Workshop Report

Morioka Salmon Workshop

bridging fisheries research and education for sustainable salmon fishery

February 8-10, 2016
Hotel Metropolitan Morioka New Wing
Morioka, Iwate, Japan

Iwate University
Sanriku Fisheries Research Center


Morioka Salmon Workshop
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Preface

Iwate University decided to establish a new graduate school and undergraduate course of fisheries science to promote rehabilitation of the fisheries industry in Sanriku-region heavily damaged by a massive earthquake and devastating tsunami on March 11, 2011. Sanriku fisheries industry is largely relying on salmon catch. The purpose of this workshop, open for public, was to help launch a new fisheries science education in Iwate University for promotion of salmon research to help sustain Sanriku fisheries industry. The organizing committee of the workshop planned to learn about the latest findings and advanced concept of salmon research by renowned workers from world salmon/fishery community, besides a survey on advanced fishery education systems in related countries.

The workshop was attended by over 100 international and domestic scientists/experts and general audience including people from fisheries and non-fisheries sectors. Workshop participants provided 19 oral presentations, including a Plenary lecture and 18 invited talks, and 15 posters addressing the following topics related to world salmon research and education:

1. Pacific salmon production in North America, Russia and Japan
2. Salmon biology with selected issues of genetics, physiology and ecology
3. Salmon and fisheries education with selected issues of ecosystem, socio-economics, regional program, and global marketing

Presenters indicated salmon production could be affected by expected climate or ecosystem change at varying spatial and time scales in the North Pacific. Potential ecological interactions affecting marine survival of juvenile salmon were identified as a probable key factor linked to the fluctuation of ocean salmon resources. Innovative studies using genetic and other biological techniques continue to provide new information on the conservation and enhancement of wild salmon stocks. Salmon aquaculture, such as those represented by Atlantic salmon model, could have potential for changing global salmon production systems and fisheries economics.

On behalf of the Workshop Organizing Committee, we thank all presenters for sharing information and ideas on salmon research and education at the meeting and for submitting materials for this volume. Material in this report has not been peer-reviewed and does not necessarily reflect the views of authors' agencies or institutions. Some of the researches included here are preliminary. Abstracts have been minimally edited for style, clarity and future publication process.

Syuiti Abe
Technical Editor
Organizing Committee for Morioka Salmon Workshop

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Plenary lecture

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Planning for the Future of Pacific Salmon Production

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Keywords: Pacific salmon, marine survival, production trends, future forecasting

Introduction

Problems with our understanding of future Pacific salmon (*Oncorhynchus* spp.) abundances relate to the poor understanding of the factors affecting their survival in the ocean and mostly in the early marine period. Part of the difficulty is the relatively recent understanding that the relationship between the number of spawning adults and subsequent recruitment of individuals to a fishery or to a spawning population or both can be strongly influenced by ocean and climate conditions that are non-random. As there is little doubt that the accumulation of greenhouse gases in the atmosphere will affect the productivity of the ocean and as we begin to understand the planetary forces that cause natural trends in climate, including regime shifts, it should be clear that it is the time to determine how marine survival is regulated. and develop reliable forecast models. Understanding the mechanisms that regulate the marine survival of Pacific salmon is no longer something that would be nice to know; the understanding is the only way Pacific salmon production can be optimized in our future climate. It is the objective of my presentation to provide examples of the consequences of not understanding the mechanisms that regulate Pacific salmon production as well as identify how the factors affecting marine survival might be researched.

An example of the consequences of not understanding marine survival

Canada's hatchery program that began in the late 1970s was expected to double Canada's annual Pacific salmon catch by about 2005, and proponents of the program assumed that the percentage catch by all countries would be about the same. The general belief among scientists was that there was substantial capacity for increased salmon production before the ocean rearing capacity would become a limiting factor. Canadian scientists told their government officials that beginning in the 1930s, major losses through environmental damage and overfishing had reduced salmon production to about one half of the potential. It was proposed that by adding more hatchery-reared juvenile Pacific salmon of all five major species, the annual gross commercial fishing revenues would more than double. Furthermore, the increased taxes on these increased revenues would about pay for the program. However, by about 2005, the Canadian catch of all salmon decreased by about 2/3 of the catch in the early 1970s (Fig. 1) and was less than 20% of the forecasted production in 2005. At the same time, Canada's share of the total Pacific salmon catch by all countries decreased from about 15% in the early 1970s to about 3%.

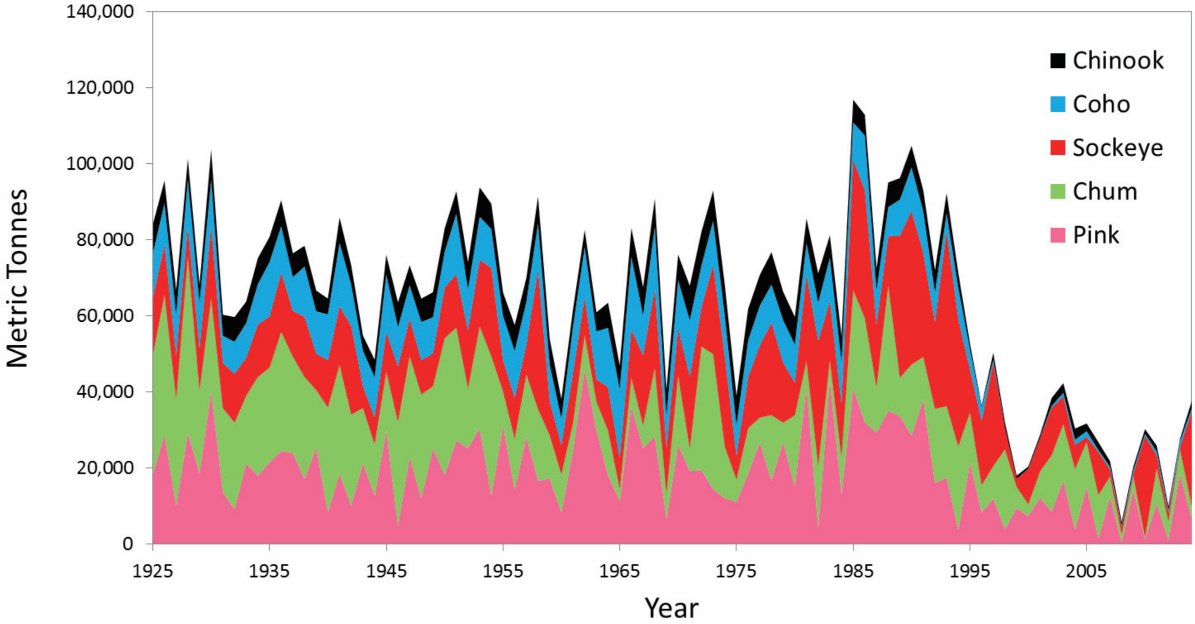


Figure 1 The total commercial catch of all species of Pacific salmon by Canada from 1925-2014

The problem was that changes in the ocean ecosystem around British Columbia were not random as was expected. There was evidence that prior to the 1970s, this might have been the case, but it was a surprise that the ocean environment changed and marine survival declined (Beamish et al. 1995, 1999a, 2008, 2010). The declining trend in survival of Chinook and Coho salmon may have started about the time of the 1977 regime shift (Benson and Trites, 2002) which was also the start of the hatchery program. Other changes contributed to the decline in the Canadian percentage of the total catch by all countries, as the catch of pink and chum salmon by Japan, Russia and the United States increased. The increasing hatchery production of chum and pink salmon in Japan, Russian and the United States, contributed to the increased catches as did an improved ocean survival of wild fish. I think it is fair to conclude that the inability of the hatchery program in British Columbia to meet the targets was an unpleasant surprise, while the hatchery successes in Japan and Russia were pleasant surprises. There is another surprise waiting for all countries that are depending on continued improved production of pink salmon.

A new surprise

It is well known that the two-year life cycle of pink salmon prevents the interbreeding of brood lines. It is less well known that there are significant genetic influences between brood lines (Seeb et al. 2011, Beacham et al. 2012). I will show that there are also consistent differences in the productivity between the brood lines and that this difference is increasing in recent years.

The total catch of pink salmon by all countries has increased steadily since 1970 and is now at historic high levels (Fig. 2) accounting for more than 50% of the total catch of all Pacific salmon in even-numbered years. From 1970 to 2014 the catches in all odd-numbered years exceeded the catches in even-numbered years, except in 1993 and 1997 (Fig. 2). Beginning in 2001, the difference in catches between odd-and even-year pink salmon increased as the catches in even years flattened (Fig. 3). A few years ago, I speculated that the genetic differences between the brood lines reflected metabolic differences in which odd-year pink salmon use more energy for growth and store less energy as lipid in the early marine period (Beamish, 2012). This strategy would place a dependency on finding adequate prey offshore, during the winter. It is possible that the warming of the ocean has produced more prey in the winter and that prey became even more abundant since 2001. A recent study by M.E. Prechtl and M.V. McPhee (unpublished data, School of Fisheries & Ocean Sciences, University of Alaska Fairbanks, Juneau AK 99801) provides the first evidence that the speculation may be valid. They found that odd-year juvenile pink salmon had significantly greater IGF-1 levels than even-years populations and the odd-year populations had a significantly lower energy density, indicating that the juveniles in the odd-year populations were most likely allocating more energy to growth and less to lipid storage than the even-year populations. It is likely that there may even be populations within the odd-year brood line that are exceptionally resilient to future changes in the ocean environment. Research of the mechanisms involved could discover clues to the basic mechanisms that regulate the early marine survival of all Pacific salmon species. The message is that comparative studies of the marine survival of odd-and even-year pink salmon may provide a better understanding of how survival is determined in the ocean for all Pacific salmon.

An example of the cost and consequences of not having reliable forecast models

Poor returns of sockeye salmon to the Fraser River occurred in 2007 and 2008, but it was the unexpected exceptionally poor return in 2009 (Fig. 4) that convinced the Prime Minister of Canada to have a judicial inquiry into the reasons for the poor returns. Advisors to the Prime Minister believed that poor returns were alarming and the cause could best be identified by a Provincial Supreme Court Judge with powers of subpoena. The commission of inquiry began hearings in the summer of 2010. In the fall of 2010, the return of sockeye salmon was the largest in recorded history, but the reasons for the exceptionally large return were not considered. In the final report, (Cohen 2012) the commissioner, the Honourable Bruce Cohen, determined that the cause of the poor return in 2009 was a result of marine conditions in the early marine period in 2007. He wrote that "abnormally high freshwater discharge, warmer-than-usual sea surface temperatures, strong winds, and lower-than-normal salinity may have resulted in abnormally low phytoplankton and nitrate concentrations that could have led to poor zooplankton production."

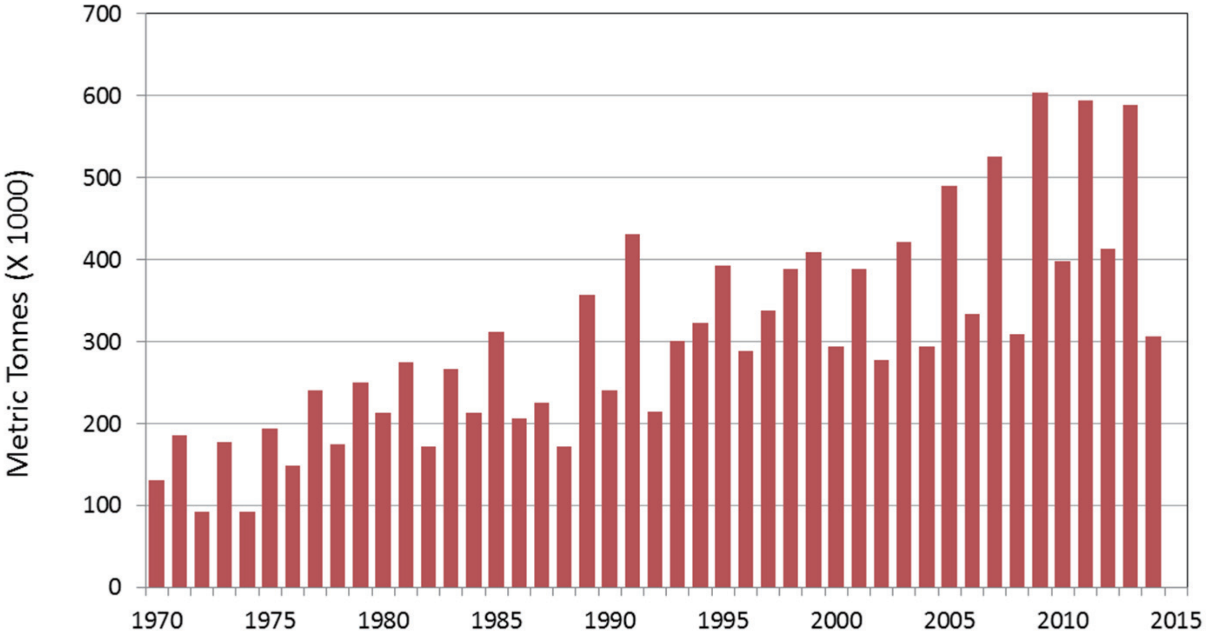


Figure 2. The total commercial catch of Pink salmon by all countries from 1970-2014

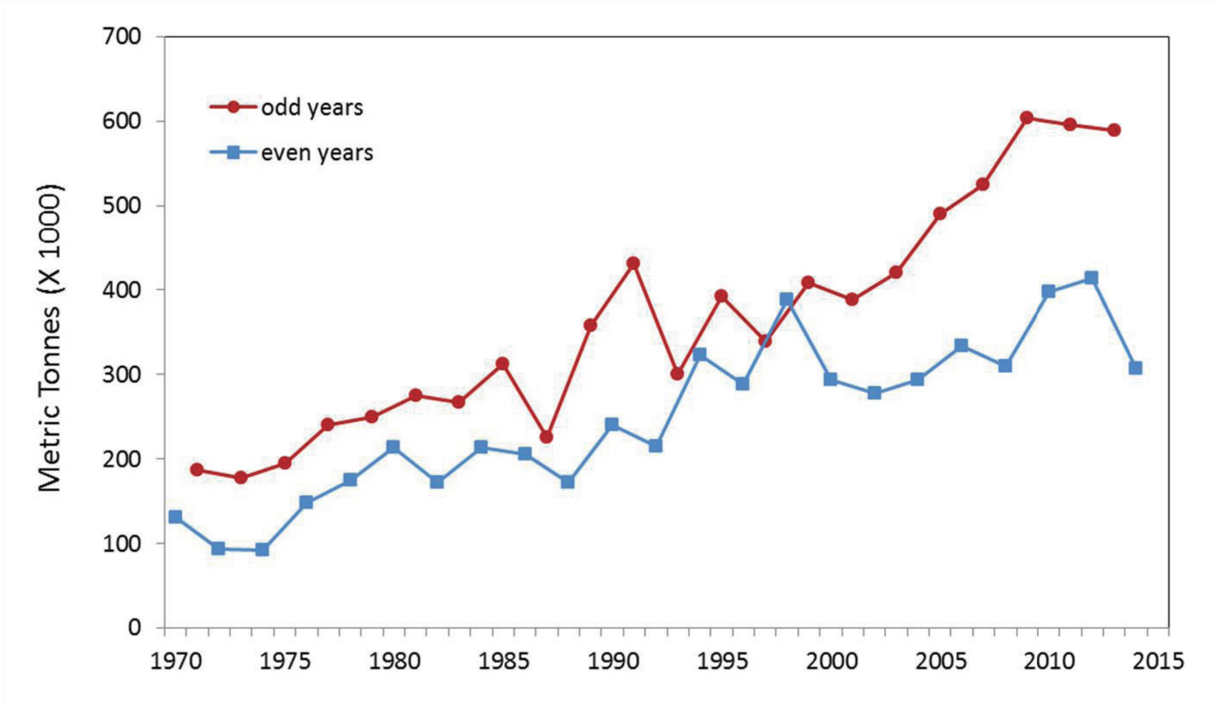


Figure 3. A comparison of the trends in catches in odd-numbered and even-numbered years. A difference in catch trends begins to increase about 2001.

His decision was based on evidence that was eventually published in Thomson et al. (2012), Beamish et al. (2012), and Preikshot et al. (2012). However, the main focus of the inquiry moved away from the poor return in 2009 and concentrated on the declining trend in production that began in the early 1990s (Fig. 4). The Commissioner was unable to explain the trend and wrote “some I suspect hoped that our work would find the smoking gun- a single cause that explained the two-decade decline in productivity. The idea that a single event or stressor is responsible for the 1992-2009 declines in Fraser River sockeye is appealing but improbable.” After three years, a cost of over 40 million dollars to all involved and the countless efforts by many people, the only certainty was that we continue not to understand what controls the production of Fraser River sockeye salmon. It was agreed that extreme ocean and climate conditions affected sockeye salmon production, but it was not concluded that the declining trend in production was also a result of climate and ocean conditions even though there was published evidence that this was a possible explanation for Fraser River sockeye salmon (Beamish et al. 2004). and other species such as Pacific halibut (McCaughran 1997, Clark and Hare 2002).

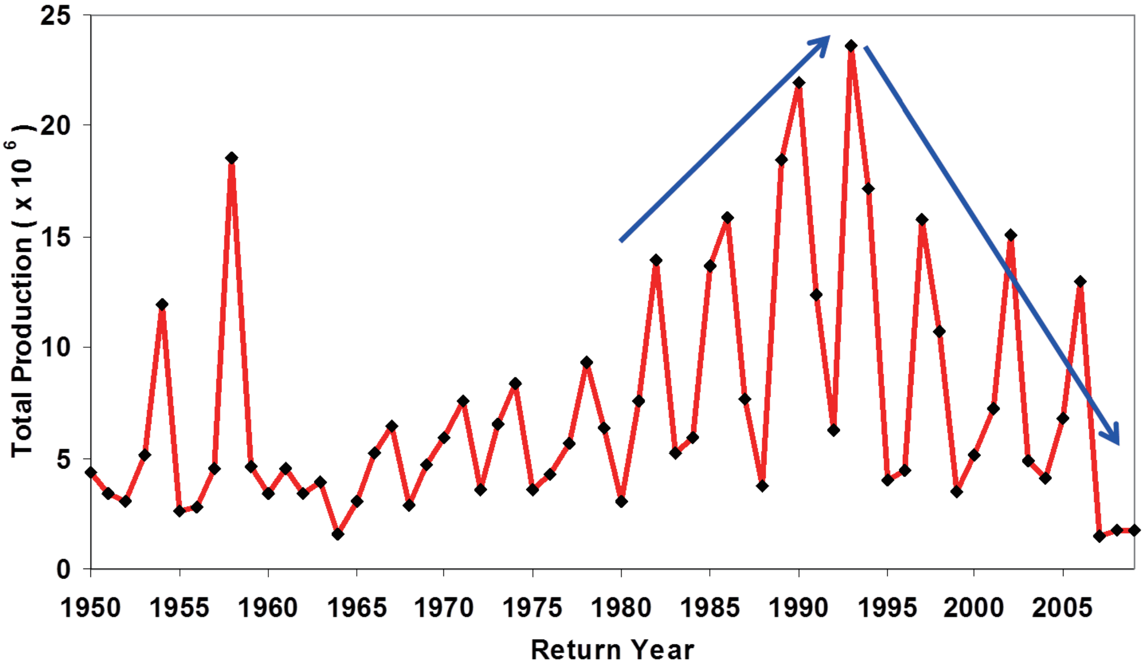


Figure 4. The total returns (catch and escapement) of sockeye salmon to the Fraser River from 1950-2009. The four-year cycles are natural. Arrows show the increasing trend from early 1980 to 1993 and the subsequent declining trend to 2009. The poor returns in 2007, 2008, and 2009 are circled.

Applying the Krogh Principle to understand the early marine survival

Understanding the factors affecting the marine survival of juvenile Pacific salmon is a difficult problem. In comparative physiology, one way of solving a difficult problem is to select an animal that had structures best suited for the particular study. The Krogh Principle (Krogh 1929, Lindsted 2014) stated that “for a large number of problems there will be some animal of choice or a few such animals on which it can be most conveniently studied”. Accordingly, the selection of a particular animal can greatly reduce the variability associated with trying to study a number of animals. The principle could be applied to the problem of identifying the mechanisms regulating the marine survival of salmon by selecting a population that more clearly shows how early marine survival is regulated. The Harrison River sockeye salmon population is a population within the Fraser River drainage that has survived much better than all other sockeye salmon populations in the river in recent years (Beamish et al. 2016). The population accounted for a small percent of the total return historically, but from 2005 to 2013, there was a large increase in percentage (Fig. 5). The juvenile sockeye salmon from the Harrison River are sea-type salmon which means that they enter ocean in their first year of life, unlike the other populations that are lake-type and spend at least one year in a lake or a river before entering the ocean. A major difference between the life history types is that the sea-type are much smaller when they enter the ocean and they enter the ocean about an average of eight weeks after the lake-type juveniles. In the study by Beamish et al. (2016), it was observed that there was a strong relationship (R^2=0.86) between the abundance of the juvenile Harrison River sockeye salmon in the fall of the their first ocean year in the Strait of Georgia and the total return of adults, indicating that ecosystem conditions in the Strait of Georgia were most likely the reason for the

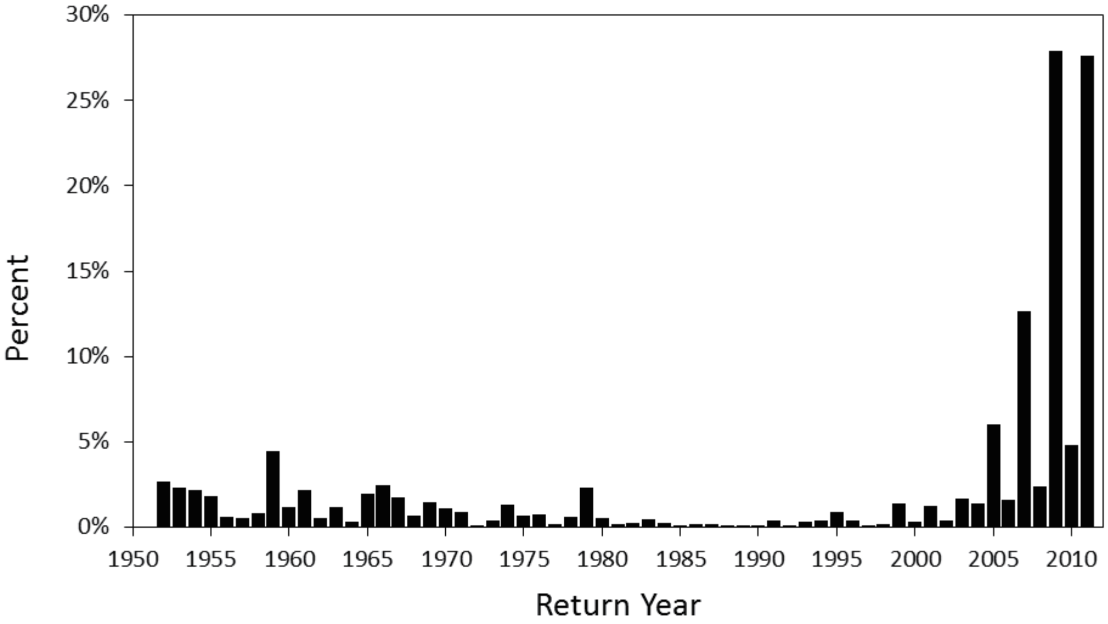


Figure 5. The percent of the population of sea-type of sockeye salmon from the Harrison River in the total return of all sockeye salmon to the Fraser River from 1952-2013

reason for the recent improvement of production. The conditions causing the improvement were not identified except that it was determined that the juveniles were highly selective for a species of hyperiid amphipod that was not previously identified as being abundant. A possible explanation is that the particular amphipod species (*Primo abyssalis*) became more abundant as a result of an ecosystem change, resulting in a large abundance of prey later in the year, when the Harrison River smolts entered the ocean. Despite their small size, the juvenile sea-type sockeye salmon may have found food quickly and grew quickly supporting the general belief that juvenile Pacific salmon that grow faster, sooner, survive better. There could be additional reasons for the improved survival such as reduced predation. The point is that the Harrison River population can be conveniently studied in the Strait of Georgia and the contrasting survival with the lake-type juveniles that enter the ecosystem earlier and do not survive as well could be a focus for studies of marine survival. If other examples of extremely anomalous survival can be identified in other areas for other species, a coordinated international research effort could greatly improve the understanding early marine survival of all species of Pacific salmon.

Why accurate forecasts are important to Japan

Of immediate importance to Japan is the necessity to understand the mechanisms regulating Japanese chum salmon production. The declining production of chum salmon from Japan and the increasing catch of chum salmon from Russia (Fig. 6) make it clear that understanding the mechanisms that regulate

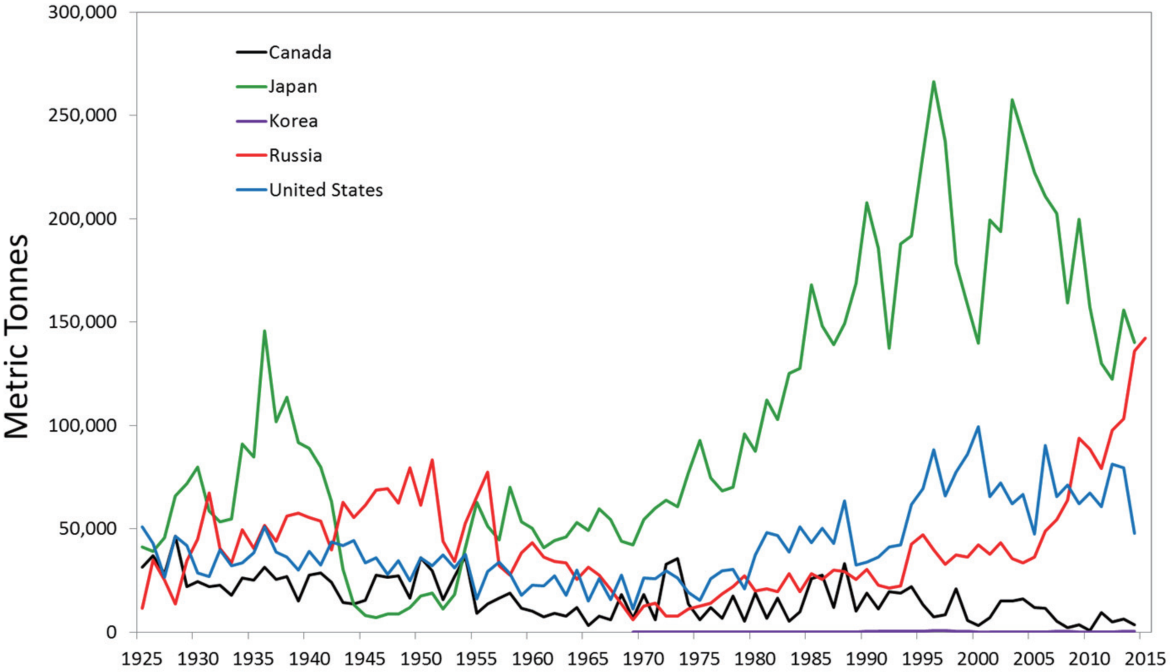


Figure 6. The catch of chum salmon by the five Pacific salmon producing countries from 1925-2014. The catches by Japan and Russia were about equal in 2014 (circled). The 2015 Russian catch is preliminary and exceeds the Japanese 2014 catch.

marine survival is no longer something that would be nice to know; the understanding is the way chum salmon production in the two countries can be optimized in a future of unexpected changes in the ocean ecosystem.

Including trends in survival in forecasts

I think we agree that there is a random component to ocean variability that affects salmon survival, but I think we also agree that there are trends in the ocean environment that have major influences on the production of a particular species over relatively large areas (Beamish et al. 1999b), Trends and shifts in trends, or regime shifts, are real problems that make it difficult to develop reliable forecast models. For example, it is important to know when the relative influences of parameters within a model have been changed.

There is a well-known understanding that discoveries are often made by thinking differently. I will finish my presentation by thinking a little differently.

Beamish and Bouillon (1993) may have been the first to show that there are large scale trends in Pacific salmon production that are related to natural trends in climate. They showed that there were trends in the total catch of all Pacific salmon species that changed about the same time as climate regime shifts that have been generally recognized as occurring in 1925, 1947, 1977, 1989, and 1998 (Minobe 1997, Hare and Mantua 2000). The most important of these regime shifts was in 1977 (Overland et al. 1999, Benson and Trites, 2002) and literally dozens of studies have documented a wide variety of changes resulting from the 1977 regime shift. It is the trend in the strength of the Aleutian Low pressure that matches the production of all species of Pacific salmon, with winters of very low pressures (strong Aleutian Lows) related to trends in increased Pacific salmon production and weak periods with reduced production trends. Rauthe and Paeth (2004) showed that it is the Aleutian Low that dominates the climate over the North Pacific Ocean, thus there is little doubt that climate occurs in trends and the trends are related to Pacific salmon production. But, what causes these natural trends in climate and can they be readily detected after they change, or even better can they be predicted?

There are a number of indices of climate over the subarctic Pacific, but a rarely used index of winter atmospheric circulation over the North Pacific is the Pacific Circulation Index (PCI, King et al. 2006). The index was developed by following the method of Girs (1971) and is the North Pacific equivalent of the Atmospheric Circulation Index (Klayshtorin, 1998). The index identifies the dominant wind direction for the particular winter and is expressed as a cumulative sum (Murdoch 1979). Importantly, the procedure clearly identifies when dominant wind direction change and both the PCI and the Aleutian Low Pressure Index change about the same time when the Aleutian Low Pressure Index is expressed as a CuSum (Fig. 7). If a change in the trend of the dominate direction of the winter winds is an index of changes in the trend of the Aleutian Low and thus in the trends of Pacific salmon production, is there is a possibility of quickly detecting when there are changes in the trends in the winds and the Aleutian Low.

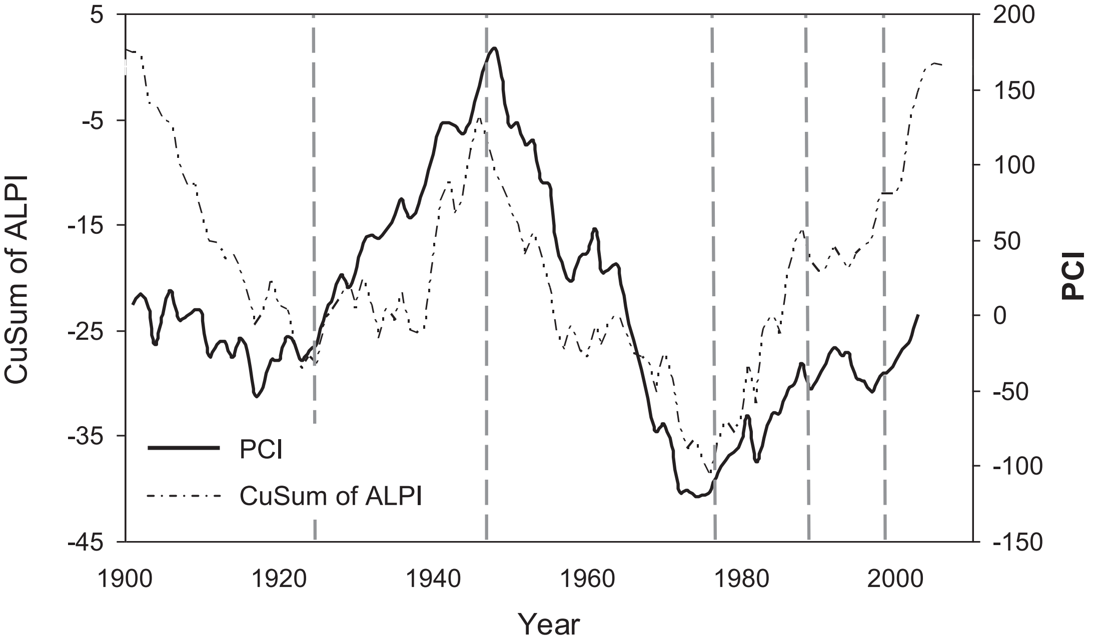
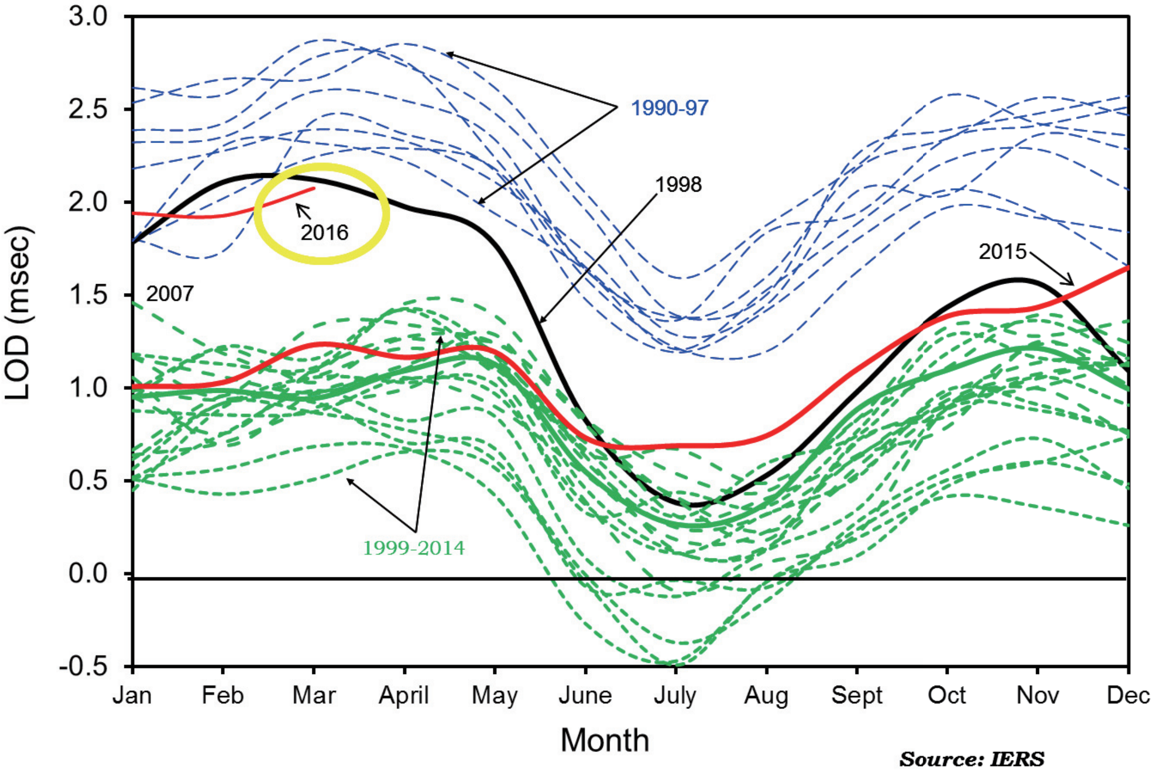


Figure 7. The Pacific Circulation Index (PCI) and the cumulative sum (CuSum) of the Aleutian Low Pressure Index (ALPI) from 1900 to 2003 (Beamish et al. 2009). The Vertical dashed lines identify the regime shift years.

