink salmon, even-year, odd-year, abundance, returns, forecast, West Kamchatka, East Kamchatka

The importance of pink salmon to the fishery of the Russian Far East can scarcely be exaggerated because this species determines the total catch of Pacific salmon in the region. Fishery science already has provided a wealth of biological data about density and stock abundance of pink salmon during different periods of the life cycle, but often we find ourselves running into something we cannot explain. For example, abrupt transformations in populations when seemingly there is nothing to indicate a forthcoming, and potentially striking, change. It is well known that pink salmon have the simplest life-cycle among Pacific salmon species, but forecasting the stock dynamics of this species is more complicated and results are more uncertain than with other species.

For this study we used a cluster analysis to examine the basis of the dynamics of pink salmon escapement in different rivers of West and East Kamchatka. It has been demonstrated that the even- and odd-year lines of pink salmon in West Kamchatka have, at minimum, two well recognized population groups: the southern group that comprises populations from the Ozernaya River to the Kol River, and the northern group that includes populations from the Vorovskaya River to the Pyatibratka River (Fig. 1). In West Kamchatka the boundary between the two groups for both odd- and even-year brood lines is located along 55°N latitude.

East Kamchatka pink salmon populations are poorly structured. Major pink salmon populations exist in the Karaginsky and Olutorisky Gulfs, and minor populations are located in the Karaginsky, Kronotsky and Avachinsky Gulfs.

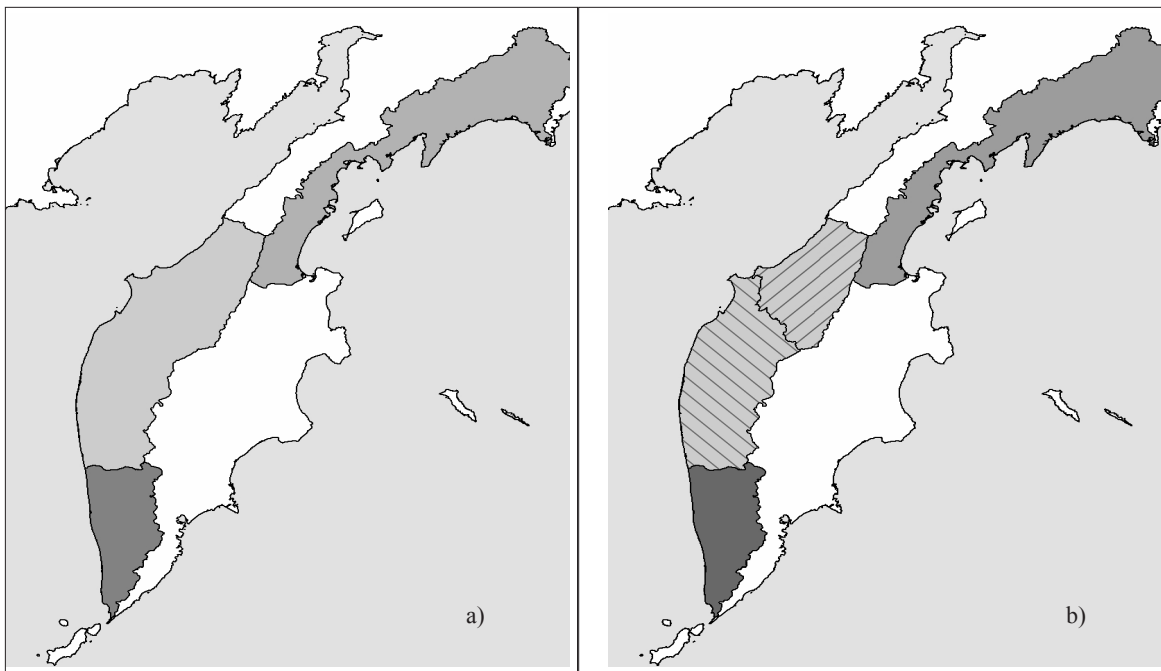


Fig. 1. Structure of pink salmon stocks in Kamchatka. Even-year brood line (a left panel), and odd-year brood line (b, right panel).

It is known that differentiation of pink salmon populations is difficult, even when using genetic methods. Absence of genetic distances (homogeneity) for species with a short life-cycle means that it is possible, or in fact quite likely, that large scale inter-regional movements of pink salmon took place in the past. Straying of fish and fluctuations in the abundance of spawners returning to different rivers are typical processes for pink salmon.

Since the late period of the 20th century, we observed fluctuations in the contribution of populations from West and East Kamchatka to the total regional pink salmon production. During this period, the proportion of the northern group in total production has increased and the proportion of the southern group has decreased. The shift of pink salmon runs to more northerly areas in recent years (especially in West Kamchatka) has raised interest in making a detailed analysis that takes into account the known structure and previous knowledge of Kamchatka pink salmon.

The contribution of the northern group of pink salmon in West Kamchatka was impressive until the 1980s (Fig. 2). In the early years, the large proportion of fish in the northern group contributing to the total run of West Kamchatka pink salmon resulted from the existence of the Japanese drift-net fishery and the operation of motherships in southern commercial fishing areas (Lagunov 1946). That period was over in 1978, when the fishery within the 200-mile economic zone was limited. The contribution of the northern group of pink salmon began to increase again at the end of 20th century. We suggest that fluctuations of West Kamchatka pink salmon within the two structural units of production is normal (perhaps of a regular character), and connected with the cyclic dynamics of climate. This suggestion raises the following question: Which determinant propels the dynamics of the relative contributions of the northern and southern groups in escapement, fluctuations in prespawning runs, or fluctuations in production of the two groups?

It is unlikely that migration fidelity in returning to natal spawning grounds plays a role. Comparison between parental abundance and returns to West (Fig. 3) and East (Fig. 4) Kamchatka indicates there is reliable homing of pink salmon to the spawning grounds under normal conditions, although we do not exclude the possibility of limited low-level of straying by spawners. In addition, slight deviations in the abundance of returns can easily be explained by removal of pink salmon aggregations during their transit through areas where there are marine trap-nets. However, we think that production fluctuations are most likely directed by climate changes and temperature, which improves the environment for pink salmon production at the northern boundary of pink salmon freshwater distribution.

Experience from September–October trawl surveys has shown that the abundance of juvenile salmon, as a rule, has already been formed by the time juveniles emigrate to the open waters of the Pacific Ocean. Therefore, data obtained in trawl surveys conducted during this time period can be used to forecast returns (Fig. 5). Abundance of juvenile migrants in the river is usually well correlated with parental stock abundance, but poorly correlated to subsequent return of fish as adults. Hence, the principle determinant in pink salmon run formation should occur in the early marine period of life. The data we have regarding pink salmon habitat during this period are comparatively poor. However, it is known that movement of pink salmon smolts into cold sea water can result in high mortality (Karpenko 1998). Of course, mortality can also result from low capacity of the forage base to support salmon during periods when pink salmon are in the river, estuaries, and coastal waters.

We used the ALPI Index and the Delta P Index as general predictors for testing the effects of climate conditions on formation of stock abundance of the northern and southern groups of pink salmon. The Delta P index was suggested by O.B. Tepnin (Head of the Oceanographic Laboratory, KamchatNIRO). The Delta P index relates the Aleutian maximum pressure and Siberian minimum pressure, and it is an indirect indicator of the intensity of atmospheric processes in the Russian Far East. Interestingly, we could not find correlations between these indices and the general abundance pattern of West Kamchatkan pink salmon.

The occurrence of straying provides an indirect confirmation of abundance fluctuations by the presence of abundant fish in rivers that are usually negatively affected by strong human impacts and have poor adult returns for several years. For example, we have observed this several times in the Avacha and Paratunka Rivers, which are located near the city of Petropavlovsk–Kamchatsky in the most populous region of Kamchatka. There will be a sudden increase of pink salmon catches in the Kamchatsky Gulf and the Kamchatka River basin that occurs by straying of adult pink salmon from the Karaginsky Gulf.

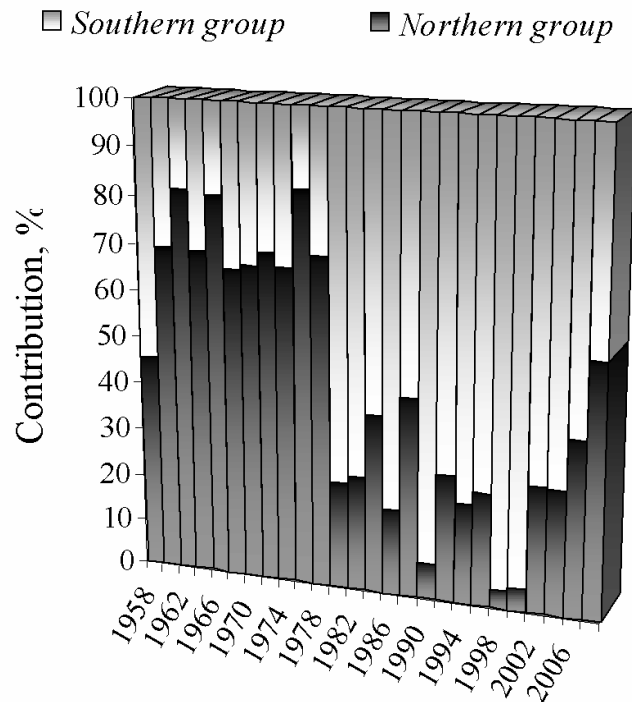


Fig. 2. Relative contributions (%) of northern and southern groups of pink salmon to the total production in West Kamchatka, odd years, 1958–2009.

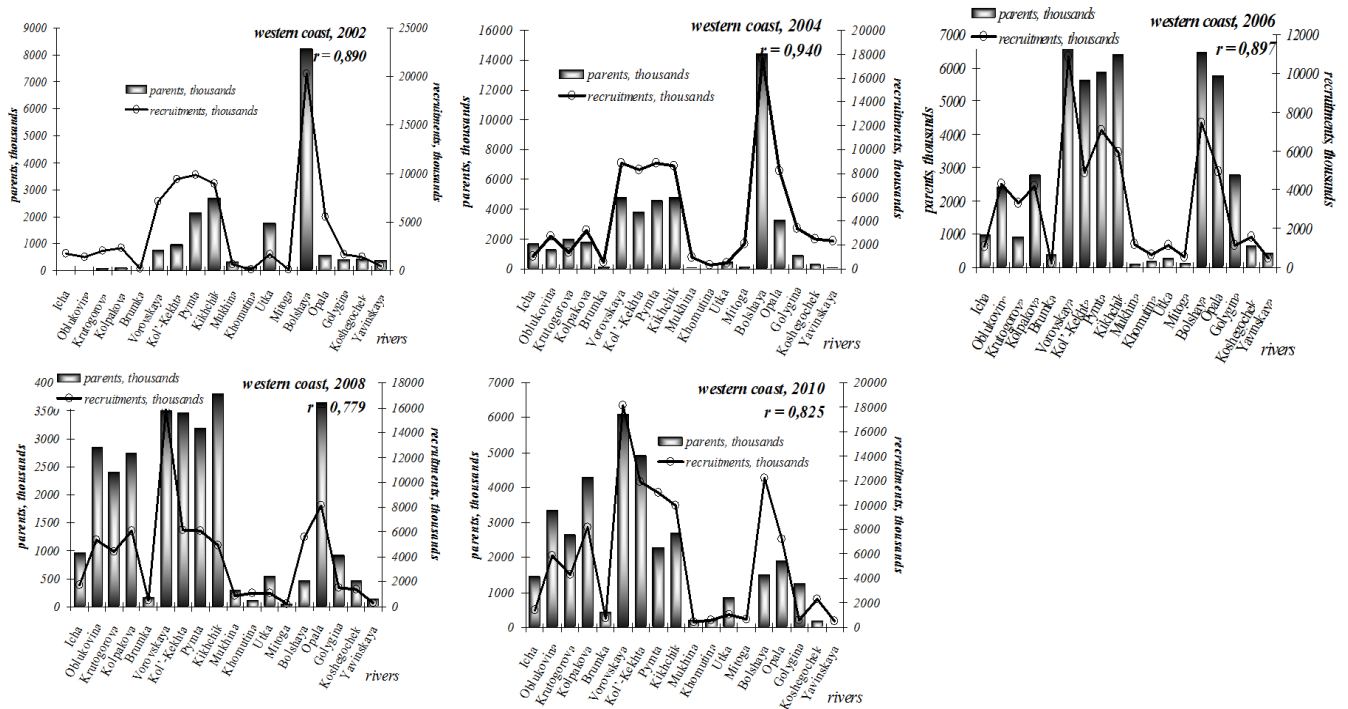


Fig. 3. Relationship between parental abundance and the number of pink salmon returning to the rivers of West Kamchatka in even-numbered years, 2002–2010.

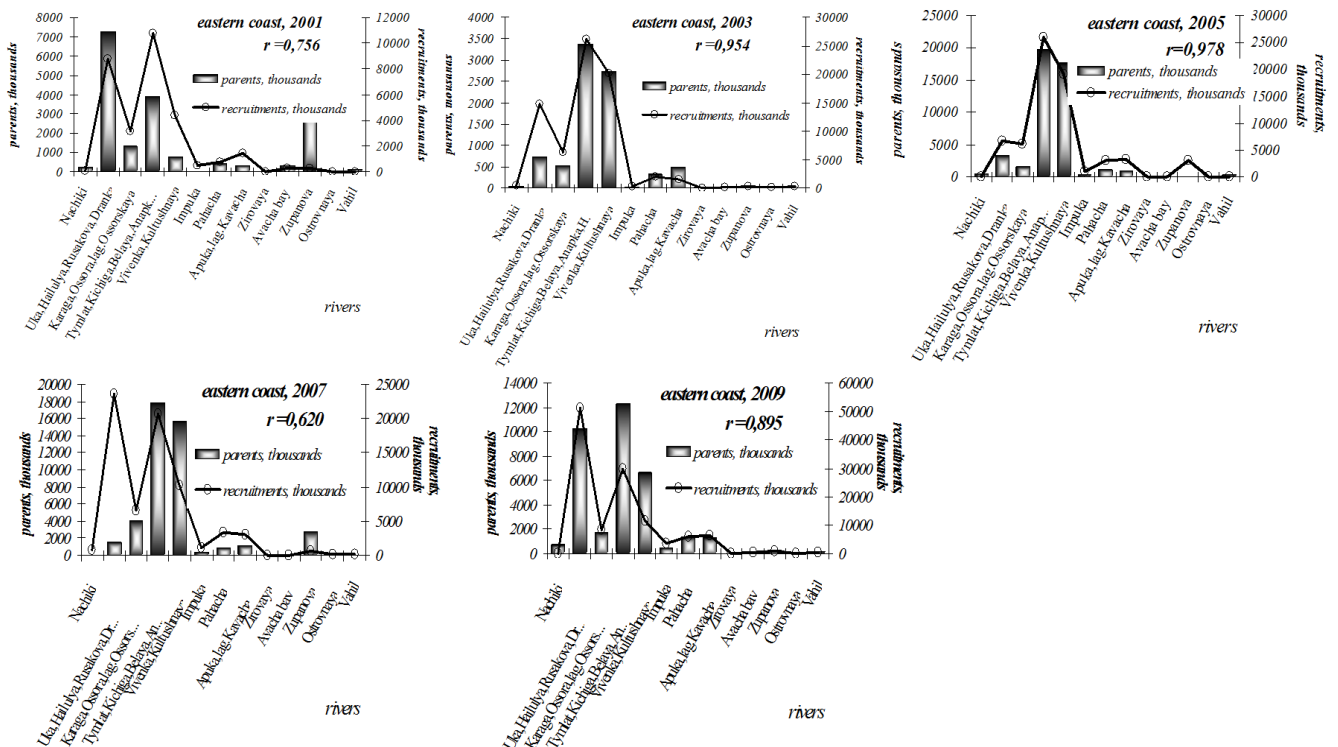


Fig. 4. Relationship between parental abundance and the number of pink salmon returning to the rivers of East Kamchatka in odd-numbered years, 2001–2009.

We conclude that the unit of pink salmon stock abundance, the population, exists through time as a relatively stable temporal and spatial group of subpopulations that have a limited and insignificant—but permanent—exchange of individuals at the boundaries of commercial fishing districts. For example, these populations include West Kamchatka, North Kamchatka, and probably the Kamchatka River. In the Kamchatka River, the number of pink salmon that stray into the river in odd-numbered years can be significant. For West Kamchatka pink salmon, we think the exchange between geographically close populations is more intense than between distant populations and that the exchange of strays is proportional to the distance between stocks. The same mechanism also occurs in East Kamchatka, but sometimes the pink salmon runs can get reoriented around Karaginsky Island (Fig. 5). When that happens, we can observe episodic straying and settlement of pink salmon onto spawning grounds that are distant from their natal spawning area.

In contrast to results obtained by some others, during periods of relatively stable conditions we have good agreement between forecasts and observed pink salmon returns using traditional stock-recruitment models (Ricker and Shepherd model; Ricker 1954; Shepherd 1982; Kriksunov 1995). When there are sudden changes in some of the parameters, we have observed unexplained returns that are interpreted statistically as outliers. Over time as we have gained more experience with these variable parameters, the models have provided useful forecasts. Two recent odd-year cycles indicated record high levels of pink salmon stock abundance in Northeast Kamchatka. Although we have no explanations for the mechanism supporting these extra-high abundant runs, at the very least we believe that most regulation of pink salmon abundance occurs in the early marine period of life.

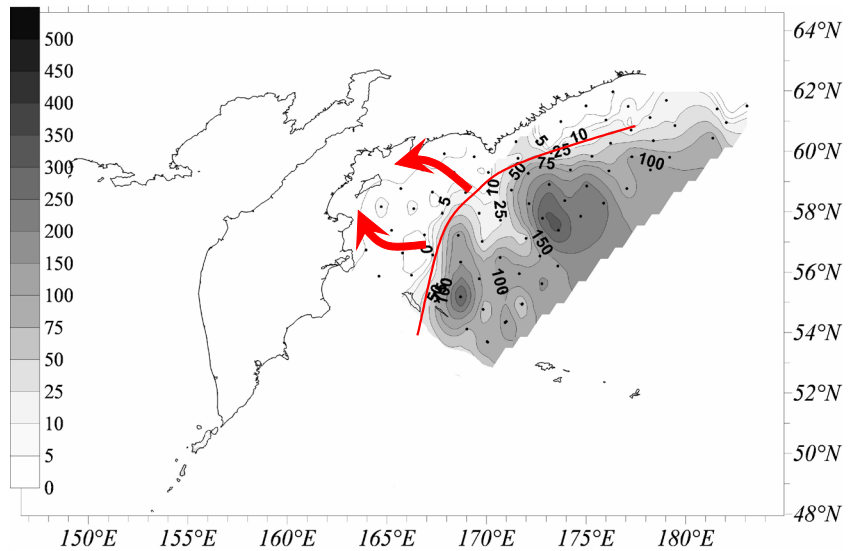


Fig. 5. The migration route of pink salmon returning to spawning rivers in Northeast Kamchatka.

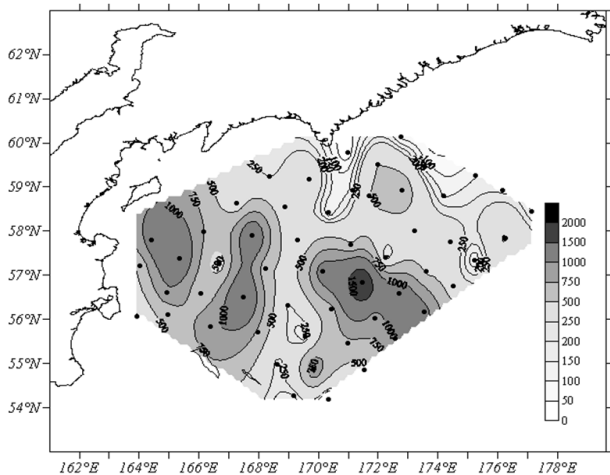


Fig. 6. Abundance pattern of juvenile pink salmon (fish/1-hr of trawling) in the coastal waters off Northeast Kamchatka during the fall. Catch data provided by the survey cruise of the R/V Professor Kaganovsky (September 23 – October 10, 2010).