There is a large amount of speculation involved, but recognizing that there can be rewards by thinking differently, I suggest that there is value in researching the relationship in the changes in the pattern of the Length of Day or LOD. The LOD is an expression of the rotational speed of the crust and mantle which are referred to as the "solid earth". LOD is the difference between the astronomically determined duration of the day and the standard LOD that was determined to be 86,400s on January 1, 1958. There are seasonal changes in the LOD and there are longer term trends (Eubanks 1993). It is the change in the pattern of longer term trends that may be helpful in identifying when there are major regime shifts as the changes in trends can be determined accurately and it may even be possible to forecast a change, at least a few months in advance. The principle is that because energy in a body rotating in a frictionless environment is conserved, any change in the rotational velocity of one of the four shells of the planet (core, solid earth, hydrosphere, and atmosphere) must be transferred to another shell (Eubanks 1993). The amount of energy that is transferred in a 1-millisecond change is huge. A 1-millisecond change in the LOD represents a transfer of energy equivalent to the energy produced by 1 million power stations of 100 megawatts each year, or 6-10 times the global energy consumption or about 30% change in the mean zonal wind velocity. In Beamish et al. 2009, it was shown that there was an abrupt change in the seasonal pattern of the LOD in 1998 (Fig. 8). The seasonal data used in the figure became available in 1984 and also showed a change in 1989. Both 1989 and 1998 were regime shift years as reported previously. There were no major changes in the season pattern of LOD after 1998 until late 2015 and early 2016 (Fig. 8). The change between January 2015 and January 2016 represents a slowing down of the solid earth by about 1-millisecond. If the change persists, it is possible that we may see a major regime shift in 2016 that will affect the productivity of Pacific salmon. Importantly, a focus on the energy transfers and the factors that cause the shifts may discover a method of improving the long-term forecasts of Pacific salmon production by quickly detecting when survival trends and correlations might change.



Source: IERS

Figure. 8. The average monthly length of day (LOD) showing the seasonal trends with a slowing down in the Northern Hemisphere winter and a speeding up in the summer. The pattern from 1990-1997 (dashed purple lines) changes to a new pattern in 1998 (solid black line).The pattern from 1998 to 2015 (dashed green lines) appears to have changed in December 2015 (solid red line) with a new pattern possibly beginning in 2016 (solid red line).

Conclusion

We have difficulty forecasting Pacific salmon production either in the short term or long term because we poorly understand both the causes of early marine mortality and the trends in ocean and climate variability that affect the production of particular species. In the past, the effects of climate and ocean variability were thought to be random and thus were not a focus of research. However, beginning about 25 years ago, it was determined that there were natural trends in Pacific salmon production that were related to climate and ocean trends. It is expected that both natural trends and changes resulting from greenhouse gas accumulations will become more influential in the production of Pacific salmon and it is time to focus research to determine the processes that affect marine survival. We will eventually have this understanding and we will eventually have reliable forecast models. The fastest and least expensive way of developing reliable models is a coordinated, international research effort. As Bill Ricker said, "everything is simple after it is discovered" and students in the future will wonder why it took so long to develop the forecast models that they will learn early in their university careers.

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The use of marine ecosystem metrics for preseason forecasts of salmon harvest

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Keywords: pink salmon, chinook salmon, adult returns, harvest forecasts

Annual forecasts of pink salmon (*Oncorhynchus gorbuscha*) harvest and Chinook salmon (*Oncorhynchus tshawytscha*) returns to the Yukon River were developed to advise fishery managers, members of fishing industries, and the public. Although the forecasts were developed independently for different species and widely separated geographic localities (Fig. 1), the projects illustrate the utility of using marine ecosystem metrics for forecasting future harvest of salmon and how to effectively communicate results and uncertainty to stakeholders.

Figure 1. Two regions in Alaska where salmon forecast models were performed: pink salmon harvest in Southeast Alaska and upper Yukon Chinook salmon return strength in the Yukon River in Western Alaska.

The presentation consists of exploring the specifics of each example by following a "road map" that describes the series of steps necessary to connect ecosystem metrics to output response variables in order to develop products useful to salmon managers and stakeholders. The steps of the road map are as follows: Step 1) Identify a problem in need of a solution with climate driven ecosystem services; Step 2)

Understand and define processes and relationships between climate, fish production and behavior, and fishery performance; Step 3) Develop research products based on the relationships, and Step 4) Operationalize research products through timely, dependable delivery to managers and stakeholders.

For the pink salmon fisheries in Southeast Alaska, the problem (Step 1) was identified as the high degree of uncertainty introduced into planning for harvesting, processing and marketing by the high level of variability in annual pink salmon abundances (Fig 2) and the correspondingly low level of precision of pre-season pink salmon forecasts. Motivation to find a solution was added by the large economic value of the fishery, and the importance of pink salmon to the ecosystem. The challenge posed by lack of mechanistic understanding (Step 2) of relationships between climate, fish behavior (juvenile abundance and ocean distribution) and fishery performance (adult production) for this species was overcome by using the working hypothesis that those climate driven processes that drive mortality during the pink salmon's early marine life history is high, variable, and affects year class strength, thus, after this critical period, surveys assessing juveniles in seaward migration corridors can predict year class strength, however ocean state suitability can also impact fish during annual ocean residence. Through research (Step 3) the solution was readily identified as an accurate and reasonably precise forecast of annual harvest (Fig. 3). Developing the forecast based on the relationships was accomplished in a quantitative (step-wise linear regression) and qualitatively (six ecosystem metrics significantly correlated with harvest the next year) (Orsi et al. 2012). The qualitative measure of uncertainty also incorporated traffic light colors by correlation score: Ranked scores were averaged across each year (harvest: high, average, and low) (Fig 4).

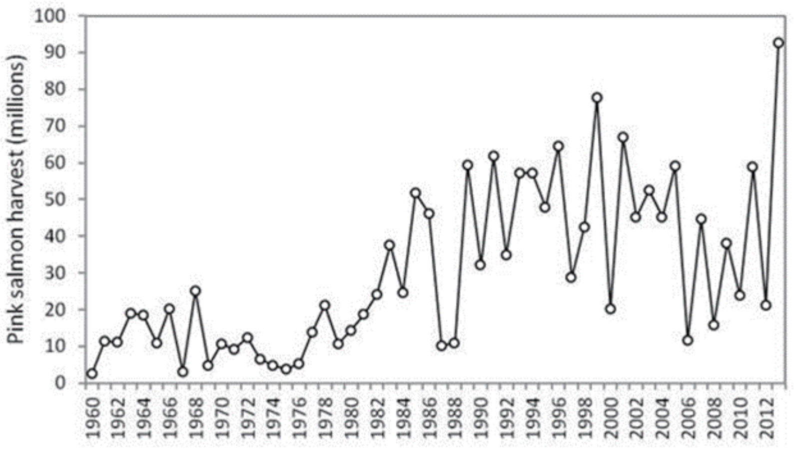


Figure 2. Variability of commercial pink salmon harvest in Southeast Alaska since 1960. Over this period harvests have ranged from 2-95 M fish, with the overall production composition of 97% wild stock based.

To operationalizing the research (Step 4), timely communication was accomplished to the Alaska Department of Fish and Game (ADFG) so the ecosystem information could be incorporated into their forecasts (10 months prior to the fishery). As a final step in operationalizing the forecast, the pre-season pink salmon forecast was presented to resource stakeholders at the SEAK Purse Seine Task Force Meeting (7 months prior to fishery), and later a pink salmon forecast web site was updated with the appropriate

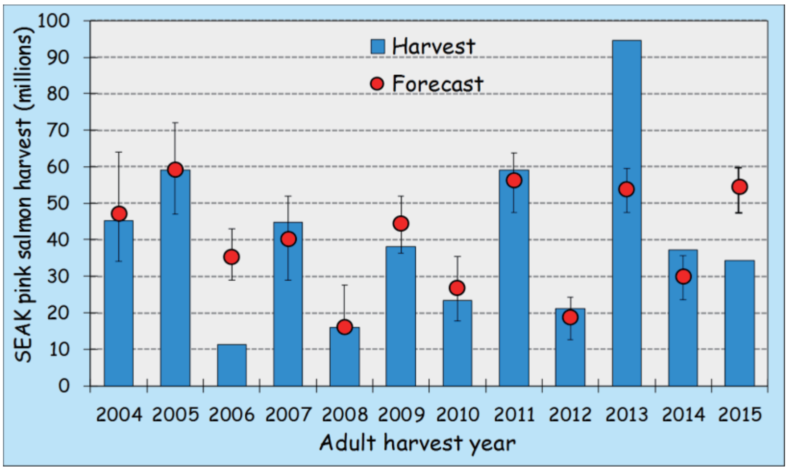
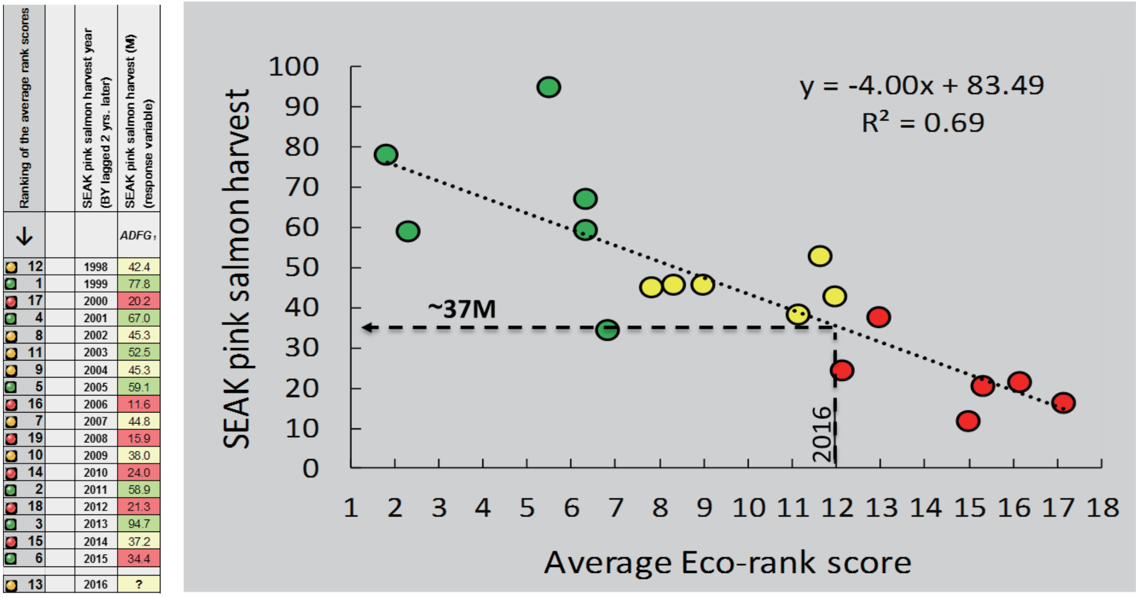


Figure 3. Pre-season harvest forecast of pink salmon to Southeast Alaska (circles) with 80% confidence intervals and the actual harvests seven months later (bars).



Ranking of the average rank scores		SEAK pink salmon harvest year (BY lagged 2 yrs. later)	SEAK pink salmon harvest (M) (response variable)
↓			ADFG₁
🟡 12		1998	42.4
🟢 1		1999	77.8
🔴 17		2000	20.2
🟢 4		2001	67.0
🟡 8		2002	45.3
🟡 11		2003	52.5
🟡 9		2004	45.3
🟢 5		2005	59.1
🔴 16		2006	11.6
🟡 7		2007	44.8
🔴 19		2008	15.9
🟡 10		2009	38.0
🔴 14		2010	24.0
🟢 2		2011	58.9
🔴 18		2012	21.3
🟢 3		2013	94.7
🔴 15		2014	37.2
🟢 6		2015	34.4
🟡 13		2016	?

Figure 4. Qualitative traffic light forecast based on average rank score of six significant ecosystem metrics: juvenile pink catch, peak migration month, proportion of pinks in salmon catch, adult coho predation index, and the North Pacific Index. Rank score for the 2016 pink salmon harvest was 13th out of 19th position.

data and linked to other web sites (SECM project).

For Yukon River Chinook salmon in Western Alaska, the problem (Step 1) was identified as the high level of uncertainty introduced into harvest management by large interannual fluctuations in return strength each year (Fig 5). A sense of urgency in finding a solution has been added by a fall to levels of abundance low enough to precipitate a Federal disaster declaration for the fisheries. Further urgency is added by the presence of an international treaty with Canada that requires U.S. fisheries to pass through a minimum number of adult upper Yukon (Canadian-origin) Chinook above the Canadian border each year which has become difficult as total annual abundances have declined. As with SE Alaska pink salmon, challenge posed by lack of mechanistic understanding (Step 2) of relationships between climate, fish behavior (juvenile abundance and ocean distribution) and fishery performance (adult production) for Yukon Chinook was overcome by using the working hypothesis that mortality during Chinook salmon's early marine life history is high, variable, and affects year class strength, thus, after this critical period, surveys assessing juveniles in the north Bering sea seaward can predict year class strength, however ocean state suitability can also impact fish during annual ocean residence. Using research (Step 3), a time series of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) abundance was constructed for the Canadian-origin (Upper Yukon) stock group of the Yukon River from late-summer (typically during the month of September) pelagic rope trawl surveys in the northern Bering Sea, (BASIS) 2003-2015. Abundance is estimated from trawl catch-per-unit-effort data, genetic stock composition, and mixed layer depth in the northern Bering Sea. Juvenile Chinook salmon abundance estimates for the Canadian-origin stock group have ranged from 0.6 million to 2.6 million juveniles with an overall average of 1.5 million juvenile Chinook salmon from 2003 to 2015 (Fig. 6). The Canadian-origin Juvenile abundance index is

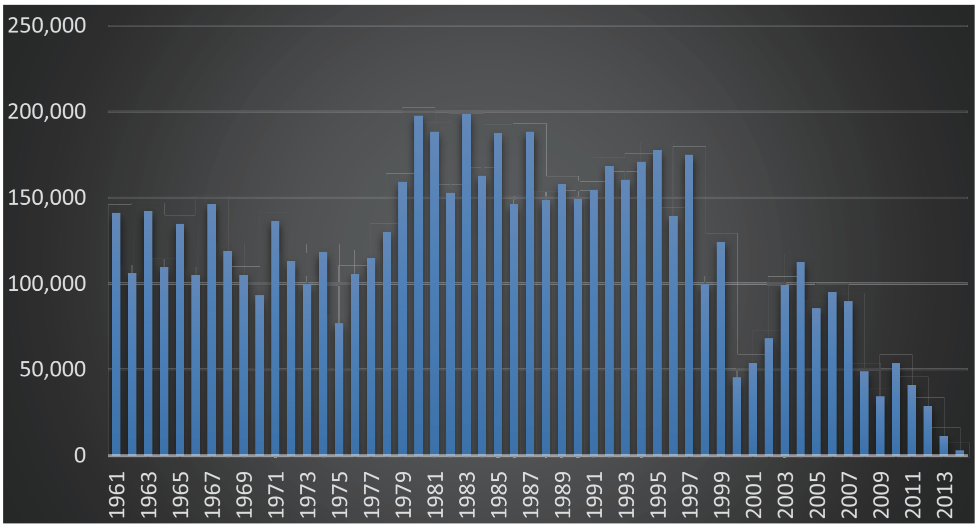


Figure 5. Yukon River Chinook salmon harvest

significantly correlated with adult Canadian-origin returns (Fig. 7) which allows a reasonably accurate projection of future returns of the Canadian- origin stock group to the Yukon River (Fig 8). To operationalizing the research (Step 4) this forecast is presented to the Yukon River stakeholders through the Yukon River Joint Technical Committee.

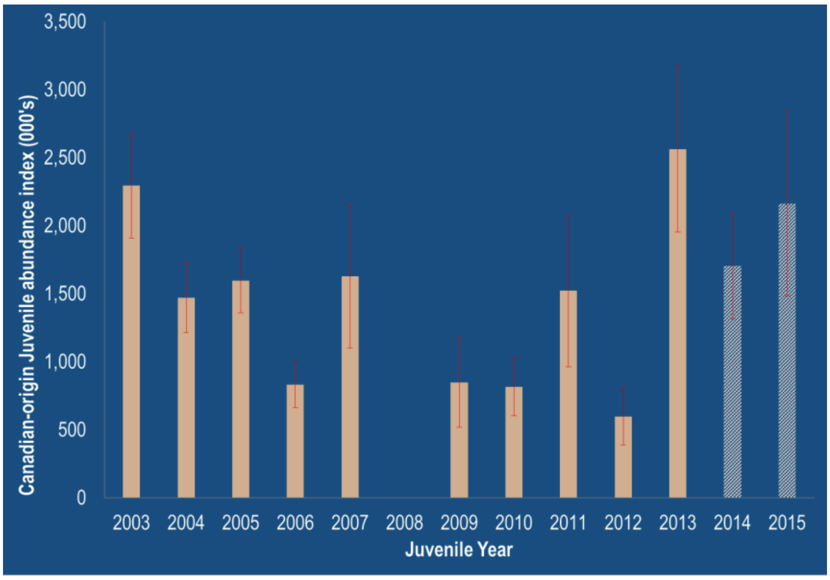


Figure 6. Canadian-origin juvenile index in the northern Bering Sea (average cv of 23%)

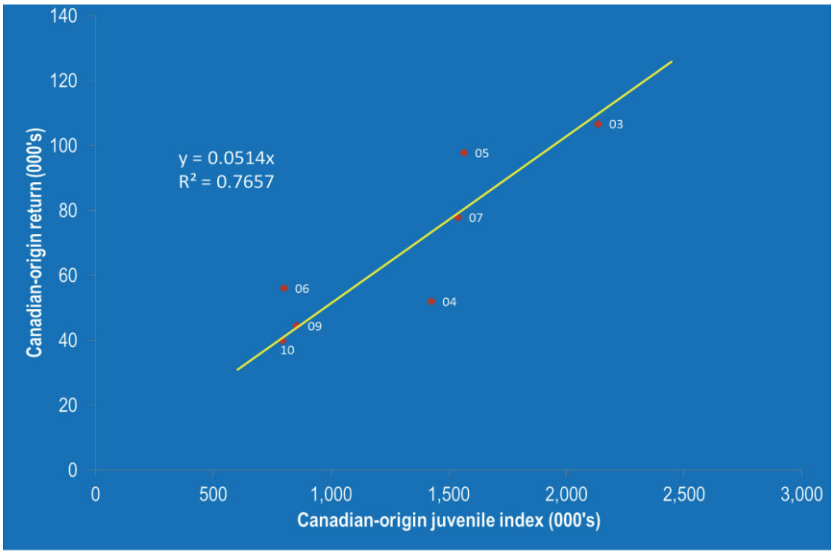


Figure 7. Relationship of Canadian-origin juvenile index and adult returns

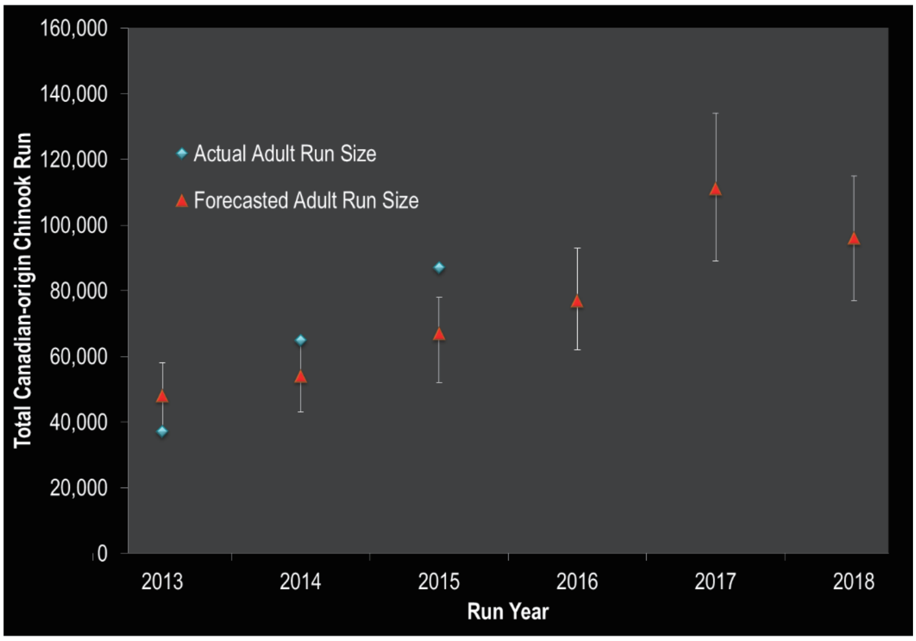


Figure 8. Accuracy of Canadian-origin juvenile index forecast to adult returns of the last three years and future predictions

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Applying genetic markers to manage sustainable fisheries for salmon in Alaska

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Keywords: Pacific salmon, Alaska fisheries, genetic management, SNP markers

Abstract: The state of Alaska is home to some of the largest runs of both hatchery and wild salmon in North America. On one hand, there are different fisheries issues between Alaska and Sanriku; on the other hand, the rapid progress made in Alaska to apply genetic markers to manage fisheries can provide important insights as Sanriku fisheries are revitalized. The Alaska Department of Fish and Game maintains a large genetic laboratory that conducts DNA analyses on over 100,000 individual salmon each year. Salmon species of primary interest include chum salmon, sockeye salmon, pink salmon, and Chinook salmon. Evaluating levels of genetic variability provides insights into hatchery breeding programs and is used to assess the impacts of hatchery stocks on wild stocks. One tool, called parental-based tagging, uses the presence of genetic marks to assign migrating fish back to their hatchery of origin. Natural genetic variation that differentiates stocks of each species provides an important tool to 1) track migration on the high seas, 2) assess stock-specific bycatch in marine fisheries that target other species, and 3) assess stock composition in near-shore fisheries that intercept fish from many different regions. All of these applications improve sustainable management of salmon stocks. I'll review examples of these applications and focus on the use of genetic data to shape fisheries that harvest sockeye salmon in Bristol Bay in the Eastern Bering Sea.

Background

Here I summarize cooperative research conducted by the University of Washington and the Alaska Department of Fish and Game to use applied genetics to inform the management of Pacific salmon. In this partnership the university uses innovative techniques to provide genetic solutions to conservation problems faced by the management agency; the agency then applies the solutions (or gene markers), sometimes in real time, to shape fisheries decisions in order to manage stocks on a sustainable basis.

Genetic research on Pacific salmon has relied upon the development of thousands of DNA markers in the species of interest. Single nucleotide polymorphisms (SNPs; see Fig. 1), single base substitutions in the genetic code, were first found by Japanese scientists to be useful to identify stocks of chum salmon in the Pacific Ocean and Bering Sea (mitochondrial DNA studes; Abe *et al.* 2004; Sato *et al.* 2004). Active research to further develop dozens of SNPs in nuclear DNA lead to more fine-scale identification of stocks that were harvested in the coastal areas and rivers of Alaska (Smith *et al.* 2005a; Smith *et al.* 2005b). The University of Washington recently reported the use of advanced DNA sequencing techniques to provide genomic maps of thousands of SNPs in chum salmon (Waples *et al.* 2016), sockeye salmon (Everett *et al.* 2012; Larson *et al.* 2016b), pink salmon (Limborg *et al.* 2014), and Chinook salmon (Everett & Seeb 2014; McKinney *et al.* 2016). These thousands of SNPs provide the basis of many genetic studies today and into the future. Some of these SNPS are linked to adaptively important traits like thermotolerance (Everett & Seeb 2014; Larson *et al.* 2016a) and may play and important role in interpreting and dealing with the effects of climate change on hatchery production. Panels of these SNPs are also used in more routine studies of migration (Habicht *et al.* 2010; Sato *et al.* 2012; Larson *et al.* 2013), hatchery effects (Jasper *et al.* 2013), and harvest (Dann *et al.* 2013).

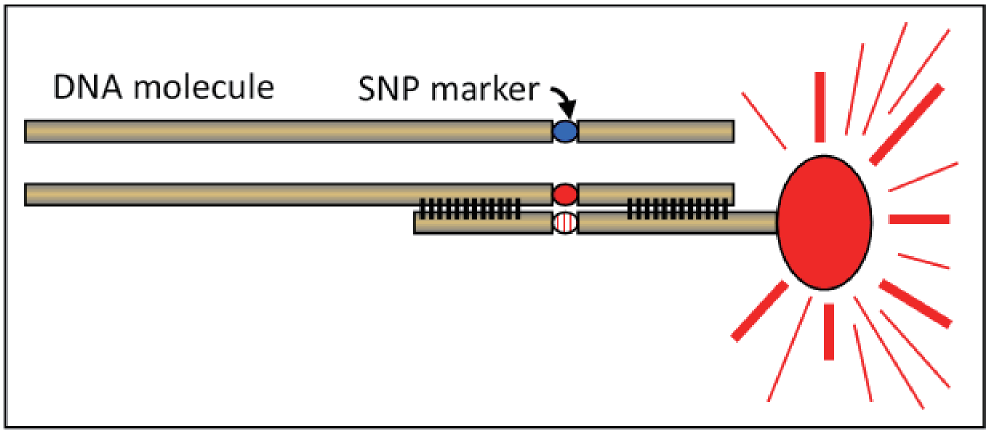

Figure 1. Representation of DNA molecules (brown bars) with a DNA marker in the form of a single nucleotide polymorphism (SNPs, the small blue and red circles in the two upper molecules). A DNA marker assay (bottom brown bar) can be designed to bind to only one of the SNPs, signaling the presence of a specific SNP with a colorimetric or other identifiable signal (large red oval). Individual fish have unique SNPs, populations of fish can be separated by the frequencies of sets of SNPs, and different species have clearly identifiably different SNP markers.

Applications

Agencies, especially Alaska Department of Fish and Game, cooperate to collect data on the presence and frequecies of SNPs in populations of chum salmon, sockeye salmon, pink salmon, and Chinook salmon from around the Pacific rim (see for example Habicht *et al.* 2012; Sato *et al.* 2014). These data are catalogued into baseline data sets for later use. These catalogues of SNPs enable the identification of unknown fish, frozen fillets in the market for example, to species, country, or sometimes river drainages or hatcheries in a country (see Fig. 2).

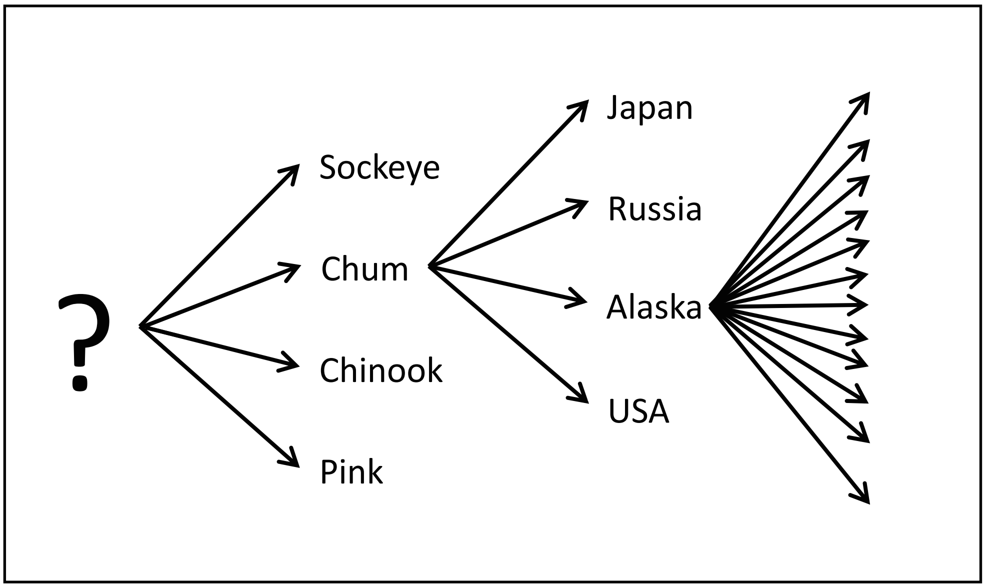

Figure 2. Catalogues of SNP markers clearly assign unknown fish (such as fillets in a market) to species of origin (step 1 below). More detailed analysis can assign unknown fish to country of origin (step 2). Finally, when more complete data catalogues are available, unknown fish can be assigned to local regions or sometimes rivers or hatcheries of origin (step 3).

Species identification can be especially valuable to fight fish fraud (see www pages such as http://www.theatlantic.com/business/archive/2015/03/bait-and-switch/388126/). The value of salmon can be highly variable among species, and studies have documented fraud in labeling. Agencies such as the Marine Stewardship Council (https://www.msc.org/) and others use SNP markers to insure truth in labeling.

Country of origin determination is especially important where international treaties control the harvest of migratory salmon. Fishery disputes over the harvest of USA and Canadian stocks of salmon are often mediated by genetic data.

Finally, the state of Alaska has been particularly successful with the use of SNP markers to manage fisheries. Some stocks of fish demonstrate large annual variations in productivity, and SNP markers are used to quantify the harvest of those specific stocks in migrating mixtures. Fishery districts and fishing time can be adjusted to protect weaker stocks while targeting the larger, more productive ones in any given year. In this fashion sustainability of the weaker stocks is insured while forgone harvest on the stronger stocks is minimized, providing the highest possible value to the fishing fleets.

The best example of this sustainable management occurs in the sockeye salmon fishery in Bristol Bay on the eastern edge of the Bering Sea. By many measures this is one of the highest value salmon fisheries in North America, and the fishery is intensively managed. There are nine primary stock groups that co mingle in the fishery; each can have dramatic annual variation in productivity, often controlled by local climate events during the freshwater incubation and rearing in the lakes (Fig. 3). Annual harvest of Bristol Bay sockeye salmon can vary from only a few million fish up to a peak of 40 million fish that was observed in the early 1990s. Fishery managers prosecute an every-other-day test fishery as the fish migrate from the Bering Sea North of the Alaska Peninsula. The genetic data inform the relative strength of the primary stock groups, and the fishing effort on each is adjusted to optimize catch and escapement (see complete description in Dann *et al.* 2013).

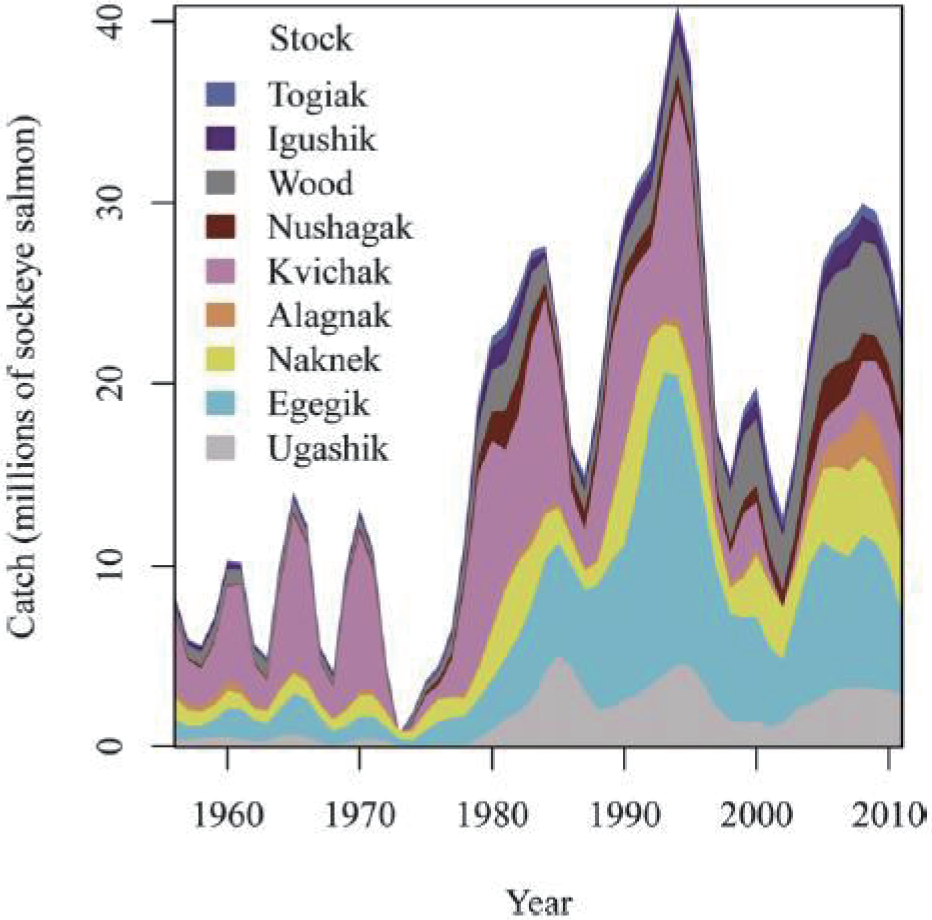

Figure 3. Commercial catch of sockeye salmon in Bristol Bay, Alaska, from 1959 to 2011 demonstrating the large annual variability in total surplus fish available for harvest and large annual variability in productivity of individual stocks. Taken from Dann *et al.* (2013).

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Russian salmon production: past, present, future

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Keywords: Pacific salmon, Russian catch, species-specific trends, future hatchery program

Over the past three decades, Russian salmon fisheries have been in favorable conditions. Commercial catch increased from 76-189 th. t in 1980s to 168-551 th. t in 2000-2010s resulting from increasing salmon populations. Pink salmon dominated the total salmon catch (63 %) followed by chum (14%), sockeye (3%), coho (1%), chinook (0.3%), and cherry (<0.01%).

Species-specific interannual trends showed different patterns (Fig. 1). Pink, chum, and sockeye tended to increase from 1980s to 2010s. Chinook salmon gradually decreased. Coho salmon tended to decrease from 1980s to the mid-2000s and sharply increased in 2007-2015. In 2009-2015, salmon production was at high level with record catch of pink (425 th. t in 2009), chum (142 th. t in 2015), sockeye (51 th. t in 2013) and coho (14 th. t in 2014 and 2015).

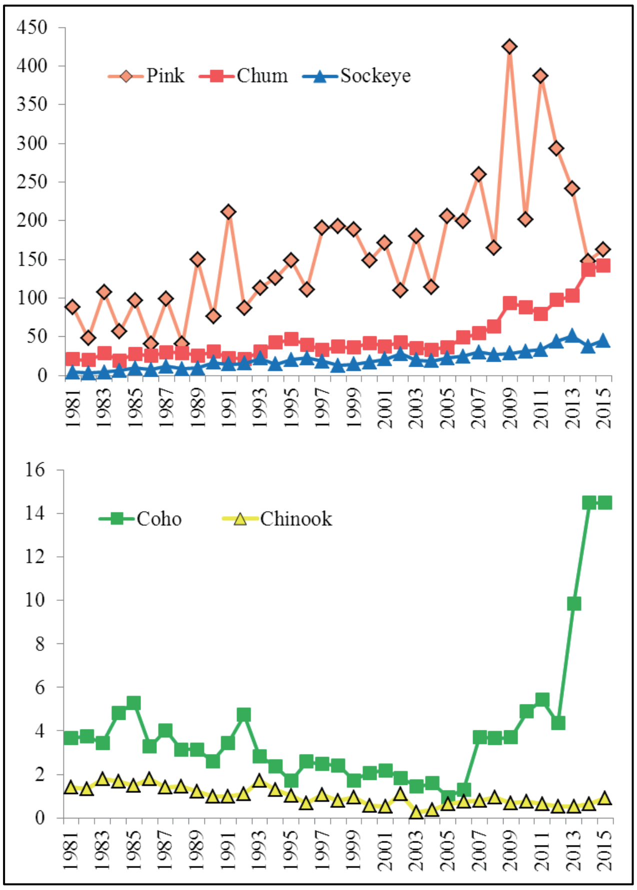

Figure 1. Russian salmon catch (th. ton) in 1981-2015

Kamchatka and Sakhalin are the main salmon regions in Russia. In 1970-2010s, their percentage in the total harvest averaged 72% (25% eastern Kamchatka, 20% western Kamchatka, 27% eastern Sakhalin).

Pink salmon catches fluctuated a lot due to change in even and odd stocks abundance. In general, it tended to increase in most regions from 1970s to 2000s. As for last years, there was a downfall of catches in the most productive pink regions (Sakhalin, Kuril Islands, Kamchatka). It seems that the south pink populations became less productive while the north ones tended to increase.

Catches of most chum salmon stocks greatly increased in 2000-2010s in Amur River, Kamchatka, Sakhalin and Kurile Islands. Similar trends showed main sockeye stocks (in Western and Eastern Kamchatka). Coho and chinook are abundant in Kamchatka. From 1970s to early 2000s, their catches changed similarly while in mid-2000s coho catches began to rise.

Most Russian salmon stocks are comprised of wild populations. Share of hatchery salmon is relatively small. Number of fish released from Russian salmon hatcheries varied but did not change greatly in 1970-2010s (0.5-1.0 bln ind.). This contributed about 10-15% to national salmon fisheries.

Pink and chum were the major hatchery fish (Fig. 2). They averaged 50.6% and 48.5% of the total fish released.

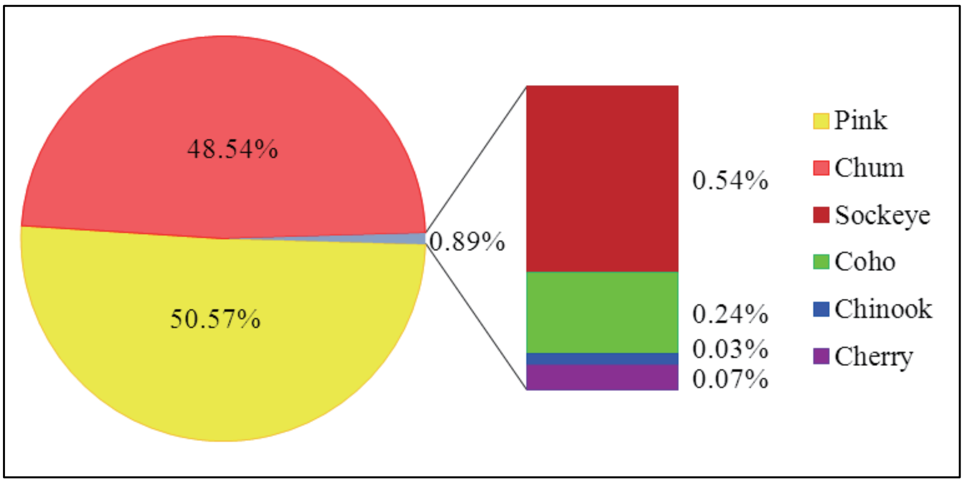

Figure 2. Salmon species shares in Russian hatchery releases, 1970-2014

In 2000s, number of chum salmon increased and reached 0.6 bln ind. (60%). Most Russian salmon hatcheries (43 of 65) are located in the Sakhalin-Kuril region.

Russia has a large potential for artificial reproduction of Pacific salmon and plans to expand hatchery program. Sakhalin, Primorye and Khabarovskiy region are considered to be reasonable areas for salmon hatcheries.

Status of chum salmon populations and research program for their rehabilitation in the Pacific coast of northern Japan

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Keywords: chum salmon, production trends, juvenile survival, optimum hatchery release

Chum salmon (*Oncorhynchus keta*) are an important biological and economic resource for North Pacific rim countries. All-nation commercial catch of chum salmon increased from approximately 130,000 tons (40 million fish) in the 1970s to over 400,000 tons (116 million fish) in 1996 (Fig. 1). Since then, the annual catch has fluctuated between 280,000 tons (85 million fish) and 370,000 tons (107 million fish). Japan has accounted for over 50% of total chum salmon catch on annual basis, but the recent coastal catch has a trend of decreasing. In contrast, Russian chum salmon catch has drastically increased since the mid 2000s, making up 40% of total catch in 2015.

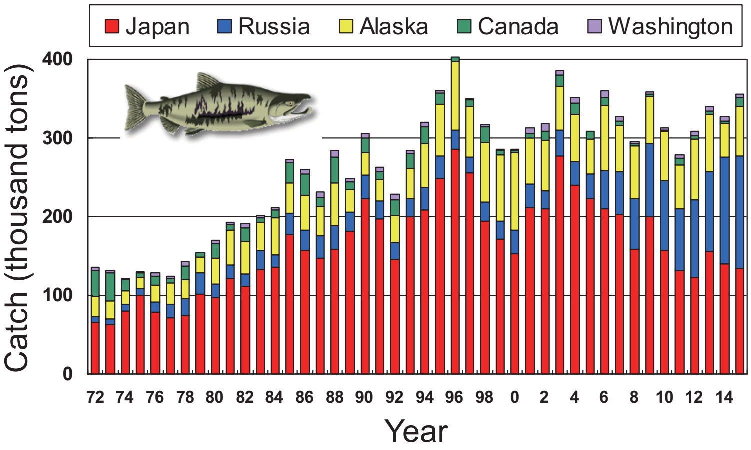


Figure 1. Annual changes in commercial coastal catches of chum salmon by regions, 1972-2015

According to an increase of annual otolith-marked chum salmon releases from Russian (n=343 million fry in 2012) and Japanese hatcheries (n=240 million fry in 2012), Chistyakov and Bugaev (2013) reported 211 otolith marked juvenile chum salmon caught in the Okhotsk Sea during October and early November 2012. Among them, 169 fish (79%) originated from hatcheries in Honshu and Hokkaido, including all regional populations in Japan (Fig. 2). Thus their findings proved the migration model that Japanese juvenile chum salmon migrate into the Okhotsk Sea by autumn (Urawa 2000; Urawa et al. 2001). The recovery rate of Japanese otolith-marked fish was variable among regional populations: highest in the Hokkaido Okhotsk region, and lowest in the Honshu Pacific region (Fig. 3). The body size of otolith-marked fish showed a trend of increasing with a distance of regional populations to the Okhotsk Sea, suggesting that larger fish have more chance of survivals when they migrate for long distance along the coast to the Okhotsk Sea. In addition, regional difference in body size may affect their survival during first winter.

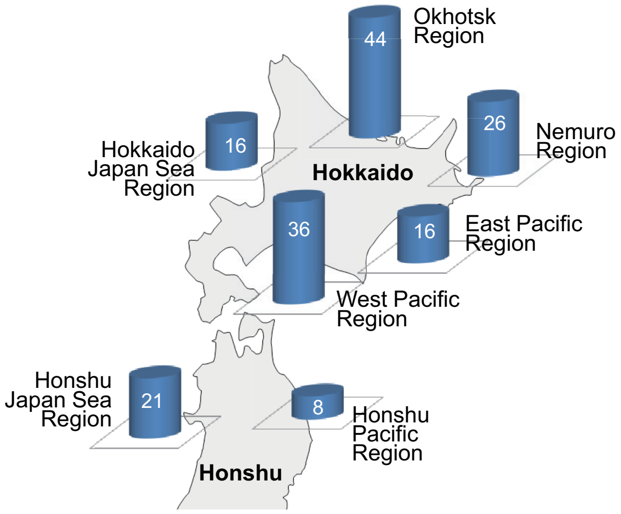
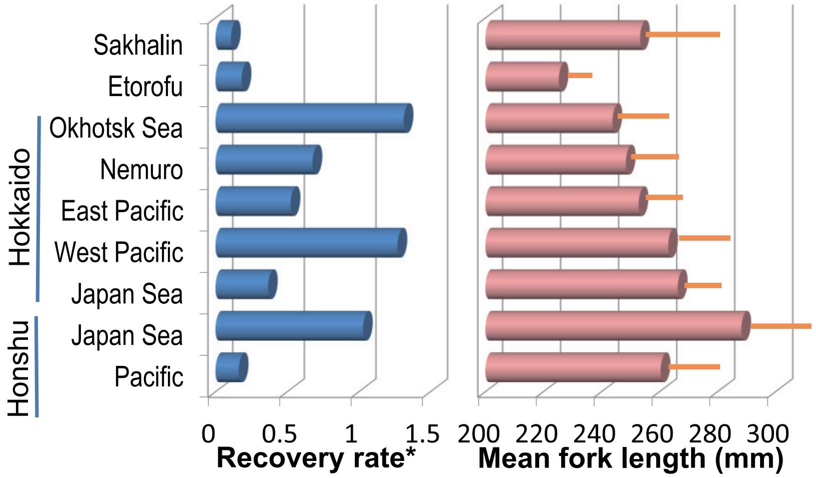


Figure 2. Regional origins of otolith-marked juvenile chum salmon caught in the Okhotsk Sea during the fall of 2012. Numerals indicate the number of otolith-marked juveniles caught. Data source: Chistykov and Bugaev (2013)



*(# of marked fish caught in the Okhotsk Sea/# of hatchery releases) x 10^6

Figure 3. Recovery rate and mean fork length of region-specific otolith marked juvenile chum salmon caught in the Okhotsk Sea during the fall of 2012. Data source: Chistykov and Bugaev (2013).

In Japan, the recent decrease of chum salmon catch is evident along the Pacific coast of Hokkaido and Honshu, including Sanriku area. To rehabilitate chum salmon production in these regions, the

Fisheries Agency of Japan has promoted a research program since 2013. The program has been planned to test a working hypothesis that significant mortalities of juvenile chum salmon occur during their early migration toward the Okhotsk Sea. Key hatcheries are encouraged to release otolith-marked chum salmon fry at particular timing and body size. Fish are sampled at several stations along the Pacific coast of Hokkaido to identify the stock-specific migration route and timing, growth patterns, predation, and habitat environment.

Preliminary results indicated that juvenile chum salmon released from hatcheries in the Sanriku area came alongside the west Pacific coast of Hokkaido in early and mid-June, and migrated through the southeast coast of Hokkaido between late June and early July (Fig. 4). Larger juvenile chum salmon (over 10 cm in fork length) migrated ahead in coastal waters around 9-11ºC, and smaller ones followed them after several week delay. The coastal sea surface temperature (SST) was strongly affected by the Coastal Oyashio (cold current): decreased less than 5 ºC during winter and spring, while rapidly increased over 13ºC in early summer (Fig. 5). The sharp fluctuation of coastal SST may disturb the growth opportunity and migration of juvenile chum salmon, resulting in their mortalities before reaching the Okhotsk Sea (Fig. 6). To improve the survival of hatchery-released chum salmon, the following considerations are suggested: (1) critical time/body size of juveniles, which allow them to migrate from specific coastal water to the Okhotsk Sea, (2) growth and migration speed of juveniles in coastal water, and (3) fluctuation of coastal SST and prey abundance (Fig. 7).

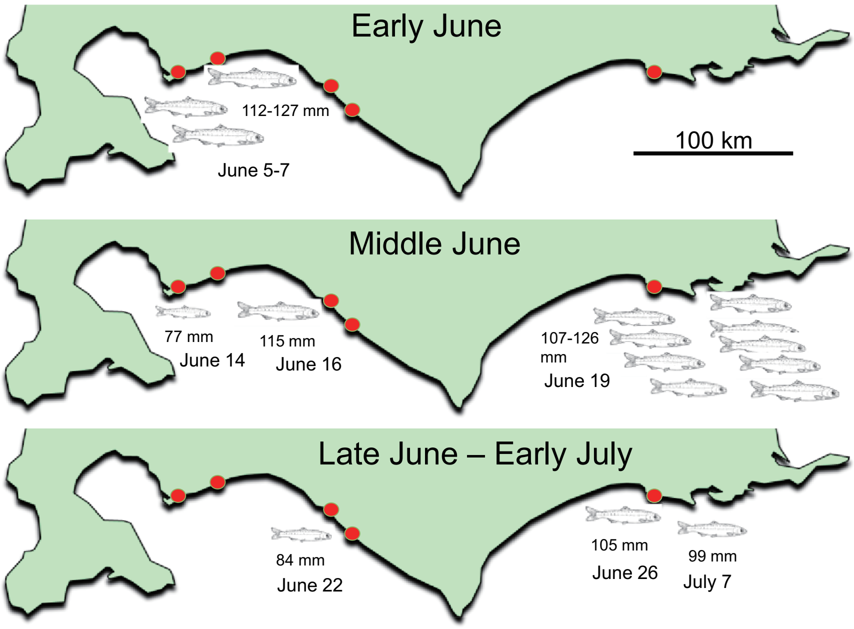


Figure 4. Distribution of Sanriku-origin otolith-marked chum salmon juveniles along the Pacific coast of Hokkaido in 2012. Numerals indicate the range of fork length. Data source: Anonymous (2014).

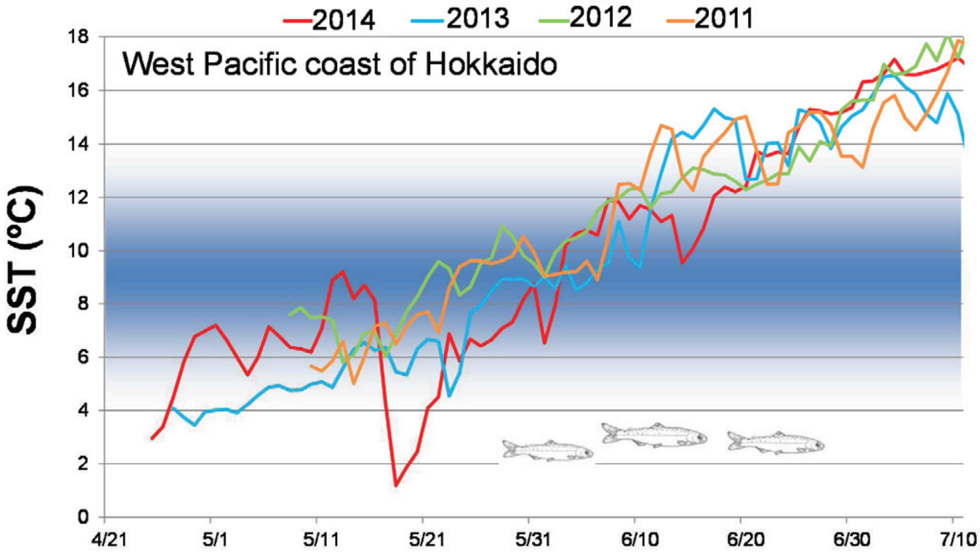


Figure 5. Annual changes in coastal sea surface temperature (SST) in the west Pacific coast of Hokkaido. Data source: Anonymous (2015).

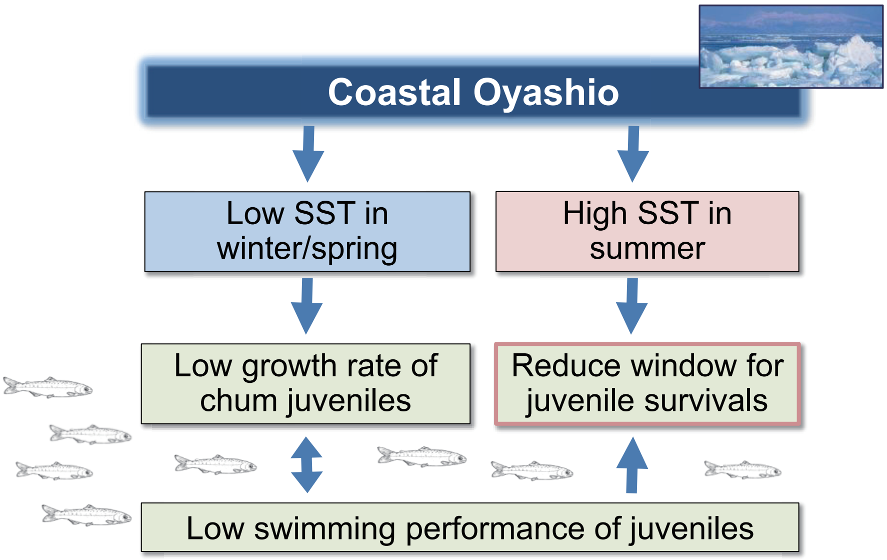


Figure 6. Negative scenario for the cold current "Coastal Oyashio" to affect the survival of juvenile chum salmon. Costal Oyashio develops during winter and spring, decreasing coastal SST, which will potentially reduce the growth rate of juvenile chum salmon after sea entry in spring. Small body size of juveniles results in their low swimming performance. On the other hand, surface-low salinity water of Coastal Oyashio is easily heated during early summer. Thus, window of juvenile survivals may be reduced by low swimming performance as well as by loss of habitats due to rapid SST increase.

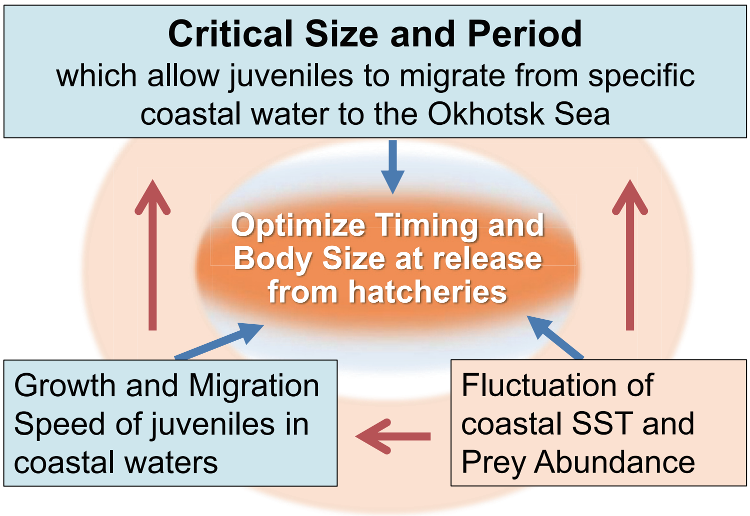


Figure 7. How can the survival of juvenile chum salmon be improved under the negative scenario? There may be “Critical Size and Period”, which allow juveniles to migrate from specific coastal water to the Okhotsk Sea. This hypothesis is inspired from Beamish & Mahnken (2001). In their hypothesis, if fish fail to get enough growth in the first ocean year, growth-dependent mortalities may occur in the following winter. I have modified their hypothesis, and if juvenile chum salmon fail to get critical size in coastal water at particular period, significant mortalities may occur in early summer before migrating to the Okhotsk Sea, which determine brood year strength. Critical size may be determined by coastal SST and prey abundance, and also growth and migration speed of juveniles in coastal waters. These factors should be considered to optimize timing and body size at release from hatcheries.

Acknowledgments

The research program to rehabilitate chum salmon production in the Pacific coast of Japan (2013-2015 fiscal years) was funded by the Fisheries Agency of Japan (FAJ). The program was jointly conducted by: the Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Agency, the Iwate Fisheries Technology Center, the Tokachi/Kushiro Salmon Enhancement Association, the Hidaka Salmon Enhancement Association, the Shimoakka Fisheries Cooperative Association, the Miyako Fisheries Cooperative Association, and the Japan Fisheries Research and Education Agency (formerly the Fisheries Research Agency).

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Recent status of chum and pink salmon stocks in Hokkaido, northern Japan

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Keywords: Hokkaido, chum salmon, pink salmon, region-specific trends, optimum hatchery program

Hokkaido is the main area of salmon production in Japan (Fig. 1). Chum salmon returns to Hokkaido rapidly increased during the last quarter of the 20th century (Kaeriyama 1999). Since the 1990s, chum salmon returns to Hokkaido remained at historic highs, averaging 51 million fish per year from 1994 to 2007. Since 2008, however, returns to Hokkaido have decreased averaging 40 million fish per year. Chum salmon returns to Hokkaido decreased in 2014 and 2015 (Fig. 2). That was because of the low return of 2010 brood year stock returned as age-4 fish in 2014 and age-5 fish in 2015. Different fluctuation trends have been observed among regions within Hokkaido (Miyakoshi et al. 2013); returns of chum salmon to the Okhotsk coasts have remained high, but in contrast, returns to the Pacific coasts have been decreasing in the last 6 years. These phenomena may be affected by environmental factors but there is still insufficient understanding of the causes.

Chum salmon stocks returning to Hokkaido have been sustained by hatchery programs. Annually, approximately one billion hatchery-reared juvenile chum salmon are stocked from Hokkaido. Economically, the Hokkaido chum salmon hatchery program is successful. However, loss of genetic diversity is one of the concerns when hatchery programs are used for sustainable management of salmon stocks. Chum salmon spawners are collected for broodstock in ~70 rivers and resulting juveniles are stocked into ~140 rivers. Thus, many rivers receive eggs taken from spawners captured in the other rivers. In recent hatchery programs in Hokkaido, transplants of eggs within the 5 geographical regions (Fig. 1) are permitted; however, transplants among the regions are restricted by the Hokkaido Prefectural Government. Although intensive hatchery programs have been conducted for more than 120 years (more than 25 generations) there has been no evidence indicating that Japanese chum salmon populations have lower genetic diversity (Beacham et al. 2008).

Ecological effects by artificial breeding are also a concern when hatchery programs are undertaken for successive generations. For Hokkaido chum salmon populations, the run timing has changed due to the hatchery selection (Nagata and Kaeriyama, 2004). Although there were early- and late-run populations of chum salmon in Hokkaido until the early 1980s, the late-run early- and late-run populations of chum salmon in Hokkaido until the early 1980s, the late-run both population had almost disappeared by the late

1990s, which was related to the artificial selection in hatchery programs. Recently, hatchery managers have become aware that such extreme intentional selection is undesirable, and the late-run population has been gradually recovering. Further biological monitoring of such intensively enhanced species is required and it is important to incorporate new scientific information into the hatchery program.

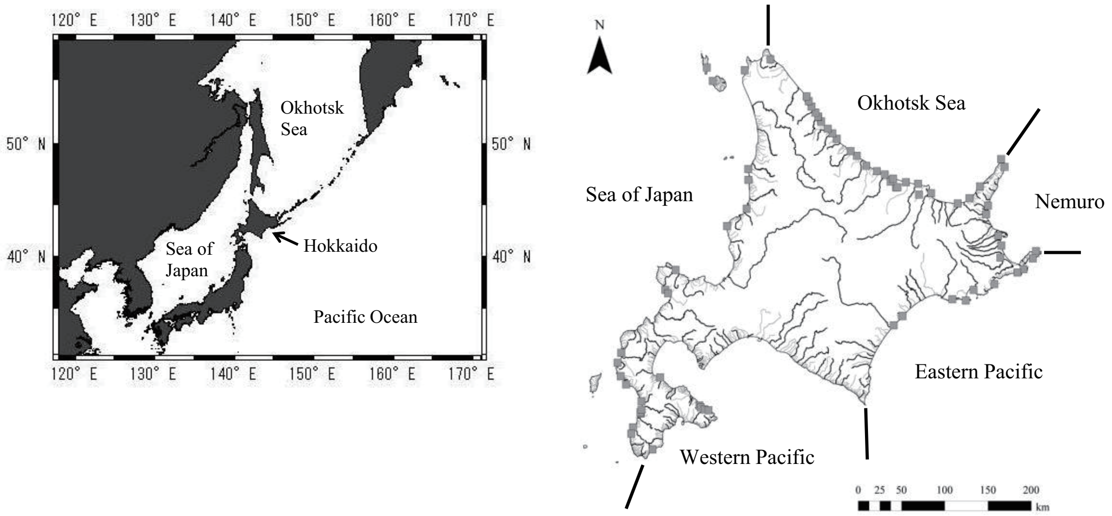

Figure 1. Location of Hokkaido and 5 regions for management of salmon hatchery program and fishery.

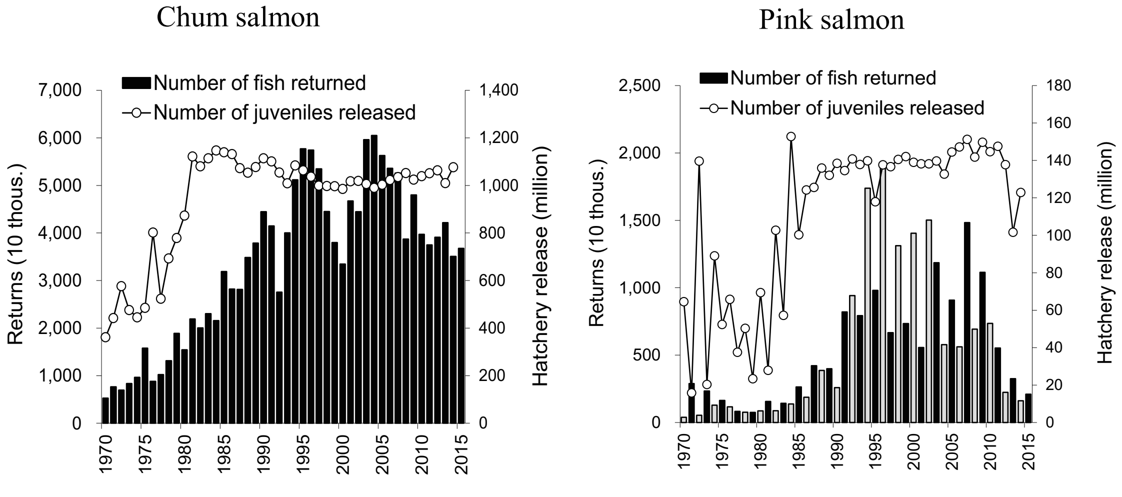

Figure 2. Number of returns and releases of chum and pink salmon in Hokkaido

Pink salmon returns to Hokkaido also increased rapidly since the 1990s. Even-year pink salmon returns increased in the 1990s but decreased since the 2000s. Odd-year returns increased during the 2000s.

However, both even- and odd-year returns are rapidly decreasing since 2012. The recent rapid decrease of returning pink salmon may be primarily due to the environmental factors. To enhance pink salmon stocks, 130 million hatchery-reared juvenile pink are stocked annually in Hokkaido. Understanding of the stocking effectiveness of hatchery programs of pink salmon in Hokkaido has been still insufficient.

Chum and pink salmon stocks have been enhanced by hatchery programs; in particular, the Hokkaido hatchery program for chum salmon constitutes one of the largest salmon hatchery programs in the world. The management system for hatchery programs has been established and almost constant numbers of hatchery-reared juveniles are released. As the hatchery programs will likely be the main management tool in the future in Japan, re-evaluation of the current hatchery programs may be needed in order to recover and sustain the chum and pink salmon stocks in Hokkaido.

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Chum salmon (*Oncorhynchus keta*) production in the Sanriku-region, Japan

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Keywords: chum salmon, Sanriku-region, 2011 catastrophe, future production trends

The Sanriku-region spans Aomori, Iwate and Miyagi Prefectures on the Pacific coast of northern Honshu Island in Japan. The region's characteristic saw-tooth shaped coastline with many bays renders the environmental condition suitable for growing juvenile chum salmon (*Oncorhynchus keta*). Chum salmon production in Iwate Prefecture is the 2nd highest in Japan (approximately 10 percent) and the hightest in the Sanriku-region (approximately 80 percent). Such high level of salmon production has been maintained mostly by artificial propagation programs for the past half century. The number of chum fry released has increased from 46 million fish in 1964 (1963 brood) to 420 million in 1988 (1987 brood). Subsequently, annual release of approximately 440 million fry continued until 2010 (2009 brood). Chum salmon catch, including river and inshore set net catch, in Iwate was 0.2 million fish in 1964 to over 10 million fish from 1984 onwards, associated with the increased release of chum fry, and reached the largest, approximately 24 million fish, in 1996. Then, the homing adult fish tended to decrease in recent years, resulting in the smallest catch of approximately 2.8 million in 2011 since the start of full scale hatchery operations in 1992. On March 11, 2011, a massive earthquake and devastating tsunami destroyed most of coastal salmon hatcheries. Although some of the hatcheries were restored by autumn 2011, the number of chum fry released decreased to 291 million fish in 2012 (2011 brood). During 2012 to 2015, the chum fry releases increased from 291 to 409 million along with the restoration of damaged hatcheries. Chum fry are usually released during March to May every year in Iwate Prefecture. Therefore, it is possible that alevin and fry (2010 brood) in hatcheries hit by the 2011 tsunami mostly would not have survived, which might have causally affected chum salmon runs of particular year classes in subsequent years. We surveyed the age composition of upriver migrating adult chum salmon in three representative rivers in Iwate Prefecture. Here we report the results of our surveys and discuss the effects of the earthquake and tsunami on the current and future chum salmon runs.