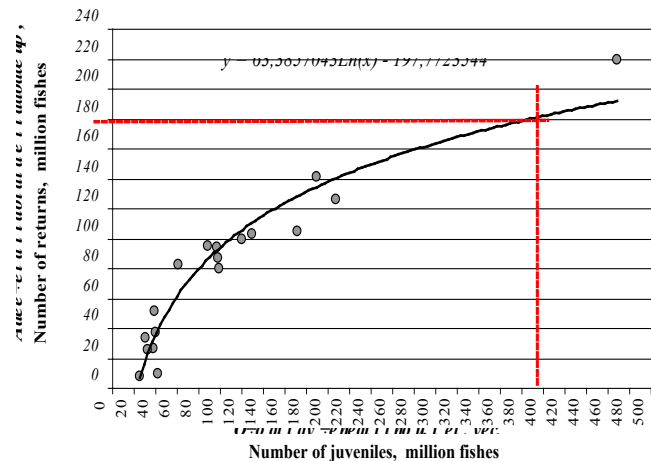


Fig. 7. Relationship between total abundance of juvenile pink salmon caught on research cruises and adult returns to the Kamchatka coast. Red lines indicate expected adult returns to East Kamchatka in 2011. Data provided by the fall surveys of KamchatNIRO and TINRO-Center.

Trawl surveys for estimation of juvenile pink salmon abundance in the Bering Sea in September–October have proven to be useful for forecasting (Figs. 6 and 7). However, interpreting the data from juvenile salmon trawl surveys in the Okhotsk Sea has proven more complicated because the fall surveys catch mixed-stock aggregations of pink salmon that requires stock-identification of the mixture. The mixed-stock aggregations include large groups of pink salmon originating from West Kamchatka, Sakhalin, or Kuril Islands and we need to identify the groups in order to improve forecasting of adult returns to those areas (Fig. 8). Current methods of differentiating juvenile pink salmon on the basis of scale structure have shown poor reliability. We hope using genetic markers will help us achieve our goal of obtaining reliable differentiation of the stocks in these aggregations (Shpigalskaya et al., this report). In the near future we believe the use of genetic markers will provide reliable regional stock identification of juvenile pink salmon in the Russian Far East (Shpigalskaya et al., this report).

In conclusion, we summarize the following basic points:

1. Local stocks of Kamchatka pink salmon in particular rivers exist as spatially and temporally, more or less, stable groups at a subpopulation level. At the most basic level, the subpopulations of Kamchatka pink salmon include Southwestern, Western, Northeastern and the Kamchatka River.
2. One of the possible determinants of changes in relative contribution of subpopulations to total stock production of pink salmon can be the increase in production at the edge (northern edge) of freshwater distribution of pink salmon. In particular, this is happening in association with climate changes that have taken place in Kamchatka during the last decade.
3. Abundance of pink salmon is formed primarily in the early marine period of life. Studying the processes that determine survival of juvenile pink salmon in the early marine period will help our understanding of what controls pink salmon population abundance and improve forecasts of pink salmon returns.
4. In the waters off East Kamchatka, current application of marine trawl survey results on the abundance of juvenile pink salmon aggregations during the fall is an effective tool in forecasting the abundance of adults returning the following year. In the Okhotsk Sea (West Kamchatka), we need to develop more effective tools to reliably and easily differentiate mixed-stock aggregations of pink salmon.

REFERENCES

- Karpenko, V.I. 1998. The early period of sea life of Pacific salmon. Moscow. VNIRO Publ. 165 pp. (In Russian).
- Kriksunov, E.A. 1995. The theory of reinforcement and interpretation of fish populations dynamics. *Vopr. Ichthyologii* 35(3): 302–321. (In Russian).
- Lagunov, I.I. 1946. About Japanese fishery on North Kuril Islands. Kamchatka Branch of TINRO. Petropavlovsk–Kamchatsky. 40 pp. (In Russian).
- Ricker, W.E. 1954. Stock and recruitment. *J. Fish. Res. Board Can.* 11(5): 559–623.
- Shepherd, J.G. 1982. A versatile new stock and recruitment relationship to fisheries and the contraction of sustainable yield curve. *J. Cons. Int. Explor. Mer.* 40: 67–75.

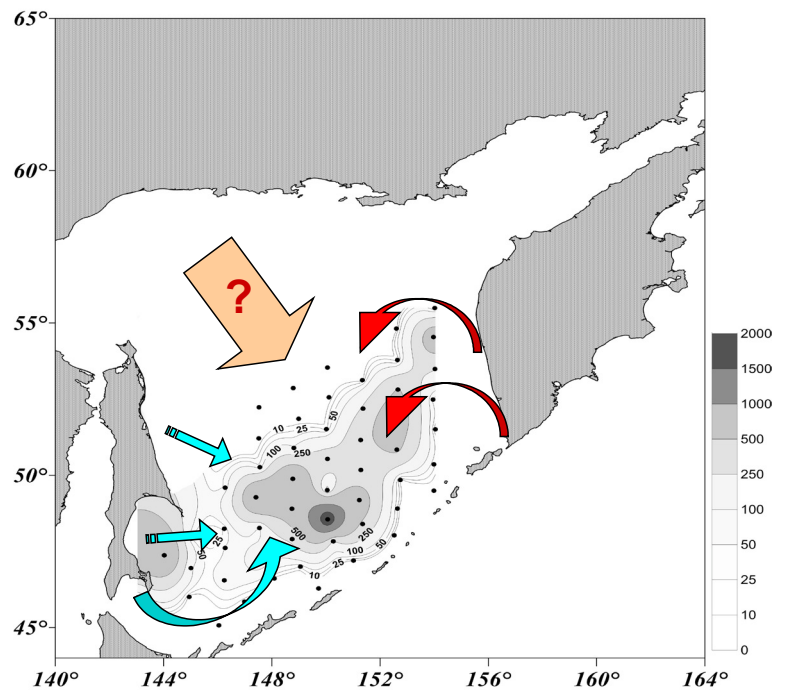


Fig. 8. The general scheme of mixed-stock juvenile pink salmon aggregations in southern Okhotsk Sea, October–November.

The Association of Long-Term Changes in West Kamchatka Pink Salmon Catches with Climate Regime Shifts in the Northern Hemisphere

Andrei S. Krovnin and Nataliya V. Klovach

*Russian Federal Research Institute of Fisheries and Oceanography (VNIRO),
17 Verkhnyaya Krasnoselskaya, Moscow 107140, Russia.*

Keywords: pink salmon, sea surface temperature anomaly, West Kamchatka, North Pacific Gyre Oscillation, Atlantic Multidecadal Oscillation

In this study, an attempt was made to consider how multi-decadal changes in the state of Russian Far East salmon stocks are related to the leading large-scale climatic patterns in the Northern Hemisphere. As an example, we used information on pink salmon stocks originating from West Kamchatka (WK), and based our study on data from the 1951-2010 period. The data included monthly mean sea surface temperature anomalies (SSTA) from the ERSST v. 3b data set, geopotential heights at the 500-hPa surface from the NCEP/NCAR Reanalysis, monthly values of various climatic indices in the Northern Hemisphere, and catch statistics for WK pink salmon stocks.

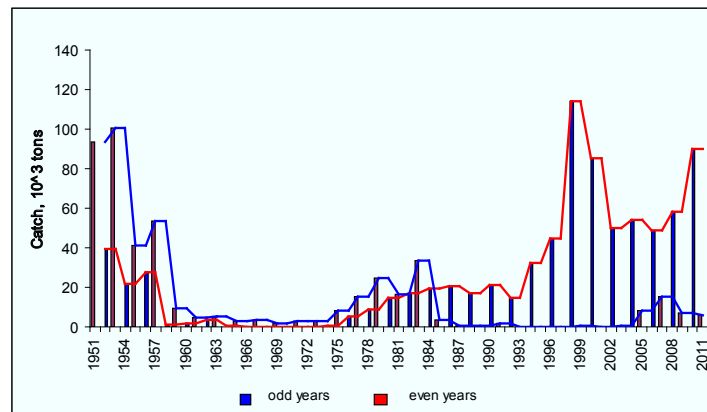


Fig. 1. West Kamchatka pink salmon catches for fish returning in odd-numbered and even-numbered years, 1951-2011.

During the 1950s, WK pink salmon catches dropped sharply from more than 100 thousand tons (in odd-numbered years) to a few thousand tons, and catches continued at a very low level until the early 1970s, when they started to increase (Fig. 1). The catches in odd-numbered years increased until 1983, when catches declined to very low levels. The period from 1984 to the present time is characterized by the predominance of pink salmon returning to West Kamchatka in even-numbered years. Catches of even-year pink salmon started to rise sharply in 1994, reached a maximum in 1998, and catches have remained at a high level until the present.

We separated our analysis into two periods: from 1951 to 1988, when odd-year generations were dominant, and from 1972 to 2010 when, in general, even-year generations dominated. Although the early part of the second period was dominated by odd-year returns, our selection for the year beginning the second period was made for two reasons. The first reason was to make the length of the pink salmon catch time series of both odd- and even-numbered years the same, and the second reason was that the correlation coefficient between the catches of odd and even years during 1971-1984 exceeded 0.90.

The most prominent feature of the correlation pattern between the WK pink salmon catches in odd-numbered years and the mean winter (January-April) SSTA field in the North Pacific and North Atlantic was the existence of a pronounced meridional dipole east of the North American coast, with the centers along 50°N and 30°N (Fig. 2a). In the North Pacific, the correlation pattern was characterized by an extensive domain of positive correlations stretching from the southwestern part of the ocean to the northeastward, which was surrounded by areas of negative correlations to the north, east, and southeast. However, these correlations were generally weaker as compared to the correlations calculated for the North Atlantic. The centers of positive and negative correlations in the southwestern North Pacific and the southern Sea of Okhotsk, respectively, might be considered as a dipole similar to that for the North Atlantic, but with inverse polarity.

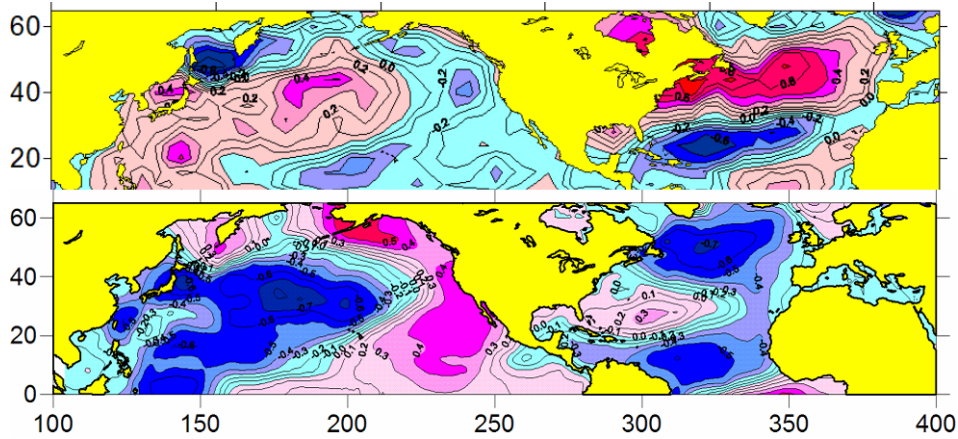


Fig. 2. Correlation pattern between West Kamchatka pink salmon catches in odd-numbered years and the mean winter (January-April) SSTA field in the North Pacific and North Atlantic (a, upper panel); pattern of the corresponding EOF2 (10% of total variance) of the SSTA field (b, lower panel) during the 1951-1988 period.

The described pattern corresponds to the EOF2 (10% of total variance) of the combined North Pacific and North Atlantic SSTA field, but with the opposite sign (Fig. 2b). The North Atlantic dipole was expressed rather well. In the North Pacific, the correlations were generally stronger, as compared to those in Fig. 2a. However, the dipole in its western part of the North Pacific was weaker. Instead, there was evidence of opposite SSTA variations between the central North Pacific and the Gulf of Alaska. This resembles the North Pacific Gyre Oscillation pattern (NPGO; Di Lorenzo et al. 2008) in its negative phase.

The EOF2 pattern in the North Atlantic can be further interpreted as the four-pole structure described by Krovnin (1995) on the basis of his cluster analysis of data from the 1957-1991 period. In his study the correlation coefficient between the first principal component (PC) of the two time series representing the anomalies averaged over the northwestern and southwestern regions in the North Atlantic and catches in odd years was -0.58 ($p < 0.05$).

The time series of EOF2 PC scores and WK pink salmon catches in odd-numbered years in 1951-1988 indicated that catches started to increase after 1973, following the shift of the EOF2 phase from negative to positive (Fig. 3).

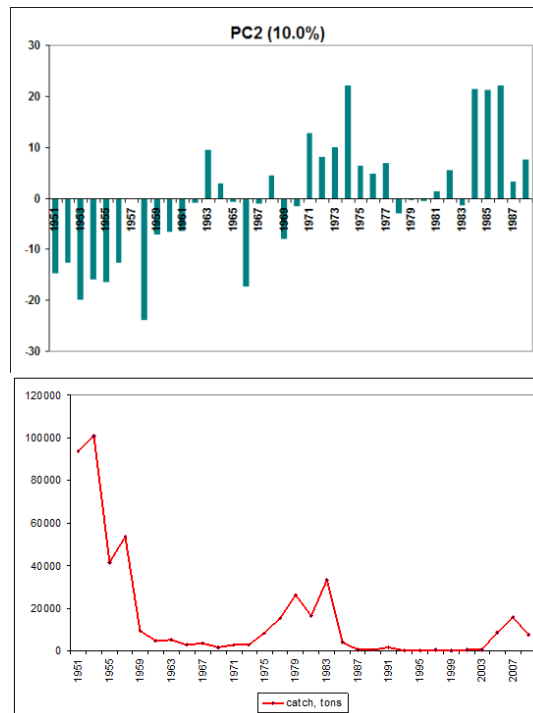


Fig. 3. Time series of PC2 scores that represent 10% of the total variance (a, upper panel) and West Kamchatka pink salmon catch (tons) in odd-numbered years, 1951-1988 (b, lower panel).

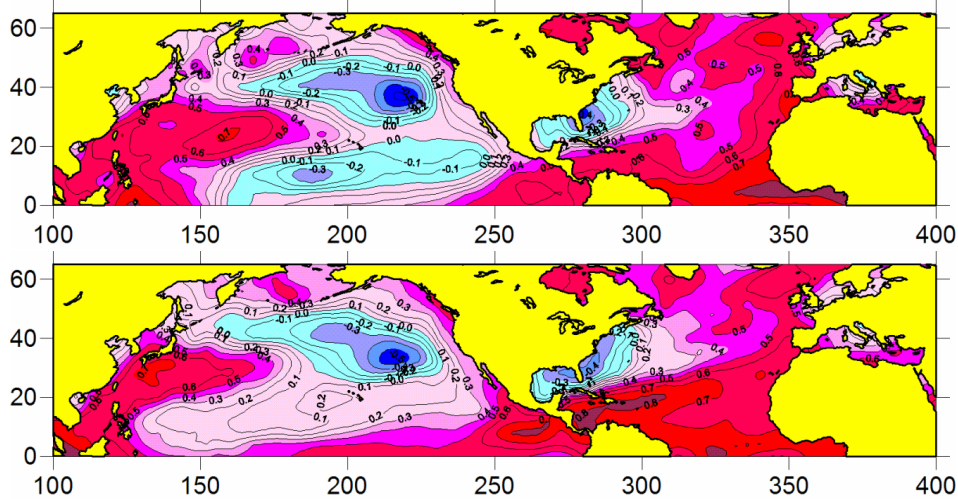


Fig. 4. Correlation pattern between West Kamchatka pink salmon catches (even-numbered years) and the SSTA field in the North Pacific and North Atlantic (a, upper panel); pattern of the leading EOF1 (29% of total variance) of the SSTA field (b, lower panel) during the 1972-2010 period.

The correlation pattern between the WK pink salmon catches in even-numbered years and the SSTA field for the 1972-2010 period was characterized by high positive correlations covering most of the North Atlantic (positive phase of the Atlantic Multidecadal Oscillation (AMO); Fig. 4a). In the North Pacific, a tongue of high positive correlations stretched from the Asian coast eastward in the area south and southeast of Japan. Domains of strong and weak negative correlations were located to the northeast and southeast, respectively, of the area of high positive correlations. A comparison of the map with the patterns of the leading EOFs of the combined SSTA field showed almost complete coincidence with the EOF1 pattern, which explained 29% of the total variance (Fig. 4b).

The combined analysis of the EOF1 pattern and correlation pattern between the EOF1 PC and geopotential heights at the 500-hPa surface for the 1972-2010 period showed that the EOF1 was associated with simultaneous development and following establishment of the positive phases of the Atlantic Multidecadal Oscillation (AMO) and North Pacific Oscillation (or NPGO-like SSTA mode).

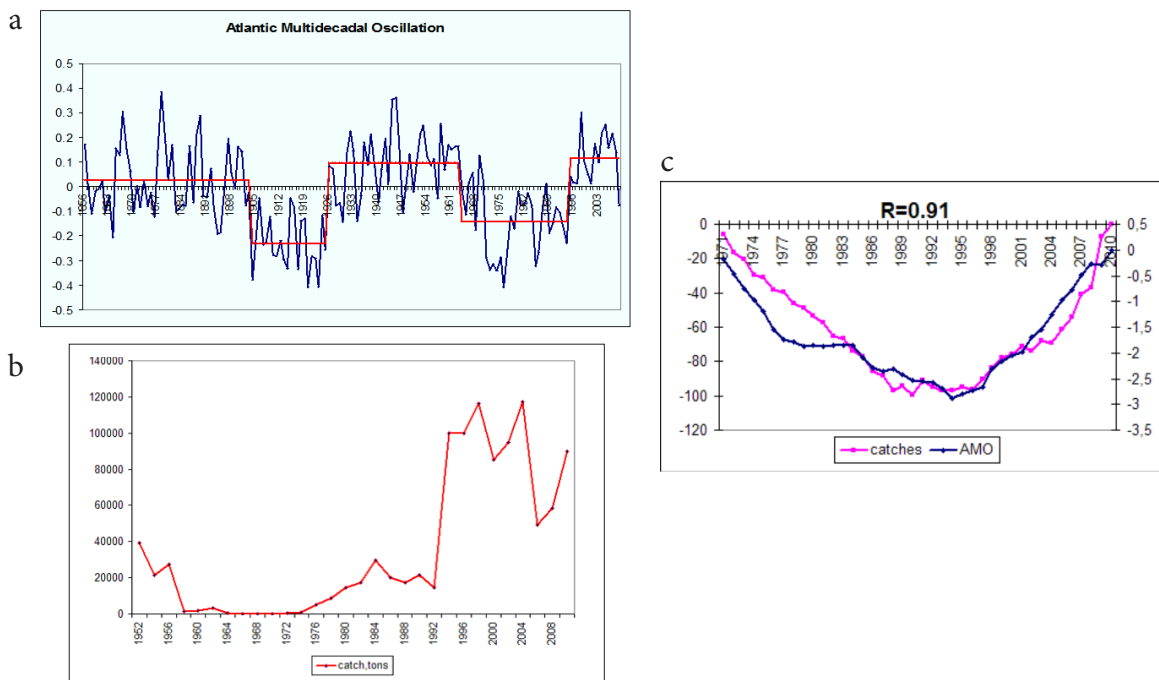


Fig. 5. Variations in the Atlantic Multidecadal Oscillation (AMO) index, 1856-2009 (a, upper left panel); West Kamchatka pink salmon catches in even-numbered years, 1952-2010 (b, lower left panel); correlation coefficient between cumulative sums of total Russian Far East pink salmon catches and the AMO index, 1971-2010 (c, right panel).

The positive and negative phases of the AMO index for the 1856-2009 period are demonstrated in Fig. 5a. The present positive phase was established in 1995, and the sharp increase in salmon catches was observed between 1992 and 1994, i.e., at approximately the same time (Fig. 5b). Moreover, the correlation coefficient between the cumulative sums of the AMO index and anomalies of total catch of all Russian Far East pink salmon stocks during 1972-2010 was 0.91 (Fig. 5c). Thus, the change in phase of the large-scale mode of SSTA variability in the Northern Hemisphere resulted in changes in state not only of West Kamchatka pink salmon stocks, but also of other Russian Far East pink salmon stocks independent of the predominance of odd- or even-year generations.