A comparison of the returns of chum salmon released from net pens and rivers in Nemuro Bay, eastern Hokkaido, northern Japan

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Keywords: Hokkaido chum salmon, net pen release, adult returns, maturation rate

Releases of chum salmon *Oncorhynchus keta* fry from net pens in seawater began in the early 1970s in Iwate Prefecture (Iioka, 1982; Koganezawa and Sasaki, 1985). Net pen releases were introduced in the late 1970s in Hokkaido, and the proportion of net pen to whole releases increased from 2.6% to ca. 10% (Kron, 1985; Kobayashi, 2009; Nogawa and Yagisawa, 2011; Seki, 2013). The efficiency of net pen releases has been examined only in Iwate Prefecture, the Pacific coast of Tohoku, northeastern Honshu (Iioka, 1982), and not in Hokkaido. The environment of the net pen release sites in Hokkaido differed from that in Iwate Prefecture; therefore, the efficiency of net pen release and patterns of adult returns might differ between Hokkaido and Iwate Prefecture. In the present study, coastal and river adult returns following net pen and river releases were compared to examine the efficiency of net pen releases in Hokkaido.

Materials and Methods

Chum salmon fry were reared in the Okunishibetsu hatchery and were marked by clipping either the left or the right ventral fin in 2006 and 2007 (Table 1). Left ventral fin-clipped fry (LV) were transplanted to net pens in the Betsukai fishing port, and were released after rearing for one month. Right ventral fin-clipped fry (RV) were released from the hatchery 6–7 d after transplanting LV to the net pens. Surveys for the

Table 1. Number, body size, and release date of marked fish released from the net pens and rivers in 2006 and 2007.

Release years	Release sites	Clipped fin	Fertilization Date	Transportation or release	Fork length at transportation or release (mm)	Body weight at transportation or release (g)	Number of released fish	Date of release from net pens	Fork length at release from net pens (mm)	Body weight at release from net pens (g)
2006	Net pens	Left ventral	1 Nov. 2005	21 April, 2006	49.8	0.95	123,300	22 May, 2006	60.2	1.93
	River	Right ventral	1 Nov. 2005	28 April, 2006	50.6	1.22	104,200			
2007	Net pens	Left ventral	2 Nov. 2006	19 April, 2007	52.1	1.21	127,604	16 May, 2007	60.0	2.12
	River	Right ventral	2 Nov. 2006	25 April, 2007	50.8	1.09	127,270			

returned marked fish were conducted between 2008 and 2012. In the coastal area, surveys were conducted in 18 nearshore set nets along the Betsukai coast of Nemuro Bay and a small set net in the Betsukai fishing port (Fig. 1). In the Nishibetsu River, adult fish were captured at the salmon weir. All captured fish were analyzed for markings. For each marked fish found in the surveys, fork length and sexual maturation were evaluated, and scales were extracted for age determination. The degree of sexual maturation was classified into four ranks (S, A, B, and C) according to body color. Release sites and brood years were determined for each marked fish based on marks and age.

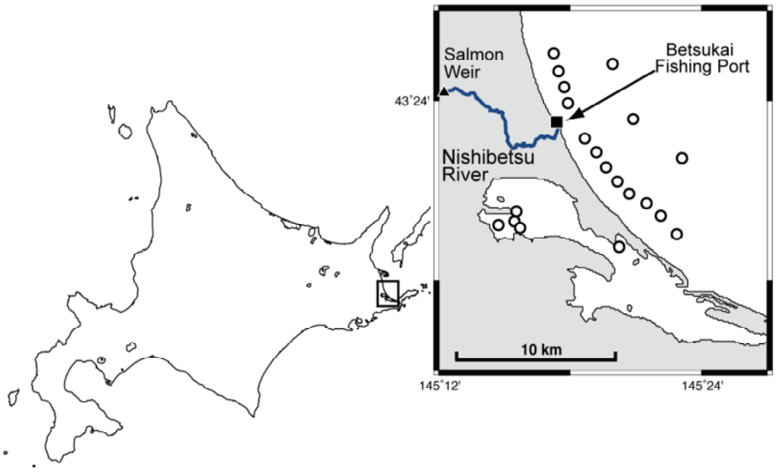

Figure 1. Study area at the Betsukai coast. Open circles indicate the locations of set nets, closed square the location of the Betsukai fishing port, and the closed triangle the location of a salmon weir.

The number of marked fish landed at the Betsukai coast was estimated using a two-stage sampling survey for each age of marked fish in each year (Kitada et al., 1992, 1993; Miyakoshi et al., 2001). For fish released by each method of each brood year, the total number estimated was summed for ages 4 and 5 of the 2005 brood year and ages 3–5 of the 2006 brood year.

Results and Discussion

Coastal catches: Durations and peak timing of capture did not differ between net pen and river releases over the two brood years. The estimated numbers of net pen-released fish in the Betsukai coast were about twice those of river-released fish over the two brood years. Ratios of the number of fish caught in the Betsukai fishing port to those caught in the nearshore set nets were significantly higher for the net pen-released fish than for the river-released fish. For fish caught in the nearshore set nets, sexual maturity was similar between net pen- and river-released fish of both sexes. However, for net pen-released fish, the fish of both sexes caught in the Betsukai fishing port reached sexual maturation faster than those caught in the nearshore set nets. These results suggested that net pen-released fish returned to release sites at maturity

(Novotny, 1980; Koganezawa and Sasaki, 1985).

River catches: Maturation periods of returned adult fish released from net pens and rivers peaked between about 10 days before and after their fertilized dates, and there were no differences between net pen- and river-released fish over the two brood years. The number of fish released from net pens found in the Nishibetsu River was 1/4–1/3 times as many as those from rivers.

Contributions to fisheries and enhancement: The economic efficiency of net pen release was higher than that of river release. However, the reproductive efficiency of net pen release was one-fourth that of river release.

Conclusions

Net pen release could effectively enhance catches in the Betsukai coast. However, net pen release probably does not contribute considerably to salmon enhancement in the rivers. Therefore, it should not be applied to the areas where adult fish are insufficient to carry out enhancement programs.

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Effect of turbidity in rearing water on the early life stages of chum salmon *Oncorhynchus keta*

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Keywords: chum salmon, water turbidity, growth inhibition, juvenile survival

Introduction

Chum salmon is a part of the important fishery resources and salmon hatching business has been actively in northeastern Japan. Especially, salmon account for 18% of fish catches in Iwate prefecture (Ogawa and Shimizu 2012 ; Pocket Tohoku Regional Statistics of Agriculture, Forestry and Fisheries 2015). Artificial production of healthy juveniles is required to stem the sudden decline since 2010 in the numbers of returning chum salmon, *Oncorhynchus keta*, in northeastern Japan (Fig. 1). Therefore it is necessary to improve homing rate by stable artificial production. Then both ground and river water are utilized in the rearing process. For this reason, significant mortalities have been observed when river water with a high turbidity was used in the rearing tanks (Fig. 2). Many studies have been conducted to find the effect of turbidity on fish, however research on the salmon eggs and juvenile salmon did not make big progress.

To solve this problem, the effect of water-borne particles on hatching, growth and survival of juvenile salmon was examined, and temporal changes in the turbidity of river water recorded.

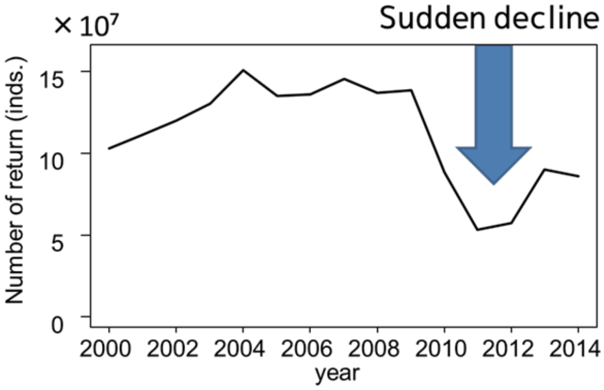

Figure 1. Chum salmon return in northeastern Japan. Data from National Research and Development Agency Hokkaido National Fisheries Research Institute (http://salmon.fra.affrc.go.jp/zousyoku/ok_relret.htm) (2016/01/29)

Materials and Methods

Effect of sediment on fertilized eggs: Eggs of chum salmon were obtained from a salmon hatchery immediately after fertilization. The fertilized eggs were placed in microplates and kaolinite particles (mean dia.; 9.5 μm) added at sedimentary rates of 1.2, 46, 102, 158, 214 and 550 mg/cm^2 (Fig. 3). Hatching tanks (83 cm width × 33 cm depth × 29 cm height) were filled with ground water and microplates with a covering of kaolinite were placed on the bottom of the tank. We flew ground water 50 liters per minute to hatching tanks. The water temperature was maintained at 11–13 °C. The experiments were repeated six times at each condition.

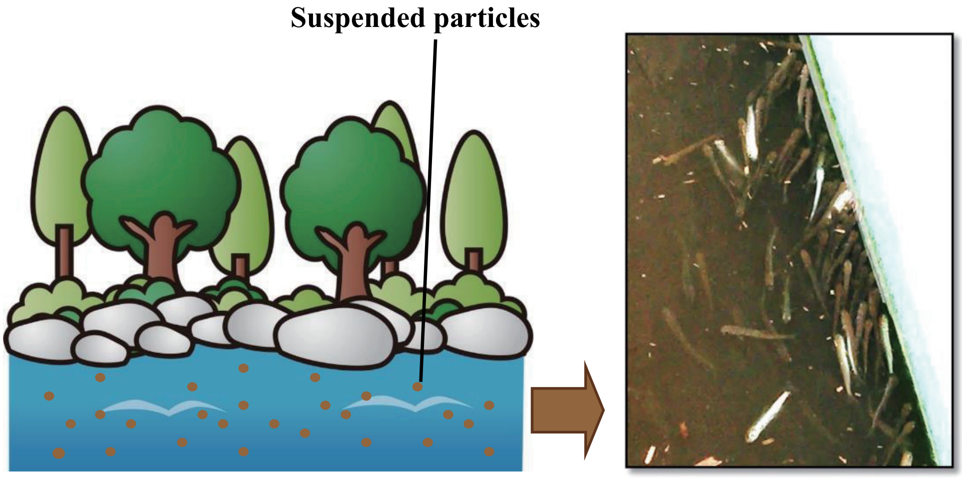

Figure 2. Illustration and photograph of dead juvenile salmon in rearing water with a high turbidity.

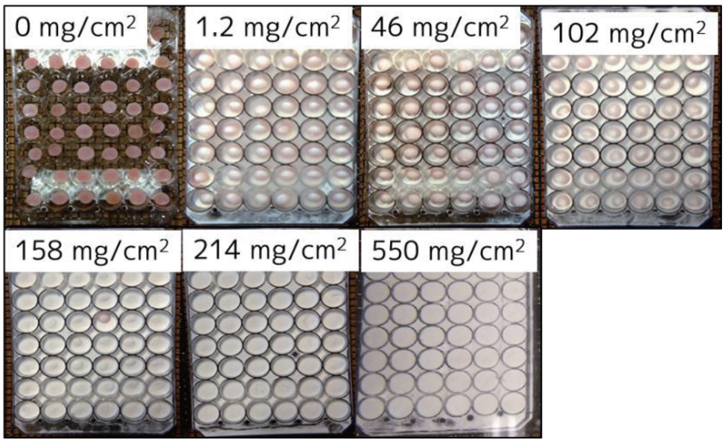

Figure 3. Fertilized eggs with kaolinite particle deposits at various concentrations

Effect of kaolinite suspension on juvenile salmon: The fertilized eggs hatched after 47 days (accumulated temperature: 502 °C), and alevins were cultured in the dark until the yolk sac disappeared and fry were obtained. The experimental setup is composed of rearing cage (16 cm width× 11 cm depth× 13 cm height) , test tank (60 cm width × 30 cm depth × 30 cm height), pre-tank (53 cm width × 35 cm depth × 29 cm height), and pump. The temperature and turbidity (kaolinite concentrations) of the rearing water were regulated in a pre-tank and the water circulated continuously via a pump (Fig. 4). Juvenile salmons were reared in rearing cage in a test tank. The experimental periods were 3 and 85 days. In 3 days turbidities were 0, 4000, 7000, 10000 and 20000 mg/L. In 85 days, turbidities were 0 and 4000 mg/L (Table 1).

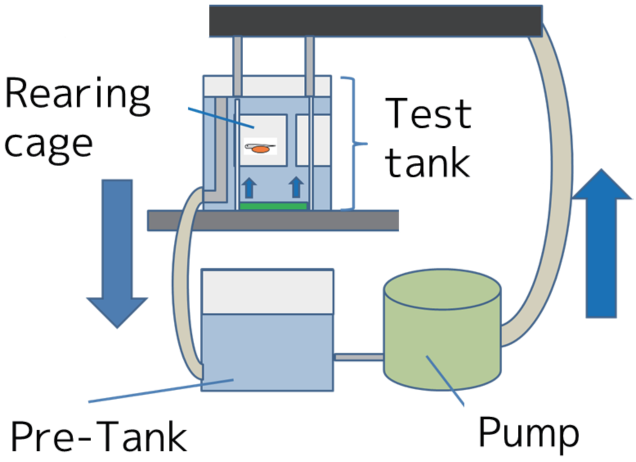

Figure 4. Schematic diagram of the experimental system

Table 1. Experimental conditions.

	85 days	**3 days**
Turbidity (mg/L)	**0 and 4000**	**0, 4000, 7000,10000, 20000**
Number of fish (indi./cage)	**100**	**60**

Temporal changes in turbidity at Ugegawa River: Water temperature, turbidity, chlorophyll a concentration, dissolved oxygen (DO) and pH were recorded at the water intake of the Ugegawa River Salmon Hatchery (URSH) between November 2013 and July 2015 using a turbidity meter (INFITY-CLW; JFE Advantech Co., Ltd., Nishinomiya, Japan) and a water quality meter (WQC-24; DKK-TOA Corp., Tokyo, Japan) (Fig. 5). Water sampling was done in 4th April 2014 when turbidity indicated the highest value. We derived past precipitation data from the Meteorological Agency.

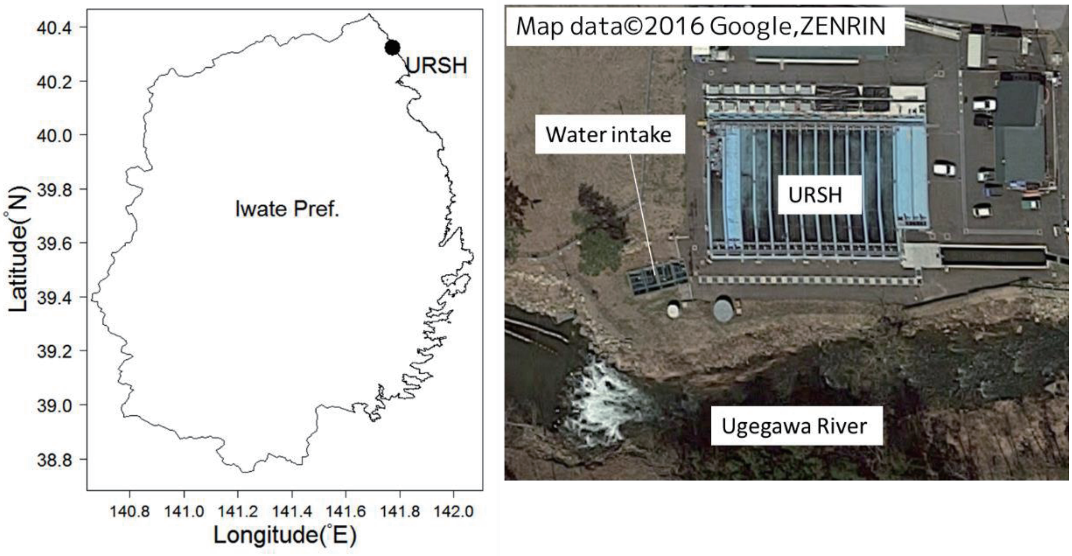

Figure 5 Location of the Ugegawa River Salmon Hatchery (URSH) and station of sensors set at URSH.

Results

Effect of sediment on fertilized eggs: Normally, hatching of fertilized egg in clear water is over 90% at an accumulated temperature (℃) of 610 degree-days. However, hatching rate declined when sedimentary particles were deposited on the eggs: the greater the number of particles, the lower the hatching rate. A sedimentary deposit of 1.2, 46, 102, 158 and 214 mg/cm² resulted in a hatching rate of 79, 76, 71, 62 and 34% at an accumulated temperature of 660 degree-days. Steel-Dwass test revealed that a significant reduction of hatching rate with increasing sediment quantity at an accumulated temperature of 660 degree-day ($P<0.05$).

Effect of kaolinite suspension on juvenile salmon: Survival rate was over 95% when salmon fry were maintained for 3 days in water with a turbidity of 0, 4000, 7000, 10000, 20,000 mg/L; however, there is no significant difference between clear and turbid conditions ($P>0.05$). Nevertheless, when juveniles were cultured for 1 month at a turbidity of 4000 mg/L, body size was significantly smaller than in juveniles reared in clear water. We found that there is significant difference between clear and turbid conditions ($P<0.01$) using Student's *t* test.

Temporal changes in turbidity at Ugegawa River: Turbidity of Ugegawa River water was high after rainfall in spring. The highest turbidities were nearly 350 mg/L in 2014 and 2015. Mean size of the particles was 42 µm and ignition loss was 24%. The trend in turbidity corresponded with the precipitation. Additionally, the highest chlorophyll a concentration in 2015 was three times greater than in 2014. In addition, when turbidity increased, temperature and DO were unchanged. Mortality of salmon fry due to high turbidity occurred in 2014 but not in 2015.

It is unknown why the mortality occurred by high turbidity. It has to examine that the relation to the mortality and the size, quality, and quantity of the particles in future studies.

Conclusion

Deposition of suspended particles is a factor in the reduced hatching rate of chum salmon eggs and high turbidity of the rearing water inhibits the growth of salmon fry. However, it is unclear why salmon fry died at a turbidity of 350 mg/L in URSH but the causes require clarification through further studies.

Acknowledgment

We thank Mr. Segawa of the Iwate Salmon Propagation Association for collection and culturing of salmon eggs. Part of this study was funded by MEXT Revitalization Project for the Creation of Fisheries Research and Education Center in Sanriku.

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Observations of salmon run up through river mouth with morphological change

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Keywords: chum salmon, adult returns, river mouth condition, tidal level

In Iwate Prefecture, northeastern Honshu, Japan, the return rate of chum salmon has been declining during past 20 years. Although the exact cause of this decline still remains unanswered, we recently have suggested an effect of deposition trend and river mouth clogging on salmon run in a river, which may lower the return rate more than other possible factors (Matsubayashi et al. 2015). However, little is known about the effect of morphological trend of river mouth on salmon run. In this presentation, we report the result of our preliminary field survey for correlation between homing chum salmon behavior and river mouth morphology. Our final goal is to elucidate how river mouth clogging and morphological trend of rivers affect chum salmon run.

We carried out visual observations of homing chum salmon behavior and morphological change of river mouth in the Fudai River, northern Iwate prefecture, from October 19 through 22 and October 26 through 29. We counted the number of homing salmon up and down the river mouth for a daylong.
We also calculated the tide level, another factor possibly affecting salmon run, according to the model of Matsumoto et al. (2000).

Fig1 shows the number of chum salmon up and down the Fudai River mouth per hour in each day. Although the position of river channel varied every day in the research period, no clear relationships were detected between the river mouth condition and the number of returning salmon (Fig. 1).

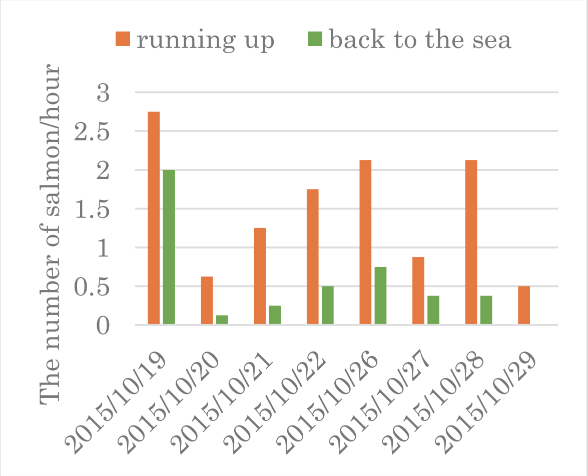

Fig. 1. The number of chum salmon (/hour) up and down the Fudai River mouth

Fig2 shows the number of salmon up and down the river mouth per hour and the tide level. It was found that the number of salmon passed the river mouth was nearly proportional to the tide level.

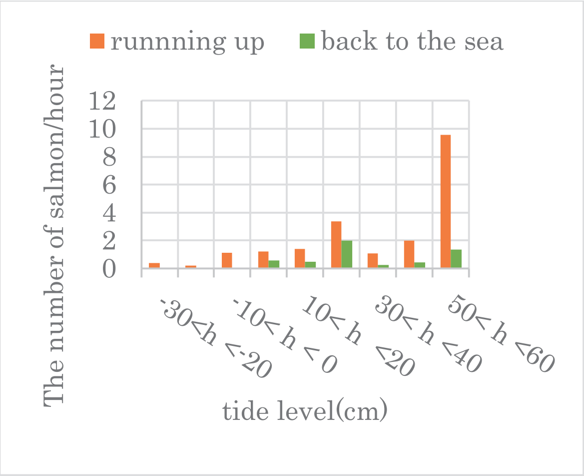

Fig. 2. The number of chum salmon (/hour) up and down the Fudai River mouth and the tidal level

Acknowledgment

We deeply thank Mr. Hiroshi Kawajiri, Kuji Extension Center, Sanriku Reconstruction Promotion Institution, Iwate University, for his administrative help. Our special thanks go to the Fudai Fishery Cooperative for providing the information of the survey points at the Fudai River mouth. This work was supported partly by the MEXT Revitalization Project for the Creation of Fisheries Research and Education Center in Sanriku.

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Target strength measurement of free-swimming fish in a controlled large experimental tank: A case study on TS measurement of whole marine life stages in chum salmon

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Keywords: chum salmon, acoustic intensities, swimming behavior, abundance estimation

Acoustic survey based on species-specific acoustic intensities (i.e. target strength: TS) contributes to the speedy abundance (or biomass) estimation of important fisheries resources and the temporal-spatial behaviors in the wide area. In order to deduce quantitative information such as the fish number per unit volume, an important requirement is to know the value of target strength appropriate to those fish that have contributed to the received signal. This study introduces our new ex situ experiment for target strength measurement on chum salmon in whole marine life stages. Live chum salmon *Oncorhynchus keta* were investing at two acoustic frequencies (38 and 120kHz) to know how they relate to the frequency of an underwater acoustic / to fish size. The TS measurements were conducted at the large experimental tank (Ca: W:10m x D:5m x H:6m, 300t) filled by seawater in Hakodate Research Center for Fisheries and Oceans, southern Hokkaido, Japan. Hatchery-reared fish (juvenile: 0-plus and 1-plus) were obtained from Sanriku Fisheries Research Center in Iwate University, and adult chum salmons were caught by a set net off Osatube, southern Hokkaido, Japan. In this presentation, we will also discuss about a future survey to estimate spatial distribution, biomass and vertical/ horizontal swimming behavior of the marine life stage chum salmon using measured target strength of this system.

Age composition and behavior of homing chum salmon, *Oncorhynchus keta*, in the Otsuchi Bay

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Keywords: chum salmon, acoustic monitor, natal river entry, homing behavior

Chum salmon, *Oncorhynchus keta*, return to the natal rivers using the olfaction 3 to 5 years after the birth. In the Otsuchi Bay, three natal rivers flow to the inner part, and all hatcheries and natural spawning sites have damaged tremendously by the tsunami on 11th, March in 2011 when the fry migrated downstream to the sea, resulting in the death of many fry. Therefore, it has been anticipated that the number of homing adults of this year class would be low and the behavior would be defective. We have examined whether salmon can choose the natal river straightforward from three rivers, or leave the bay to choose others, and how environmental disturbance in the river affects the homing behavior. The ultrasonic transmitter was loaded to salmon caught in the center of the bay, and released in the inner part. The acoustic signals from released fish were detected by receivers arranged in two rows, and the migration route was deduced based on the signal record. Age of homing salmon was estimated based on the otolith annuli, and the maturation level was deduced using plasma concentration of sex steroid hormone. The study has been performed every winter from 2013.

Annually, about half of homing salmon are 4 years old, and others are almost 3 and 5 years old. In 2013, however, the ratio of 3 years old fish which entered the sea just before or after the Tsunami was extremely low as they could not been find in our monthly search. Consistently, the ratio of 4 years old fish captured in the bay mouth was extremely lower in 2014 than that in the previous years (Fig. 1A). As well,

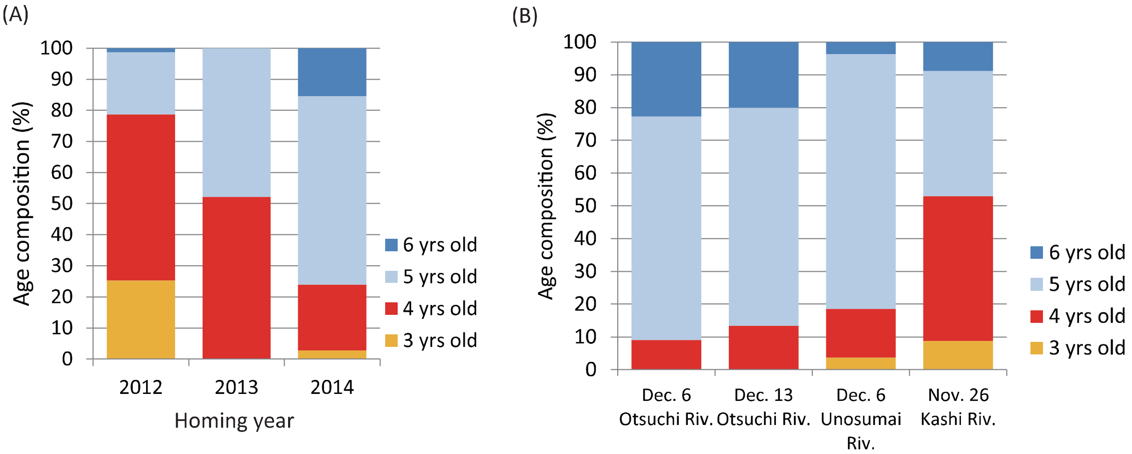

Figure 1. Age composition of homing chum salmon captured at the bay mouth in 2012 to 2014 (A) and in the Otsuchi, Unosumai and Kashi River in 2014 (B)

the ratio of 4 years old fish in 2014 were less than 20 % in the Otsuchi and Unosumai Rivers where the fry were not released just after the Tsunami. On the other hand, about half of homing salmon was 4 years old fish in the Kashi River where the fry were artificially released even just after the Tsunami (Fig. 1B). These indicate that many hatchery-reared fry and probably wild-born fry failed in the seaward migration in spring of 2011 and that artificial propagation of salmon fry largely contributes to the maintenance of salmon resources. Additionally, the excellent homing ability of chum salmon was indirectly proved.

Horizontal movement of homing salmon in the inner part of the bay were classified into four patterns; 1) river entry after first access to the river, 2) river entry after a few accesses to either river, 3) movement toward the bay mouth, and 4) movement toward the bay mouth after accesses to either river (Fig. 2). The ratio of river entry was low in November (ca. 15%) and increased in December (ca. 50%). Nevertheless, the river entry of 4 years old fish attacked by the Tsunami remained to be low in Dec. (ca. 28%), although the number of samples was low. Movement toward the bay mouth after accesses to either river was observed in only 3 salmon, but 2 fish were of the year class attacked by the Tsunami. Although it is not known at present whether the Tsunami has an effect on the behavior of homing salmon, such studies should be continued to clarify the consequences.

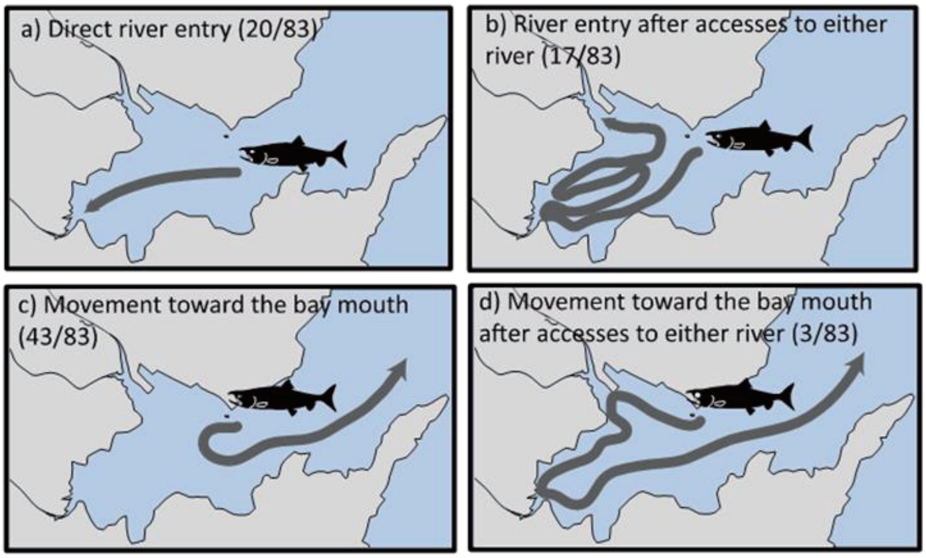

Figure 2. Imaginary pictures of four behavioral patterns of homing chum salmon in the Otsuchi River. (A) river entry after first access, (B) river entry after multiple accesses, (C) movement to the bay mouth without access to rivers, and (D) movement to the bay mouth after access to rivers.

In the Sanriku rgion, homing salmon matures finally in the bay, which is different from Hokkaido population that matures during upstream migration in the river. This finding suggests that maturation level may have an effect on the river entry of homing salmon. In order to know the maturation degree of released salmon, 17, 20β-dihydroxy-4-pregnen-3-one (DHP) concentration in the plasma was measured as an indicator of final maturation (Onuma et al. 2003, 2009). DHP concentration distributed at wide range both in fishes that entered rivers and moved to the bay mouth (Fig. 3), indicating that maturation degree is not strong motivator to the river entry.

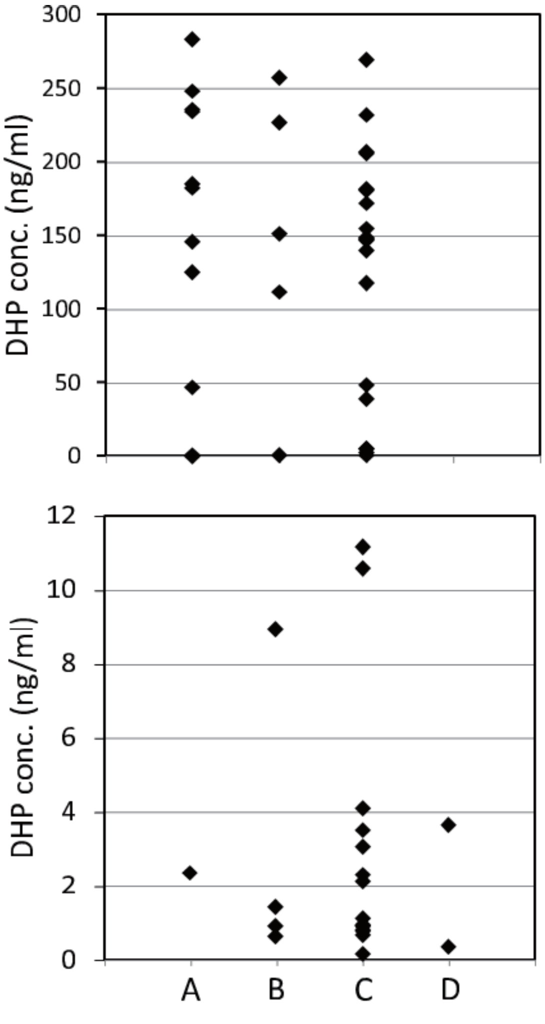

Figure 3. Plasma DHP concentration in the released of female (upper) and male (bottom) chum salmon. A to D of horizontal axis indicate behavioral pattern; river entry after river access (A), river entry after multiple accesses to either river (B), movement to the bay mouth without access to rivers (C) and movement to the bay mouth after access to either river (D).

Three natal rivers, the Otsuchi, Koduchi and Unosumai Rivers, flow into the Otsuchi Bay (Fig.2), and the former two flow to one place (northern two rivers in Fig. 2). Around 70 % of the salmon chosen the Otsuchi and Koduchi Rivers entered there after multiple accesses to either river, whereas most fish chosen the Unosumai River entered there after first access. This may be due to the difference in spreading of river water in the bay among three rivers.

In conclusion, the present findings suggest that artificial propagation largely contributes to a stable salmon catches in Sanriku area. In indented Sanriku coast, the homing adults search for their natal river through trial and error processes. Even though at least more 5 years are probably needed to clarify the effect of the Tsunami on homing salmon, accumulated data will elucidate the physiological background involved in the homing behavior.

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NPAFC Coordination: Fisheries Enforcement and Scientific Research on Salmon in the North Pacific

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Keywords: Pacific salmon, steelhead, cooperative resource management, scientific coordination

The North Pacific Anadromous Fish Commission (NPAFC) is an intergovernmental organization dedicated to the conservation of Pacific salmon and steelhead in international waters of the North Pacific. The member countries are Canada, Japan, Republic of Korea, Russian Federation, and United States. NPAFC promotes conservation of anadromous stocks in the Convention Area with implementation of conservation measures, enforcement of fishing restrictions, and promotion of scientific study of anadromous species.

The NPAFC Convention Area is located in the North Pacific Ocean and its adjacent seas that is north of 33°N in international waters, outside the 200 mile-zones of the coastal countries (Fig. 1). The Convention Area comprises 13.5 million km^2, and Pacific salmon are distributed in this area throughout the year.

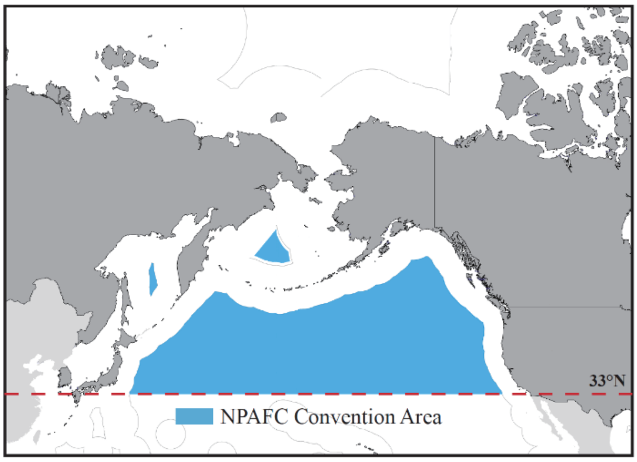


Figure 1. North Pacific Anadromous Fish Commission Convention Area is shown in blue and located in international waters of the North Pacific north of 33°N. Map credit: modified from ©FAO 2015 Regional Fishery Bodies Map, www.fao.org/fishery/rbf/npafc. Nov. 10, 2015.

NPAFC conservation measures are designed to reduce or eliminate catches of salmon in the Convention Area. These conservation measures prohibit directed fishing for anadromous fish. In the case of fishing operations directed on other species, the incidental catch of anadromous fish is to be minimized and retention of anadromous fish is prohibited. In addition, scientific research programs to be conducted by member countries involving directed fishing for or incidental takes of significant levels of anadromous fish in the Convention Area must be submitted to the Commission in advance to allow for appropriate scientific review.

NPAFC coordinates fisheries enforcement activities in the Convention Area among its member countries. The goal is to detect and eliminate illegal, unreported, and unregulated (IUU) fishing for salmon in the North Pacific. For this purpose, the Committee on Enforcement (ENFO) meets regularly to plan and coordinate each member country's salmon-related enforcement activities within the Convention Area and to exchange operational information regarding the status of patrols and possible violations of the provisions of the NPAFC Convention. The member countries' enforcement agencies coordinate their respective surface and air patrols, satellite surveillance, and at-sea and port inspections through ENFO.

Large-scale high seas pelagic driftnet (HSDN) fishing was prohibited by 1991 U.N. resolution A/Res/46/215, but this fishing method remains the most common illegal salmon fishing activity in the NPAFC Convention Area. This fishing practice is especially harmful to Pacific salmon because it harvests fish from a mixed stock that may include depleted and protected populations and it frustrates management and conservation measures undertaken by countries where such anadromous stocks originate.

Results of NPAFC enforcement coordination have shown positive results. From 1993 to 2015, 47 HSDN vessels have been detected catching salmon in the Convention Area and of those 19 vessels were apprehended (Table 1). By the end of the 1990s, several IUU fishing vessels were sighted each year. Currently, the number of detected violators has decreased because of expanded coordinated enforcement efforts by member countries.

One recent example of NPAFC enforcement coordination is the apprehension of the IUU driftnet vessel *Yin Yuan*. This vessel was first spotted by a Canadian patrol aircraft that was temporarily based in Hakodate, Japan, and had a Japanese fisheries inspector aboard. Information on suspicious activities and the vessel's position was provided to a US Coast Guard Cutter in the vicinity, which was able to board and inspect the vessel. The *Yin Yuan* was escorted to a rendezvous point and transferred to Chinese custody where the vessel was arrested and prosecuted.

The NPAFC coordinates scientific research activities in support of the NPAFC Convention through the Committee of Scientific Research and Statistics (CSRS). Support for scientific research includes coordination of research survey cruises, scientist exchanges, and sample and data requests. Scientists from member countries design and evaluate the NPAFC science plan and scientific results are reported at open symposia and workshops hosted by the Commission.

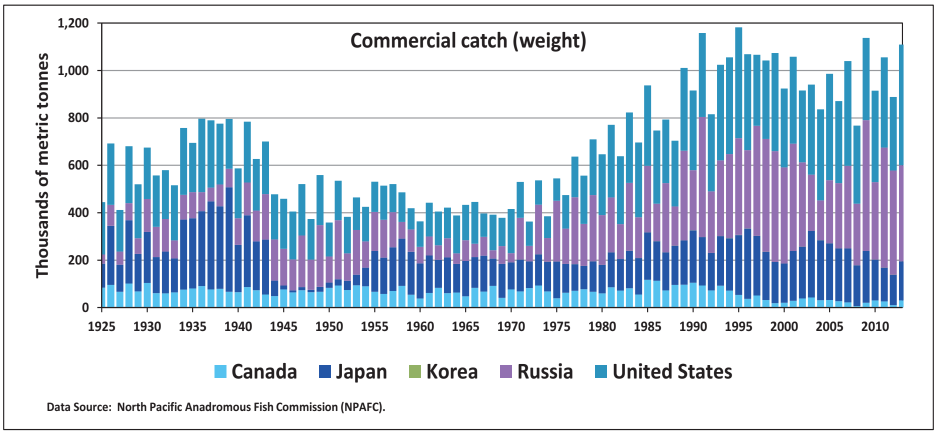
Table 1. IUU vessels detected catching salmon in the NPAFC Convention Area and the number of those vessels apprehended, 1993-2015

Year	Detections	Apprehensions
1993	6	2
1994	1	0
1995	3	1
1996	1	1
1997	6	2
1998	9	4
1999	11	3
2000	2	1
2001	0	0
2002	0	0
2003	0	0
2004	1	1
2005	0	0
2006	0	0
2007	1	1
2008	0	0
2009	0	0
2010	2	1
2011	2	1
2012	1	1
2013	0	0
2014	1	1
2015	0	0
Total	47	20

The NPAFC publishes its scientific information and makes it freely available on the Commission's website. Articles submitted at symposia are published in peer-reviewed bulletins, and extended abstracts submitted at workshops are published in technical reports. The Secretariat produces a twice-yearly newsletter on information relevant to the NPAFC community, and annually about 50 science-related NPAFC documents are submitted by the member countries and placed in the public area of the website.

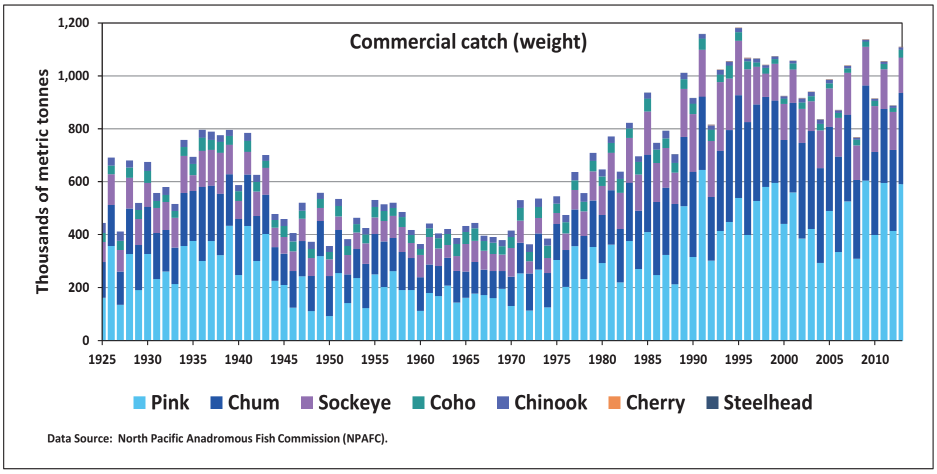
The Secretariat compiles catch and hatchery statistics and makes them available for public download from the web. These data submissions are coordinated through NPAFC's Working Group on Stock Assessment. Statistics include commercial, subsistence, and sport catches of salmon and steelhead and hatchery releases by member countries.

Pacific salmon abundance in the North Pacific, as indexed by aggregate commercial catches, remains at near all-time high levels. The highest catches have occurred since the mid-1990's with over 1 million tonnes caught (Fig. 2). Catches are dominated by pink salmon and catches are higher in odd-numbered years when odd-year runs of pink salmon are plentiful (Fig. 3). Pink and chum dominate Asian catches. In North America, in Alaska and BC, pink, sockeye, and chum have been the most abundant species caught, while in WA, OR, CA, chinook and coho salmon have been the most important.



Data Source: North Pacific Anadromous Fish Commission (NPAFC).

Figure 2. NPAFC commercial catch (thousands of metric tonnes) by member country, 1925-2013

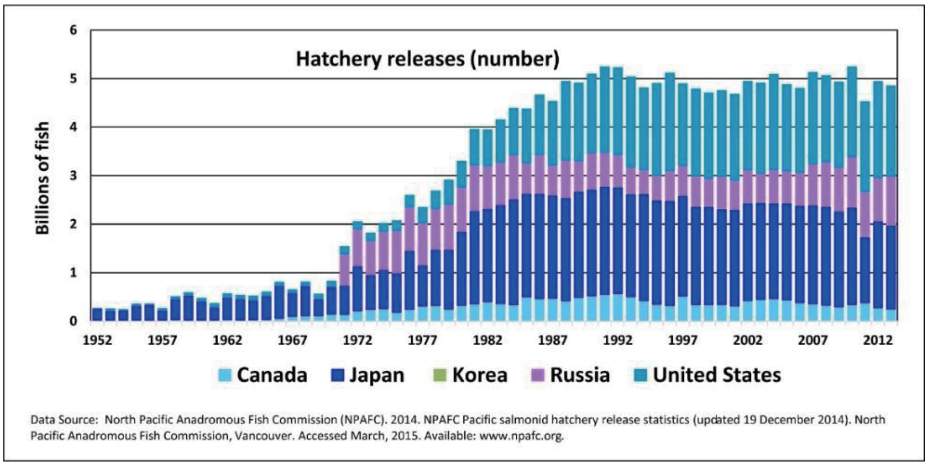


Data Source: North Pacific Anadromous Fish Commission (NPAFC).

Figure 3. NPAFC commercial catch (thousands of metric tonnes) by species, 1925-2013

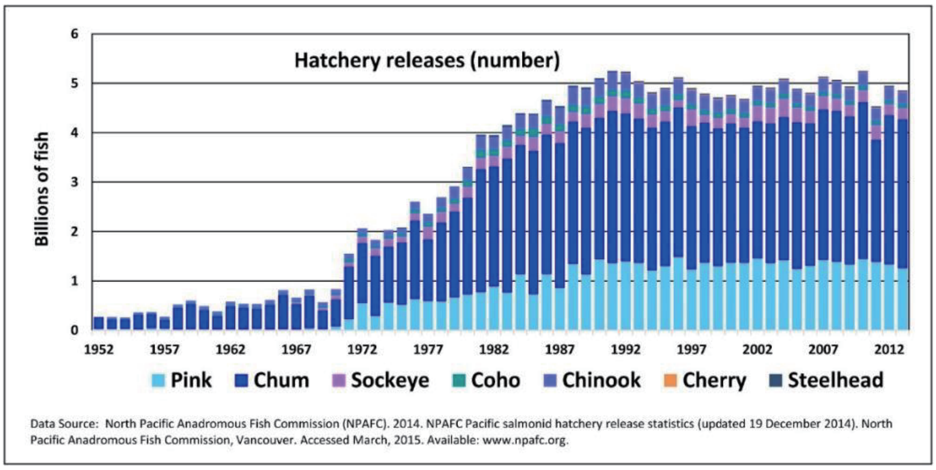
North Pacific salmon hatchery releases increased in the 1970s and have been fairly stable during the last 25 years at a total of approximately 5 billion fish released (Fig. 4). Most of the fish released from hatcheries are pink and chum salmon (Fig. 5). There was a decrease in the number of fish released in 2011 due to damage from the earthquake and tsunami in the Sanriku area that year. Favourable marine conditions for pink and chum salmon and improved hatchery technologies have played a role in increasing the abundance of chum and pink salmon in Asia.

NPAFC scientific coordination is critical to the work of the Working Group on Salmon Marking. This group manages otolith mark patterns among the member countries, so no duplicate marks are released for a given species. Placement of identifiable marks on otoliths allows biologists to track migration patterns, assess efficacy of augmentation programs, and manage wild populations and fisheries. Mark patterns are used to identify the fish's brood year and hatchery of origin.



Data Source: North Pacific Anadromous Fish Commission (NPAFC). 2014. NPAFC Pacific salmonid hatchery release statistics (updated 19 December 2014). North Pacific Anadromous Fish Commission, Vancouver. Accessed March, 2015. Available: www.npafc.org.

Figure 4. Hatchery releases (billions of fish) by country 1952-2013



Data Source: North Pacific Anadromous Fish Commission (NPAFC). 2014. NPAFC Pacific salmonid hatchery release statistics (updated 19 December 2014). North Pacific Anadromous Fish Commission, Vancouver. Accessed March, 2015. Available: www.npafc.org.

Figure 5. Hatchery releases (billions of fish) by species 1952-2013

For Brood Year 2015, there were 384 unique otolith marks being used among member countries. All salmon species are otolith marked and all member countries are otolith marking. About 50% of the unique marks are being used on chum salmon. Each country enters their mark patterns and release information into an online database hosted by NPAFC and maintained by Alaska Department of Fish and Game. The online data repository contains information including the estimated number released per unique mark and serves as a reference for scientists conducting otolith thermal mark recoveries. From 2001 to 2009 the percentage of otolith-marked fish ranged from about 23% to 33% of total hatchery releases (Fig. 6). From 2010 to 2014 the percentage of marked fish increased to a little less than 50% of total releases.

Each year, the NPAFC Secretariat hosts a 6-month paid internship at its office in Vancouver, BC. The goal of the internship program is to help early-career professionals and recent graduates gain experience and knowledge in operations of the Commission and to provide an opportunity to test their interest in international governmental organizations, management, fisheries, biology, ecology, and fisheries enforcement. Details are available on the website.

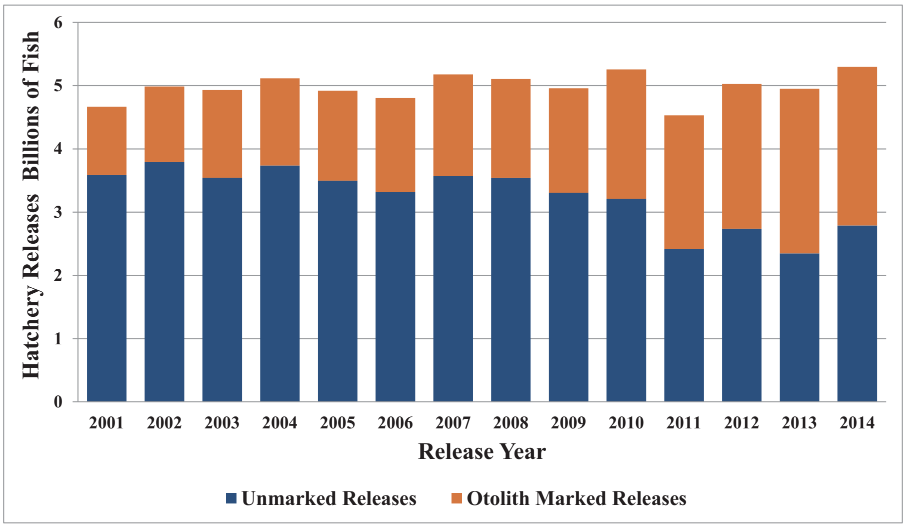


Figure 6. Estimated percentage of fish released from hatcheries by NPAFC-member countries that are otolith marked

Currently, NPAFC has a new initiative under consideration—the International Year of the Salmon—as a way to bring concerns of ocean salmon conservation to the forefront of research and public awareness. The NPAFC will shortly host the second IYS Scoping Meeting to gather potential partners who will provide input into development of the IYS implementation strategy.

Another project being coordinated by NPAFC is the production of a new book on the ocean life history of Pacific salmon, steelhead, and coastal cutthroat trout. The book will summarize information on what has become known about the ocean period of life of these species since the early 1990's. The book represents a substantial effort and will become a valuable reference for many years.

NPAFC's coordination of fisheries enforcement and scientific research has proven to be a highly successful combination that works well to promote improved conservation of Pacific salmon and steelhead in the North Pacific Ocean.

Fisheries genetics in the era of genomics

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Keywords: Pacific salmon, next generation sequencing, genetic markers, fisheries management

Abstract

The field of fisheries genetics has advanced dramatically in the last decade. Next generation sequencing (NGS) methods exponentially increased the number of available genetic markers, creating the new field of fisheries genomics. The emergence of NGS quickly led to many new opportunities including improved resolution for stock identification and identification of adaptively important genes and genomic regions; many of these improvements were facilitated by dense linkage mapping. Simultaneously, improvements in genotyping approaches have allowed screening of an unprecedented number of individuals and number of markers and enabled the expansion of techniques such as parental-based tagging (PBT) and individual assignment (IA). I will review the most widely used molecular based applications in fisheries management with a focus on recent examples that demonstrate advances powered by genomics. I will also provide a look into the future of the field. While it remains impossible to foresee all future advancements, fisheries genomics will continue to provide increasingly important information to improve management and sustainability of salmonid resources.

Genetics and Modern DNA Sequencing

Today, there are an increasing number of applications that integrate genetics and genomics into fisheries research and management; much of this progress has been catalyzed by developments in both technology and analytical methods (Ovenden et al. 2015). Next generation sequencing now enables genomics analyses through the acquisition of millions of short DNA reads and has allowed conservation and management agencies to genotype thousands of single nucleotide polymorphisms (SNPs) in salmonids and other fish species. An increasingly common approach in salmonids is to sequence DNA fragments adjacent to restriction sites in genomic DNA termed restriction site associated DNA sequencing (RAD, RAD-seq, or one of its modifications) (Miller et al. 2007, Baird et al. 2008, Andrews et al. 2016). Collectively these approaches are known as genotyping by sequencing (GBS) (Narum et al. 2013). On the analytical side, user-friendly bioinformatics software packages and an increasing number of improved statistical approaches are emerging to handle the big data generated from NGS (e.g. Bradbury et al. 2007; Catchen et al. 2013);

Genetic Stock Identification

Genetic stock identification (GSI), is an important and powerful tool used extensively in salmonids across the Pacific Rim. GSI has been used for a variety of applications including providing real time management information for important commercial fisheries (Dann et al. 2013), tracking the distribution and migration patterns of different populations in marine waters and on the high seas (Urawa et al. 2009; Habicht et al. 2010; Larson et al. 2013; Sato et al. 2014), and ensuring that multiple countries receive appropriate access to anadromous fish bound for their rivers (e.g., Smith et al. 2005; Beacham et al. 2008). GSI applications have benefited directly from NGS methods and their ability to identify SNPs to differentiate closely related populations to improve resolution of stock groups. For example, Larson et al. (2014b) identified over 10,000 SNPs in five natural populations of Chinook salmon from Western Alaska and were able to identify three groups where previously only one group was identifiable previously (Larson et al. 2014a) (Figs. 1 and 2).

Emerging methods collectively termed targeted amplicon sequencing have the potential to greatly decrease genotyping costs through cost-effective simultaneous sequencing of thousands of individuals (Lange et al. 2014; Campbell et al. 2015). These methods should allow genotyping of thousands of individuals for hundreds of SNPs in a cost-effective manner using the power of NGS. The value of targeted amplicon sequencing has recently been demonstrated in steelhead (anadromous rainbow) trout for 192 SNPs by Campbell et al. (2014) who introduced the term “Genotyping-in-Thousands” or “GT-seq” and were able to genotype over 2,000 individuals in a single lane of NGS.

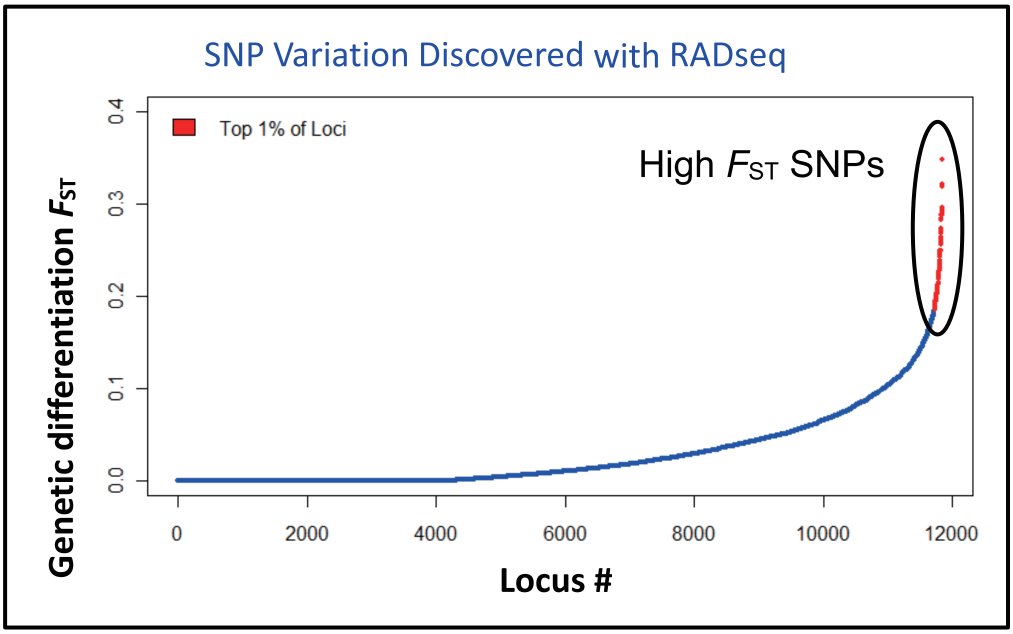

Figure 1. Graph of Chinook salmon loci sorted by increasing F_{ST}. The highest ranking loci (in red) are evaluated for genetic stock identification (GSI). Data are from (Larson et al. 2014b).

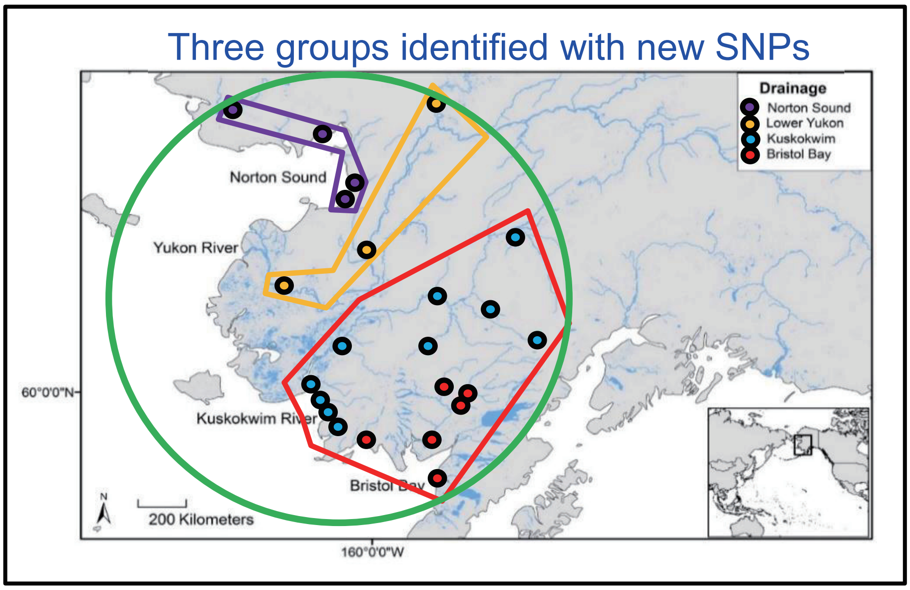

Figure 2. Increased resolution provided by SNP discovered using RAD sequencing. Previously only a single reporting group (green circle) in coastal Western Alaska was identifiable using 43 SNPs (Templin et al. 2011) or 13 microsatellites (Beacham et al. 2006). Newly discovered SNPs increased the reporting groups to three: Norton Sound, Lower Yukon, and a Kuskokwim/Bristol Bay group (Larson et al. 2014a).

Adaptively important genes: A number of recent studies have applied NGS data to identify adaptively important outlier loci in order to detect previously unidentified population structure and identify ecotypes to improve definition of management units. Many of these studies are now being combined with genetic linkage maps to identify regions of the genome that display heightened genetic divergence (e.g. genomic islands of divergence). Pearse et al. (2014) showed that life-history differentiation between resident rainbow trout and anadromous steelhead is associated with a large genomic region of one chromosome. Larson et al. (in press) investigated three ecotypes in sockeye salmon inhabiting beach, river, and stream types. Sockeye salmon that spawn in small streams are much smaller than those that spawn on beaches or in rivers because sexual selection for large body size is overwhelmed by size selective predation from bears and physical constraints of stream depth (Fig. 3, Quinn et al. 2001). The spawning environments of these ecotypes also vary in other characteristics including temperature, gravel size, and spawning density, leading to differences in egg morphology (Quinn et al. 1995; Hendry et al. 2000). Using a genetic linkage map, Larson et al. (in press) identified genomic regions (genomic islands of divergence) displaying high differentiation among ecotypes. This differentiation contrasts to weak, neutral structure throughout the rest of the genome that was not partitioned by ecotype (Fig. 4). Gene annotation revealed that the peak of one of regions contained a non-synonymous mutation in a gene involved in growth in other species.

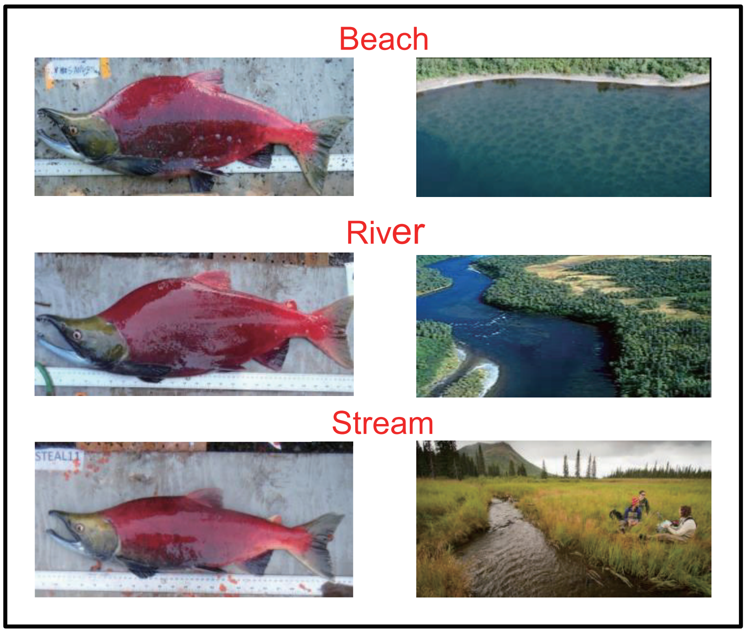

Figure 3. Photos of representative males and typical spawning habitat from the three ecotypes adapted to different environments found in sockeye salmon from Wood River lakes in Alaska. Photos of habitats courtesy of J. Armstrong (Oregon State University) and J. Ching (Alaska Salmon Program, University of Washington).

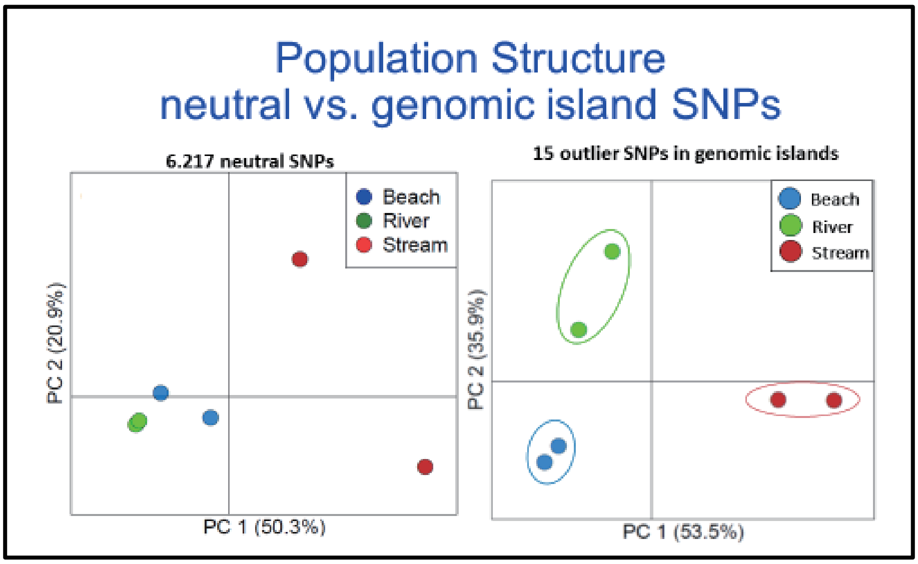

Figure 4. Principal coordinate analysis of sockeye salmon population structure at neutral SNPs and outlier SNPs from genomic islands of divergence. The neutral SNPs generally differentiate the streams from each other and from the rest of the populations. The outlier SNPs differentiate all ecotypes from each other and group the ecotypes into three relatively tight clusters likely reflecting adaptive divergence between the ecotypes. From Larson et al. (in press).

Future Directions in Fisheries Genetics and Genomics

Applications of fisheries genetics are increasingly incorporated into routine fisheries management and decision-making. Clearly, this trend will only continue in the coming decade with the ever increasing genetics and genomics tools and increasing resolution for stock identification and management applications. At the same time, the costs for these analyses is continuing to drop as NGS approaches proliferate. Finally, we are just starting to appreciate the full potential of genomic data to better understand the genes and processes underlying adaptation in salmonids.

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Ocean distribution and abundance of Japanese and other stocks of chum salmon in the summer Bering Sea estimated by genetic methods

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Keywords: chum salmon, genetic stock identification, SNP markers, ocean distribution, stock abundance

Chum salmon (*Oncorhynchus keta*) are widely distributed around the Pacific Rim. Chum salmon are also one of the important fisheries resources in the North Pacific Ocean countries, including in Japan. Stock-specific ocean distribution and abundance of chum salmon are useful information to manage chum salmon resources, because the summer Bering Sea is important growth habitat of chum salmon stocks from Asia and North America. Genetic stock identification (GSI) is a powerful tool for estimation of stock origins of chum salmon. In this study, we estimated stock origins, ocean distribution patterns, and abundance of Japanese and other stocks of immature chum salmon in the summer Bering Sea by GSI using single nucleotide polymorphism (SNP) markers.

Salmon research cruises were conducted by R/V *Hokko maru* in the 17 fixed monitoring stations in the central Bering Sea (52º 30' N-58º 33' N, 174º 49' E-174º 49' W) using surface trawl net between late July and early August in 2007, 2009, and 2011-2014. The trawl net was towed at a speed of approximately 5 knots in the surface layer (0 to 30 m depth) for one hour in daytime. Adipose fins were collected as genetic samples and were preserved in 100% ethanol until DNA extraction. After DNA extraction, each sample was genotyped for 45 nuclear SNP loci by TaqMan chemistry. The genotyping data were pooled from two or three stations nearby and used for GSI. Stock contributions (Japan, Russia, and North America) of immature chum salmon were estimated by a conditional maximum likelihood using a SNP baseline dataset from 158 populations in the Pacific Rim.

A total of 1,532-3,308 fish was annually caught at the 17 fixed monitoring stations in the central Bering Sea. Chum salmon were widely distributed in the survey areas of the Bering Sea, but CPUE (catch per unit effort) in northern areas on 180º and 175ºW lines were higher than that of other areas. These results suggest that immature Japanese chum salmon is widely distributed in the central Bering Sea, however, the distribution pattern seems nonrandom.

GSI estimated composition was 28.6-42.6% Japanese, 55.2-68.9% Russian, and 2.2-8.7% North American stocks during six survey years. Stock-specific CPUE of immature chum salmon suggests that the abundance of Russian stocks were higher than that of Japanese stocks in the summer Bering Sea. Previous studies indicated that the abundances of Japanese chum salmon were similar to the Russian stocks in the summer Bering Sea about 10 years ago (Urawa et al 2009). So, our results suggest that the abundance of Japanese stocks tends to reduce in the recent summer Bering Sea.

Trends of catch numbers, compositions of GSI, and abundance of chum salmon in the Bering Sea were different between 2014 season and other five survey years. Total catch numbers of chum salmon in 2014 were smallest in all survey years. Proportion of North American stocks in 2014 was higher than that of other survey years. Furthermore, the abundance of Japanese stocks in 2014 decreased compared with that in other survey years. In 2014 season, surface seawater temperature (SST) and vertical seawater temperature in the summer Bering Sea were higher than in other survey years (Sato et al 2015). Mean SSTs in 2014 and other five years were 11.1ºC and 8.8-9.1ºC, respectively. In 2014, the vertical distribution of seawater anomalies (relative to 2007-2014 mean values) indicated approximately +0-3ºC. These results suggests that unusual ocean condition may affect distribution pattern and/or migration timing of chum salmon, particularly Japanese stocks, in the Bering Sea in 2014.

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Reforming hatchery rearing practices to improve effectiveness of supplementation and conservation hatcheries for Pacific salmon and steelhead (*Oncorhynchus* sp.)