The important question is how long the current period of high Russian Far East salmon catches will continue. Our analysis showed that high catches coincided with the simultaneous development of positive AMO and NPGO-like phases in the North Atlantic and North Pacific, respectively. Though the values of correlation coefficients between the WK pink salmon catches and SSTA during 1972-2010 were stronger in the North Atlantic, it is obvious that the AMO cannot directly affect Far East salmon stocks. Rather, the correlations may be considered an indicator of large-scale climate variations. The stocks are affected by the physical processes existing in the North Pacific, and the beginning of a climate regime shift there may not coincide with a shift in the North Atlantic. Analysis of the SSTA field for 2011 provides evidence of a change in the dominant mode of SSTA variability in the North Pacific with establishment of a negative PDO-like pattern, while the positive AMO phase in the North Atlantic will continue (as expected) until the mid 2020s. Apparently, observed changes in the North Pacific may lead to a sharp decrease in Russian Far East salmon catches in the coming years.

REFERENCES

- Di Lorenzo, E., N. Schneider, K.M. Cobb, J.S. Franks, K. Chhak, A.J. Miller, J. McWilliams, S.J. Bograd, H. Arango, E. Curchitser, T.M. Powell, and P. Riviere. 2008. North Pacific Gyre Oscillation links ocean climate and ecosystem change. *Geophys. Res. Lett.*, 35, L08607, doi: 10.1029/2007GL032838.
- Krovnin, A. S. 1995. A comparative study of climatic changes in the North Pacific and North Atlantic and their relation to the abundance of fish stocks. *In* Climate change and northern fish populations. *Edited by* R. J. Beamish. Can Sp. Pub. Fish. Aquat. Sci. No. 121. pp. 181-198.

Recent Harvest Trends of Pink and Chum Salmon in Southeast Alaska: Can Marine Ecosystem Indicators Be Used as Predictive Tools for Management?

Joseph A. Orsi, Emily A. Fergusson, and Molly V. Sturdevant

*Ted Stevens Marine Research Institute, Alaska Fisheries Science Center,
NOAA Fisheries, 17109 Point Lena Loop Road, Juneau, AK 99801, USA*

Keywords: pink salmon, chum salmon, marine ecosystem indicators, forecast, harvest trend, Southeast Alaska

Pink and chum salmon are the principal salmon harvest components in Southeast Alaska (SEAK) commercial fisheries and were valued at greater than \$75 million from 2008 to 2010 (ADFG 2011). The combined harvests of both species in SEAK generally increased from about 10 to 50 million fish from 1960 to 2000. However, production trends have also varied annually, and over the last decade there has been evidence for a downward trend in harvest for both species. Stock structure also differs dramatically between species. Of the salmon harvested from 1997 to 2010, 98% of pink salmon were unmarked, presumably wild stocks, whereas 74% of chum salmon were identified as hatchery stocks (McNair 1998, 1999, 2000, 2001, 2002; Farrington 2003, 2004; White 2005, 2006, 2007, 2008, 2009, 2010, 2011). Recent variations in SEAK salmon production could be linked to ocean or freshwater conditions, species interactions, management or enhancement practices, or a combination thereof.

To better understand links between marine ecosystem factors and recent pink and chum salmon production in SEAK, data from a regional ocean sampling survey (the Southeast Coastal Monitoring [SECM] project) and corresponding ocean basin-scale indices were examined over the years 1997–2010. Pink and chum salmon have in common the life history trait of migrating to sea as fry, with strong dependence on the littoral marine habitat followed by rapid migration through seaward corridors as juveniles en route to the Gulf of Alaska (GOA). Regional and ocean basin metrics associated with salmon were compared to the harvest and survival response variables for pink and chum salmon in SEAK. Metrics were chosen to align with salmon early ocean life, which has been identified as a critical period of high and variable mortality (Parker 1968; Karpenko 1998; Kaeriyama et al. 2007; Wertheimer and Thrower 2007). At this time, juvenile salmon are vulnerable to marine conditions that influence year-class strength through factors such as growth, predator abundance, and seaward migration size and timing. Identifying a set of marine ecosystem indicators useful as predictive tools for forecasting returns would benefit salmon management in SEAK, particularly when sibling models are not possible, as is the case for pink salmon.

Objectives of this study were to determine whether (1) ecosystem metrics associated with juvenile pink and chum salmon are related to recent trends in SEAK salmon production, and (2) ecosystem metrics can be used as predictive tools for salmon management.

Metrics used for this study were obtained primarily from the SECM project and ocean basin-scale data sources. These ecosystem metrics were also selected to reflect time scales that affect each cohort prior to harvest. The SECM project metrics were obtained from surface trawl samples of juvenile salmon migrating to the ocean (yr_1), plankton nets, and oceanographic data taken at monthly intervals from May to August in the northern region of SEAK (58°N, 135°W; Orsi et al. 2000, 2011). The SECM project metrics used were: upper 20-m integrated water temperature in May, average mixed layer depth (MLD) in June–July, average zooplankton biomass displacement volume (Bongo net 333- μ m mesh) in June–July, peak fish CPUE ($\ln[\text{catch}+1]$) in June or July, fish energy density ($\text{kcal} \cdot \text{g}^{-1} \text{ WW}$) in July, fish size (FL, mm) on 24 July (growth proxy), seasonality (peak migration month June–August), stomach fullness (percent body weight) in July, and fish condition factor residuals in June–July. The ocean basin and regional metrics were selected as potential factors affecting juvenile salmon prior to and during their ocean residence, such as in winter (November–March, yr_{-1}) and summer (June–Aug, yr_1). These metrics included GOA (45–58°N, 130–156°W) sea surface temperatures in winter and summer (Kalnay et al. 1996), the North Pacific Index (NPI; winter and summer; Trenberth and Hurrell 1994), the Pacific Decadal Oscillation (PDO; winter and summer; Mantua et al. 1997), the Multivariate El Niño Southern Oscillation Index (MEI; winter and summer; Wolter and Timlin 1993, 1998), and the US Geological Survey monthly river discharge levels for the Mendenhall River, SEAK, in spring/summer (March–Aug, yr_1 ; USGS 2011).

Harvest and survival data were the response variables chosen for pink and chum salmon production in SEAK (Figs. 1 and 2). The harvest data was assumed to represent total return for each species and was lagged appropriately: conditions affecting juvenile salmon during their ocean entry year (yr_1) were lagged one year to adults in harvest for pink salmon (yr_{1+1}) and three years to adults in harvest for chum salmon (yr_{1+3}). This permitted comparisons of 13 years of pink harvests and 10 years of chum salmon harvests. Marine survival data from three hatcheries' salmon releases and one wild salmon

stock in SEAK were used. Pink salmon survival rates were available from Auke Creek (wild fish) and the Armstrong Keta Incorporated hatchery. Chum salmon survival rates were available from the Douglas Island Pink and Chum and Hidden Falls hatcheries. For each species of salmon, survival rates were averaged to develop an index, and complete brood year survival indices were compared for 13 years for pink salmon and 9 years for chum salmon.

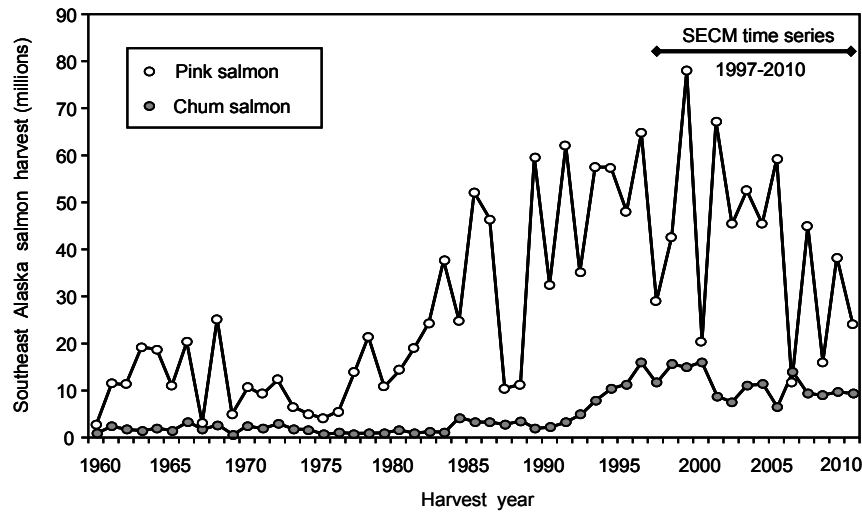


Fig. 1. Historical harvests of pink and chum salmon in the commercial fisheries of Southeast Alaska (SEAK), 1960–2010. The Southeast Coastal Monitoring (SECM) project time series (1997–2010) for juvenile pink and chum salmon is identified. The SEAK salmon harvest data provided courtesy of S. Heintz, Alaska Department of Fish and Game.

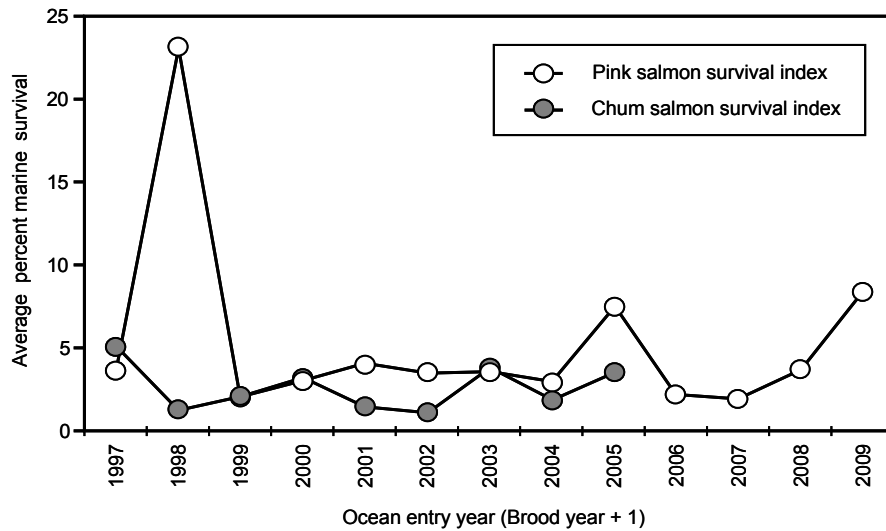


Fig. 2. Marine survival indices for pink and chum salmon (two stocks each) in the northern region of Southeast Alaska from 1998 to 2010. The pink salmon survival index is the average marine survival of Auke Creek (wild) and Armstrong Keta Incorporated (AKI, hatchery) stocks. Auke Creek data provided courtesy of J. Joyce, Auke Bay Laboratories, and the AKI data provided courtesy of B. Watson. The chum salmon survival index is the average marine survival of two hatchery stocks: Hidden Falls, Northern Southeast Regional Aquaculture Association (NSRAA) and Douglas Island Pink and Chum (DIPAC). The NSRAA data provided courtesy of C. Blair and the DIPAC data provided courtesy of R. Foht.

Pink and chum salmon responded differently to SECM project and ocean basin metrics. For pink salmon, significant ($p \leq 0.02$) correlations included: juvenile CPUE with both harvest ($r = 0.92$) and survival ($r = 0.67$), seasonality with harvest ($r = -0.74$), NPI_{summer} with harvest ($r = 0.62$), and MEI_{winter} with survival ($r = 0.73$) (Tables 1 and 2). For chum salmon, the PDO_{summer} was the only metric significantly ($p \leq 0.04$) correlated to both harvest ($r = 0.63$) and survival ($r = 0.72$). These results suggest that a critical period prior to the SECM sampling exists for juvenile pink salmon in particular, and that chum salmon are more influenced by ocean basin metrics. Other metrics were not significantly correlated with harvest or survival of either species.

Table 1. Pearson’s correlation coefficients (r) and p -values for biophysical parameters collected during the Southeast Coastal Monitoring (SECM) project’s juvenile salmon time frame (1997–2009) and associated year class strength of adult pink salmon (1998–2010) and chum salmon (2001–2010) in the northern region of Southeast Alaska. Significant ($p < 0.05$) correlations are in bold. SECM project parameters are defined in the text.

	Pink salmon				Chum salmon			
	Harvest		Survival		Harvest		Survival	
	(13 years)		(13 years)		(10 years)		(9 years)	
SECM project parameters	r	p	r	p	r	p	r	p
Integrated 20-m temp (May)	-0.04	(0.91)	0.50	(0.08)	0.24	(0.48)	0.27	(0.48)
Mixed layer (June–July)	-0.46	(0.12)	-0.07	(0.83)	-0.20	(0.55)	0.23	(0.55)
Zooplankton (June–July)	0.18	(0.56)	-0.36	(0.22)	0.26	(0.43)	0.06	(0.89)
CPUE (Peak: June or July)	0.92	(0.00)	0.67	(0.01)	0.10	(0.76)	-0.02	(0.97)
Energy density (July)	-0.16	(0.60)	0.07	(0.82)	0.36	(0.28)	0.30	(0.44)
Size-at-time (24 July)	0.26	(0.39)	0.39	(0.19)	0.36	(0.28)	0.43	(0.25)
Seasonality (June–August)	-0.74	(0.00)	-0.24	(0.44)	0.33	(0.33)	0.28	(0.47)
Fullness (% body wt)	-0.00	(1.00)	-0.12	(0.70)	0.11	(0.76)	-0.19	(0.63)
Condition residual	0.33	(0.27)	0.25	(0.42)	0.58	(0.54)	0.30	(0.44)

Table 2. Pearson’s correlation coefficients (r) and p -values for basin-scale biophysical parameters within the Southeast Coastal Monitoring (SECM) project’s juvenile salmon time frame (1997–2009) and associated year class strength of adult pink (1998–2010) and chum salmon (2001–2010). Abbreviations are defined in text and data sources are footnoted. Basin-scale parameters are temporally aligned with juvenile ocean entry year (brood year + 1), or the year prior to ocean entry year (yr_{-1}); the spring is April and May; the summer is June to August; and the winter is November to March. Significant ($p < 0.05$) correlations are in bold.

	Pink salmon				Chum salmon			
	Harvest		Survival		Harvest		Survival	
	(13 years)		(13 years)		(10 years)		(9 years)	
Basin-scale parameters	r	p	r	p	r	p	r	p
¹ SST (winter, yr_{-1})	0.16	(0.60)	0.15	(0.64)	0.27	(0.42)	0.13	(0.75)
¹ SST (summer)	0.11	(0.72)	0.19	(0.53)	0.37	(0.26)	0.52	(0.15)
² NPI (winter, yr_{-1})	-0.50	(0.08)	-0.32	(0.28)	-0.35	(0.28)	-0.01	(0.98)
²NPI (summer)	0.62	(0.02)	0.54	(0.06)	-0.01	(1.00)	-0.29	(0.45)
³ PDO (winter, yr_{-1})	0.24	(0.44)	0.33	(0.27)	0.35	(0.36)	0.13	(0.70)
³PDO (summer)	-0.04	(0.91)	0.01	(0.97)	0.63	(0.04)	0.72	(0.03)
⁴MEI (winter, yr_{-1})	0.29	(0.34)	0.73	(0.01)	-0.05	(0.90)	-0.14	(0.72)
⁴ MEI (summer)	0.10	(0.74)	-0.00	(0.99)	0.57	(0.07)	0.57	(0.11)
⁵ River (spring–summer)	-0.01	(0.98)	0.17	(0.59)	-0.01	(0.98)	0.27	(0.48)

¹ Kalnay et al. (1996) www.esrl.noaa.gov/psd/data/timeseries/,

⁴ Wolter and Timlin (1993) www.esrl.noaa.gov/psd/enso/mei/table.html,

² Trenberth and Hurrell (1994) www.cgd.ucar.edu/cas/jhurrell/indices.info.html#np,

³ USGS (2011) Mendenhall River discharge waterdata.usgs.gov/nwis/monthly

⁵ Mantua et al. (1997) www.atmos.washington.edu/~mantua/abst.PDO.html,

This paper examined the relationships of juvenile pink and chum salmon and their associated ecosystem metrics with recent trends in salmon production in SEAK. The highly significant correlation between juvenile pink salmon CPUE and subsequent adult harvest is a relationship that has been successfully incorporated into salmon forecast models for SEAK since 2004 (Wertheimer et al. 2009, 2011). In seven of the past eight years, the SECM pink salmon forecasts have been within 7% of the actual harvests, and all models included CPUE (Fig. 3) as the principal parameter. Since 2007, several models have used additional parameters in a step-wise regression approach to explain error. Forecasting pink salmon abundance has historically been problematic because information from a prior year class is not available as a leading indicator to detect brood year strength. In contrast, forecasting chum salmon has not been attempted because none of the SECM project metrics have been significantly correlated. However, the PDO_{summer} basin-scale index appears to show promise as a tool for future SEAK chum salmon forecasts.

Results from this study indicate ecosystem metrics can be used as predictive tools for pink salmon forecasting in SEAK. Further refinement of forecast methods using ocean basin metrics may permit more robust models to be developed and allow the detection of anomalous years or climate changes that may impact year class strength and give insight to controlling mechanisms within marine ecosystems.

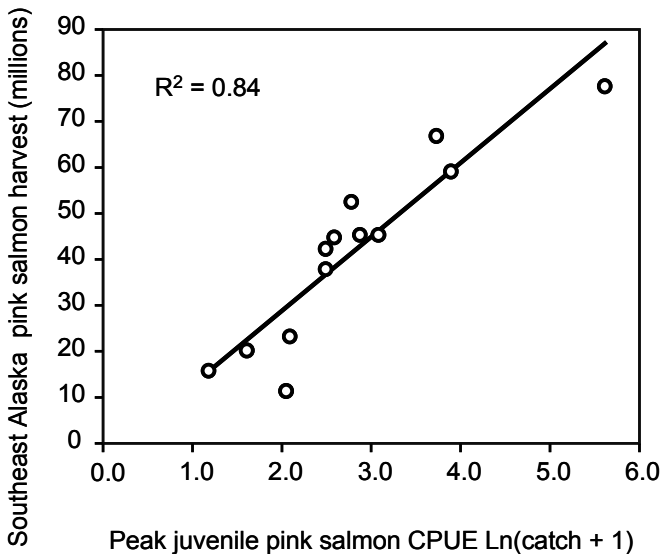


Fig. 3. The relationship between peak juvenile pink salmon CPUE Ln(catch+1) in June or July and the common property harvest of adults in the ensuing year in Southeast Alaska (1997–2009).

REFERENCES

- Alaska Department of Fish and Game (ADFG). 2011. Alaska commercial salmon harvests and exvessel values. (Available at www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmoncatch).
- Farrington, C. 2003. Alaska Salmon Enhancement Program 2002 Annual Report. Regional Information Report 5J03-05. Alaska Department of Fish and Game, Juneau. 40 pp.
- Farrington, C. 2004. Alaska Salmon Enhancement Program 2003 Annual Report. Regional Information Report 5J04-02. Alaska Department of Fish and Game, Juneau. 41 pp.
- Kaeriyama, M., A. Yatsu, M. Noto, and S. Saitoh. 2007. Spatial and temporal changes in the growth patterns and survival of Hokkaido chum salmon populations in 1970–2001. N. Pac. Anadr. Fish Comm. Bull. 4: 251–256. (Available at www.npafc.org).
- Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph. 1996. The NCEP/NCAR Reanalysis 40-year Project. Bull. Am. Meteorol. Soc. 77: 437–471. (Available at www.esrl.noaa.gov/psd/data/timeseries/).
- Karpenko, V.I. 1998. Ocean mortality of northeast Kamchatka pink salmon and influencing factors. N. Pac. Anadr. Fish Comm. Bull. 1: 251–261. (Available at www.npafc.org).
- Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteorol. Soc. 78: 1069–1079. (Available at www.atmos.washington.edu/~mantua/abst.PDO.html).
- McNair, M. 1998. Alaska Salmon Enhancement Program 1997 Annual Report. Regional Information Report 5J98-03. Alaska Department of Fish and Game, Juneau. 36 pp.
- McNair, M. 1999. Alaska Salmon Enhancement Program 1998 Annual Report. Regional Information Report 5J99-02. Alaska Department of Fish and Game, Juneau. 43 pp.
- McNair, M. 2000. Alaska Salmon Enhancement Program 1999 Annual Report. Regional Information Report 5J00-02. Alaska Department of Fish and Game, Juneau. 34 pp.
- McNair, M. 2001. Alaska Salmon Enhancement Program 2000 Annual Report. Regional Information Report 5J01-01. Alaska Department of Fish and Game, Juneau. 35 pp.
- McNair, M. 2002. Alaska Salmon Enhancement Program 2001 Annual Report. Regional Information Report 5J02-04. Alaska Department of Fish and Game, Juneau. 34 pp.