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Keywords: Pacific salmon, steelhead, survival, reproductive success, modified hatchery program

Salmon and steelhead hatcheries are used throughout the Pacific Northwest Region of the United States to supplement commercial harvest and conserve declining wild populations that have been listed as endangered under the US Endangered Species Act (ESA). But, it is widely recognized that salmon and steelhead reared in hatcheries can have lower survival and reduced reproductive success when spawning in nature compared to wild fish, and can have negative ecological and genetic effects on native wild fish. The reduced fitness of hatchery fish has been attributed to a combination of inadvertent genetic selection and environmental factors in the hatchery (e.g. embryo incubation temperatures, diet, growth regimes, and rearing densities). In this presentation I will describe results from hatchery monitoring programs and laboratory experiments aimed at understanding how environmental factors and hatchery rearing practices affect the diversity life history phenotypes of fish released from hatcheries, and contribute to reduced survival and reproductive success. The goal of this work is to improve the effectiveness of both supplementation and conservation hatcheries by modifying hatchery rearing protocols.

Atlantic salmon aquaculture in Norway

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Keywords: salmon farming, reproductive physiology, sexual maturation control, wild salmon conservation

Aquaculture of Atlantic salmon (*Salmo salar* L.) has had a tremendous development, from a production of some thousands of tons in the 1970´s to 1.2 million metric tons in 2014 (Fig 1). At present, the total revenues from salmon culture exceed those from fisheries, which makes aquaculture one of the major sources of income in Norway.

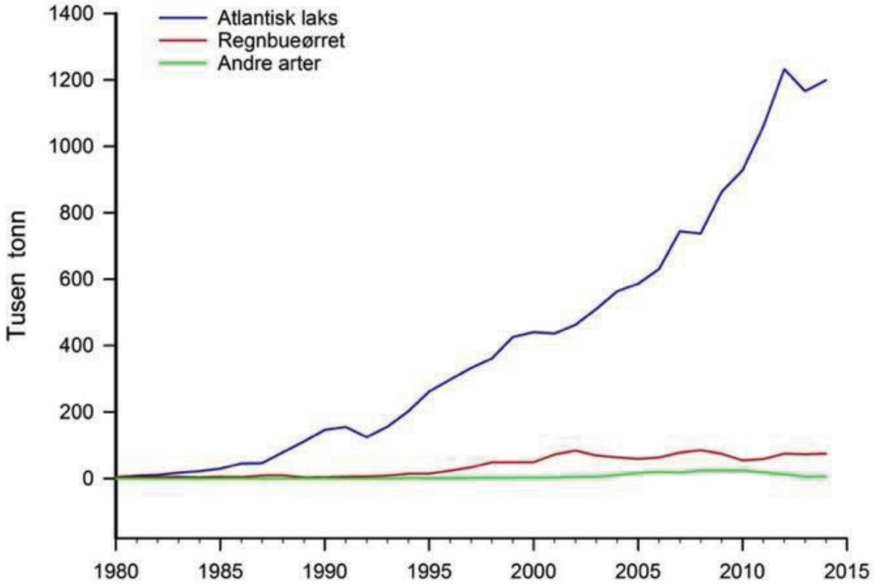

Figure 1. Production (tonnes · 10^3) of Atlantic salmon (blue line), rainbow trout (red line) and other fish species in Norway between 1980 and 2014 (source: The Norwegian Directorate of Fisheries; www.fiskeridir.no)

Production of salmon for the market is mainly carried out in open sea cages, and a number of challenges are present, which recently have made production volumes flatten out (Fig. 1). Past and present research has focused on production biology and technology, fish health - in particular vaccine development and control of sea lice, feed resource utilization, local impact on the environment and genetic interactions with wild stocks.

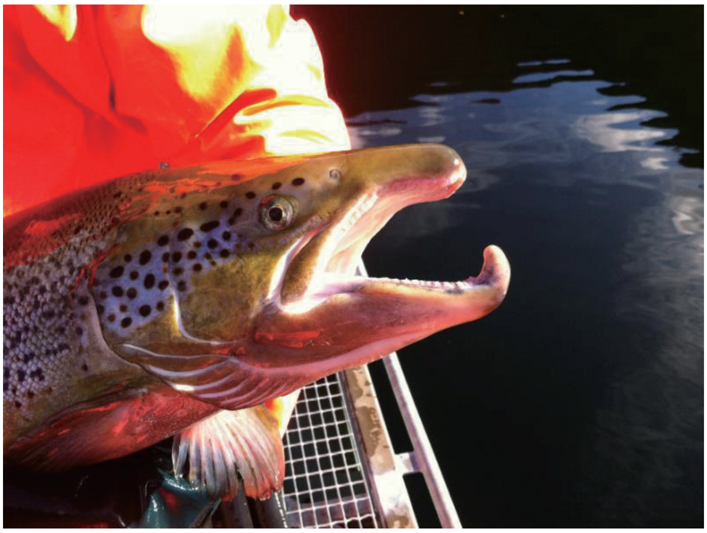

Figure 2. Mature, male Atlantic salmon. Photo: Monica Solberg Institute of Marine Research

Research in physiology has been of great importance for the development of effective and sustainable production technologies. For example, smolt production was greatly improved by use of photoperiod manipulation. Research on basic and applied reproductive physiology has been crucial in providing optimal conditions for broodstock management and production of large salmon in sea cages. Early on, the use of photoperiod control of timing of maturation was applied to obtain eggs out of season, and effects of rearing temperature were studied in order to optimize spawning and production of high quality gametes (Bromage et al., 2001; Taranger et al., 2000, 2010). High rearing temperatures during vitellogenesis and spawning were shown to have deleterious effects on spawning and egg quality (Taranger et al., 2015a). The discovery that continuous light applied on sea cages in winter both improved growth and block sexual maturation was a major contribution which has had a large impact, economically as well as on feed utilization and fish welfare (Taranger et al., 2010).

Figure 3. Atlantic salmon sea cages in the archipelago of Austevoll, Norway. Photo: Institute of Marine Research

Wild Atlantic salmon have a life history where eggs are spawned and hatched in rivers that each have their own specific stock. After smoltification, the young salmon migrates to the sea for several years before returning to its river of origin to spawn. Escaped farmed salmon that survive in the sea until maturation may migrate up into the rivers to spawn. In some rivers, >10% of the salmon have been shown to be escapees from salmon farms (Taranger et al., 2015b). There is a growing concern that genetic interactions between farmed salmon and wild stocks may lead to reduced fitness and survival of those stocks. This has prompted a large effort within genetics and genomics, in order to establish the true impact of farmed salmon on wild stocks, and to mitigate possible negative effects by producing sterile salmon that will not be able to breed with wild fish. To this end, large scale production of triploid salmon has been carried out and their special environmental and nutritional requirements have been investigated (e.g. Fraser et al., 2015; Hansen et al., 2015; Fjelldal et al., 2016). Through genome sequencing, a single gene locus VGLL3, that regulates puberty in Atlantic salmon was recently discovered (Ayllon et al., 2015). This discovery may be of great importance in order to breed more robust salmon that enter puberty at a higher age. Late entry into puberty will also result in higher mortality at sea of escaped salmon, and in this way reduce the number of escapees that will be able to enter the spawning grounds in the rivers.

Using new genomic tools, such as CRISPR/Cas9 gene editing, gonad development was blocked at the embryonic stage by gene knockout (Wargelius et al., 2016). This resulted in sterile salmon of both sexes and in this way demonstrated that Atlantic salmon have germ cell independent sex differentiation. Understanding sex differentiation and early gamete formation at the molecular level will help us develop vaccines and other tools for future production of sterile salmon.

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Physiological mechanisms of olfactory imprinting and homing in chum salmon

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Keywords: salmon homing migration, GnRH, NR1 regulation, olfactory imprinting

Abstract

The olfactory hypothesis for salmon imprinting and homing to their natal stream is well known, but the endocrine hormonal control mechanisms of olfactory memory formation in juveniles and retrieval in adults remain unclear. In brains of hatchery-reared underyearling juvenile chum salmon (*Oncorhynchus keta*), thyrotropin-releasing hormone gene expression increased immediately after release from a hatchery into the natal stream, and the expression of the essential NR1 subunit of the N-methyl-D-aspartate receptor increased during downstream migration. Gene expression of salmon gonadotropin-releasing hormone (sGnRH) and NR1 increased in the adult chum salmon brain during homing from the Bering Sea to the natal hatchery. Thyroid hormone treatment in juveniles enhanced NR1 gene activation, and GnRHa treatment in adults improved stream odour discrimination. Olfactory memory formation during juvenile downstream migration and retrieval during adult homing migration of chum salmon might be controlled by endocrine hormones and could be clarified using NR1 as a molecular marker.

The olfactory hypothesis for salmon imprinting and homing to their natal stream is well known (Hasler and Scholz 1983), but the endocrine hormonal control mechanisms of olfactory memory formation in juveniles and retrieval in adults remain unclear. The physiological mechanisms of imprinting and homing in salmon have been intensively researched using behavioral, electrophysiological, biochemical, and neurobiological methods (Ueda 2014). Many studies have also explored the hormonal control mechanisms of juvenile downstream migration and adult homing migration in relation to seawater adaptability (McCormick 2001) and gonadal maturation (Ueda 2011), respectively. However, until now, it has been impossible to link hormonal control mechanisms to imprinting and homing migration because we lacked molecular markers that would permit the evaluation of olfactory memory formation and retrieval in the salmon brain.

The N-methyl-D-aspartate receptor (NMDAR) is a glutamate receptor channel subtype and mediates most of the fast excitatory synaptic transmission in the central nervous system. It plays important roles in memory formation and retrieval in higher vertebrates (Martin et al. 2000). NMDARs are comprised of two subunits: the essential NR1 subunit and the differentially expressed NR2A-D subunit (Shipton and Paulsen 2013). The NR1 gene of chum salmon (*Oncorhynchus keta*) has recently been cloned and characterized (Yu et al. 2014), and the effects of changing salinity on NR1 gene expression have been reported (Kim et alo. 2015). However, there have been no reports addressing how NR1 might be involved in olfactory memory formation and retrieval in salmon. The thyroid hormones have been reported to play important roles in juvenile chum salmon during downstream migration (Ojima and Iwata 2007) and in olfactory cellular proliferation in coho salmon (*O. kisutch*) during a sensitive period for imprinting (Lema and Nevitt 2004). Gonadotropin-releasing hormone (GnRH) is considered a leading hormone for salmon homing migration[4], and implantation of GnRH analogue (GnRHa) was able to shorten the homing duration of lacustrine sockeye salmon (*O. nerka*) in Lake Shikotsu (Hokkaido, Japan) (Sato et al. 1997).

This study presents the first analysis of the gene expression profiles of whole-brain TRHa/b and upper head TSHβ in juvenile chum salmon, revealing that environmental changes due to the release from the hatchery to the natal stream significantly enhanced the TRHa/b expression levels and that the TSHβ expression levels and T4/T3 levels in the lower jaw increased significantly during downstream migration towards the sea. NR1 expression levels showed a significant first peak correlated with larval brain development in the hatchery (Pouwels 1978), a gradual significant increase immediately after a significant TRHa/b expression surge at the Kamaka, and a second significant peak at the mouth of their natal river. The results of *in situ* hybridization confirmed that NR1 mRNA localization increased prominently in the ventral TE at the Kamaka compared to the hatchery immediately before release into the river. Moreover, the oral administration of T4 significantly increased NR1 expression levels for 4 days.

Natal stream odor discrimination abilities were examined using the electro-olfactogram (EOG) response to stream water odors, revealing significantly greater discrimination ability for the Ishikari River (home stream) water in juvenile chum salmon collected during downstream migration compared to those at the hatchery. The olfactory memory formation capacity for stream odors likely develop when juvenile chum salmon encounter different streams during their downstream migration, and these capabilities are clearly linked to NR1 and brain-pituitary-thyroid (BPT) hormones. Cumulatively, our data suggest that during the initiation of the downstream migration of juvenile chum salmon, the environmental changes involved in the release into the river may induce the expression of the BPT hormones, which then stimulate the upregulation of NR1, enhancing the olfactory memory formation capability.

This study presents a high level of sGnRH-II gene expression in the hypothalamus in the Bering Sea, suggesting a correlation with the onset of gonadal maturation as well as the start of homing migration. During upstream homing migration from Ishikari Bay to the natal hatchery, the gene expressions levels of sGnRH-I/II and NR1 in the olfactory bulb and telencephalon showed some sexually differentiated patterns, likely due to sex-specific gonadal maturation (Ueda 2011).

Adult male chum salmon collected at the Indian Waterwheel, Chitose River showed significantly higher EOG responses to their natal stream water than to non-natal stream water. GnRHa implantation in adult male chum salmon caught in Ishikari Bay prior to entering their natal stream produced different EOG responses whether including straying fish from another hatchery or only originating from the natal hatchery. The relative EOG response of adult male chum salmon originating from the Chitose Hatchery showed significant discrimination of the Chitose River water, but that including straying fish only showed significant discrimination of the Ishikari River water. These data suggest that straying fish and accurately homing fish show different olfactory discrimination ability for their natal stream waters.

Our data on adult homing migration suggest that the activation of sGnRHI/II may cause both the onset of homing migration and the upregulation of NR1, facilitating olfactory memory retrieval as well as natal stream odor discrimination during upstream migration. This study demonstrates that the gene expression levels of NR1 in the brain are a useful molecular marker to clarify the olfactory imprinting and homing abilities of both juvenile and adult chum salmon (Ueda et al. 2016). Further biochemical and molecular biological studies investigating the protein levels and the gene expression profiles of NR1 and NR2A-D with treatments of NMDAR antagonist will be able to reveal olfactory long-term potentiation in salmon brain.

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Migration and survival of salmon in a changing climate

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Keywords: Pacific salmon, ocean migration, marine survival, climate conditions

Introduction

The number of salmon intercepted in various fisheries vary among years, due in part to highly variable natural mortality rates in the ocean (Irvine et al. 2012). This complicates our ability to accurately forecast the number of salmon returning to spawn, and provides scientific advice for managing salmon resources sustainably. For Pacific salmon, most of the natural mortality is thought to occur during two critical periods: an early mortality occurring during the first few weeks following ocean entry, and a second wave occurring during their first winter at sea (Beamish and Mahnken 2001). Hence, in order to understand the causes of this mortality, we need to determine where salmon go in the ocean, how long they reside in different regions of the ocean, the conditions they encounter in these regions and their effects on salmon during their first year at sea.

The objectives of this study are to present an overview of the approach we used to understand the impacts of climate conditions on the survival of Pacific salmon. We focus our study on Chinook salmon (*Oncorhynchus tshawytscha*) originating from the west coast of Vancouver Island, British Columbia, Canada to illustrate how the approach we used can be implemented elsewhere. We first review the migration of Chinook salmon on the west coast of North America, and present a statistical approach we used to examine how climate conditions affect Chinook salmon off the west coast of Vancouver Island.

Chinook salmon migration

Hartt and Dell (1986) presented the first general migration pattern for all species of Pacific salmon on the west coast of North America using juvenile salmon that had been tagged at sea and then recovered subsequently in coastal and terminal fisheries. They postulated that Pacific salmon generally exhibit a northward migration and utilize the narrow continental shelf as a migration highway that brings them to the Aleutians, and eventually into the Gulf of Alaska and Bering Sea, before returning to their natal river and spawn. For Chinook salmon though, it was recognized previously by Healey (1983) that their migration may differ between two life-history types, based on the length of their freshwater residence as fry. Fry that spend a full year in freshwater were referred as stream-type were believed to exhibit a rapid and extensive coastwide migration along the continental shelf following ocean entry and then rear in the Gulf of Alaska. In contrast, fry that spent a few weeks to months in freshwater prior to their seaward migration were referred to as ocean-type and were believed to slowly disperse following sea entry and establish residence on the continental shelf. It is important to note though that the model proposed by Hartt and Dell (1986) was based on the recovery of only 12 Chinook salmon that had been tagged at sea, whereas Healey (1983) relied on the recovery of immature and mature Chinook salmon marked with coded-wire tags (CWT) as fry in freshwater. Hence, further work was required to understand the migration of Chinook salmon by focusing research on juvenile Chinook salmon in the ocean environment.

Our initial research on the migration of Chinook salmon relied on the CWT recoveries from trawl surveys conducted from Oregon to Alaska over a 12-year period (Trudel et al. 2009). During that time, 1862 juvenile Chinook salmon marked with CWT were recovered in more than 5,000 sampling events. Our analyses suggested that juvenile Chinook salmon migration exhibited two distinct migration behaviour based on the origin. Stream-type Chinook salmon originating from the Columbia River generally undertook a rapid northwestward migration along the continental shelf, though some southward migration was also observed in some populations within the Columbia River basin. In contrast, nearly all other populations, irrespective of their life-history, generally remained within a few hundred kilometers of their ocean entry point. This research was limited to Chinook salmon fry reared in hatcheries, and may not reflect the migration of wild or naturally spawned Chinook salmon.

In subsequent studies, we used DNA analyses performed on nearly 7,000 juvenile Chinook salmon caught in trawl surveys conducted from the west coast of Vancouver Island to Southeast Alaska during a 14-year period (Tucker et al. 2011, 2012, 2015). The results obtained in these studies confirmed that wild and hatchery fish exhibited similar migration behaviour (Tucker et al. 2011). In particular, juvenile stream-type Columbia River Chinook salmon undertook a rapid northward migration along the continental shelf, and that other populations, such as Chinook salmon originating from the west coast of Vancouver Island remained within a few hundred kilometers of their ocean entry point for at least a year (Tucker et al. 2011). These migration behaviours were also remarkably stable during that 14-year period, despite that oceanographic conditions varied greatly, with warm and cool periods, El Niño and La Niña events (Tucker et al. 2012).

For juvenile Chinook salmon originating from the west coast of Vancouver Island, we further showed that their migration varied at a finer scale, with the northern population being restricted in a relatively small inlet at the north end of Vancouver Island (Tucker et al. 2015). Other stocks were located from their ocean entry point to the north end of Vancouver Island, and moved further offshore on the continental shelf during winter (Tucker et al. 2015). Hence, the limited geographic distribution of juvenile

Chinook salmon originating from the west coast of Vancouver Island during their first year at sea makes them an ideal candidate to assess the effects of ocean conditions on the marine survival of Pacific salmon during the two critical periods identified by Beamish and Mahnken (2001).

Chinook salmon survival model

The effects of climate conditions on the recruitment of Pacific salmon has been recognized by fisheries scientists since the pioneering work of Beamish and Bouillon (1993). This has usually been demonstrated by correlating salmon survival with various indices of climate conditions such as the Pacific Decadal Oscillation (PDO) (Mantua et al. 1997) and the North Pacific Gyre Oscillation (NPGO) (Kilduff et al. 2015) using simple or multiple regressions. However, the mechanisms linking salmon survival to climate conditions remain for the most part elusive, as many intermediate steps are often presumed rather than delineated (Baumann 1998). This is to a large extent due to the nature of the statistical methods generally used to examine the relationship between survival and climate, which requires a lack of co-linearity among the independent variables. In reality, climate and oceanographic conditions are highly interconnected to one another. For instance, northwesterly winds generally favour southward currents along the west coast of Vancouver Island, which in turns create upwelling that brings cold and nutrient-rich waters to the surface, increase primary and secondary productivity, and also brings northern copepods species, which are lipid-rich (Thomson 1981).

A number of statistical tools are now currently available to account for these interactions rather than ignoring them such as the PATH analysis, structural equation modelling (SEM), and Bayesian Belief Network (BBN). For our work on Chinook salmon, we opted to use a BBN as this approach is highly flexible, allowing the inclusion of quantitative and qualitative variables, less stringent than the PATH analysis or SEM, and can be framed in a probabilistic framework (Araujo et al. 2013; Hertz et al. 2016). Our analyses revealed that the PDO affected the marine survival of west coast of Vancouver Island Chinook salmon through its effect on the transport of northern copepods in southern waters and on the feeding ecology of juvenile Chinook salmon off the west coast of Vancouver Island during their first summer at sea (Hertz et al. 2016). Although the BBN was useful to identify these intermediate links, the mortality agents remained unknown. Presumably, fast growing fish can escape gape-limited predators or accumulate enough lipids to survive starvation throughout the winter. Further work is required to determine the factors that are causing mortality in Pacific salmon at sea.

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Genetic evaluation of chum salmon, *Onchorhynchus keta*, river population after tsunami disaster in Fukushima and Miyagi Prefecture

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Keywords: chum salmon, tsunami disaster, homing cohorts, genetic characterization

Chum salmon (*Onchorhynchus keta*) is one of the most important fishery resources in Tohoku region that facing Pacific Ocean side in Japan. The reproduction of chum salmon largely depend on the artificial propagation. The anadromous fish were caught for the artificial reproduction nearby estuary. On 11th March 2011, the tsunami attack has destroyed and terminated many facilities for salmon culture in Fukushima and Miyagi Prefecture, and many facilities cannot resume operation still now. Therefore most of salmon which are going upstream at present in such areas are offspring from natural spawning. In 2014-2015 season, salmon which come back to their own river consist of three different cohorts, which are 3years old (born in 2012, after Tsunami disaster), 4 years old (born in 2011, the year of Tsunami disaster) and 5 years old (born in 2010, before Tsunami disaster). It is expected that the comparison of these cohorts can identify the genetic change due to tsunami disaster and the effect of captive breeding in each river.

In this study, genetic characteristics of chum salmon were compared among three cohorts in three rivers, the Ukedo River (Fukushima), the Hirose River (Miyagi) and the Chitose River (Hokkaido) for identification of the effect of Tsunami and captive breeding using microsatellite DNA markers.

A total of 216 individuals were examined which collected from three rivers, the Ukedo R., the Hirose R. and the Chitose R., and nine microsatellite loci were used for the genetic characterization. Average heterozygosity (expected, *H*e and observed, *H*o), average number of alleles per locus and effective size of population (*N*e) were compared. Population differences were examined by Arlequin. *N*e's were estimated by NeEstimator and LDNe.

Significant genetic differences and variabilities were observed among rivers and cohorts. Four years old cohort indicated the highest genetic variabilities in two of three rivers, and three years cohort indicated the lowest genetic variabilities in three rivers. These tendencies were observed in *N*e's in common at all examined rivers. These results suggest that tsunami disaster does not greatly damaging the genetic diversities in the river populations of chum salmon in the southern coast of Tohoku Region.

Genetic differentiation of chum salmon in the Sanriku-region, Japan, inferred from microsatellite DNA analysis

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Keywords: chum salmon, microsatellite DNA, genetic differentiation, Iwate coast, Kitakami River

Genetic approach is expected to provide important information for conservation and fisheries resource management of salmon for their sustainable use. Population genetic analysis of chum salmon *Oncorhynchus keta,* which is an important fisheries resource around the Pacific Rim, has been demonstrated with a variety of genetic markers (e. g. Beachum et al., 2008; Sato, 2001, 2014; Yoon et al., 2008). However, genetic features of chum salmon remain to be elucidated in the Sanriku-region, Pacific coast of northern Honshu, Japan, the southernmost region of their natural distribution range. Although chum salmon is the main fishery species in the Sanriku Iwate coast, chum salmon catch, including inshore set net and river catch, has been decreasing past two decades (Shimizu, 2015). We conducted population genetic study of Sanriku chum salmon to estimate the genetic diversity and population structure for sustainable chum salmon fishery in the Iwate coast.

More than 3,500 homing chum salmon were collected from 24 hatcheries, i.e. 11 in the coastal region and 13 in the tributaries of the Kitakami River in Iwate prefecture (Fig. 1). About 600 homing fish from four Hokkaido rivers and one each of Aomori and Fukushima rivers in Tohoku region served as the reference collections (Fig. 1). Population genetic analysis such as principal component analysis, pairwise

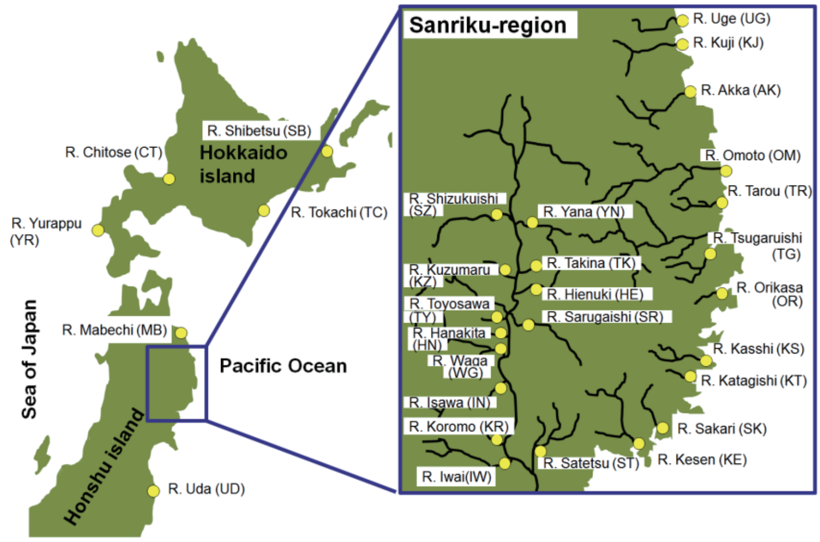


Fig. 1. Chum salmon sampling sites in northern Japan

population F_{ST} estimation, and population cluster analysis was performed with ten of 16 polymorphic microsatellite DNA markers developed using next-generation sequencing (NGS) (Tsukagoshi et al. 2015).

Our microsatellite DNA analysis of Iwate chum salmon revealed three groups of coastal early-run, coastal late-run and Kitakami samples, and genetic differentiation from samples of Hokkaido and other Tohoku regions in Japan (Fig. 2). Pairwise population F_{ST} analysis showed genetic differentiation within

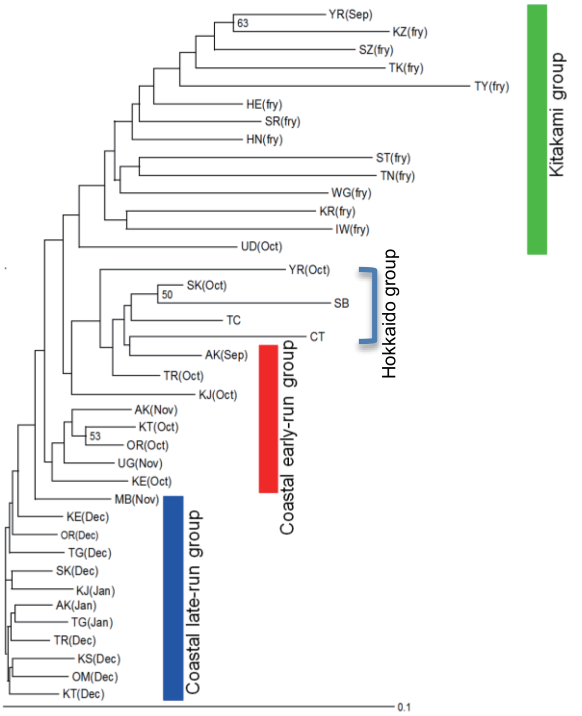
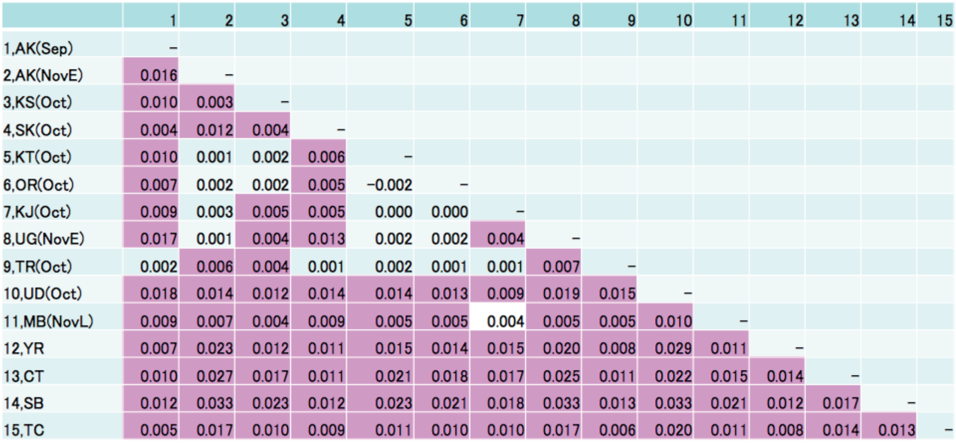


Fig. 2. Neighbor-joining population tree of chum salmon analyzed. Collection codes are the same as those shown in Fig. 1.

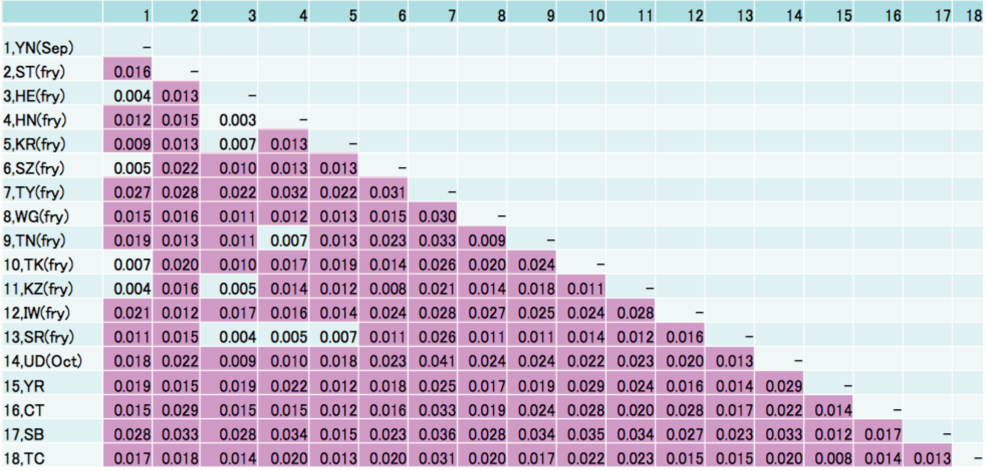
Table 1. Pairwise population F_{ST} estimates within the coastal early-run group in Iwate. Statistically significant estimates are shown in pink (P<0.05) after Bonferroni correction. Collection codes are the same as those shown in Fig. 1. Collections from other Tohoku regions (UD from Fukushima and MB from Aomori) and Hokkaido (YR, CT, SB, and TC) are used as reference.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1,AK(Sep)	–														
2,AK(NovE)	0.016	–													
3,KS(Oct)	0.010	0.003	–												
4,SK(Oct)	0.004	0.012	0.004	–											
5,KT(Oct)	0.010	0.001	0.002	0.006	–										
6,OR(Oct)	0.007	0.002	0.002	0.005	−0.002	–									
7,KJ(Oct)	0.009	0.003	0.005	0.005	0.000	0.000	–								
8,UG(NovE)	0.017	0.001	0.004	0.013	0.002	0.002	0.004	–							
9,TR(Oct)	0.002	0.006	0.004	0.001	0.002	0.001	0.001	0.007	–						
10,UD(Oct)	0.018	0.014	0.012	0.014	0.014	0.013	0.009	0.019	0.015	–					
11,MB(NovL)	0.009	0.007	0.004	0.009	0.005	0.005	0.004	0.005	0.005	0.010	–				
12,YR	0.007	0.023	0.012	0.011	0.015	0.014	0.015	0.020	0.008	0.029	0.011	–			
13,CT	0.010	0.027	0.017	0.011	0.021	0.018	0.017	0.025	0.011	0.022	0.015	0.014	–		
14,SB	0.012	0.033	0.023	0.012	0.023	0.021	0.018	0.033	0.013	0.033	0.021	0.012	0.017	–	
15,TC	0.005	0.017	0.010	0.009	0.011	0.010	0.010	0.017	0.006	0.020	0.011	0.008	0.014	0.013	–

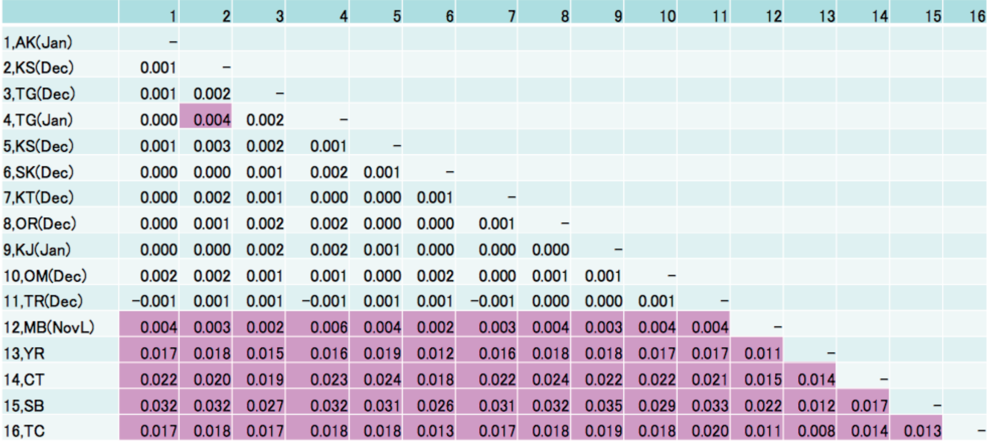
the coastal early-run (Table 1) and Kitakami groups (Table 2), but not within the coastal late-run group (Table 3). F_{ST} analysis also favored the genetic differentiation of Iwate chum salmon from those of Hokkaido and other Tohoku regions, Aomori and Fukushima. Our previous mitochondrial DNA analysis inferred moderate genetic differentiation among local populations within Sanriku and Fukushima, but no large-scale regional differences were detected (Tsukagoshi et al., in press). This may indicate a higher potential of NGS-isolated microsatellite DNA loci for salmon population genetic analysis (Tsukagoshi et al. 2015).