- Orsi, J.A., M.V. Sturdevant, J.M. Murphy, D.G. Mortensen, and B.L. Wing. 2000. Seasonal habitat use and early marine ecology of juvenile Pacific salmon in southeastern Alaska. *N. Pac. Anadr. Fish Comm. Bull.* 2: 111-122. (Available at www.npafc.org).
- Orsi, J.A., E.A. Fergusson, M.V. Sturdevant, W.R. Heard, and E.V. Farley, Jr. 2011. Annual survey of juvenile salmon, ecologically-related species, and environmental factors in the marine waters of southeastern Alaska, May–August 2010. *N. Pac. Anadr. Fish Comm. Doc.* 1342. 87 pp. (Available at www.npafc.org).
- Parker, R.R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. *J. Fish. Res. Board Can.* 25: 757-794.
- Trenberth, K.E., and J.W. Hurrell. 1994. Decadal atmosphere–ocean variations in the Pacific. *Clim. Dynam.* Berlin 9(6): 303-319. (Available at www.cgd.ucar.edu/cas/jhurrell/indices.info.html#np).
- U.S. Geological Survey (USGS). 2011. Surface-water monthly statistics for the nation. USGS 15052500 Mendenhall R., AK. (Available at waterdata.usgs.gov/nwis/monthly/).
- Wertheimer, A.C., and F.P. Thrower. 2007. Mortality rates of chum salmon during their initial marine residency. *Am. Fish. Soc. Symp.* 57: 233-247.
- Wertheimer, A.C., J.A. Orsi, E.A. Fergusson, and M.V. Sturdevant. 2009. Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters: 2008 returns and 2009 forecast. *N. Pac. Anadr. Fish Comm. Doc.* 1201. 20 pp. (Available at www.npafc.org).
- Wertheimer, A.C., J.A. Orsi, E.A. Fergusson, and M.V. Sturdevant. 2011. Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters: 2010 returns and 2011 forecast. *N. Pac. Anadr. Fish Comm. Doc.* 1343. 20 pp. (Available at www.npafc.org).
- White, B. 2005. Alaska Salmon Enhancement Program 2004 Annual Report. Fishery Management Report 05-09. Alaska Department of Fish and Game, Juneau. 44 pp.
- White, B. 2006. Alaska Salmon Enhancement Program 2005 Annual Report. Fishery Management Report 06-19. Alaska Department of Fish and Game, Juneau. 48 pp.
- White, B. 2007. Alaska Salmon Enhancement Program 2006 Annual Report. Fishery Management Report 07-04. Alaska Department of Fish and Game, Juneau. 47 pp.
- White, B. 2008. Alaska Salmon Enhancement Program 2007 Annual Report. Fishery Management Report 08-03. Alaska Department of Fish and Game, Juneau. 48 pp.
- White, B. 2009. Alaska Salmon Enhancement Program 2008 Annual Report. Fishery Management Report 09-08. Alaska Department of Fish and Game, Juneau. 47 pp.
- White, B. 2010. Alaska Salmon Enhancement Program 2009 Annual Report. Fishery Management Report 10-05. Alaska Department of Fish and Game, Juneau. 47 pp.
- White, B. 2011. Alaska Salmon Fisheries Enhancement Program 2010 Annual Report. Fishery Management Report 11-04. Alaska Department of Fish and Game, Juneau. 47 pp.
- Wolter, K., and M.S. Timlin. 1993. Monitoring ENSO in COADS with a seasonally adjusted principal component index. Proceedings of the 17th Climate Diagnostics Workshop, Norman, Oklahoma. NOAA/NMC/CAC, NSSL, Oklahoma Climate Survey, CIMMS and the School of Meteorology, University of Oklahoma, Norman, Oklahoma, USA, pp. 52-57. (Available at www.esrl.noaa.gov/psd/enso/mei/table.html).
- Wolter, K., and M.S. Timlin. 1998. Measuring the strength of ENSO events -- how does 1997/98 rank? *Weather* 53: 315-324.

Why Did the Chum Cross the Road? Genetics and Life History of Chum Salmon in the Southern Portion of Their Range

Orlay Johnson¹, Anna Elz¹, Jeffrey Hard¹, and David Stewart²

¹ NOAA, National Marine Fisheries Service, Northwest Fisheries Science Center,
2725 Montlake Blvd. East, Seattle, WA 98112, USA

² Oregon Department of Fish and Wildlife, Northwest Region Fish Division,
3406 Cherry Avenue NE Salem, OR 97303, USA

Keywords: chum salmon, genetics, range contraction, run-timing, climate change

The objectives of the study are to identify spawning chum salmon (*Oncorhynchus keta* Walbaum in Artedi, 1792) in the portion of their range south of the Columbia River, document the history of these populations, and characterize their genetics and life history. We hoped to determine if these fish were remnants of populations originating in California and southern Oregon that have migrated northward, strays from hatcheries that flourished in the 1970s and 1980s, strays from the Columbia River, or indigenous natural populations. Further, we attempted to determine if these fish display any unique genetic, behavioral, or morphological (small body, lower jaw, or kype size) characteristics that may provide a survival advantage in present or future environmental conditions.

We know that chum salmon historically had the widest distribution of any anadromous Pacific salmonid (Bakkala 1970; Salo 1991; Johnson et al. 1997). In the 1900s, chum spawned southward to the San Lorenzo River in Monterey, California, (Scofield 1916) and at least as far inland as 322 river kilometer (rkm) upstream in the Sacramento River (37° 50'N 122°W; Hallock and Fry 1967; Bakkala 1970; Fredin et al. 1977; Groot and Margolis 1991). On the Columbia River, chum salmon migrated at least as far inland as Celilo Falls near the present-day Dalles Dam (309 rkm), and there are newspaper reports that in some years this range reached 628 rkm to the mid-Snake River near Walla Walla, Washington, and the present-day Lower Granite Dam (Nehlsen et al. 1991; Johnson et al. 1997).

Early surveys reported that chum salmon were present in all streams from San Francisco to the Bering Straits (Jordan and Gilbert 1881; Jordan and Jouy 1881). In a series of early surveys of streams between the Sacramento and Columbia rivers in the early 1900s, Snyder (1908) reported that chum salmon were widely distributed and the most abundant salmon present. Adult chum salmon were also “said to be abundant in the fall, from Sacramento northward” (Eigenmann 1890). However, it should be noted that the surveys by Snyder’s party were primarily conducted in June, not a time when chum juveniles or adults would be found today. More recently, chum salmon were reported by Kostow (1995) to spawn at least as far south as Oregon’s Coquille River, while Nehlsen et al. (1991) suggested that relic chum salmon populations may occur as far south as the Elk and Sixes rivers, Oregon, at 42.8°N.

Thus, an understanding of the life history, genetics, and other biological information of chum salmon in the southern portion of their range are very important as climate change and human development begin to impact critical chum salmon habitat further north.

Recovery plans for Columbia River and Hood Canal chum salmon are presently being implemented and Oregon and other southern stocks may provide information and/or donor populations to help in the restoration and survival of other depleted populations.

Tissue samples were collected along the Oregon and Washington coasts and the Columbia River between November 15 and December 15 in 2004-2009 (Table 1). Samples in Washington State between 1995 and 2001 are from archived collections stored at the Washington Department of Fish and Wildlife (WDFW) labs in Olympia. Samples collected in the field were placed in vials containing alcohol in the field and stored at the Northwest Fisheries Science Center (NWFSC) in Seattle, Washington.

We genotyped 452 chum salmon from 14 streams collected over multiple years using 17 microsatellite DNA loci (Table 1) as described in Hillis et al. (1996), Small et al. (2006) and by L. Park (NWFSC, personal communication). Analyses were performed with sample sets from different year classes separated for each population and repeated with the year classes pooled for each population. Relationships among multiple and combined year classes for each of the sample populations were constructed. Overall tree topologies were similar, so we present the combined-years data set. Genetic analysis was conducted at the NWFSC, and standard genetic protocols and statistical analyses were employed using FSTAT2.9.3 (Goudet 2001) and GENEPOP 3.3 (Raymond and Rousset 1995) with genetic distances plotted in a neighbor-joining (NJ) tree using Populations 1.2.30 (Langella 1999).

Table 1. Location and year of chum salmon tissue samples collected along the Washington (WA) and Oregon (OR) coasts and the Columbia River. LCR is Lower Columbia River; S. OR is southern Oregon; N. OR is northern Oregon; SPS is southern Puget Sound.

Population	Drainage	Region	Year	No. Samples
Moss Cr.	Miami R.	S. OR	2004	9
Mill Cr.	Yaquina R.	S. OR	2006-09	60
Yaquina R.	Yaquina R.	S. OR	2004-09	55
Bear Cr.	Siletz R.	Mid-coast OR	2006-08	8
Coal Cr	Kilches	Mid-coast OR	2004, 2006	37
Tillamook R.	Tillamook R.	Mid-coast OR	2006, 07, 08	88
E. Foley Cr.	Nehalem R.	N. OR	2004-09	100
Necanicum R.	Necanicum R.	N. OR	2006	17
Ives Island	LCR	Columbia R.	2002	27
Lewis R.	LCR	Columbia R.	2003	22
Hardy Cr.	LCR	Columbia R.	1997	18
Grays R.	LCR	Columbia R.	2001	25
Hamilton Cr.	LCR	Columbia R.	1992, 1996	34, 22
Chinook River	Coastal CR	Columbia R.	1998	50
Dewatto R.	Hood Canal	Hood Canal (fall run)	1998	39
Blackjack Cr.	SPS	SPS (Summer run)	1996	36
Ellsworth Cr.	Willapa Bay	WA coast	1998	50
Bitter Cr.	Willapa Bay	WA Coast	1996	50
Satsop R.	Grays Harbor	WA Coast	1996	60

Preliminary results indicate that the majority of collections in the study deviated from Hardy-Weinberg equilibrium (HWE) with homozygote excess indicative of their small population numbers and small effective population sizes. There was little heterozygote excess observed, which suggests there was little outbreeding in these coastal groups. The genetic data revealed little heterogeneity among samples of chum collected in different Oregon and Washington coastal rivers. Differences between the coastal fish and Columbia River fish are small and reflect a close relationship. Kilchis River samples appear to be most closely related to Columbia River fish, although the Kilchis River is not geographically as near the mouth of the Columbia River as several other coastal rivers in this study. Preliminary analysis indicates there are few unique or private alleles in the coastal populations, and this suggests there are not “unique populations” from further south migrating into northern regions, but that these coastal fish are natural, indigenous populations.

In our genetics analysis we found heterogeneity among regional groups (e.g., Puget Sound and Oregon Coast) and some spatial structure among Washington and Oregon coastal samples. However, poor sample quality precludes more detailed conclusions at this time. Columbia River chum salmon samples also showed genetic differences from coastal chum salmon, but at a lower level than from other areas.

Life history data collected followed protocols established by Oregon Department of Fish and Wildlife (ODFW) and in the NOAA chum salmon status review (Johnson et al. 1997). The ODFW and WDFW staff collected historical run-timing and other life history data. Preliminary results of size, age, and meristic fin counts did not indicate any differences among chum salmon on the coast, or in the Columbia River and Puget Sound. Preliminary results of run timing analysis from datasets provided by WDFW and ODFW indicate that there is a narrower time of return for the Oregon coastal fish than for Washington fish. However, analyses are ongoing and often observers did not use consistent methods, so comparisons among rivers are difficult.

From historical records it appears that chum salmon once ranged in healthy numbers from southern Oregon to the Columbia River, and they were present in significant numbers south to mid-California. Populations began a decline in the southern-most portion of the range in the mid 1880s, and by the 1960s the only consistent populations in this region were in northern Oregon. However, even in northern Oregon chum salmon have declined dramatically since the 1950s.

Special thanks to the many field personnel who have helped us over the years. From ODFW we thank: Mark Lewis, Corvallis Office; Michael Sinnot, North coast District Office; and Robert Buckman, District Biologist, Central Coast Office. We thank WDFW staff for help with securing samples and field work, especially Jennifer Van Barga and Maureen Small, Genetics Division, Olympia. Dan Rawding, Vancouver Washington Office helped with sample identification. Valerie Tribble and Gil Lensegrave of the WDFW Data Group provided run-timing data for Washington chum salmon. Also we appreciate the assistance provided by Curt Holt and Bryce Glaser, WDFW Coastal Group. Eric Loudenslager, Humboldt State University, Arcata; and Peter Moyle, UC Davis, also provided samples and advice. Special thanks to Laurie Weitkamp and field crews at the Newport Oregon Field Station, NWFSC.

REFERENCES

- Bakkala, R.G. 1970. Synopsis of biological data on the chum salmon, *Oncorhynchus keta*, (Walbaum) 1792. FAO Fish. Synop. 41. US Fish. Wildl. Serv. Circ. 315. 89 pp.
- Eigenmann, C.H. 1890. The food fishes of the California fresh waters. Biennial Report 11, 1888-1890 (11): 53-65. Calif. Fish Game, Sacramento.
- Fredin, R.A., R.L. Major, R.G. Bakkala, and G. Tanonaka. 1977. Pacific salmon and the high-seas salmon fisheries of Japan. NWAFC Processed Rep. 324 pp.
- Goudet, J. 2001. FSTAT, a program to estimate and test gene diversities and fixation indices (version 2.9.3). Updated from Goudet (1995). (Available at www.unilch/izea/software/fstat.html).
- Groot, C., and L. Margolis. 1991. Pacific salmon life histories. UBC Press, Vancouver. 564 pp.
- Hallock, R.J., and J.D.H. Fry. 1967. Five species of salmon, *Oncorhynchus*, in the Sacramento River, California. Calif. Fish Game, Fish. Bull. No. 53(1): 5-22.
- Hillis, D.M., B.K. Mable, and C. Moritz. 1996. Molecular systematics. Sinauer Associates, Inc., Sunderland, Mass. 655 pp.
- Johnson, O.W., W.S. Grant, R.G. Kope, K. Neely, F.W. Waknitz, and R.S. Waples. 1997. Status review of chum salmon from Washington, Oregon, and California. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-NWFSC No. 32.
- Jordan, D.S., and C.H. Gilbert. 1881. List of the fishes of the Pacific coast of the United States, with a table showing the distribution of the species. Proc. U.S. Nat. Mus. 3: 452-458.
- Jordan, D.S., and P.L. Jouy. 1881. Check-list of fishes from the Pacific coast of North America, distributed by the Smithsonian Institution in behalf of the United States National Museum, 1881. Proc. U.S. Nat. Mus. 4: 1-18.
- Kostow, K. 1995. Biennial report on the status of wild fish in Oregon. Ore. Dep. Fish Wildl. Internal Report. (Available from ODFW, P.O. Box 59, Portland, OR 97207.)
- Langella, O. 1999. Populations: a population genetic software. 1.2.28 ed: CNRS UPR9034.
- Nehlsen, W., J.E. Williams, and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2): 4-21.
- Raymond, M., and F. Rousset. 1995. Genepop (version 1.2), population genetics software for exact tests and ecumenicism. J. Hered. 86: 248-249.
- Salo, E.O. 1991. Life history of chum salmon, *Oncorhynchus keta*. In Pacific salmon life histories. Edited by C. Groot and L. Margolis. UBC Press, Vancouver. pp. 231-309.
- Scofield, N.B. 1916. The humpback and dog salmon taken in San Lorenzo River. Calif. Fish Game, Fish. Bull. 2(1): 41.
- Small, M.P., A.E. Frye, J.F. Von Barga, and S.F. Young. 2006. Genetic structure of chum salmon (*Oncorhynchus keta*) populations in the lower Columbia River: are chum salmon in Cascade tributaries remnant populations? Conserv. Genet. 7: 65-78.
- Snyder, J.O. 1908. The fishes of the coastal streams of Oregon and northern California. Bull. U.S. Bureau Fish. 27 (21 Oct. 1908): 153-189.

Estimation of the Influence of Some Climatic Factors on the Abundance of Asian Pink and Chum Salmon

Alexander V. Bugaev and O.B. Tepnin

*Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO),
18, Naberezhnaya Str., Petropavlovsk-Kamchatsky 683602, Russia*

Key words: pink salmon, chum salmon, catch trends, climatic indices, time series

Salmon stock abundance currently shows unusual growth against the background of changing climate conditions on the Earth, especially in the North Pacific. The patterns described by these processes raise lively interest and discussion among researchers. Some experts believe that fish production responds to climate-ocean changes (Klyashtorin and Lyubushkin 2007; Beamish 2008; Kaeriyama et al. 2009; Kotenev et al. 2010). Others consider current processes as normal and to be within observed natural variation of long-term processes at the ecosystem level (Shuntov and Temnykh 2009). Clearly all research indicates that the influence of biotic and abiotic factors on a particular species or ecosystem is complex and mostly indirect.

We analyzed pink and chum salmon in our research because both species are highly abundant in Asia. Russia and Japan are the countries that catch all of the pink and chum salmon commercial catch in the region. In the last 100 years, pink and chum salmon catches have fluctuated from 50 to 400 million fishes (Irvine et al. 2009). We think that commercial catch statistics can be used as a reliable indicator of stock abundance and that it can represent the long-term trends in abundance dynamics.

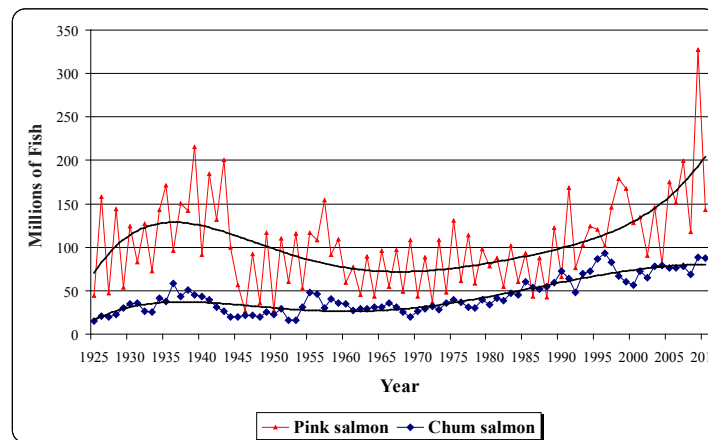


Fig. 1. Dynamics of the combined river, near shore, and drift-net catches of Asian pink and chum salmon (millions of fish), 1925-2010.

This analysis was a kind of test, and it should be noted that research like this often provides preliminary insight. Experts in different countries often correlated one or two climate indices to production of particular species in a geographic region. When close correlations were not revealed, researchers often ignored the use of alternative climate indices. When associations were found, investigators tried to estimate the correlations for particular time intervals. We tested nine climate indexes (AFI, ALPI, NP, PCI, GLB.Ts+dSST, N.HEMI, PDO, LOD, Sun Spot) that reflect meteorological and ocean conditions in the North Pacific, independent of whether associations with salmon catches had been found previously, or not. With this exploration, we did not intend to give an explanation for the nature of associated patterns between salmon abundance and climate.

We analyzed the dynamics of pink and chum salmon catches in Asia in 1925-2010 (Fig. 1). Trends in the catch density of pink and chum salmon were similar. Pink salmon catches showed more extensive fluctuations at the beginning and at the end of the time interval. The pink salmon stocks are almost entirely from the Russian Far East because the abundance of wild and hatchery pink salmon produced in Japan is low in comparison. As for chum salmon, the situation is different. The principle increase in the abundance in the 1990-2000s was due to a contribution of approximately 70% by Japanese hatchery production.

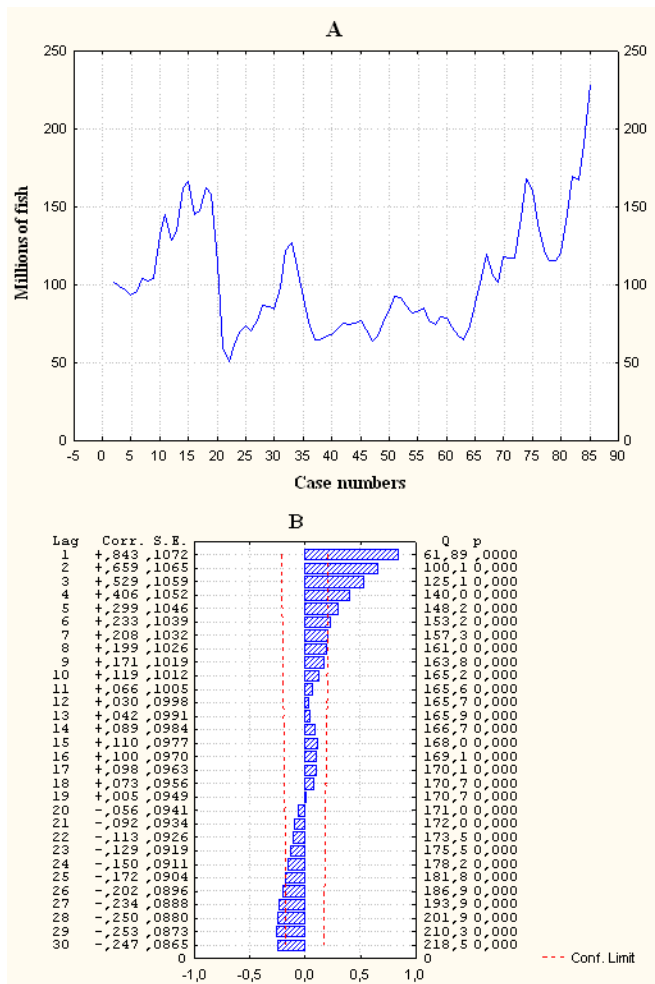


Fig. 2. Diagrams showing the Asian pink salmon catch time series for 1925-2010 using a 2-point moving average (A, upper panel), and averaged autocorrelation function (B, lower panel). Lag is the time lag, Corr. is the correlation, S.E. is the standard error, Q is the white-noise estimate, P is the probability.

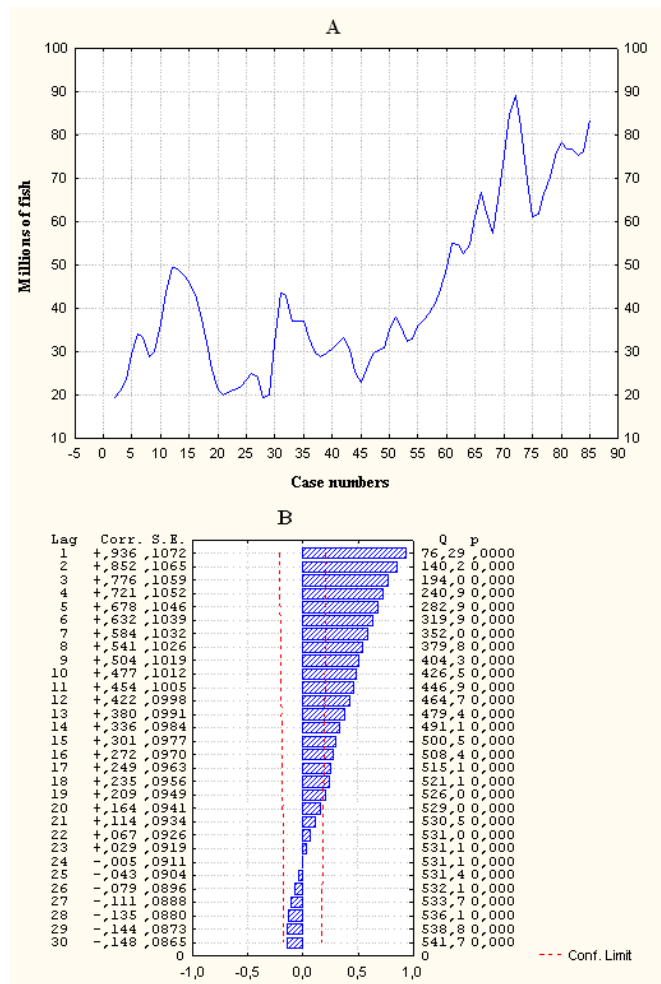


Fig. 3. Diagrams showing the Asian chum salmon catch time series for 1925-2010 using a 2-point moving average (A, upper panel), and averaged autocorrelation function (B, lower panel). Lag is the time lag, Corr. is the correlation, S.E. is the standard error, Q is the white-noise estimate, P is the probability.

Table 1. Pearson's correlation coefficients obtained from comparison of the catches of Asian pink and chum salmon and climatic indices based on a 2-point moving average. $N_{line} = 84, p < 0.001$.

Indexes		Pink	Chum	Pink + Chum
No	Code			
1	AFI	0.30	0.28	0.33
2	ALPI	0.18	0.25	0.23
3	NP	-0.18	0.03	-0.12
4	PCI	0.17	-0.38	-0.03
5	GLB.Ts + dSST	0.54	0.89	0.74
6	N.HEMI	0.64	0.82	0.78
7	PDO	0.21	0.30	0.27
8	LOD	-0.41	-0.06	-0.32
9	Sun Spot	-0.19	-0.13	-0.19

Time-series analysis has demonstrated that more accurate results can be obtained by using the 2-point sliding mean (Figs. 2 and 3). We used the 2-point sliding mean for the time sequence of salmon catch and climate indices. This approach helped remove low- and high-frequency components of the time-series and smoothed the data with no loss in general dynamics.

The function of pink salmon autocorrelation was shaped in a sinusoidal wave (Fig. 2). The fading sequence demonstrated an alternation of sign at the 20th lag (step). The unstable sequence can be used in further analysis because biological periodicity in pink salmon abundance fluctuations in even- and odd-numbered years could be excluded. The time sequence for chum salmon is stable in even- and odd-numbered years, making it suitable for further correlation analysis (Fig. 3).

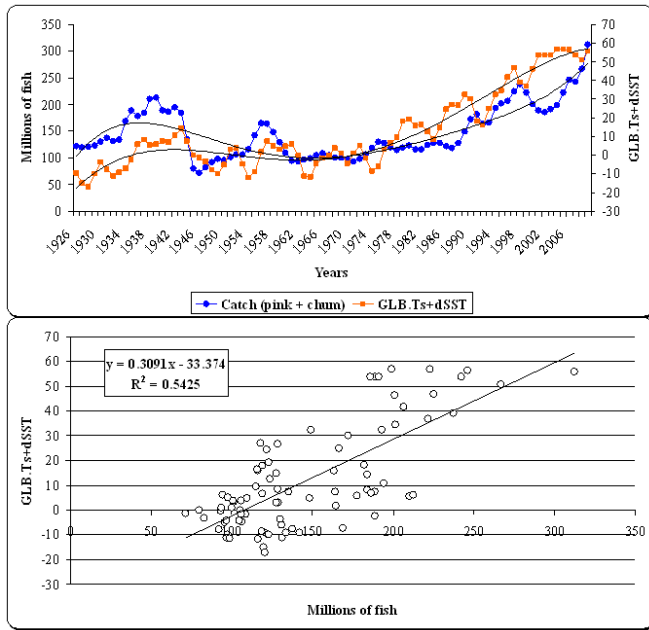


Fig. 4. Diagrams showing the influence of the climate indices GLB.Ts+dSST on the catch of Asian pink and chum salmon (millions of fish). Data represent the 1925-2010 time period using a 2-point moving average.

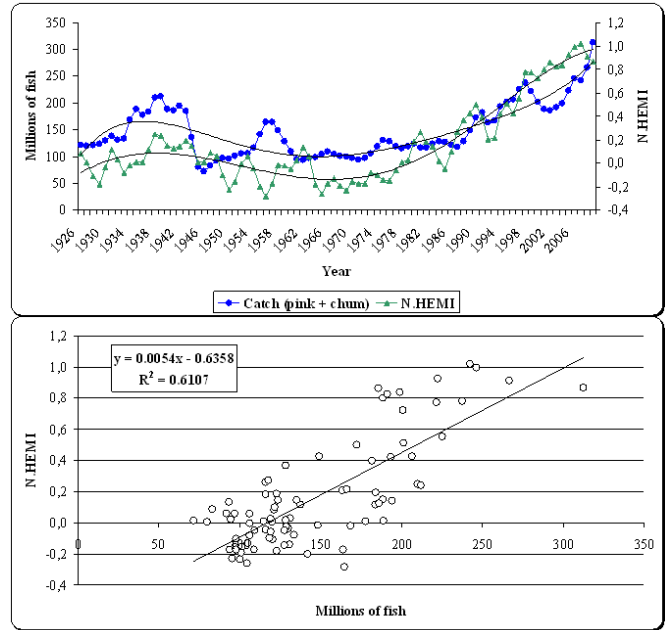


Fig. 5. Diagrams showing the influence of the climate index N.HEMI on the catch of Asian pink and chum salmon (millions of fish). Data represent the 1925-2010 time period using a 2-point moving average.

Table 2. Multiple regression of Asian pink and chum salmon catches and climatic indexes based on a 2-point moving average. $N_{line} = 84$, $df = 5.72$, $p < 0.001$. R is the coefficient of multiple correlation, b_0 is the estimated intercept, $Beta$ is the regression coefficients, SE is the standard error of the estimate, F is the F-statistic, df is the degrees of freedom, P is the probability.

Dependent variable (catches, millions of fish)	Predictors	R	b_0	$Beta$	SE	F
Pink	AFI	0.61	96.66	-0.30	24.63	8.40
	ALPI			-0.19		
	GLB.Ts+dSST			-0.46		
	N.HEMI			0.92		
	PDO			0.58		
Chum	AFI	0.88	34.45	-0.24	8.35	51.23
	ALPI			-0.17		
	GLB.Ts+dSST			0.59		
	N.HEMI			0.30		
	PDO			0.42		
Pink + Chum	AFI	0.77	131.11	-0.32	26.96	20.85
	ALPI			-0.21		
	GLB.Ts+dSST			-0.09		
	N.HEMI			0.80		
	PDO			0.61		

The highest correlation was found between the catches of Asian pink and chum salmon and indices of global air and surface water temperature anomalies (GLB.Ts+dSST and N.HEMI; Table 1; Figs. 4 and 5). This correlation demonstrates a stable character for both pink and chum salmon. The correlation coefficients for five of the nine climate predictors and chum salmon were higher than the coefficient for same climate predictors and pink salmon ($R = 0.82-0.89$ and $R = 0.54-0.64$, respectively). The summary coefficient for the two species combined was also high ($R = 0.74-0.78$). Correlation coefficients of the other four climate predictors and salmon catch were lower ($R = \pm 0.3$). In general, we did not observe strong correlations between Asian pink and chum salmon catch dynamics and the climate indices. In view of the more than 80-year span of the time series, we think the estimations we obtained were statistically real.

We investigated the complex character of the indirect and mutual influence of several climate factors (AFI, ALPI, GLB.Ts+dSST, N.HEMI, PDO) on the catch dynamics of Asian pink and chum salmon using multiple regression (Table 2; Fig. 6). Similar to the correlation analysis described above, the highest correlation ($R = 0.88$) between the climate indices and salmon catch was demonstrated for chum salmon. The correlation for pink salmon and climate indices was not as tight ($R = 0.61$). The coefficient of correlation between both species combined and climate indices was $R = 0.77$.

The data we obtained can be used to further explore the association between climate factors and the abundance of pink and chum salmon. On our view, real progress in this field can be achieved when more thorough analysis of the linkages between climate and aquatic biota focuses on the complex multi-factor ecosystem conditions in the Bering Sea and North Pacific Ocean.

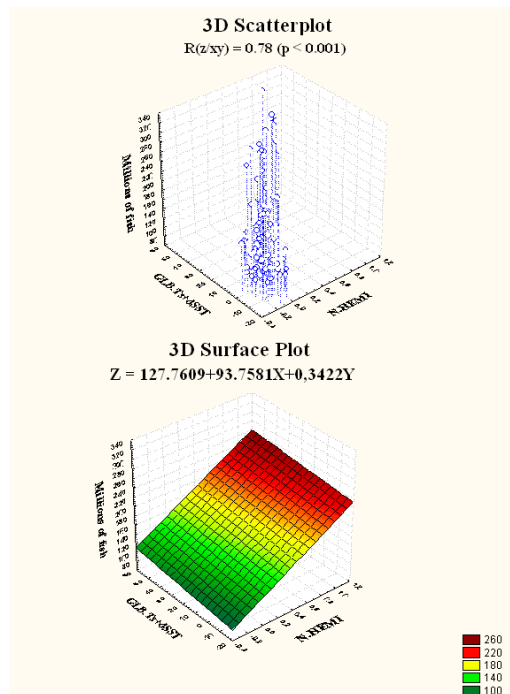


Fig. 6. Three-dimensional diagrams showing the influence of the climate indices GLB.Ts+dSST and N.HEMI on the catch of Asian pink and chum salmon (millions of fish). Data represent the 1925-2010 time period using a 2-point moving average.

REFERENCES

- Beamish, R.J. (*Editor*). 2008. Impacts of climate and climate change on the key species in the fisheries in the North Pacific. PICES Sci. Rep. 35. 218 pp.
- Irvine, J.R., Fukuwaka M., Kaga T., Park J., Seong K.B., Kang S., Karpenko V.I., Klovach N.V., Bartlett H., and E. Volk. 2009. Pacific salmon status and abundance trends. N. Pac. Anadr. Fish Comm. Doc. 1199. 153 pp. (Available at www.npafc.org).
- Kaeriyama, M., H. Seo, and H. Kudo. 2009. Trends in run size and carrying capacity of Pacific salmon in the North Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull. No 5: 293-302. (Available at www.npafc.org).
- Klyashtorin, L.B., and A.A. Lyubushin. 2007. Cyclic climate changes and fish productivity. VNIRO Publishing, Moscow, Russia. 223 pp. (In English).
- Kotenev, B.N., M.A. Bogdanov, A.C. Krovnin, and G.P. Muryi. 2010. Climate changes and catches dynamic of Far Eastern salmon. Vopr. Prom. Oceanology. VNIRO Publishing, Moscow. 7(1): 60-92. (In Russian).
- Shuntov, V.P., and O.S. Temnykh. 2009. Current status and tendencies in the dynamics of biota of the Bering Sea macroecosystem. N. Pac. Anadr. Fish Comm. Bull. No 5: 321-331. (Available at www.npafc.org).

Cyclic Climate Changes and Production of Pacific Salmon: The Possibility of Forecasting

Leonid Klyashtorin and Natalia Klovach

*Russian Federal Research Institute of Fisheries and Oceanography (VNIRO),
17, V. Krasnoselskaya, Moscow 107140, Russia*

Long-term fluctuations of Pacific salmon production reflect the dynamics of climatic and ecological conditions over the North Pacific. The PDO and ALPI, the main climatic indices in the North Pacific, show synchronous 60- to 65-year fluctuations with clear maxima in the 1940s and early 2000s. The PDO is based on average annual North Pacific sea surface temperatures, which is a main ecological factor affecting biological productivity in the region. The 150-year sea surface temperature time series in the Gulf of Alaska shows the same dynamics as the PDO and ALPI, i.e., 60- to 65-year regular fluctuations. The total Pacific salmon catch in the 20th and early 21st century fluctuated in line with the PDO and ALPI dynamics: a clear maximum in the 1920-1940s followed by a depression in the 1950-1970s and a new maximum in the 1990-2000s. Three commercial salmon species, chum, sockeye and pink salmon, are known to provide approximately 95% of the total Pacific salmon production. Chum and sockeye production passed their maximum at the end of 20th century, whereas pink salmon production (both Asian and North American) still continues to increase slowly. The total Pacific salmon catch dynamics passed its maximum in the early 2000s, again in agreement with the dynamics of both the PDO and ALPI indices. We have reasons to expect the next descending trend in the PDO will likely start in the 2010-2020s and it will be accompanied by a corresponding decline in Pacific salmon. A simple stochastic model based on the 60- to 65-year cyclic climate oscillation can be used to foresee the main trends in Pacific salmon populations on a decadal scale. The model indicates a general decrease in Pacific salmon production is likely to take place in the 2010-2020s.

Evaluation of the Habitat for Downstream Migration of Chum Salmon in the Wusuli River Using a Suitability Index

Wei Liu¹, Pei-Rong Zhan¹, Ji-Long Wang¹ and Xiong-Wei Liang^{1,2}

¹Heilongjiang River Fishery Research Institute, Chinese Academy of Fishery Sciences, Harbin 150070, China

²Wildlife Resource College, Northeast Forestry University, Harbin 150040, China

Keywords: chum salmon, downstream migration, habitat suitability index, HSI; instream flow incremental methodology, IFIM, Wusuli River

An animal's habitat is its dwelling place and contains a combination of biotic and abiotic environmental factors and resources that an animal depends on to maintain normal life (Chen and Gao 1992; Yan and Chen 1998). Water reductions and deterioration of ecological functions in aquatic habitats lead to discontinuity of spatial distribution within the ecosystem. This exerts direct impact on species' behavior, population size, and survival (Young et al. 1991). Developed from theories on animal habitat selection, ecological niche differentiation, and restriction factors, the Habitat Suitability Index (HSI) is a tool used to evaluate habitat by constructing functional relationships. The HSI model and the Instream Flow Incremental Methodology (IFIM) when used together can help scientists determine the condition of salmon habitat (Duker 1977; Kaeriyama et al. 1978).

Chum salmon (*Oncorhynchus keta*) is a unique species in the North Pacific, and they can migrate over 3,000 km in their river migrations as juveniles and adults (Liu et al. 2010a). Chum salmon is an important ecological environmental indicator, and it is of high scientific and economic value (Bakkala 1970). The migrations of salmon connect the fresh water, estuary, and ocean ecosystems of the North Pacific, which integrates the food chain of water, land, and air (Helle 1979).

The Heilongjiang and Wusuli rivers are major tributaries of the Amur River. The Heilongjiang River and the Wusuli River and its tributaries contain important spawning sites for chum salmon (Liu et al. 2010b; Tang et al. 2010). The Wusuli River is located (43°06'-48°17'N, 129°10'-137°53'E) between China and Russia: China is westward of the main channel centerline and Russia is eastwards of it (Fig. 1). The Wusuli River is 905 km long with a main stem of 492 km. The main tributaries include the Muling, Abuqin, and Naoli Rivers located in China, and the Yiman, Bijin, Heluo (Huoer) Rivers located in Russia. The Wusuli River watershed size is 187,000 km², of which 61,500 km² is located in China. The Wusuli River basin encompasses more than 170 small and large tributaries, most of which are supplied mainly by rain and snow. The upper river and midstream areas pass through the longitudinal valley between China's Wanda Mountain and Russia's Sichote-Alin Mountain and it flows onto a flood-plain mire and wetland. Normal water depth is 2-5 m. There is an average of 148 days of freeze-up in most years and maximum ice thickness is 1.15 m. Date of ice break-up on the river was April 20 in 2010 and April 15 in 2011. There is adequate water in spring with the supplement of abundant snow melt, and water temperature is relatively low. China has established the National Nature Reserve of Heilongjiang Treasure Island, the Naoli River, the Sanjiang Wetland, and the Provincial Nature Reserve of Wusuli. These reserves have completely enclosed the original wetland ecosystem on the Sanjiang plain. These natural reserves have been placed on the "List of International Important Wetlands".

China began successful artificial propagation of chum salmon in the Haiqing section of Wusuli River in the 1950s and established a chum salmon breeding station in Raohe County. Chum salmon habitat now faces deterioration from a variety of both natural and artificial impacts, including climate warming, pollution, vegetation and wetland reduction, decreasing water supply, shrinkage of chum distribution, blockage of fish migration, deterioration of spawning sites, and overfishing. These factors have endangered the species in this area. Because microsatellite analysis of chum salmon genetic diversity in the Heilongjiang River indicates stock declines are not caused by genetic factors, there is a possibility of rebuilding the stock (Chen et al. 2004). However, it is uncertain whether the ecological environment in the river is recoverable to the point of producing chum salmon.

We evaluated the Wusuli River for its suitability as a downstream migration corridor for chum salmon. We used the HSI and IFIM in our study to help us find feasible suggestions for ecological protection and to provide a scientific basis of achieving chum salmon population recovery. Our study area included the Hutou, Raohe, and Haiqing sections of the Wusuli River (Fig. 1). These sites were selected because of their historical importance as chum salmon spawning and migration sites.

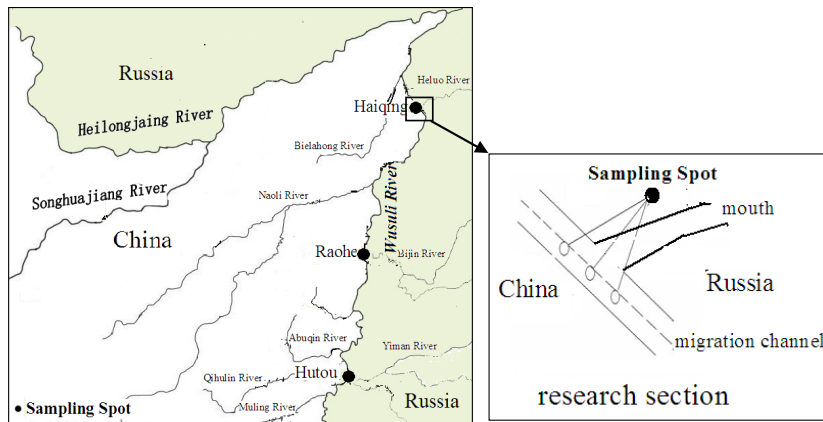


Fig. 1. Map of the region of the Wusuli River with inset showing sampling locations.