Table 2. Pairwise population F_{ST} estimates within the Kitakami group in inland Iwate. Statistically significant estimates are shown in pink (P<0.05) after Bonferroni correction. Collection codes are the same as those shown in Fig. 1. Collections from Fukushima (UD) and Hokkaido (YR, CT, SB, and TC) are used as reference.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1,YN(Sep)	–																	
2,ST(fry)	0.016	–																
3,HE(fry)	0.004	0.013	–															
4,HN(fry)	0.012	0.015	0.003	–														
5,KR(fry)	0.009	0.013	0.007	0.013	–													
6,SZ(fry)	0.005	0.022	0.010	0.013	0.013	–												
7,TY(fry)	0.027	0.028	0.022	0.032	0.022	0.031	–											
8,WG(fry)	0.015	0.016	0.011	0.012	0.013	0.015	0.030	–										
9,TN(fry)	0.019	0.013	0.011	0.007	0.013	0.023	0.033	0.009	–									
10,TK(fry)	0.007	0.020	0.010	0.017	0.019	0.014	0.026	0.020	0.024	–								
11,KZ(fry)	0.004	0.016	0.005	0.014	0.012	0.008	0.021	0.014	0.018	0.011	–							
12,IW(fry)	0.021	0.012	0.017	0.016	0.014	0.024	0.028	0.027	0.025	0.024	0.028	–						
13,SR(fry)	0.011	0.015	0.004	0.005	0.007	0.011	0.026	0.011	0.011	0.014	0.012	0.016	–					
14,UD(Oct)	0.018	0.022	0.009	0.010	0.018	0.023	0.041	0.024	0.024	0.022	0.023	0.020	0.013	–				
15,YR	0.019	0.015	0.019	0.022	0.012	0.018	0.025	0.017	0.019	0.029	0.024	0.016	0.014	0.029	–			
16,CT	0.015	0.029	0.015	0.015	0.012	0.016	0.033	0.019	0.024	0.028	0.020	0.028	0.017	0.022	0.014	–		
17,SB	0.028	0.033	0.028	0.034	0.015	0.023	0.036	0.028	0.034	0.035	0.034	0.027	0.023	0.033	0.012	0.017	–	
18,TC	0.017	0.018	0.014	0.020	0.013	0.020	0.031	0.020	0.017	0.022	0.023	0.015	0.015	0.020	0.008	0.014	0.013	–

Table 3. Pairwise population F_{ST} estimates within the coastal late-run group in Iwate. Statistically significant estimates are shown in pink (P<0.05) after Bonferroni correction. Collection codes are the same as those shown in Fig. 1. Collections from Aomori (MB) and Hokkaido (YR, CT, SB, and TC) are used as reference



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1,AK(Jan)	–															
2,KS(Dec)	0.001	–														
3,TG(Dec)	0.001	0.002	–													
4,TG(Jan)	0.000	0.004	0.002	–												
5,KS(Dec)	0.001	0.003	0.002	0.001	–											
6,SK(Dec)	0.000	0.000	0.001	0.002	0.001	–										
7,KT(Dec)	0.000	0.002	0.001	0.000	0.000	0.001	–									
8,OR(Dec)	0.000	0.001	0.002	0.002	0.000	0.000	0.001	–								
9,KJ(Jan)	0.000	0.000	0.002	0.002	0.001	0.000	0.000	0.000	–							
10,OM(Dec)	0.002	0.002	0.001	0.001	0.000	0.002	0.000	0.001	0.001	–						
11,TR(Dec)	−0.001	0.001	0.001	−0.001	0.001	0.001	−0.001	0.000	0.000	0.001	–					
12,MB(NovL)	0.004	0.003	0.002	0.006	0.004	0.002	0.003	0.004	0.003	0.004	0.004	–				
13,YR	0.017	0.018	0.015	0.016	0.019	0.012	0.016	0.018	0.018	0.017	0.017	0.011	–			
14,CT	0.022	0.020	0.019	0.023	0.024	0.018	0.022	0.024	0.022	0.022	0.021	0.015	0.014	–		
15,SB	0.032	0.032	0.027	0.032	0.031	0.026	0.031	0.032	0.035	0.029	0.033	0.022	0.012	0.017	–	
16,TC	0.017	0.018	0.017	0.018	0.018	0.013	0.017	0.018	0.019	0.018	0.020	0.011	0.008	0.014	0.013	–

The present findings suggest anthropogenic effects such as artificial transplantation, particularly for the coastal late-run group, to shape the observed population structure of Iwate chum salmon, besides geographical and temporal factors. The final goal of our genetic research is to identify major chum salmon stocks, if any, which chiefly contribute to salmon returns in Iwate coast. If such stocks are found, then we can propose an effective resource management plan for those stocks, which will help improve current hatchery operation and optimize the salmon enhancement strategy in Iwate and other prefectures in Sanriku.

This work was supported partly by the MEXT Revitalization Project for the Creation of Fisheries Research and Education Center in Sanriku.

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Genetic population structure of masu salmon in the Sanriku-region, Japan, inferred from microsatellite DNA analysis

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Keywords: masu salmon, Iwate coast, microsatellite DNA, genetic differentiation

Masu salmon, *Oncorhynchus masou*, is endemic to the Far East and commercially important in Russian, Japanese and Korean coasts surrounding the Sea of Japan and the Sea of Okhotsk (Chikuni, 1985; Kato, 1991). Although hatchery programs have been conducted in Japan, commercial catch of masu salmon has decreased over years (Miyakoshi, 2006). Use of a genetic approach would provide the important information for planning salmon conservation and resource management for sustainable use. However, genetic variation and differentiation among masu salmon populations so far demonstrated with genetic markers are still insufficient to estimate population structure and to address the ocean migration patterns, and the consequence of hatchery-wild interactions (Yu et al. 2010, 2012). In the present study, we conducted the population genetic study of Sanriku masu salmon to estimate the genetic diversity and population structure for sustainable masu salmon fishery in Iwate Prefecture.

About 500 fish of 11 collections from six rivers and five coastal areas in Iwate (Fig. 1). Additional 300 fish from three rivers in Hokkaido and one each of Miyagi (the Kitakami River mouth) and Toyama (the Sea of Japan coast) rivers served as the reference collections (Fig. 1). Population genetic analysis including the neighbor-joining population cluster analysis and pairwise population F_{ST} estimation was performed with 15 polymorphic microsatellite DNA markers developed using next-generation sequencing (NGS) (Tsukagoshi et al. 2015).

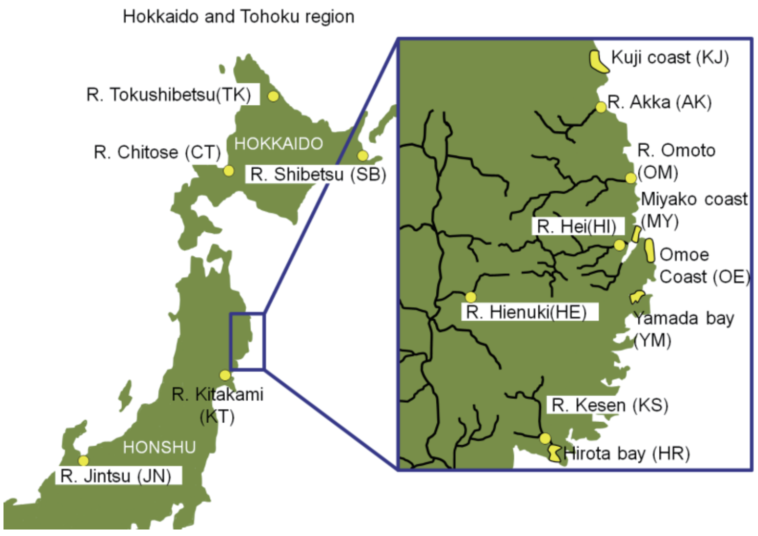

Figure 1. Masu salmon sampling sites in northern Japan

The population cluster analysis suggested the genetic differentiated of Sanriku masu salmon from those of Hokkaido and Toyama, the Sea of Japan coast (Fig. 2). In addition, the genetic differentiation between the river samples was apparent in Hokkaido and the Sanriku region, although such spatial or geographical differentiation was not clear between the river and coastal samples and with the coastal samples in the Sanriku region (Fig. 2). Pairwise population F_{ST} estimates favored distinct genetic differentiation between the river samples in each region, but no such differentiation between the river and coastal samples and within the coastal samples in the Sanriku region (data not shown).

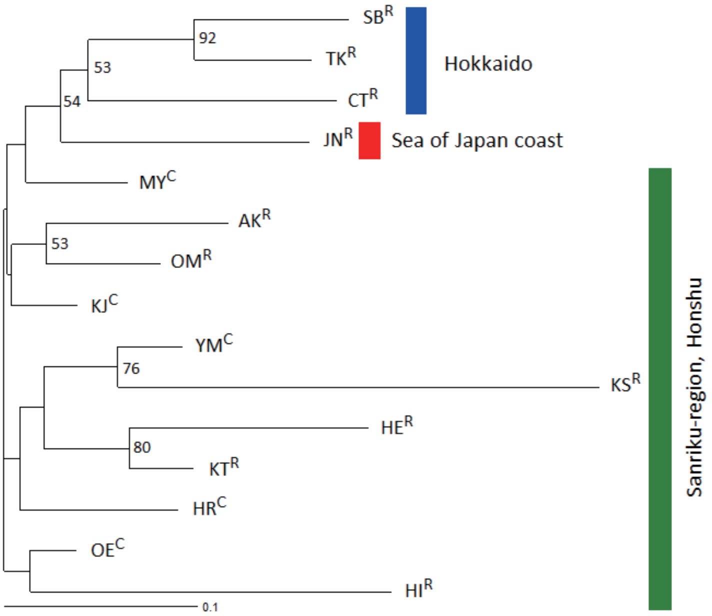

Figure 2. Neighbor-joining population tree of masu salmon analyzed. Collection codes are the same as those shown in Fig. 1. C and R superscripts indicate coastal and river collections, respectively.

The observed lack of the differentiation within the coastal samples implies a random distribution or homogenous migration of masu salmon along the Sanriku coast. Also, no differentiation between the river and coastal samples suggest that masu populations examined herein are reproduced in the Sanriku-region, and that they contribute as the region’s fisheries resources, although hatchery operations have been minimal so far for Sanriku masu salmon.

Even though the present study is rather preliminary in nature, the obtained findings suggest that the hatchery program for masu salmon should be conducted carefully taking into consideration of genetic differentiation among rivers and regions in Sanriku.

This work was supported partly by the MEXT Revitalization Project for the Creation of Fisheries Research and Education Center in Sanriku.

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Next-generation sequencing (NGS)-based development of polymorphic microsatellite DNA markers of pink salmon in the Sanriku-region, Japan, for their genetic characterization

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Keywords: pink salmon, microsatellite DNA, genetic differentiation, even and odd year fish

Pink salmon, *Oncorhynchus gorbuscha,* are the most abundant, having widest natural distribution range, among Pacific salmon species (Heard 1991). They virtually have high commercial value around the North Pacific. However, the genetic characteristics of this species mostly remain to be elucidated with competent molecular genetic markers for their effective resource management and sustainable use. Here, we isolated and characterized polymorphic microsatellite DNA markers with tri- or tetra- nucleotide repeat motif for pink salmon, using next-generation sequencing (NGS). Also, we estimated the genetic diversity and population structure of pink salmon in theSanriku region, Pacific coast of northern Honshu, Japan, using those isolated loci, to preliminarily elucidate the genetic features of this species at the southernmost edge of their natural distribution range (Heard 1991).

About 200 even- and odd-year pink salmon were collected from four coastal sites (set net catch) and one river in the Sanriku region, and 139 homing fish from three Hokkaido rivers served as the reference collections (Fig. 1). Novel polymorphic microsatellite (ms) DNA loci were isolated using NGS approach. In brief, NGS was performed with a Miseq machine with 251 bp paired-end reads from an Illumina paired-end shotgun library. Collection of tri- and tetra-nucleotide microsatellite repeat from NGS data (Table 1) was achieved using MSATCOMMANDER (Faircloth 2008), and 54 primer pairs were designed with Primer3 (Rozen and Skaletsky 2000) for testing stable amplification and polymorphisms of

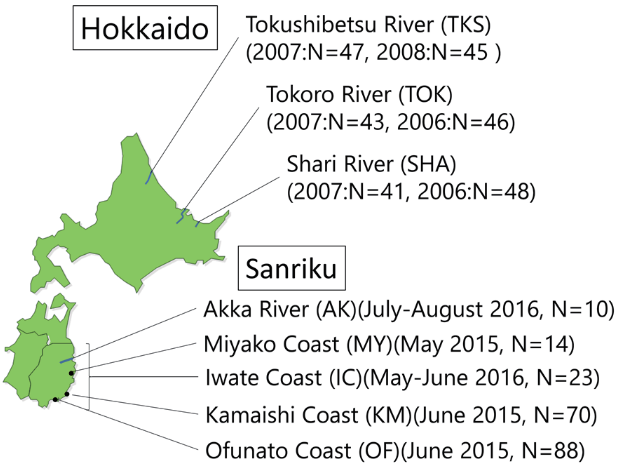

Figure 1. Pink salmon sampling sites in the Sanriku-region and Hokkaido.

Table 1. Summary of NGS results in pink salmon, using Miseq machine with 251 bp paired-end reads.

Category	Numbers
Total number of Bases (Mbp)	10,986.5
Total number of reads	44,474,828
Mean length of all reads (bp)	247.03
Total number of Bases of contig after assembly (Mbp)	789.3
Total number of contig after assembly	1,277,501
Mean lengh of contig after assembly (bp)	617
Total number of tri-nucleotide repeats (≧ten repeats per primer)	1843
Total number of tetra-nucleotide repeats (≧ten repeats per primer)	1175

msDNA loci. Thus, a total of 13 highly polymorphic msDNA loci were isolated with the present NGS approach.

Population genetic analysis such as genetic diversity estimation (calculation of observed and expected heterozygosities and allelic richness), principal component analysis, and pairwise population F_{ST} estimation was performed with 15 microsatellite DNA markers including eight of the above 13 novel and

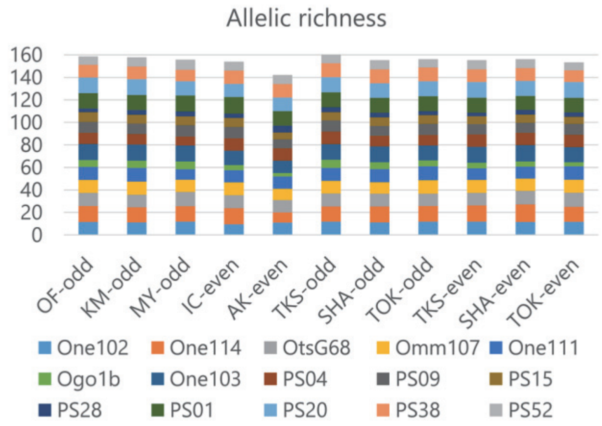

Figure 2. Component of allelic richness of 15 msDNA loci in 11 pink collections

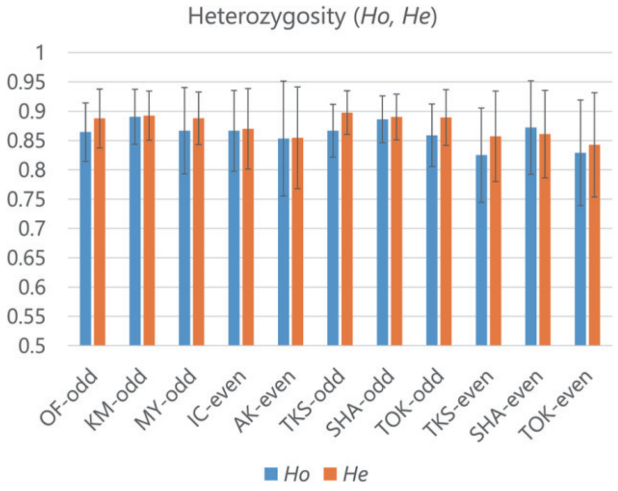

Figure 3. Mean of the observed (*Ho*) and expected heterozygosities (*He*) in 11 pink collections

seven previously reported microsatellite loci (Olsen et al. 1998, 2001; Rexroad et al. 2001; Williamson et al. 2002). The observed allelic richness (Fig. 2) and heterozygosities (Fig. 3) in Sanriku pink salmon were comparable to the values observed in fish from Hokkaido. Principal component analysis showed genetic differentiation between even- and odd-year samples in both Sanriku and Hokkaido pink salmon (Fig. 4). However, pairwise F_{ST} estimates (Table 2) and principal component analysis of Sanriku and Hokkaido pink salmon inferred no significant genetic differentiation between them.

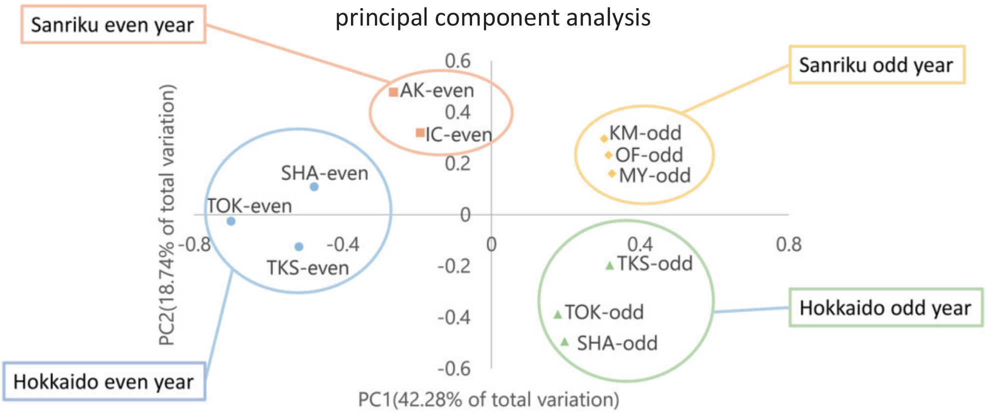

Figure 4. Principal component analysis showing the genetic relationship of 11 pink collections

Table 2. Pairwise population F_{ST} estimates for 11 pink salmon collections

	OF-odd	KM-odd	MY-odd	IC-even	AK-even	TKS-odd	SHA-odd	TOK-odd	TKS-even	SHA-even	TOK-even
OF-odd	0.000										
KM-odd	0.000	0.000									
MY-odd	0.001	0.001	0.000								
IC-even	0.014	0.012	0.016	0.000							
AK-even	0.025	0.024	0.023	0.011	0.000						
TKS-odd	0.008	0.007	0.011	0.023	0.034	0.000					
SHA-odd	0.017	0.013	0.021	0.026	0.043	0.007	0.000				
TOK-odd	0.012	0.010	0.014	0.022	0.036	0.004	0.001	0.000			
TKS-even	0.027	0.027	0.030	0.014	0.025	0.028	0.023	0.018	0.000		
SHA-even	0.025	0.025	0.026	0.010	0.022	0.024	0.030	0.026	0.007	0.000	
TOK-even	0.037	0.037	0.039	0.019	0.026	0.040	0.035	0.031	0.003	0.008	0.000

▨ $p<0.05$, significant after Bonferroni correction

The present finding suggested a high gene flow between Sanriku and Hokkaido pink salmon populations. Otherwise, the Sanriku pinks are mostly from non-spawning populations of northern origin simply migrating along the northeastern coast of Honshu, as pink salmon spawning has rarely been reported in the Sanriku region to-date.

This work was supported partly by the MEXT Revitalization Project for the Creation of Fisheries Research and Education Center in Sanriku.

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Diversity of the intestinal microflora in chum salmon (*Oncorhynchus keta*)

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Keywords: salmon fry, lactic acid bacteria, rearing condition, health monitoring

Introduction

Chum salmon (*Oncorhynchus keta*) is one of the most significant fishery products in Sanriku, northern Japan. More than four hundred million fry are released from hatcheries every year to maintain and increase chum salmon resources in Iwate Prefecture, Sanriku, Japan. Released fry grow in the Sea of Okhotsk and the Bering Sea for 3- 5 years and return to their home stream to bear offspring. However, the homing rates have steadily decreased over the last 15 years. Furthermore, almost all hatcheries were destroyed by tsunami after the Great East Japan Earthquake on March 11, 2011. Therefore, our aim is the recovery and reconstruction of the salmon fishing industry in Sanriku. To achieve this improvement in the protocols for rearing "healthy" salmon fry is necessary. However, the health status indicator is still undeveloped. Recent studies suggest that intestinal bacteria play a fundamental role in the health of various fish (Ringo and Gatesoupe 1988; Balcázar et al. 2009; Kanther et al. 2011; Cruz et al. 2012; Semova et al. 2012). In the following investigations, we compare the species composition of intestinal bacteria between "healthy" and "unhealthy" fry using molecular fingerprinting methods and sequence analysis.

The intestinal microflora of chum salmon fry in the Sanriku coast

Chum salmon fry were collected from fixed sampling points in the Yamada Bay and Kamaishi Bay of Iwate Prefecture in May 2012 and May and June, 2013. Total nucleic acid was obtained from intestine tissue specimen extracted from salmon fry. To analyze the phylogenetic diversity of intestinal bacteria, the nucleotide sequence of the partial segment of amplified 16S rRNA gene, was obtained using next-generation sequencing. Our results indicated that lactic acid bacteria related to the genus *Leuconostoc* were detected as the dominant species in the intestine of salmon fry from both bays. The results of phylogenetic classification suggest that the predominant species was closely related with *Leuconostoc inhae* (Kim et al. 2003), which was isolated from the Korean fermented food, Kimchi. The ratio of the predominant species to total bacterial population was analyzed by rea-ltime polymerase chain reaction methods using predominant species-specific primers and the universal primers. Larger salmon fry had more lactic acid bacteria. The data suggest that healthy salmon fry from the two bay areas have more lactic acid bacteria affiliated with the genus *Leuconostoc*. The microstructure analysis of otoliths suggested that larger fry (i.e., “healthy”) fry grow for more than one month in the bay prior to migration to the northern sea. The predominant species might contribute to health maintenance via the regulation of metabolic and- /or immune activities.

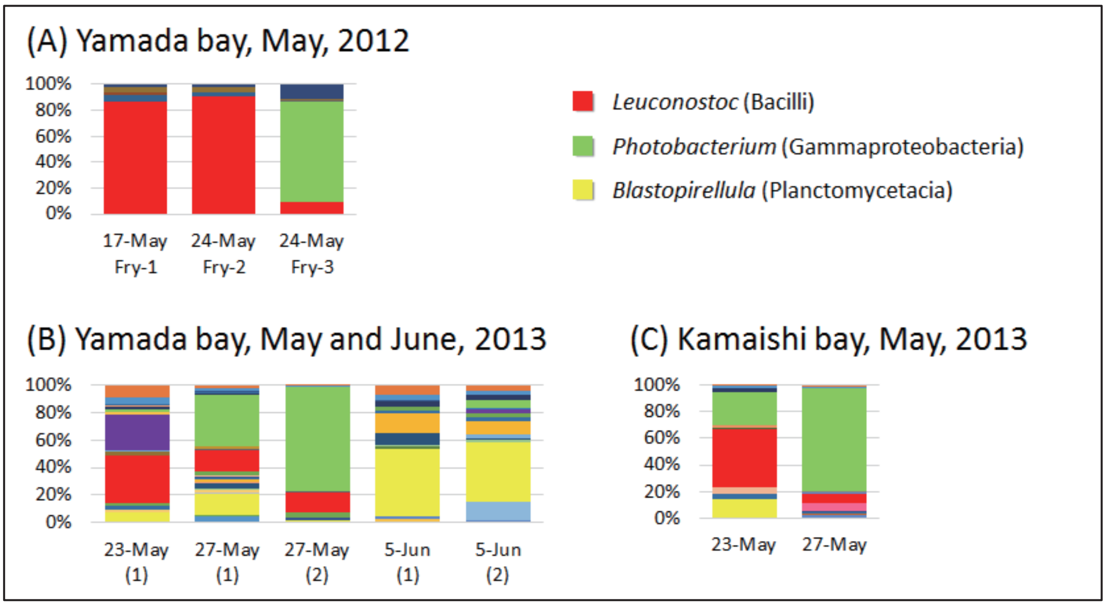


Figure 1. Intestinal microflora of chum salmon fry in the Yamada Bay and Kamaishi Bay analyzed by 16S amplicon sequencing

The intestinal bacteria of chum salmon fry under various rearing conditions

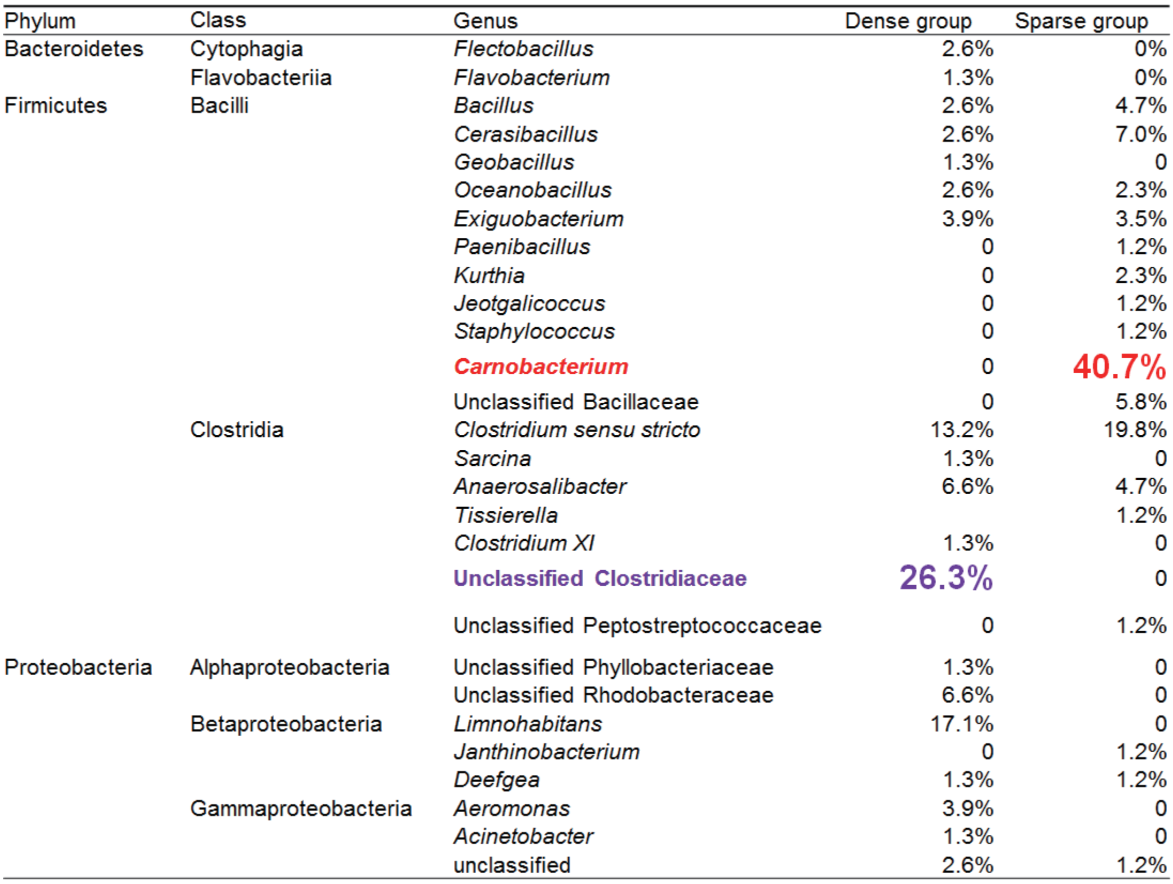
In general, salmon fry were raised from fertilized egg to 1.3 g in weight in a hatchery in Iwate Prefecture. Rearing conditions could have affected the health status of the fry after release. However, Wong et al. (2013) reported that variations in rearing conditions result in only minor changes in the intestinal species composition. They used the adult fish for the experiments. In our study, younger fry were reared in various conditions and used for analyzing the species composition of intestinal bacteria.

Sparse vs. Dense

Salmon fry (average body weight, 0.5 g) were reared for 4 weeks under sparse (10 kg/m^3) or dense (40 kg/m^3) conditions. Freshwater (8°C) was used for rearing. Water was supplied at the rate of twice the volume of a tank per hour. Commercial extruded crumble-pellet diet was fed, and the feeding rate was 3% of total fish body weight. Dissolved oxygen ranged 2- 8 mg/L in the dense group, and 8- 10 mg/L in the sparse group. Body size was significantly smaller in the dense group compared with that in the sparse group.

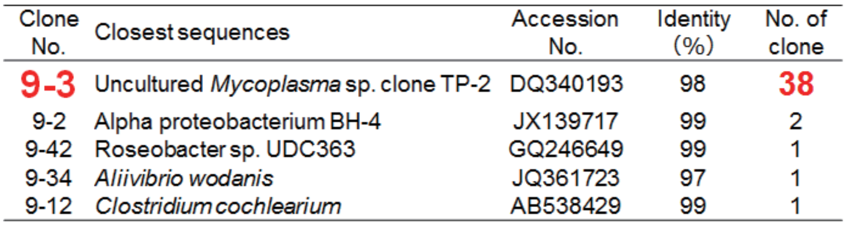
The intestinal bacteria of each group were analyzed using 16S rRNA gene clone library analysis, as shown in Table 1. Lactic acid bacteria affiliated with the genus *Carnobacterium* were the dominant species in the sparse group, whereas, some anaerobic bacteria were frequently detected in the dense group.

Table 1. Species composition of the intestinal bacteria of chum salmon fry reared in sparse and dense conditions



Phylum	Class	Genus	Dense group	Sparse group
Bacteroidetes	Cytophagia	*Flectobacillus*	2.6%	0%
	Flavobacteriia	*Flavobacterium*	1.3%	0%
Firmicutes	Bacilli	*Bacillus*	2.6%	4.7%
		Cerasibacillus	2.6%	7.0%
		Geobacillus	1.3%	0
		Oceanobacillus	2.6%	2.3%
		Exiguobacterium	3.9%	3.5%
		Paenibacillus	0	1.2%
		Kurthia	0	2.3%
		Jeotgalicoccus	0	1.2%
		Staphylococcus	0	1.2%
		Carnobacterium	0	**40.7%**
		Unclassified Bacillaceae	0	5.8%
	Clostridia	*Clostridium sensu stricto*	13.2%	19.8%
		Sarcina	1.3%	0
		Anaerosalibacter	6.6%	4.7%
		Tissierella		1.2%
		Clostridium XI	1.3%	0
		Unclassified Clostridiaceae	**26.3%**	0
		Unclassified Peptostreptococcaceae	0	1.2%
Proteobacteria	Alphaproteobacteria	Unclassified Phyllobacteriaceae	1.3%	0
		Unclassified Rhodobacteraceae	6.6%	0
	Betaproteobacteria	*Limnohabitans*	17.1%	0
		Janthinobacterium	0	1.2%
		Deefgea	1.3%	1.2%
	Gammaproteobacteria	*Aeromonas*	3.9%	0
		Acinetobacter	1.3%	0
		unclassified	2.6%	1.2%

Table 2. Species composition of the intestinal bacteria of chum salmon fry reared in high-temperature conditions



Clone No.	Closest sequences	Accession No.	Identity (%)	No. of clone
9-3	Uncultured *Mycoplasma* sp. clone TP-2	DQ340193	98	**38**
9-2	Alpha proteobacterium BH-4	JX139717	99	2
9-42	Roseobacter sp. UDC363	GQ246649	99	1
9-34	*Aliivibrio wodanis*	JQ361723	97	1
9-12	*Clostridium cochlearium*	AB538429	99	1

Low temperature vs. High temperature

Salmon fry were reared for 19 days under low (8°C) or high (15°C) temperatures of seawater. A total of 50 fry were reared in each group. Water was supplied at the rate of twice the volume of a tank per hour. Commercial extruded crumble-pellet diet was fed, and the feeding rate was 3% of total fish body weight. One fifth of the high-temperature group fry died in the latter half of the experiment. The intestinal bacteria of the surviving fry were analyzed using 16S rRNA gene clone library analysis, as shown in Table 2. The dominant clone (number. 9-3) was affiliated with genus *Mycoplasma* (Fig. 2).