Three replicate sampling stations were located in the junction of the Wusuli River and three other rivers: Heluo River, Bijin River, and Yiman River (Fig. 1). Stations were situated about 30-50 m above or below the river mouth along the main stem for a total of nine sampling stations. We collected samples continuously for 10 days from the last third of April to the beginning of May 2010, which is during the time period of downstream chum salmon migration. Temperature, dissolved oxygen (DO), pH value, transparency (SD), substrate, depth, and flow velocity data were collected at 30-50 cm water depth. Alkalinity (Alk), hardness (TH), NH_4^+ , NO_2^- , COD (chemical oxygen demand), and plankton samples were collected and brought to the laboratory for determination by national standard methodologies. The comprehensive pollution index method using pH, COD, DO, NH_4^+ , TN (total nitrogenous-compounds), and TP (total phospho-compounds) were measured according to surface water and environmental quality grading standards. Plankton diversity was based on the evaluation standard for aquatic organism in rivers and reservoirs using the Shannon-Wiener index. Values presented for each section are averages of the three stations.

The HSI for chum salmon downstream migration in relation to water temperature and DO are shown in Fig. 2-1 and 2-2 and results from model conditions for water temperature, flow velocity, depth and substrate for chum salmon during downstream migration are shown in Figs. 2-3 through 2-6. The minimum HSI value by factor was determined to be the final HSI value at each sampling site. The critical values used to evaluate the HSI and IFIM habitat were the same. The habitat was suitable for downstream migration of chum salmon if $0.8 \leq \text{HSI}$ or $\text{IFIM} \leq 1$; habitat was less suitable if $0.6 \leq \text{HSI}$ or $\text{IFIM} < 0.8$; habitat was marginally suitable if $0.4 \leq \text{HSI}$ or $\text{IFIM} < 0.6$; and habitat was not suitable for chum salmon migration if HSI or $\text{IFIM} < 0.4$.

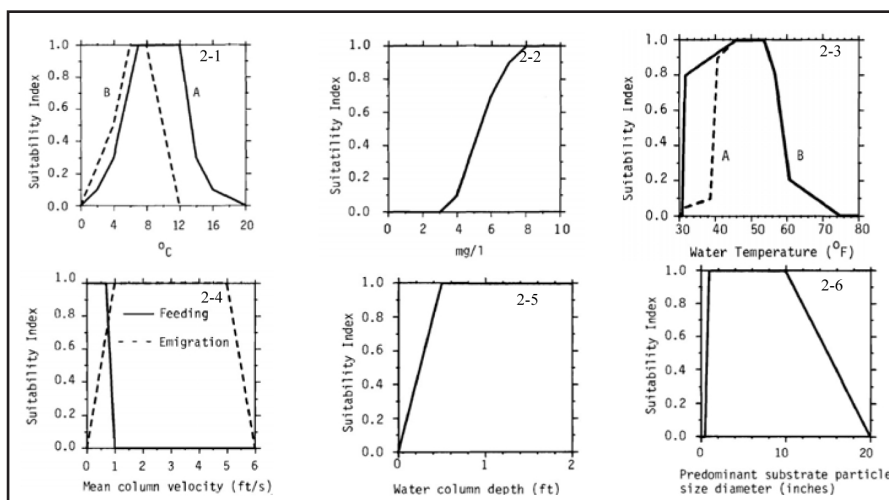


Fig. 2. Temperature, DO, substrate particle size, velocity, and water column depth in relation to the HSI. Fig. 2-1: solid line A is the highest temperature during the day and dotted line B is the lowest temperature. Fig. 2-3: solid line is the downstream migration model, and dotted line is the feeding model. Fig. 2-4: solid line is feeding period, and dotted line is condition in the downstream migration channel.

Table 1. Summary of the HSI values with respect to temperature and DO for evaluation of downstream migration habitat of chum salmon in the Wusuli River.

Survey section	Temperature		HSI of T°	DO (mg/l)	HSI of DO	HSI
	high	low				
Hutou	7.5	6.4	1.0	8.9	1	1.0
Raohe	6.5	5.6	0.9	9.0	1	0.9
Haiqing	6.2	5.4	0.85	9.1	1	0.85

According to our results, water temperature HSI values were 0.85-1.0 and dissolved oxygen HSI values were 1.0 (Table 1). Water temperature at the survey sections ranged from 6.2 to 7.5°C. Water temperature and DO in the Hutou, Raohe, and Haiqing sections declined one by one. These three sections are distributed from upstream to downstream and from south to north, which follows the geographical law of hydrology, weather, and climate. Based on the minimum HSI value of temperature and DO, we concluded the HSI of the three Wusuli River sections (Haiqing, Raohe and Hutou, values 0.85, 0.9 and 1.0, respectively) demonstrated the Wusuli River main stem was suitable habitat for chum salmon downstream migration.

Table 2. Results of the IFIM model for quality of the habitat for downstream migration of chum salmon. Vel is water velocity; Depth is water depth; Sub is substrate particle size diameter; T is water temperature.

Survey section	Vel (m·s ⁻¹)	IFIM of Vel	Depth (m)	IFIM of Depth	Sub (cm)	IFIM of Sub	T (°C)	IFIM of T	IFIM
Hutou	0.6	1	7	1	2	0.8	7.5	1	0.8
Raohe	0.7	1	8	1	3	1	6.5	0.95	0.95
Haiqing	0.7	1	8	1	2.5	0.99	6.2	0.93	0.93

The IFIM values ranged from 0.93 to 1.0; flow velocity ranged from 0.6- to 0.7 m·s⁻¹ and all IFIM of velocity values were 1.0 (Table 2). Water depths ranged from 7 to 8 m, and all IFIM of depth values were 1.0. Substrate particle diameters ranged from 2.5 to 3 cm and IFIM of substrate values ranged from 0.8 to 1.0. Results reveal the minimum IFIM of the Hutou section was 0.8, the Raohe section was 0.95, and the Haiqing section was 0.93. These results showed all sections studied were suitable habitat for downstream migration of chum salmon.

Table 3. Results of water quality analysis to evaluate the habitat for downstream migration of chum salmon. SD is transparency; Alk is alkalinity; TH is water hardness, COD is chemical oxygen demand, TN is total nitrogenous compounds, and TP is total phospho-compounds.

Survey station	SD (m)	Alk (mg/L)	TH (CaCO ₃ mg/L)	pH	COD (mg/L)	NH ₄ ⁺ (mg/L)	NO ₂ ⁻ (mg/L)	TN (mg/L)	TP (mg/L)
Hutou	0.8	0.32	8.9	7.5	7.9	0.0089	0.0003	0.24	0.053
Raohe	0.8	0.26	0.51	7.8	7.8	0.0075	0.0003	0.22	0.013
Haiqing	1.2	0.44	0.84	7.8	8.3	0.1	0.0002	0.25	0.041

Analysis of water quality variables, NH₄⁺, NO₂⁻, TN (total nitrogenous compounds), and TP (total phospho-compounds), indicated values were within the normal range for downstream migration of chum salmon (Table 3). Input of these parameters into the comprehensive pollution index indicated that the Hutou, Raohe, and Haiqing sections were all lightly polluted, but could satisfy water quality standards for migrating salmon. Water hardness (TH) values varied widely from 0.51 to 8.9 mg/L. The Hutou section had the highest relative hardness, which may be caused by the large amount of calcium carbonate brought into Wusuli River during snow melt. The COD was high and ranged from 7.8 to 8.3. These high values were related to the unique regional environment in Northeast China.

The average density of plankton in each sampling section varied widely. Results showed the average diatom density was 78.01% of total phytoplankton. The Shannon-Wiener index for phytoplankton was 1.033. The water quality was determined to be moderately polluted according to the evaluation standard of aquatic organisms in rivers. Zooplankton was dense in the spring, averaging about 89.9% of total plankton. There were 23 zooplankton species observed at each section including four types of protozoa, 14 rotifers, three cladocerans, two copepods, and some larval forms. Rotifers were the most abundant zooplankton species. The Shannon-Wiener index for zooplankton was 1.51. The water quality was determined to be as slightly polluted according to the evaluation standard of aquatic organisms in reservoirs. The high density of zooplankton in spring could provide prey for juvenile chum salmon during their downstream migration.

Strong chum salmon runs are beneficial to human society because healthy chum salmon stocks facilitate social and economic development. Our results showed the Wusuli River and its tributaries have suitable habitat for chum salmon downstream migration. Therefore, it is necessary to insist on prioritizing protection of their habitat.

Forest and wetlands can maintain supply of water to rivers in the dry season and maintain water quantity and depth, a necessity for normal downstream migration. Increasing protection of surrounding forest and wetlands and returning land located along the river into these habitat types will reduce sedimentation in rivers and improve environmental quality. Flushing of sediment from farms and bare land into the river can cause deterioration of salmon habitat. Projects, such as dredging, dam construction, sand excavation, and stone removal, cause serious damage to water quality and substrate by making the river turbid and causing sludge to accumulate on the river bottom. Sludge in key sections of the Wusuli River should be removed to reveal the gravel substrate and give chum salmon a suitable environment for spawning. It is also necessary to supervise and manage the pollution along the river so domestic sewage and plant effluent enter the river only after treatment.

Basic habitat conditions need to be restored in order to reconstruct it for the salmon community. It is necessary to increase efforts to protect and manage the ecological environment of the Wusuli River basin by focusing on prevention and supervision. Such efforts should include strict control of key regions along the river, management planning, and developing scientific approaches to utilize water and forest resources that protect the ecological balance. Furthermore, relevant departments should increase technical investments to protect vegetation and wetland areas along the Wusuli River and its tributaries in order to return natural harmony to the river.

REFERENCES

- Bakkala, R.G. 1970. Synopsis of biological data on the chum salmon, *Oncorhynchus keta*, (Walbaum) 1792. FAO Fish Synop. 41. US Fish. Wildl. Serv. Circ. 315. 89 pp.
- Chen, H.P., and Z.X. Gao. 1992. Ecology of wild animals. Northeast Forestry University Press, Harbin, China. 386 pp. (In Chinese)
- Chen, J.P., C.Z. Dong, and D.J. Sun. 2004. Study of population chum salmon in Heilongjiang River by microsatellite marker. Acta Hydrobiol. Sinica 6: 607-612. (In Chinese).
- Duker, G.J. 1977. Nest site selection by chum salmon (*Oncorhynchus keta*) in a spawning channel. M.Sc. thesis, Univ. Washington, Seattle. 113 pp.
- Helle, J.H. 1979. Influence of marine environment on age and size at maturity, growth, and abundance of chum salmon, *Oncorhynchus keta* (Walbaum), from Olsen Creek, Prince William Sound, Alaska. Ph.D. thesis, Oregon State Univ., Corvallis. 118 pp.
- Kaeriyama, M., S. Sato, and A. Kobayashi. 1978. Studies on a growth and feeding habit of the chum salmon fry during seaward migration in the Tokachi River system. 1: Influence of thaw on a growth and feeding habit of the fry. Sci. Rep. Hokkaido Salmon Hatchery 32: 27-41. (In Japanese).
- Liu, W., P.R. Zhan, and C.G. Zhao. 2010a. Study on morphological development of fall chum salmon *Oncorhynchus keta* otoliths in Heilongjiang River. Acta Hydrobiol. Sinica 6: 1069-1076. (In Chinese).
- Liu, W., B.J. Zhi, P.R. Zhan, D.L. Qin. 2010b. Effects of salinity on haematological biochemical indices and liver tissue in juvenile *Oncorhynchus keta*. Chinese J. Appl. Ecol. 21(9): 2413-2420. (In Chinese).
- Tang, F.J., W. Liu, F.L. Xu, B. Ma, T.B. Huo, and Z.F. Jiang. 2010. Analysis on the variation of chum salmon (*Oncorhynchus keta*) population homing to Amur River system in China. J. Shanghai Ocean Univ. 19(1): 81-86. (In Chinese).
- Yan, Z.C., and Y.L. Chen. 1998. Animals' habitat environment. Chinese J. Ecol. 17(2): 43-49. (In Chinese).
- Young, L., G.M. Zheng, and Z.W. Zhang. 1991. Winter movements and habitat use by Cabot's Tragopans *Tragopan caboti* in southeastern China. Ibis 133(2): 121-126.

Transfer of Marine-Derived Nutrients by Pink Salmon (*Oncorhynchus gorbusha*) to Terrestrial Ecosystems in the Shiretoko World Natural Heritage Area, Japan

Yousuke Koshino¹, Hideaki Kudo², and Masahide Kaeriyama²

¹Graduate School of Fisheries Sciences, Hokkaido University,
3-1-1, Minato-cho, Hakodate, Hokkaido 041-8611, Japan

²Faculty and Graduate School of Fisheries Sciences, Hokkaido University,
3-1-1, Minato-cho, Hakodate, Hokkaido 041-8611, Japan

Keywords: pink salmon, stable isotope analysis, marine-derived nutrients, brown bear, flooding

Pacific salmon (*Oncorhynchus* spp.) transport marine-derived nutrients (MDN) to terrestrial ecosystems and enhance the biodiversity and productivity of North Pacific ecosystems (Kline et al. 1990; Wipfli et al. 1998). The MDN is incorporated into the terrestrial ecosystems through various pathways. The Shiretoko World Natural Heritage area in eastern Hokkaido is one of few locations where chum (*O. keta*) and pink salmon (*O. gorbusha*) naturally spawn in Japan. Despite the conservation status of the peninsula, salmon upstream escapement has been limited by the construction of a number of artificial structures, such as fish traps and dams. In addition, the contribution of MDN to freshwater and riparian ecosystems is poorly understood in this region. Our objective is to quantify the effect and range of MDN incorporation in the terrestrial ecosystem using stable isotope analysis.

We surveyed two streams on the Shiretoko Peninsula between July-October, 2006-2009. In the Rusha River Pacific salmon, such as pink salmon, chum salmon, and masu salmon (*O. masou*), enter the rivers to spawn in autumn. The escapement of pink salmon to the Rusha River ranged from 10,000 to 58,000 individuals during 2006 and 2008. Although there are three dams on the lower reach, salmon are able to pass each dam. The Akai River, a tributary of the Iwaubetu River system, has dams with a drop of 5 m located 1 km upstream from the mouth. We surveyed the area of the Akai River between these dams, which is inaccessible to spawning salmon. We analyzed carbon and nitrogen stable isotope ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) of organisms in freshwater and riparian habitats of the Rusha River during pink salmon spawning and pre-spawning periods and in the Akai River that has no spawning salmon. To identify pathways of MDN uptake, we examined the stomach contents of Dolly Varden (*Salvelinus malma*) using the index of relative importance (IRI; Pinkas et al. 1971), counted the number of pink salmon carcasses, and classified their mode of transport. The MDN enrichment of organisms in the Rusha region was calculated by a mass-balance equation (Chaloner et al. 2002).

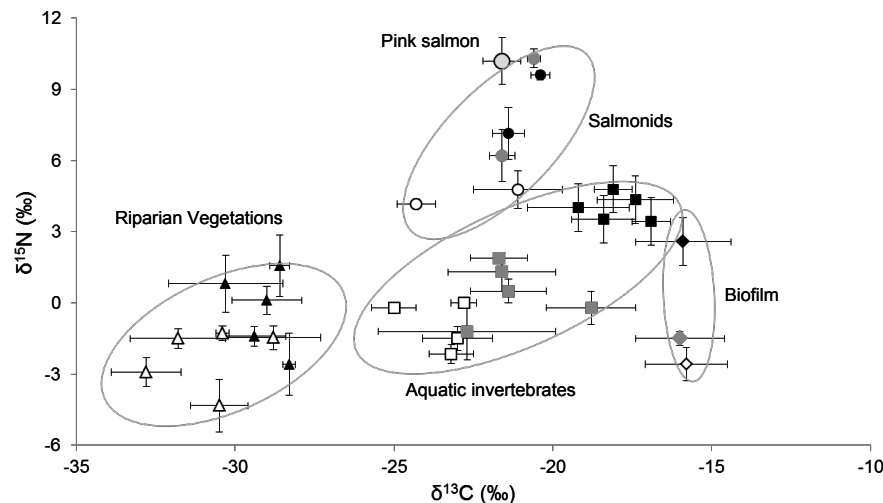


Fig. 1. Trophic shifts of freshwater biota in Rusha River (pink salmon spawning and pre-spawning periods) and Akai River (no spawning salmon). Solid symbols: Rusha River (salmon spawning period); shaded symbols: Rusha River (pre-spawning period); open symbols: Akai River (no spawning salmon).

In freshwater, stable isotope values for the biofilm and aquatic invertebrates were higher during the spawning period in the Rusha River than during the pre-spawning period in the Rusha River, or in the Akai River (Fig. 1, $p < 0.05$). The $\delta^{15}\text{N}$ values for Dolly Varden were more than 9‰ throughout the year in the Rusha River, but only 4.8‰ in the Akai River (Fig. 1). In the Rusha River, Dolly Varden fed mainly on aquatic invertebrates during the pre-spawning period (Fig. 2). However, they shifted from aquatic invertebrates to pink salmon eggs and sea lice during the salmon spawning period.

Results of stable isotope analysis using the growth section analysis method (Mizukami et al. 2005) indicated the feeding history of brown bear was classified as four types: marine, terrestrial, marine to terrestrial, and marine and terrestrial. The nitrogen stable isotopic values of riparian willow (*Salix* spp.) were negatively correlated with the distance from the Rusha River ($R^2 = 0.90$, $p < 0.05$; Fig. 3). The proportion of MDN enrichment that could be traced to pink salmon averaged 25%. We counted a total of 412 bear-killed and 1024 senescent pink salmon carcasses in the riparian area between 22 September and 8 October, 2009 (Fig. 4). Transport of the salmon carcasses to the riparian zone was associated with a heavy rain event on 2nd and 3rd October, 2009, during which precipitation exceeded 100 mm and the water level increased rapidly to 90 cm in the Rusha River (Fig. 5).

In summary, pink salmon import MDN to the freshwater and riparian ecosystems of the Rusha River. In our study, this was evidenced by higher $\delta^{15}\text{N}$ values in the aquatic organisms during the spawning period in the Rusha River compared with those in the Akai River, which does not have spawning salmon. Dolly Varden shifted their prey to consumption of salmon eggs during the spawning period. This suggested that pink salmon eggs represent an important food source for Dolly Varden to overwinter. Thus, the spawning migration of salmon may change the food-web structure of freshwater ecosystems. All bears analyzed were categorized into four feeding history types and almost all brown bears fed heavily on pink salmon in the autumn. Riparian vegetation derived 20% of their nitrogen from salmon. We observed a progressive decline in $\delta^{15}\text{N}$ values in riparian willows as the distance from the river increased, suggesting that the majority of MDN was assimilated by the vegetation within 50 m of the river. In addition, physical processes also affected material transport into the riparian area. In our study, more than twice the number of carcasses was transported into the riparian zone by flooding than by bears. Thus, flooding events play an important role in transporting salmon carcasses over a long distance and incorporating MDN into the riparian ecosystem. The MDN enrichment of organisms in the Rusha River region was typically lower than those in North America (Kline et al. 1990, Chaloner et al. 2002). This difference may be caused by the artificial constructions in the Rusha River.

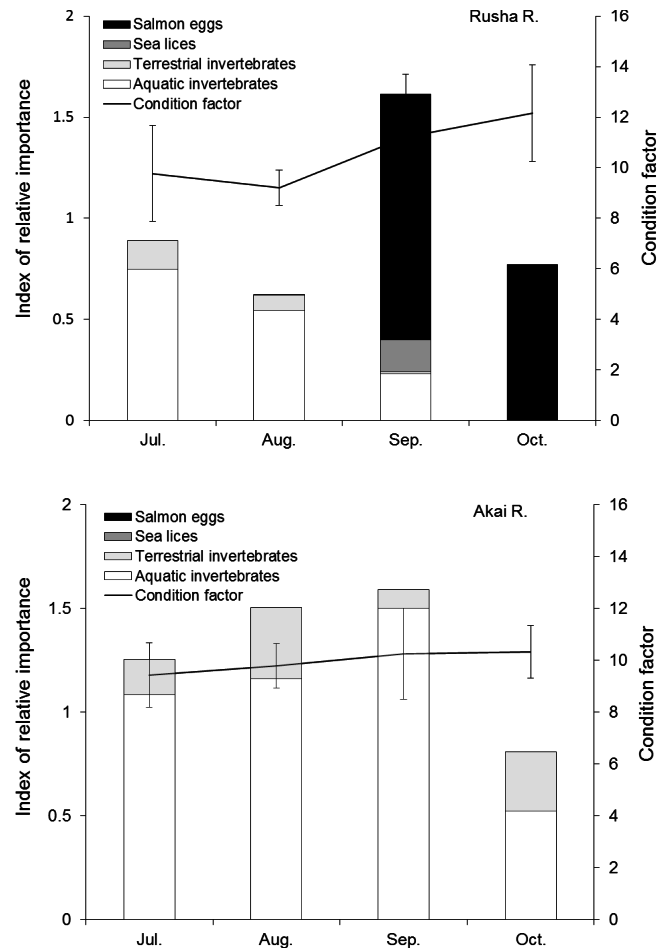


Fig. 2. Monthly changes in the index of relative importance (columns) and condition factor of Dolly Varden (mean \pm 1 standard error) in the Rusha (upper panel) and Akai (lower panel) Rivers, July-October, 2007-2008. The IRI is an indicator of the relative importance of prey animals in the diets of a predator (Pinkas et al. 1971).

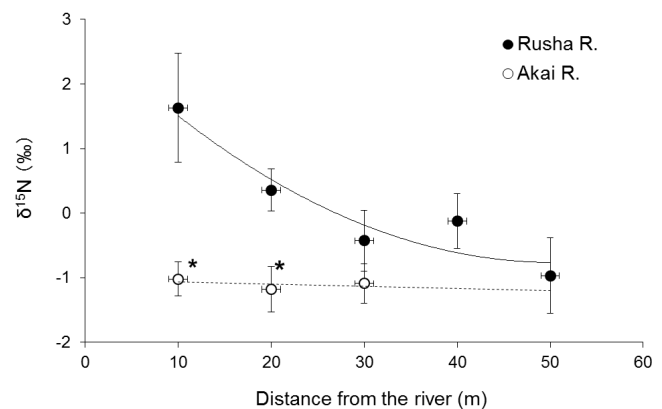


Fig. 3. Relationship between the distance from the river and $\delta^{15}\text{N}$ values of willow leaves in the riparian zone of the Rusha River ($y = 0.0014x^2 - 0.1402x + 2.7701$, $r^2 = 0.90$) and Akai River ($y = -0.0035x - 1.0267$, $R^2 = 0.19$). Data: mean \pm 1 S.E. * $p < 0.05$.

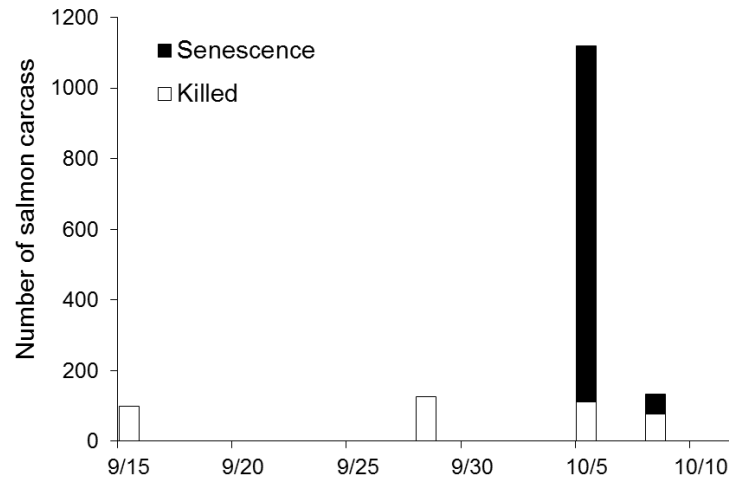


Fig. 4. Number of pink salmon killed by bears or following senescence and deposited in the riparian area of the Rusha River, 2009.

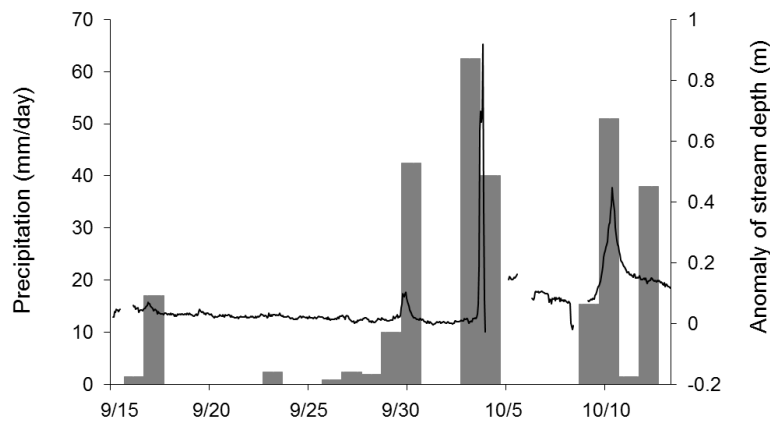


Fig. 5. Temporal change in stream water level (anomaly, shown by the line) of the Rusha River and precipitation (column) during the pink salmon spawning season, 2009.

In conclusion, the MDN transported by pink salmon are incorporated into the majority of trophic levels via several pathways in the terrestrial ecosystem around the Rusha River. To evaluate the significance of escapement of wild salmon to terrestrial ecosystems, it is critical to understand how freshwater and terrestrial pathways interact.

REFERENCES

- Chaloner, D.T., K.M. Martin, M.S. Wipfli, P.H. Ostrom, and G.A. Lamberti. 2002. Marine carbon and nitrogen isotopes in southeastern Alaska stream food webs: evidence from artificial and natural streams. *Can. J. Fish. Aquat. Sci.* 59: 1257–1265.
- Kline, T.C., J.J. Goering, O.A. Mathisen, P.H. Poe, and P.L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I. $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ evidence in Sashin Creek, southeastern Alaska. *Can. J. Fish. Aquat. Sci.* 47: 136–144.
- Mizukami, R.N., M. Goto, S. Izumiyama, H. Hayashi, and M. Yoh. 2005. Estimation of feeding history by measuring carbon and nitrogen stable isotope ratios in hair of Asiatic black bears. *Ursus* 16: 93–101.
- Pinkas, L., M.S. Oliphant, and L.K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. *Calif. Fish Game Fish.* 152: 1–105.
- Wipfli, M.S., J. Hudson, and J. Caouette. 1998. Influence of salmon carcasses on stream productivity: response of biofilm and benthic macroinvertebrates in southeastern Alaska, U.S.A. *Can. J. Fish. Aquat. Sci.* 55: 1503–1511.

Wrap-Up Presentation Given at the Conclusion of the Workshop

James Balsiger

*U.S. Department of Commerce, NOAA, National Marine Fisheries Service,
Alaska Region (F/AK), P.O. Box 21668, Juneau, AK 99801, USA*

Let me start by thanking Dick Beamish and Nancy Davis for inviting me to participate in this workshop. I am humbled to be asked to summarize this great collection of papers and presentations by the world's leading experts on Pacific salmon. It's a daunting task, and I'm likely to miss many important points, but let me offer a few comments anyway.

The Workshop is on "Explanations for the High Abundance of Pink and Chum Salmon and Future Trends." Our very first speaker presents a reasonable explanation for the current high abundance of both pink and chum salmon that we are seeing in North America and also on the western side of the North Pacific Ocean and Bering Sea. To be really successful, a cohort needs both good conditions for near shore early growth and survival, and good winter feeding conditions. Dick Beamish noted that Bill Ricker himself fifty years ago had pointed out the futility of looking for that single unique cause that was a universal driver of salmon cohort success. Rather, we were instructed to look for the cause or causes that were affecting (maybe differently) each individual stock.

Dick Beamish had an interesting thought that perhaps pink salmon have a different energy strategy than other salmon species in that they use the energy they consume in the juvenile stages near shore to grow at the expense of storing energy for overwintering. I find this quite intriguing and note that he was among the presenters who gave us some idea of something new we might examine to increase our ability to predict future trends.

He also suggested that a possible venue for advancing the science would be for the scientific community to have an International Year of the Salmon and I would suggest that is worthy of consideration by the salmon user community.

I want to contrast the attention to tiny detail, every area is different, each stock has its own special need, with the idea brought up in several papers that basin-wide inputs such as regime shifts, or maybe even global-wide inputs such as global climate change might over a time scale of decades overwhelm the micro-ecosystem effects of the near shore juvenile rearing area. Kentaro Morita and other presenters noted that warming climate or increasing temperatures in a relatively long term warming cycle may have differential negative impacts on those species that spend more of their life history in fresh water. While it is difficult for us to accept a time will come when cold water will be unavailable to salmon in the ocean, it is easier to imagine that some salmon rearing rivers and lakes will lose cold water salmon habitat. Thus, those species, like coho and Chinook, with a relatively long fresh water stage may not do as well during warming trends as those species that have a relatively short fresh water stage, such as pink and chum salmon. And, while this workshop is for pink and chum, I think that research designed at monitoring fresh water success is necessary. Smolt production estimates are difficult and expensive, and so have often been discontinued. Technology may provide some innovative ways to monitor out-migrants. I suggest that this is a fruitful area for research.

Throughout the two days of the workshop, density dependency, or competition for food, or carrying capacity arose in many papers. The topic is treated rather gingerly in this polite collection of scientists. With six species of salmon, hundreds of wild stocks, and hundreds of hatcheries with nearly as many production protocols dictating time of release, size of release, and volume of release, it is very difficult to produce the definitive study on this question. One presenter even suggested that migration routes may be different dependent on the density of other stocks in what might be called the "normal" foraging area. Do chum really leave the Bering Sea if pink salmon show up in great abundance? We saw numerous papers here correlating growth and survival of one species with the abundance of some segment of some other species. The confounding circumstance that arises from the great variation in stocks on the commons has prevented a conclusion on whether there is likely an over-all expectation of decreased productivity in any run due to enhanced productivity of some other run. Part of the answer here lies in the ability to identify the hatchery or stream of origin of salmonids obtained by research vessels or observers aboard commercial vessels. Much work has been completed on this, but the expansion of base lines and the development of more precision in identification of stocks are important. I am particularly intrigued by the idea of parental based tagging brought up by Bill Templin. Using parent stock genome characteristics to identify offspring results in potentially free tag placement (but not, of course, tag reading.) A better understanding of spatial distribution seems key to answering the density dependent growth and survival questions. It also would allow a slightly different line of inquiry into examination of interaction with other species (groundfish) and, don't say this out loud, interaction with other fisheries.

Suam Kim suggested that we have enough indication of changes in productivity that it is incumbent on the scientific community to seek an audience with policy and managerial types. I looked around the audience to see who those people

might be and I suppose I am the only one that is so identified here, so maybe the message is for me. Randall Peterman went even further to suggest that we needed a new construct for international cooperation. I note that some in the audience warned of the potential downside of dealing with policy and managers while there is still much uncertainty around the effects of climate change, or while there is still much uncertainty about a finite reachable carrying capacity. I would recommend that consideration be given to finding a way to begin a non-threatening dialogue with the managers towards the idea that strategic planning and strategic preparedness is a good thing. Policy types run models as well as the population scientists and for the same reasons. They allow the exploration of scenarios that might exist, or might never exist, or at all costs should be avoided. And without any suggestion for research, I would note that it is usually easier for managers to discuss allocations in time of good stock production, rather than when those stocks are in decline.

Dr. Radchenko (I think—though my notes are often not very clear, and my memory is clearly suspect) had a clever cartoon of a Duracell battery as he noted “it’s all about the energy.” Many of the presenters here had a focus on energy, and clearly that is the driver we are interested in. It would be interesting to see if, and at what stage, animals exhibit a prey preference. I know that if you use the wrong color hoochie, you aren’t going to catch a Chinook salmon. So, at some stage a preference for prey can be made by salmon. Laboratory experiments might shed light on whether or to what extent young fish can avoid low energy plankton, seek high energy plankton, or if they really just eat what they encounter.

Finally, based on Michio Kishi’s presentation, I make a strong recommendation to eat salmon.

This is what I have.

Thanks again to Dick and Nancy and the organizing committee for the invitation to attend. Thanks to all the presenters for the mental stimulation. Thanks to the staff for arranging this fine, fine venue for this workshop.

Workshop Synopsis

Nancy D. Davis

Deputy Director, NPAFC

and

Richard J. Beamish

Chairperson of the Workshop Organizing Committee, Pacific Biological Station

The intent of the workshop was to bring experts together and get as close as possible to identifying exactly why pink and chum salmon abundances and catches continue to increase. As with any important event, it is reasonable to ask how successful we were, recognizing that such an assessment can also be a function of individual expectations. A number of agencies provided financial and logistical support; some provided funds without being asked. This, surely, was an indication that the topic was important and timely and that agencies had confidence in the NPAFC and the participants. Every invited speaker agreed to participate, another indication that people considered the workshop necessary. The location was perfect, the breaks were long enough for meaningful discussion, and everyone seemed to be ready for some serious thinking.

Although we did not identify exactly why pink and chum salmon abundances continue to increase, we did consolidate interpretations. The synopsis is our summary of the workshop. We benefited from the excellent notes taken by Dawn Steele. To summarize interpretations, the first four sections of the synopsis are organized around the targets for the workshop: (1) identify pink and chum salmon production trends by region, (2) identify reasons for high production of pink and chum salmon and low production of other salmon species, (3) predict future production of salmon, and (4) identify key areas of future research. The latter two sections include advice for fisheries management and a summary of conclusions drawn from the workshop. References cited in the synopsis refer to the authors as they are listed in this technical report.

Pink and Chum Salmon Production Trends by Region

Since the 1980s, the patterns of pink salmon catch in the Russian Far East have shown increased variability, including unexpectedly high and low returns (Radchenko). Radchenko suggested the reason for increased production variability is complex. More dependency on finding prey in the winter may help explain why there has been increased variability in Russian catches of pink salmon and possibly all odd-year pink salmon catches. One of the determinants of change in stock abundance of Kamchatkan pink salmon is the relative contributions of northern subpopulations (Shevlyakov and Koval). Pink salmon catches of southern Chukotka have increased, particularly for odd-year runs. In 2011 pink catches were almost equal to chum salmon catches, which were the dominant run (Khokhlov).

Pink salmon populations returning to Hokkaido increased substantially from 1975 to 2000 (Iida et al.). Despite stable hatchery fry releases, recent pink salmon catches exhibit a biennial oscillation dominated by odd-year runs.

Total chum salmon production from the western Pacific (Korea, Japan and Russia) has increased since the 1970s, with catches reaching 350,000 metric tonnes in recent years (Kim et al.). Chum salmon traditionally contributed the majority (70–88%) of salmon production along the southern coastline of Chukotka from fish spawning in the Anadyr River watershed (Khokhlov). Since 1995, Anadyr chum salmon abundance has been increasing and abundance trends for these fish show fluctuations in the 40- to 50-year period. Since 2000, Kamchatka chum salmon catches along both coasts have increased threefold as compared to the previous decade (Zavarina).

The trend for total annual returns of Japanese chum salmon from 1965–2010 shows increases for Honshu and Hokkaido, followed by a decrease in Honshu since the late 1990s and in Hokkaido since the early 2000s (Qin and Kaeriyama). Fluctuations in returning Japanese chum salmon stocks have increased recently (Nagasawa and Azumaya). Freshwater survival is high because most Japanese chum salmon originate in hatcheries and managers expect consistent returns. However, large inter-annual fluctuation in rates of chum salmon returning to different areas of Hokkaido has been observed since the late 2000s (Miyakoshi and Nagata). Miyakoshi and Nagata observed recent returns of chum salmon are historically high in the Okhotsk Sea region, relatively low in the Sea of Japan region, and highly variable in the Pacific Ocean region of Hokkaido.

Pink and chum salmon are abundant in the Gulf of Alaska and the fish in this region originate from nine major production areas of Asia and North America (Heard and Wertheimer). Alaska commercial harvest (as a proxy for run strength) showed declines in the 1950s and 1970s. Since the start of hatchery programs in the 1970s, pink

and chum salmon abundance have rebounded. The Pacific Decadal Oscillation (PDO) shifted at around this time, and likely had positive effects on pink and chum salmon survival (Heard and Wertheimer). With chum hatchery development in 1979, hatchery chum have become an increasingly large proportion of total chum salmon commercial harvest in Southeast Alaska and Prince William Sound. In Kodiak, the contribution of hatchery chum salmon is much lower (Heard and Wertheimer).

In Southeast Alaska, pink and chum salmon represent 93% of the total salmon harvest (Orsi et al.). Most of the pink harvest is wild production and most of the chum salmon harvest is hatchery production (Piston and Heinl). Piston and Heinl reported pink salmon harvests, which started increasing in the 1980s, have declined since 2000, with periodic shifts between odd- and even-year dominance. While remaining at high levels, pink salmon harvests have declined from an average of 49 million per year in the 1990s to an average of 40 million fish per year since 2001. Chum salmon catches began increasing in the 1990s, largely due to hatchery enhancement, and have also declined since 2000. Estimated harvests of wild chum did not rebound to the same degree as pink salmon and have recently declined to levels similar to those of the 1970s (Piston and Heinl).

Generally, pink salmon assessments show increasing productivity of Fraser River and Puget Sound populations over the long term, with odd-year runs doing better than even-year runs for fish from the same watershed (Irvine et al.). Total returns of Fraser River pink salmon increased after the 1977-78 regime shift, decreased after the 1989 regime shift, increased again after the 1998 regime shift, and were unusually high in 2010 and 2011 (Beamish). Beamish observed a weak relationship between Fraser River fry abundance and total returns for the same brood year, but no clear relationship between downstream fry counts and CPUE of juveniles in July and September surveys in the Strait of Georgia, or between total adult returns and CPUE in juvenile surveys. Average size of juvenile pink salmon has been larger in July, but no meaningful relationship was found between larger juvenile body size and total adults returns.

Surveys in the northern California Current catch juvenile pink and chum salmon at different periods (Weitkamp et al.). Pink salmon are caught only in September in the northern section off Washington State. These fish likely originate from Puget Sound and the Fraser River and enter the ocean around the southern end of Vancouver Island. Their survey results show little relationship between juvenile pink salmon abundance and adult returns from the same brood year. Chum salmon are more abundant in May and June, and by September are mostly gone from the northern survey section. These chum salmon likely originate from the many short coastal rivers and juveniles appear to grow rapidly through the summer. Sampling programs in the early 1980s indicated juvenile chum salmon were much larger than those sampled in recent years. The reasons for this may be increased size-selective mortality, less competition with Chinook salmon in the 1980s, or other unspecified reasons (Weitkamp et al.).

Population abundance of chum salmon originating in the Columbia River and southwards to Newport, Oregon, is highly variable and has fallen more than 80% from historic levels (Johnson et al.). Genetics and run-timing data show that Oregon coastal chum salmon are a single evolutionarily significant unit, and they have a narrower time window for spawning than other Northwest chum stocks. Chum salmon are resilient, but their need for access to rivers and estuaries necessitates preservation of lower river spawning habitats (Johnson et al.).

Reasons for High Production of Pink and Chum Salmon and Low Production of Other Salmon

At the workshop, explanations for the high production of pink and chum salmon fit into three general areas that are not exclusive, but may be working in combination to produce the current trends of salmon abundance. First, environmental factors provide opportunities for salmon to consume prey more frequently, thus allowing them to grow more quickly. Second, particular biological and life history characteristics of pink and chum salmon make them more responsive than other salmon species to favourable environmental conditions. Third, human activities, such as improved stock enhancement, reductions in harvest, and responsible fisheries management, contribute to increased production of pink and chum salmon.

Environmental factors contributing to high abundance of pink and chum salmon

There was convincing evidence given at the workshop that large-scale atmospheric processes can be used as an index of pink and chum production. Favourable ocean conditions for salmon production (at least in northern areas) may have increased ocean carrying capacity. Salmon prey production links climate variability to growth of individual salmon and that prey production appears to be increasing.

Wild pink salmon abundance increased in most regions of the North Pacific after the mid 1970s regime shift. The recent rise of abundance and biomass in Russian far eastern salmon stocks, and West Kamchatka pink salmon stocks in particular, could be related to the shift of dominant modes of sea surface temperature variability in the North

Pacific and North Atlantic in the second half of the 1990s (Krovvin and Klovach). These observations identify the importance of integrating the larger-scale hemispheric and possibly planetary influences into regional interpretations of climate effects and salmon production.

Agler et al. suggested the growth of western Alaska chum salmon and Bugaev and Tepnin mentioned catches of Asian pink and chum salmon were under the indirect influence of a complex of indicators for climate and of sea condition. Comparison of the PDO and Japanese chum salmon returns dating back to the 1960s shows high synchronicity since the early 1990s (Nagasawa and Azumaya). Recent increases in Hokkaido chum salmon returns may be due to favourable ocean conditions (Miyakoshi and Nagata). High abundance of Gulf of Alaska pink and chum salmon was attributed, at least in part, to favourable ocean conditions after the 1976/1977 regime shift that led to increased survival (Heard and Wertheimer). Abundance remained relatively high after the 1989 regime shift and in some regions of southeast and central Alaska (excluding Prince William Sound) further increases suggest environmental factors played a role (Ruggerone et al.). Large returns of pink salmon to the Fraser River and Puget Sound also point to pink salmon production increases due to favourable ocean conditions (Beamish). Productivity in the northern California Current is strongly driven by the PDO, with a negative PDO linked to good survival for juvenile salmon (Weitkamp et al.).

Evidence was presented indicating the depth and stability of the mixed layer depth in winter and spring was linked with climate. A mechanism was described for bottom-up control of pink salmon biomass (Chiba et al.). Change in climate produces a shallow mixed-layer depth in winter and weak water-column stratification in spring, which leads to an increase in spring-summer copepod abundance and greater pink salmon biomass.

It is the linkage between climate and prey production through ocean processes that appears to be the key to improving the ability to forecast more accurately. This makes sense; but exactly how can a large-scale climate state have such important impacts on the thousands of populations of pink and chum salmon in their early marine period throughout the Subarctic Pacific? Part of the explanation appears to be in the feeding strategy of pink and chum salmon. For northern salmon populations, increases in sea temperature (within limits) benefit fish growth, and this is likely a major factor for the high survival of Kamchatka salmon in recent decades (Karpenko and Koval). While there may not be a direct relationship between temperature and food, warmer sea temperatures could indicate increased production of preferred food items for salmon. Conversely, in spring with low sea surface temperatures in nearshore areas, the delay of juvenile chum salmon migration out of the littoral zone can adversely affect survival (Kasugai et al.).

Biological and life history characteristics contributing to high abundance of pink and chum salmon

Workshop attendees identified unique biological and life history characteristics of pink and chum salmon that enable them to preferentially benefit from current climate conditions. The life history of pink and chum salmon ensures they enter the ocean quickly after eggs hatch and enter early in the year, coinciding with earlier springs and earlier zooplankton prey availability (Ruggerone et al.).

Both pink and chum salmon spend the majority of their lives at sea. Vertical and horizontal migration at sea allows salmon to choose their preferred temperatures. This could mitigate (to some degree) the impact of warming environmental conditions (Morita). Species with long obligatory freshwater life phases in streams and rivers, such as masu, coho, and Chinook salmon, may experience lower survival rates because their movement is limited, making it harder for them to find preferred temperatures over the long term (Morita).

There was general agreement among workshop participants that brood year strength is determined early in the marine year for both pink and chum salmon. In particular, pink salmon abundance is formed in the early marine period (Shevlyakov and Koval), primarily by fry abundance (Kaev), number of spawning females (Beamish), and early marine survival (Beamish; Kaev; Orsi et al.). Pink salmon grow rapidly at sea and show a high risk/high reward life strategy with a higher survival rate per egg than other salmon (Ruggerone et al.). During coastal residency, juvenile salmon growth is strongly correlated to survival, however, external conditions such as zooplankton abundance has not yet been linked directly to salmon body size (Hasegawa et al.). Studies in both Russia and British Columbia suggest as few as 10% to 50% of juveniles survive their first month at sea. After this early phase, mortality may be low from this point on until return of adults (Orsi et al.). Rapid growth at sea likely contributes to higher overall survival.

Analysis of pink salmon scale growth patterns show that faster growing fish have higher survival and larger fish survive stressful winters better (Beamish). Several growth studies show pink salmon that survive the initial marine entry period have higher growth at sea (Ruggerone et al.). Early marine growth is known to be important to survival, while density dependent impacts are more apparent in later life (Radchenko; Ruggerone et al.).

Among Pacific salmon, species-specific feeding strategies have dramatic effects on survival and growth. Specific morphological and physiological features play a role in their feeding strategies and growth rates (Karpenko and Koval). Beamish suggested pink salmon may have different seasonal lipid storage patterns than other salmon that could enable them to be more responsive to fluctuations in ocean conditions. Pink salmon grow much faster than chum salmon over the marine winter, spring, and following summer because they consume more high- and average-caloric prey species (Karpenko and Koval). This plays a role in their readiness to spawn after one year at sea.

There may be different feeding strategies in the early marine period for odd- and even-year pink salmon. It is possible odd-year pink salmon store fewer lipids and continue to grow with the expectation that the energy needed in the winter can be found from improved prey production (Beamish). Different feeding and energy-use strategies could also explain why odd-year pink salmon tend to be larger than even-year pink salmon. From about the time of the 1977 regime shift, total catches of both odd- and even-year lines of pink salmon increased. However, it is relevant that in the past two decades it is the catch of odd-year pink salmon that has continued to increase. This suggests possible differences in food production and utilizations between the two broodlines in the past two decades. There are clear genetic differences between the odd- and even-year salmon (Seeb et al.).

Chum salmon consume the widest prey spectrum among Pacific salmon (Karpenko and Koval). Possessing an elongate digestive tract and high rate of digestion, chum salmon are uniquely adapted among the salmon species to digest gelatinous zooplankton having low energy content. Chum salmon survive because of less competition with other salmon for lower-caloric food (Karpenko and Koval). With a slower growth rate and variable maturity schedule, chum can remain at sea for a longer period than pink salmon.

Workshop participants presented several viewpoints on whether the large abundance of pink salmon, particularly in the Bering Sea and other locations, could negatively affect the abundance of chum and sockeye salmon. The mechanism suggested is food competition as there is diet overlap between pink, sockeye, and chum salmon. Cyclic changes in chum salmon lipid levels, diet, and returns to Hokkaido coincided with dominant odd-year run pink salmon (Kaga et al.; Saito et al.). Sockeye salmon responses to competition include reduced adult length at age at the end of the second year at sea, reduced sockeye smolt survival and abundance, and delayed maturation (Ruggerone et al.). However, there was no negative impact demonstrated between Asian pink salmon abundance and smolt-to-adult survival of Bristol Bay sockeye salmon (Wertheimer and Farley). The reason might be measurement error, or shifts in the distribution of Asian pink salmon in the ocean (Ruggerone et al.). Ruggerone et al. suggested shifts in ocean conditions may be the primary driver of species abundance, and competition may have a secondary effect that becomes more important when prey production is poor.

The importance of competition and density dependent interactions at sea in determining overall stock abundance will remain an open question until evidence clearly shows that shared prey resources are limited. Under present conditions, however, competitive interactions do not appear to stop abundances of pink and chum salmon from increasing.

Some participants expressed doubt there is limited forage supply for salmon in the North Pacific. Analysis of a long-term data series (1980–2011) of zooplankton sampling and salmon feeding conditions indicates there is sufficient food supply for salmon (Naydenko). Naydenko suggested that in the upper pelagic layer of the Russian far eastern seas and Northwest Pacific consumption of forage resources by salmon was insignificant and recent increases in salmon abundance would not cause significant changes to the trophic structure of the region. Declining body size at return for Anadyr chum salmon was associated with strong growth reduction after the first year of life in past decades in the Bering Sea and North Pacific (Zavolokin et al.). Negative correlations between temperature indices and Anadyr chum salmon growth after the first year indicate warming of the North Pacific, rather than density-dependent interactions, may adversely impact chum salmon growth after the early marine period of life (Zavolokin et al.). Russian studies continue to show it is unlikely the food supply for Pacific salmon is limiting once they arrive in the open ocean because salmon do not form schools at sea, which may explain continuing increases of pink and chum salmon.

Human activities contributing to high abundance of pink and chum salmon

Increased total catches of pink and chum salmon are related to management changes as well as climate changes. Hatchery production is the most important intervention, but reduced exploitation rates and the concern for the protection of freshwater habitats have also contributed to increased abundances. Recent increases in Hokkaido chum salmon adult returns result from improved hatchery techniques, particularly by increasing the size of fish at release and improving release timing to maximize smolt survival (Miyakoshi and Nagata). In the Magadan

region, production is increased by annual release of artificially-reared chum into rivers that produce wild pink salmon (Safronenkov and Volobuev). These rivers do not support wild chum because they have no natural chum salmon spawning habitat. Because pink and chum salmon return at different times this procedure eliminates inter-specific ecological risks (Safronenkov and Volobuev). Elimination of the high seas fisheries for Pacific salmon in the North Pacific contributed to increases in pink and chum salmon abundance in the Gulf of Alaska (Heard and Wertheimer) and to total North Pacific production (Morita). By reducing fishing mortality for odd-year Fraser River pink salmon, responsible fisheries management largely explains increases in their adult returns in recent years (Irvine et al.). Better treatment of wild stocks and improved international coordination among North Pacific salmon producing countries through bilateral relationships and the NPAFC contributed to high abundance of salmon in the Gulf of Alaska (Heard and Wertheimer).

Future Production of Salmon

Workshop organizers requested participants speculate about what they thought was the likely future production of pink and chum salmon. Would it remain high, stable, or decrease through time? Most presenters suggested current high levels will likely decrease in the future. Krovnin and Klovach suggested salmon catches in the Russian Far East are likely to remain high for at least the next five years and may remain so through the end of the current warm phase of the Atlantic Multidecadal Oscillation (another 10 to 16 years). Based on a 60- to 65- year cyclic climate oscillation model, Klyashtorin and Klovach suggested a general decrease of Pacific salmon production in the 2010-2020s. According to the cyclic hypothesis, the change, when it occurs, will initiate a general declining trend in both pink and chum salmon, perhaps to levels that occurred before the mid 1970s. However, hatcheries, now a major producer of juveniles, make it difficult to relate impacts of future cyclic shifts back to the pre-1970s. In addition, there are decadal-scale climate changes within these longer 60-year cycles. These considerations aside, it remains important to recognize that large-scale climate events can affect abundance trends in pink and chum salmon.

Increasing pink salmon abundance in the Chukotka region was noted by Khokhlov, who speculated that areas previously dominated by chum salmon may be replaced by pink salmon as the principle catch. Kaev suggested abrupt changes in catches and synchronous declines of early-run pink salmon in the Sakhalin-Kuril area might indicate environmental instability and presage future abundance declines. If the forage base of the North Pacific is limited, Karpenko and Koval speculated future increases in Pacific salmon productivity will be limited and difficult to forecast. Strong density-dependent effects at high population levels could adversely affect salmon growth and future productivity (Aglar et al.; Qin and Kaeriyama).

A continued warming climate will likely negatively affect species dependent on long freshwater life stages (Morita). Koshino et al. suggested decreased future abundance of naturally spawning fish will reduce transport of marine-derived nutrients to terrestrial ecosystems. The sea surface temperature warming trend predicted for the East Sea may cause Korean chum salmon to have trouble accessing the cool open waters of the North Pacific, significantly affecting ocean migration patterns (Kim et al.). Qin and Kaeriyama warned that continued global warming will decrease the ocean's carrying capacity by reducing the area of chum salmon distribution, and they predicted Hokkaido chum salmon could lose their migration route to the Okhotsk Sea by 2050 and suffer a population crash by 2100.

Key Areas for Future Research

Presenters made a number of suggestions for future research. These included addressing the appropriate scale in research questions; examining salmon food availability; studying conditions of salmon ocean growth, feeding, body condition, and fecundity; investigating salmon ocean migration and distribution; increasing capabilities for stock identification; and determining useful indicators for salmon run forecasting.

Several presenters emphasized the importance of choosing the appropriate scale of predictors and response indicators for salmon populations. Radchenko suggested future work focus on spatial differentiation of seasonal races and regional groupings because fish seem to be responding to local environmental differences at small scales. Heard and Wertheimer suggested if survival patterns correlate better at the meso-scale (100 km), it might be advantageous to find important environmental correlates at the same scale, rather than at larger scales. Comparison of marine growth patterns between close and more distantly located populations of British Columbia pink, chum, and sockeye salmon was proposed (Oka et al.). Orsi et al. suggested a large scale indicator was linked to chum harvest and survival rates, and both large and small scale indicators were linked to pink salmon harvest and survival in the Gulf of Alaska.

More extensive use of zooplankton data to evaluate salmon food availability and quality was suggested. Bevan et al. emphasized differences in nutritional quality of salmon prey, especially fatty acid composition, varies significantly between species and life history stages. Bevan et al. and Radchenko suggested future research focus on

salmon productivity and prey availability at area and time scales relevant to salmon feeding. Analytical techniques for detecting stable nitrogen isotopes in amino acids could be used to improve estimation of salmon trophic level variation by eliminating the contaminating effects of isotope signals in phytoplankton and source water (Chiba et al.).

Suggestions were made to have future studies concentrate on investigations of salmon growth, feeding, body condition, and fecundity. Comparison of winter and spring growth on fish scales from spatially diverse populations of chum salmon could be used to estimate winter growth conditions (Zavolokin et al.). Diet differences between odd- and even-year juvenile pink salmon was proposed as a way to look at long-term consequences for salmon production (Kaev). Beamish advised future studies to determine if pink salmon have a unique seasonal pattern of lipid storage and utilization. Along similar lines, Radchenko suggested gathering data on salmon energy contents and physiology at sea to develop an index of optimal physiological conditions for each life phase with the goal of improving run forecasts. For future stock status assessments, Irvine et al. suggested examining fecundity in addition to spawner abundance to improve measurement of stock productivity.

Expanding investigations on salmon distribution and migration in the inshore zone and ocean wintering areas was suggested (Radchenko). Kim et al. indicated migration and distribution experiments are needed to monitor possible shifts in ocean distribution in response to changing environmental conditions. Future increases in otolith-marked releases of Japanese chum salmon and additional high-seas sampling will help to increase accuracy of forecasting returns to Japan (Urawa et al.). Shevlyakov and Koval suggested run forecasting of East Kamchatka stocks would be more informative if there were easy methods to differentiate stocks caught in mixed-stock aggregations. Orsi et al. suggested further refinement of geospatial migration models of major stock and age groups of Southeast Alaska salmon.

Several presentations proposed future research to enhance genetic techniques in providing information on stock distribution. There was a suggestion to expand the PacSNP baseline to include additional SNPs that would be useful for fine-scale local analysis of stock distribution (Templin et al.). Sato et al. speculated that maturing chum salmon caught in the Chukchi Sea surveys might be on their way to spawn in Arctic Rivers and suggested genetic baselines be expanded to include rivers from that region.

Future research directions are increasing the capabilities of salmon stock identification using genetic, scale pattern, and otolith analyses. Shpigalskaya et al. suggested Cytb/D-loop polymorphism of the mtDNA fragment is an informative marker for regional separation of pink salmon stocks in mixed-stock samples and Seeb et al. reported on progress in comparing even- and odd-year pink salmon DNA sequencing for widely divergent North American stocks. Future research on stock identification based on scale patterns of pink salmon will require more baseline information to characterize all pink salmon spawning regions (Savin et al.). Chistyakova et al. demonstrated sufficient variation and resolution to differentiate chum salmon stock origins at a regional level using otolith microstructure.

Identifying control mechanisms using ecosystem metrics and process studies for developing better forecast models was proposed (Orsi et al.). Process studies and development of models of ocean salmon survival (Shevlyakov and Koval) including salmon prey and salmon predators (Khokhlov), and models linking climate, salmon, and their prey (Bugaev and Tepnin) were suggested to better understand salmon population abundance and improve salmon run forecasting. Increased coordination and communications among researchers will help to identify promising ecosystem indicators and researchers might consider developing an annual ocean salmon assessment report (Orsi et al.).

Advice for Fisheries Management

Although suggesting advice for fisheries management was not a specific target of the workshop, several presenters made proposals. Fisheries managers were advised to prepare for greater future variability in salmon production. Initiating a discussion establishing international agreements for management of the common pool of ocean salmon prey resources was suggested to reduce competition among stocks (Peterman et al.). Conclusions from modeling current climate, ocean carrying capacity, market, and chum salmon stock conditions indicated that the present hatchery releases of about 1 billion Japanese chum salmon maximizes total income to fishermen (Kishi et al.). Hatchery managers might consider revising their practices to address future climate and habitat changes (Miyakoshi and Nagata). Careful hatchery operations are needed to protect genetic diversity and fitness of wild salmon (Yu et al.). Restoration efforts to improve freshwater environments and technical investments for protecting wetlands are crucial for management of salmon resources (Liu et al.). Kim et al. suggested experts from across different disciplines need to work together effectively and begin considering climate impacts on salmon behaviour, production, and economics in fishery management plans. If ocean salmon carrying capacity decreases in the future, the need for

sustainable, adaptive Pacific salmon management plans that include powerful feedback control systems for climate, biological, and ecosystem factors will become paramount (Qin and Kaeriyama).

Conclusions

It appears we are closer to the explanation for the recent increase in chum and pink salmon abundance, but we still lack the understanding that will allow forecasts to be used in the long-term planning of fisheries and hatcheries. The short period in fresh water and the early ocean entry of pink and chum salmon fry are well synchronized to an apparent earlier production of prey in the nearshore area. The warmer ocean appears to be producing more prey for both pink and chum salmon. The feeding strategies of pink and chum salmon seem well matched to increased production of higher and lower caloric prey in the open ocean in the winter and spring. Odd-year pink salmon are more productive and grow larger than even-year pink salmon because they may eat more and use more of their energy for growth. However, if 60-year cycles affect plankton production, it is possible that within the next two decades there will be a reversal of the present trend. If Subarctic Pacific warming continues, salmon could begin to lose their migration route to ocean rearing areas and that could lead to loss of some stocks by the turn of this century.

Although the workshop did not answer the question, it did bring a better focus to the work that needs to be done. The solution will eventually appear and, like many things, it will appear simple. However, the solution may appear sooner rather than later, if the friendly and productive working relationships that were developed at the workshop are continued.

List of Participants

<i>Canada:</i>	Atkinson, Mary-Sue Beamish, Richard Bevan, Daniel Bison, Robert Blackbourn, David Crawford, William Evans, Jason Fegan, Lauren Fitzpatrick, Lana Fox, Daniel Friesen, Michael Greene, Peter Hawkshaw, Sarah Herts, Eric Irvine, James Kristianson, Gerry Mahoney, Jason Marliave, Jeff Mathias, Karin McKinnell, Stewart Nelson, Ben Neville, Chrys Oka, Gladys Peterman, Randall Rickard, Paul Riddell, Brian Ross, Cheryl Saunders, Mark Steele, Dawn Sweeting, Ruston Tadey, Joe Todd, Kristy Tompkins, Arlene Van Will, Pieter	<i>Russia</i>	Bugaev, Alexander Kaev, Alexander Khokhlov, Yury Klovach, Nataliya Koval, Maxim Melnikov, Oleg Naydenko, Svetlana Radchenko, Vladimir Shpigalskaya, Nina Temnykh, Olga Volobuev, Vladimir Zavarina, Lidia Zavolokin, Alexander
		<i>United States</i>	Agler, Beverly Balsiger, James Blikshteyn, Mihael Brenner, Richard Doherty, Susan Ericksen, Randy Farley, Edward Focht, Rick Gillis, Karen Heard, William Johnson, Orlay Juanes, Francis Lincoln, Richard Munro, Andrew Myers, John Myers, Katherine Neimeier, Paul Orsi, Joseph Oxman, Dion Piston, Andrew Rand, Peter Ruggerone, Greg Seeb, Lisa Sheridan, Tommy Smith, Gary Stormer, David Templin, William Volk, Eric Weitkamp, Laurie Wertheimer, Alex Woodruff, John
<i>China:</i>	Liu, Wei		
<i>Japan</i>	Abe, Syuiti Chiba, Sanae Hasegawa, Koh Iida, Masaya Kaga, Toshiki Kasugai, Kiyoshi Kishi, Michio Koshino, Yousuke Miyakoshi, Yasuyuki Morita, Kentaro Nagasawa, Toru Saito, Toshihiko Sato, Shunpei Urawa, Shigehiko		
<i>Korea</i>	Baek, Jae Min Kim, Jin Yeong Kim, Ju-Kyoung Kim, Suam	<i>NPAFC Secretariat</i>	Chan, Claudia Davis, Nancy Fedorenko, Vladimir Morris, Wakako