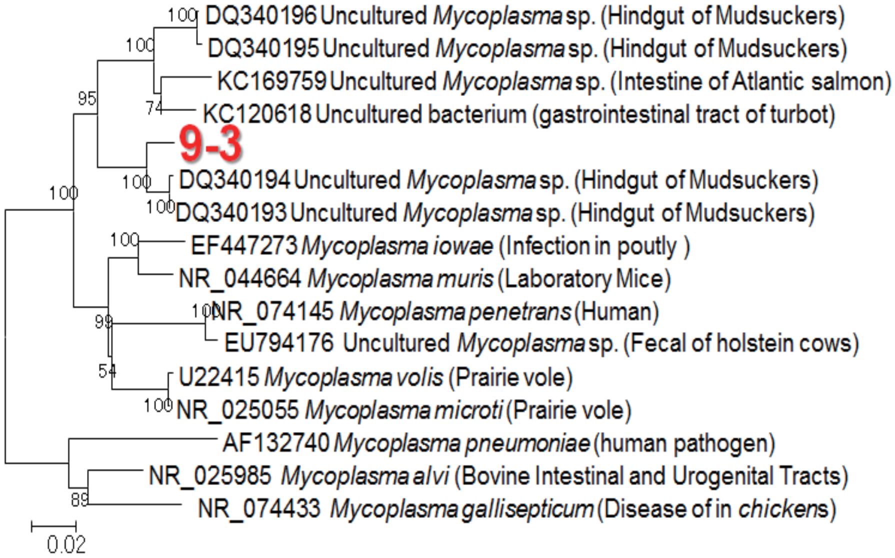


Figure 2. Phylogenetic relationship between 9-3 and *Mycoplasma* spp. based on 16S rRNA sequencing

Holben et al. (2002) found novel *Mycoplasma* phylotype in the gastrointestinal tract of Norwegian and Scotish salmon using 16S rRNA gene clone analysis. Interestingly, they found that the novel *Mycoplasma* phylotype comprised approximately 96% of total microbes in the distal intestine of Scotish wild salmon. They also analyzed the residual short-chain fatty acids in the gastrointestinal tract and speculated lactic acid production by *Mycoplasma* in the gastrointestinal tract of salmon. Recent molecular-based analysis of intestinal microflora revealed the universal distribution and dominance of *Mycoplasma* ribotypes in the fish (Bano et al. 2007). From the available evidences, *Mycoplasma* found in chum salmon fry might play some beneficial roles.

Conclusions

This study was the first to analyze the intestinal microflora of chum salmon fry of the Sanriku region using molecular biology techniques. Lactic acid bacteria affiliated with the genus *Leuconostoc* were detected as the dominant species in chum salmon fry collected from the Sanriku coast. Larger fry had more lactic acid bacteria. When chum salmon fry were reared under sparse or dense conditions, lactic acid bacteria affiliated with the genus *Carnobacterium* were the dominant species in the sparse group. In contrast, some anaerobic bacteria were frequently detected in the dense group. When chum salmon fry were reared under low (8°C) or high (15°C) temperatures, *Mycoplasma* bacteria were frequently detected in the high-temperature group. We discovered significant inter-subject variability and differences between intestinal species composition. The characterization of this immensely diverse group of flora is the first step in elucidating its role in the health of salmon fry.

Acknowledgments

We would like to thank Mr. Y. Shimizu of Iwate Fisheries Technology Center for his support with fry sampling in the bay areas and the analysis of otolith microstructure. We are grateful to Katagishi Hatchery in Kamaishi, Iwate, Japan, for supplying chum salmon fry for rearing experiments. We are also grateful to Mr. S. Akera for his technical support in rearing fry. This work was supported by the MEXT Revitalization Project for the Creation of Fisheries Research and Education Center in Sanriku.

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Changes of insulin-like growth factor mRNA levels of chum salmon fry

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Keywords: salmon fry, GH/IGF-I, isada krill extracts, growth stimulation

Chum salmon (*Oncorhynchus keta*) is one of the most important fishery products in Tohoku area, Japan. Salmon fry are reared in freshwater (FW), mimicking conditions of a hatchery enhancement program. In Iwate Prefecture, over 400 million salmon fry are released from a hatchery every year, but the homing rate has been lower than 1% in recent years. This may be due to high mortality and predation on salmon fry staying inside the bay after being released from the hatchery. The growth hormone (GH) and insulin-like growth factor (IGF-I) axis plays an essential role in the regulation of somatic growth and seawater (SW) adaptation in salmon (Moriyama et al. 2000). Our previous study showed different response of GH and IGF-I mRNA expressions to ambient salinities between salmon fry retained in FW and in those transferred to SW (Iwata et al. 2012). Based on results of the study, the rising activity of the GH/IGF-I axis seems to promote the hypoosmoregulatory ability first, and then the axis achieves the body growth. To enhance the homing rate of salmon, the objective of this study was therefore to examine growth and physiological variables associated with seawater adaptability and somatic growth, monitoring IGF-I mRNA expression.

The role of IGF-I after transfer from FW to SW

By about 10 days after transfer from FW to SW, hepatic IGF-I mRNA expression in salmon fry was lower than that of fish kept in FW, whereas by about 30 days following transfer to SW, hepatic IGF-I mRNA expression increased relative to FW fish (Iwata et al. 2012). In gills, however, IGF-I mRNA expression of fish transferred from FW to SW became higher than that of FW fish as early as 14 days following transfer. These results suggest that the development of the osmoregulatory system is prioritized in early growth soon after entry into the seawater.

The growth-promoting effect of isada krill on chum salmon fry

To enhance the homing rate of chum salmon, it is important to stimulate somatic growth as well as SW adaptability during the early stage of fish. Isada krill (*Euphausia pacifica*) is important component as prey organisms including salmon (Tojo et al. 2008), and krill has functional substances, such as long-chain polyunsaturated fatty acids, EPA and DHA (Yamada et al. 2011). To stimulate somatic growth of salmon fry, we investigated the growth-promoting effect of isada extract to salmon fry. Feeding of HCl/acetone and/or alkaline extracts of isada krill in a dry pellets resulted in stimulation of somatic growth of salmon fry, activating IGF-I mRNA expression in the liver. This result suggests that growth stimulating factor maybe exist isada krill.

Acknowledgments
This research was supported by the MEXT Revitalization Project for the Creation of Fisheries Research and Education Center in Sanriku and by AFFRC, Japan.

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Proteomic response of chum salmons to thermal acclimation

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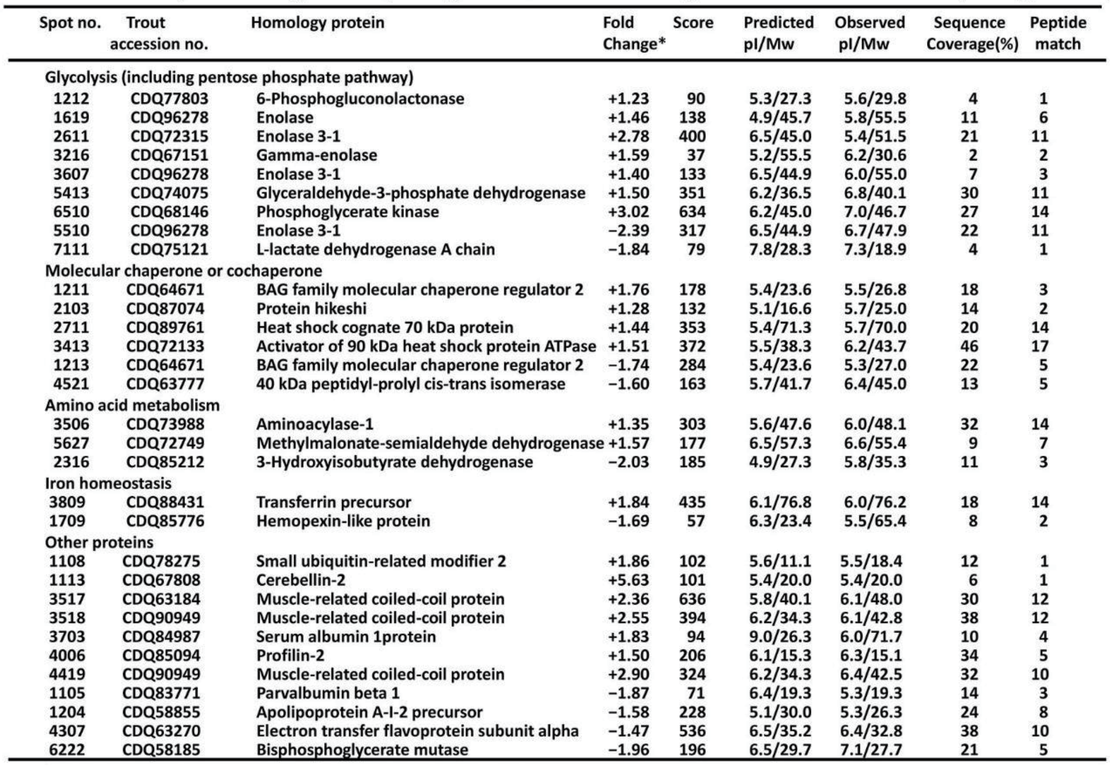
Keywords: salmon fry, temperature acclimation, glycolysis proteins, ATP production

Chum salmon (*Oncorhynchus keta*) is a major fishery resource in the Sanriku-region. The number of salmon returning to Sanriku-rivers is subjected to considerable annual variation. Whereas the exact reason for such variation mostly remains unknown, possible causal factors that include rising sea temperature associated with climate change and retention of coastal warm water mass are thought to be one of. To conserve stable chum salmon stocks in the Sanriku-region, production of salmon with thermal tolerance will be helpful. In ectothermic fish, there is a hypothesis that the upper thermal tolerance was attributed to mismatch between capacity of oxygen supply and oxygen demand with increment in temperature, i.e., the concept of OCLTT (Farrell, 2009; Pörtner, 2010). However, the molecular mechanism of thermal tolerance is still unclear, and no information for thermal acclimation of chum salmon is available so far.

Here, we investigated changes in sarcoplasmic protein abundance in response to temperature acclimation (10^{o}C and 18^{o}C). In two-dimensional gel electrophoresis from soluble fraction of muscle protein, 644 protein spots were observed, and 31 of these were differentially abundance between two

Table1. Protein spots with significantly changed in abundance among acclimated chum salmon. (*t*-test, $p < 0.05$)



Spot no.	Trout accession no.	Homology protein	Fold Change*	Score	Predicted pI/Mw	Observed pI/Mw	Sequence Coverage(%)	Peptide match
Glycolysis (including pentose phosphate pathway)								
1212	CDQ77803	6-Phosphogluconolactonase	+1.23	90	5.3/27.3	5.6/29.8	4	1
1619	CDQ96278	Enolase	+1.46	138	4.9/45.7	5.8/55.5	11	6
2611	CDQ72315	Enolase 3-1	+2.78	400	6.5/45.0	5.4/51.5	21	11
3216	CDQ67151	Gamma-enolase	+1.59	37	5.2/55.5	6.2/30.6	2	2
3607	CDQ96278	Enolase 3-1	+1.40	133	6.5/44.9	6.0/55.0	7	3
5413	CDQ74075	Glyceraldehyde-3-phosphate dehydrogenase	+1.50	351	6.2/36.5	6.8/40.1	30	11
6510	CDQ68146	Phosphoglycerate kinase	+3.02	634	6.2/45.0	7.0/46.7	27	14
5510	CDQ96278	Enolase 3-1	−2.39	317	6.5/44.9	6.7/47.9	22	11
7111	CDQ75121	L-lactate dehydrogenase A chain	−1.84	79	7.8/28.3	7.3/18.9	4	1
Molecular chaperone or cochaperone								
1211	CDQ64671	BAG family molecular chaperone regulator 2	+1.76	178	5.4/23.6	5.5/26.8	18	3
2103	CDQ87074	Protein hikeshi	+1.28	132	5.1/16.6	5.7/25.0	14	2
2711	CDQ89761	Heat shock cognate 70 kDa protein	+1.44	353	5.4/71.3	5.7/70.0	20	14
3413	CDQ72133	Activator of 90 kDa heat shock protein ATPase	+1.51	372	5.5/38.3	6.2/43.7	46	17
1213	CDQ64671	BAG family molecular chaperone regulator 2	−1.74	284	5.4/23.6	5.3/27.0	22	5
4521	CDQ63777	40 kDa peptidyl-prolyl cis-trans isomerase	−1.60	163	5.7/41.7	6.4/45.0	13	5
Amino acid metabolism								
3506	CDQ73988	Aminoacylase-1	+1.35	303	5.6/47.6	6.0/48.1	32	14
5627	CDQ72749	Methylmalonate-semialdehyde dehydrogenase	+1.57	177	6.5/57.3	6.6/55.4	9	7
2316	CDQ85212	3-Hydroxyisobutyrate dehydrogenase	−2.03	185	4.9/27.3	5.8/35.3	11	3
Iron homeostasis								
3809	CDQ88431	Transferrin precursor	+1.84	435	6.1/76.8	6.0/76.2	18	14
1709	CDQ85776	Hemopexin-like protein	−1.69	57	6.3/23.4	5.5/65.4	8	2
Other proteins								
1108	CDQ78275	Small ubiquitin-related modifier 2	+1.86	102	5.6/11.1	5.5/18.4	12	1
1113	CDQ67808	Cerebellin-2	+5.63	101	5.4/20.0	5.4/20.0	6	1
3517	CDQ63184	Muscle-related coiled-coil protein	+2.36	636	5.8/40.1	6.1/48.0	30	12
3518	CDQ90949	Muscle-related coiled-coil protein	+2.55	394	6.2/34.3	6.1/42.8	38	12
3703	CDQ84987	Serum albumin 1protein	+1.83	94	9.0/26.3	6.0/71.7	10	4
4006	CDQ85094	Profilin-2	+1.50	206	6.1/15.3	6.3/15.1	34	5
4419	CDQ90949	Muscle-related coiled-coil protein	+2.90	324	6.2/34.3	6.4/42.5	32	10
1105	CDQ83771	Parvalbumin beta 1	−1.87	71	6.4/19.3	5.3/19.3	14	3
1204	CDQ58855	Apolipoprotein A-I-2 precursor	−1.58	228	5.1/30.0	5.3/26.3	24	8
4307	CDQ63270	Electron transfer flavoprotein subunit alpha	−1.47	536	6.5/35.2	6.4/32.8	38	10
6222	CDQ58185	Bisphosphoglycerate mutase	−1.96	196	6.5/29.7	7.1/27.7	21	5

* Change in abundance of spot volume in 18^{o}C-acclimated salmon compared to 10^{o}C-acclimated salmon .

acclimated groups (Table 1). Among these spots, 20 were involved in glycolysis, molecular chaperone, amino acid metabolism and iron homeostasis.

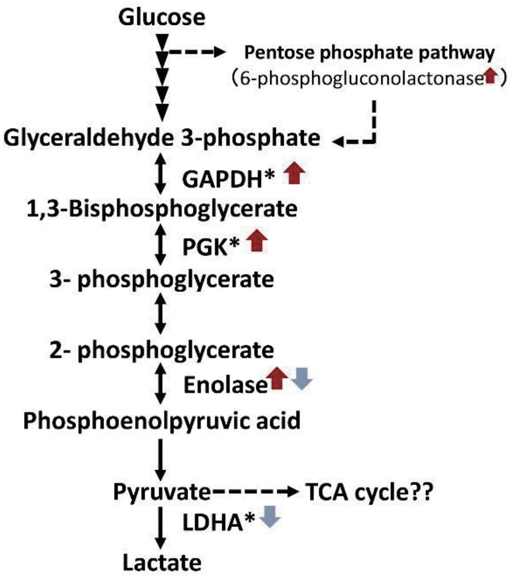


Figure 1. Schematic representation for glycolysis pathway. The colored allows indicated the change of protein expression pattern in 18ºC acclimated fish group compared to 10ºC acclimated group. *GADPH, Glyceraldehyde-3-phosphate dehydrogenase; PGK, phosphate glycerol kinase; LDHA, L-lactate dehydrogenase A chain.

In terms of glycolytic enzyme, phosphoglycerate kinase and glyceraldehyde-3-phosphate dehydrogenase abundance increased in 18ºC-acclimation group, but L-lactate dehydrogenase A chain abundance decreased (Fig. 1). These results suggested that thermal acclimated salmon had the high capacity of ATP production by glycolysis, which may enhance an anaerobic ATP generation due to inadequate oxygen supply caused by thermal acclimation.

This work was supported by the MEXT Revitalization Project for the Creation of Fisheries Research and Education Center in Sanriku.

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Homing chum salmon with unusually yellowed body caught in the Sanriku coast

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Keywords: homing salmon, unusual body color, internal discoloration, jaundice symptoms

A male chum salmon (*Oncorhynchus keta*) with yellowed body color differed from ordinary nupital coloration was caught by set net at Uge coast in the northern Iwate Prefecture in the mid-November, 2015 (Fig. 1). The yellow discoloration was observed in entire abdominal part of the fish from lower jaw to caudal fin, periorbital region and oral cavity (Fig. 2). According to Yagi fish market personnel, the number of such discolored salmon was about 10 out of 232,000 fish captured in fishing period from September to December, 2015. Although the incidence was extremely low, the discolored salmon mostly occurred from the mid-October to mid-November. Similarly yellowed male chum salmon were captured in the Miyako Bay of the central Iwate coast in November 2010 and October 2014.

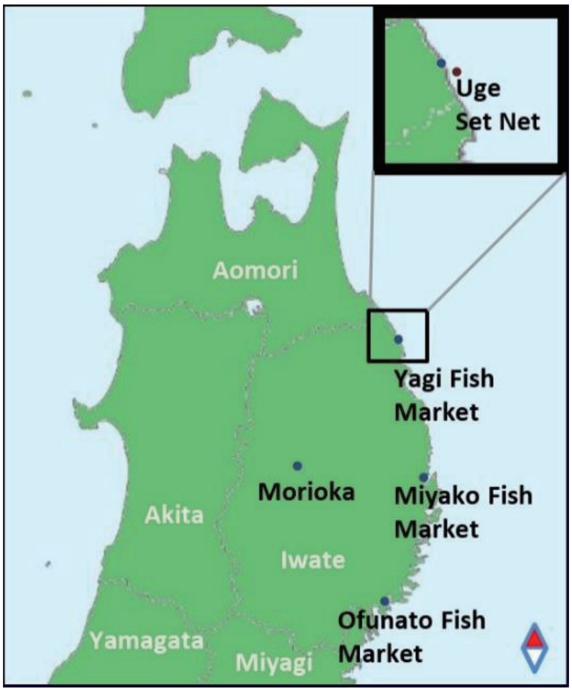

Figure 1. Map of the sampling site

Figure 2. Pictures of yellowed chum salmon landed at the Yagi Fish Market

External appearance and autopsy findings of salmon caught in 2014 included: (i) yellowed whole body with significantly discolored gelatinous periorbital region, (ii) discoloration of vertebrae, gill lamellae, scale, muscle, and liver in yellow, with hypertrophic spleen, (iii) pale gill color suggesting a decrease of red blood cells, and (iv) yellowish blood plasma and coelomic fluid (Fig. 3). These symptoms were similar to those of aquacultured yellowtail (*Seriola quinqueradiata*) with jaundice (Sorimachi et al., 1993), suggesting that the autopsied salmon also developed jaundice.

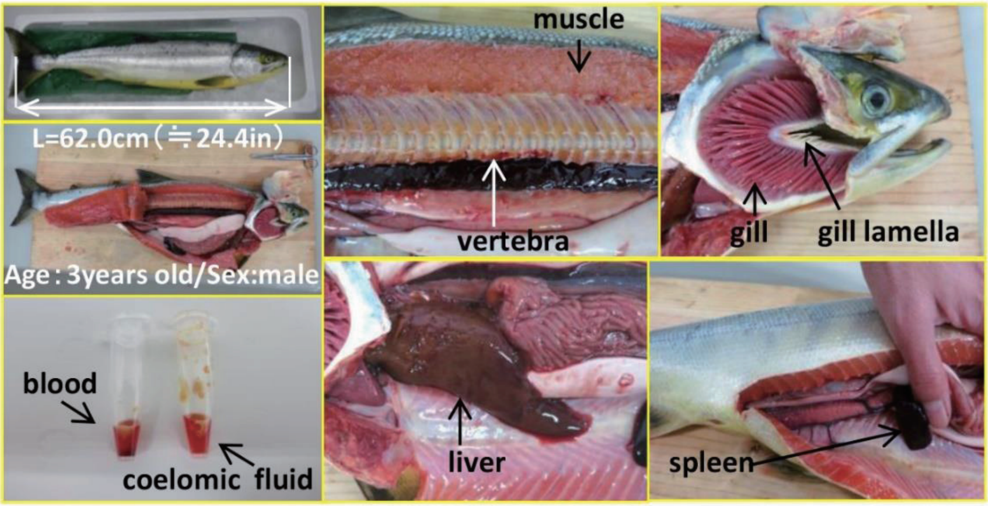

Figure 3. External appearance and autopsy findings of the chum salmon caught in 2014 (pictures by Fisheries Research Agency)

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Migration history of masu salmon *Oncorhynchus masou masou* in Miyako Bay, Iwate, Japan, as inferred from otolith microchemistry

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Keywords: masu salmon, migratory life cycle, otolith Sr:Ca ratio, ocean entry

Masu salmon (*Oncorhynchus masou masou*) is an anadromous fish from the Sanriku Coast, Iwate Prefecture (Kato 2002), with a high market value. Its high price reflects its good taste and the scarcity of the resource. It is caught only from spring to early summer, in contrast to chum salmon which is caught in autumn. Also, "Masu-no-sushi" is prized in Toyama Prefecture as a famous local delicacy. Thus, masu salmon has been an important and traditional fisheries resource over a long time (Mayama 1992). However, masu salmon landings in the Sea of Japan side have decreased significantly and the Ministry of the Environment has listed masu salmon as a near threatened species (Maehata and Goto 2015). Knowledge on the life history and migration is necessary to achieve sustainable use of natural resources and to promote conservation activities, but very little is known on masu salmon caught in Miyako Bay, Iwate Prefecture.

In order to clarify the life cycle of masu salmon, we studied its migratory cycle by means of otolith analysis. The otoliths of fishes are formed by continuous, layered deposition of minerals (mainly calcium carbonate) and the chemical composition of a given layer is thought to reflect the environmental conditions at the time of its deposition. As there is little re-absorption after initial deposition, studying the otolith is an effective way to trace the life history of fish (Gauldie et al. 1994; Arai and Tsukamoto 1998; Secor et al. 1998; Umino et al. 2001; Sasaki et al. 2006). Attempts to forecast migration using otolith Sr:Ca ratios have been reported for masu salmon in the Kaji River, Niigata Prefecture, but there are no reports for this or other fish species in the coastal area of Iwate Prefecture (Matsuzaki et al. 2014). We studied the migration life cycle of adult masu salmon caught from the waters of Miyako Bay by X-ray electron probe microanalysis of the elemental composition of the otoliths.

A total of 54 adult masu salmon were collected for this study in Miyako Bay during May 2013 and April and June 2014. The sagitta otoliths were collected, rinsed in anhydrous ethanol, air-dried, and stored in micro tubes until analysis. The left side otoliths of 2 randomly chosen individuals from each of the sampling years were embedded in epoxy resin and grinded to expose the nucleus. Once the nucleus has been exposed, cross sections were polished further with diamond paste (6 μm particle size) and colloidal silica suspension to a mirror-finish. Otolith specimens were then sputter-coated with Pt/Pd and analyzed under an Electron Probe Micro Analyzer (JEOL JX-8320 and JXA-8900). Sr and Ca measurements were carried out from the otolith nucleus to the edge along the longest axis of the otoliths using an acceleration voltage of 15 kV, sample current of 1.2×10^{-8} A, a beam diameter of 10 µm, and a spacing of 10µm. Furthermore, conversion from the X-ray intensity of Ca and Sr used $CaSiO_3$ and $SrTiO_3$ as standards and their concentrations were shown as Sr:Ca ratio.

Figure 1 shows the changes in Sr:Ca ratio in the otoliths of the 4 specimens analyzed in this study. All specimens showed increased Sr:Ca ratios near the otolith edge. In otoliths of adult salmon caught in 2013, increased Sr:Ca ratios were observed at 1050 µm and 1250 µm, with average Sr:Ca ratios of 1.59×10^{-3} and 0.74×10^{-3} from the otolith nucleus to the inflection point and average ratios of 3.52×10^{-3} and 3.52×10^{-3} from the inflection point to the otolith edge. In otoliths of adult salmon caught in 2014, increased Sr:Ca ratios were observed at 800 µm and 890 µm, with average Sr:Ca ratios of 1.58×10^{-3}, 1.31×10^{-3} and 3.18×10^{-3}, 4.08×10^{-3} respectively for the nucleus-inflection point and inflection point-edge areas.

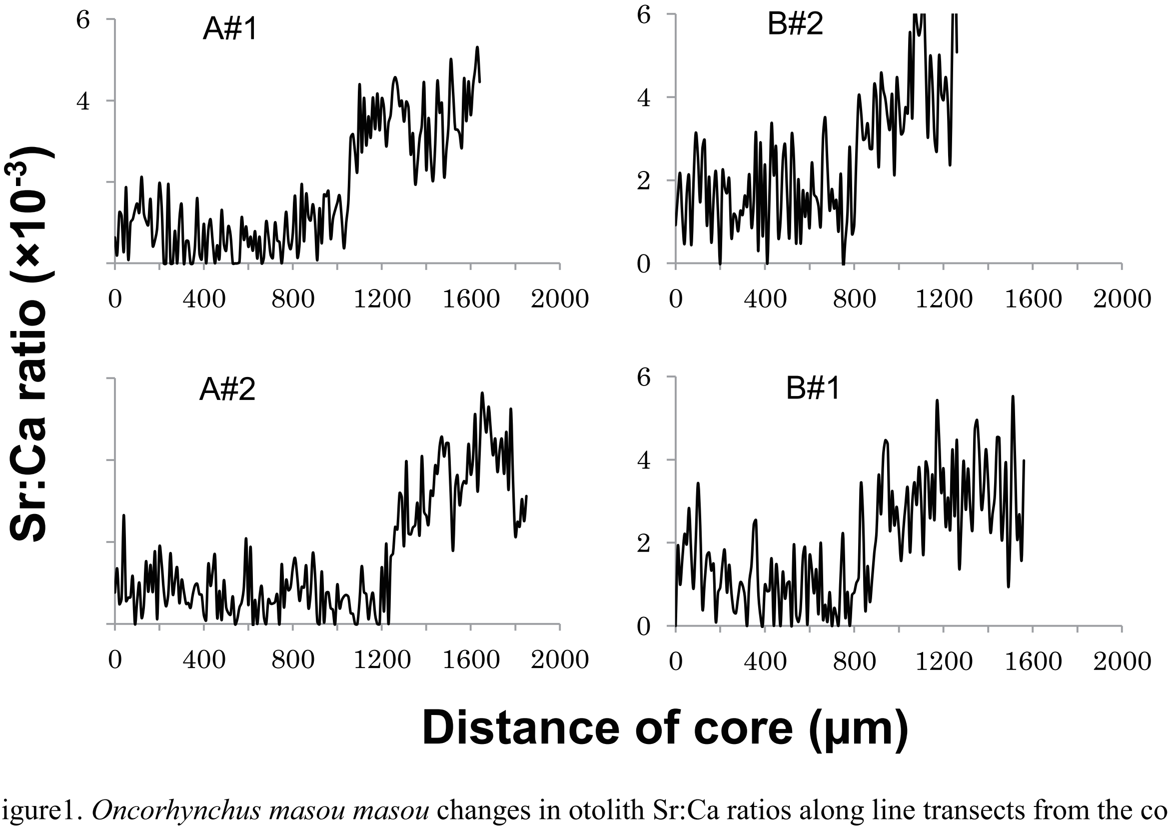

Figure1. *Oncorhynchus masou masou* changes in otolith Sr:Ca ratios along line transects from the core to the edge of the sagittal otolith samples from Miyako Bay. Individuals A#1 and A#2 were caught in 2013 while B#1 and B#2 were caught in 2014.

Since otoliths grow by accretion of concentric layers and since the otolith primordium is formed in early stages of development before entering the sea, the sudden change from low Sr:Ca ratios in the center of the otolith to the high Sr:Ca ratios near the otolith edge (c.a.700-1200 μm from the otolith nucleus) likely indicates when the animals entered the sea. This assumption is supported by the results of other studies. For example, Arai and Tsukamoto (1998) reported that young and adult masu salmon collected from Sanpoku coast off Murakami City, Niigata Prefecture, had increased Sr:Ca ratios near the edge of the otolith. Furthermore, they reported that the Sr:Ca ratio of the otoliths during freshwater- and sea-life averaged 1.35×10^{-3} and 3.46×10^{-3}, respectively, and that these ratios changed sharply at a distance of approximately 950 μm from the otolith nucleus. Our results indicate Sr:Ca ratios of less than 2×10^{-3} and more than 3×10^{-3} for freshwater and ocean life, respectively, for masu salmon from Miyako Bay. These results agree with those from Kasugai et al. (2014) for landlocked masu salmon collected in Lake Kussharo, Hokkaido Prefecture and the inflowing rivers and from Umino et al (2001) for *Oncorhynchus masou ishikawae* (a subspecies of masu salmon) collected in the Ohta River, Hiroshima Prefecture.

Future studies using this analysis will help to obtain detailed information on the duration of freshwater and marine life stages, the timing of the downstream and run-up, and the diversity of migratory patterns among masu salmon individuals, which is essential to promote the sustainable use of this species' natural resources.

Acknowledgments

Specimens used in this study were kindly provided by Mr. S. Horono, Mr. A. Kitamura, and Mr. S. Utsunomiya from the Hei River Fishery Cooperative and Mr. S. Yamauchi from the Miyako Seafood Commercial Cooperative. Mr. T. Yanagisawa (Trout Heart's Fishing Club) and Mr. Y. Miyazaki (Kanagawa Prefectural Museum of Natural History) provided invaluable advice and information. We are grateful also to all collaborators from Miyako City, Iwate Prefecture, and the Tokyo University of Marine Science and Technology, in particular to Mrs. M. Ohtsuki, for help with EPMA analysis.

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Ecosystem-based sustainability science of Pacific salmon and paradigm shift of fisheries education

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Keywords: salmon production, climate change, adaptive management, dietary education

Pacific salmon (*Oncorhynchus* spp.) play important roles not only for seafood resources of human, but also as ecosystem services in the Subarctic North Pacific ecosystems. Their production dynamics are influenced by natural factors (e.g. the long-term climate change) and human impacts (e.g. global warming effect, overfishing, and hatchery program). Marine-food should be reproducible resources for human. However, world fish catches have peaked since the 1990s despite increase in aquaculture production (Fig. 1), causing destruction of aquatic ecosystem, marine pollution, and threats to marine food security. In this century, marine ecosystem conservation and stable marine-food product are most important issues for human beings with increase in human population and impacts such as global warming.

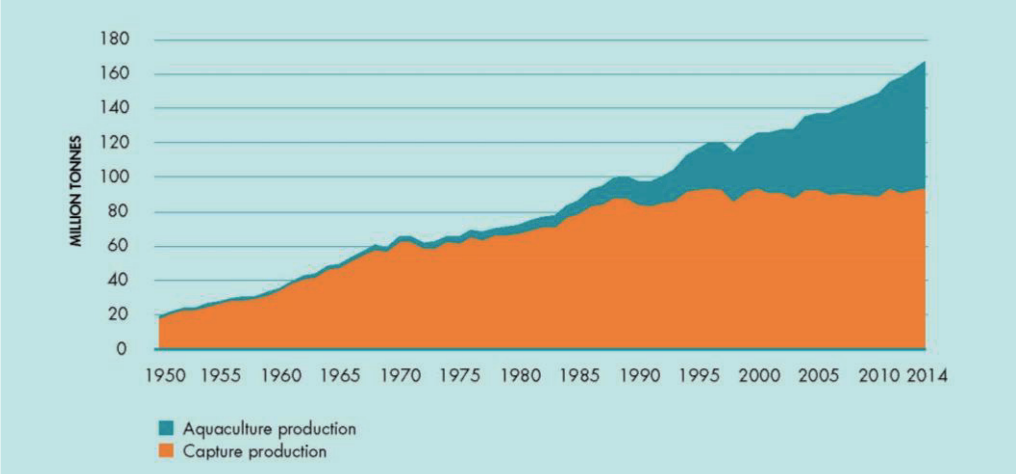

Figure 1. World capture fisheries and aquaculture production (FAO 2016)

I have researched on the ecology of Pacific salmon; i) life history, ii) trophic dynamics and feeding habitats (Fig. 2), iii) population dynamics including the population density-dependent effect, iv) relationship between long-term climate change and carrying capacity, v) biological interaction between wild and hatchery populations, and vi) influence on their transportation of the marine-derived nutrients to the land ecosystem, for the past decades. I presented my research outcome on biological interactions between Pacific salmon and aquatic- and land-ecosystems including 1) the long-term climate change and salmon production dynamics, 2) influence of the super tsunami and coastal environment (Oyashio and Tsugaru warm currents) on the Sanriku chum salmon populations (Fig. 3), 3) their feeding habit and trophic level in the ocean ecosystems, 4) influence of the global warming on salmon, and 5) ecological service of salmon for the land-ecosystem at this symposium.

- Life history → Evolution & Adaptability
  Kaeriyama 1989, Kaeriyama et al. 2013; Stearley and Smith 1993; Murata et al. 1996; Quinn 2005
- Feeding pattern → Species specificity & Plasticity
  - Nekton feeder → Sit-and-wait feeding pattern: Chinook, Steelhead
  - Zooplankton feeder → Forage feeding pattern: Chum, Pink
  - Alternative feeder → Using both feeding patterns as the situation demands: Sockeye, Coho

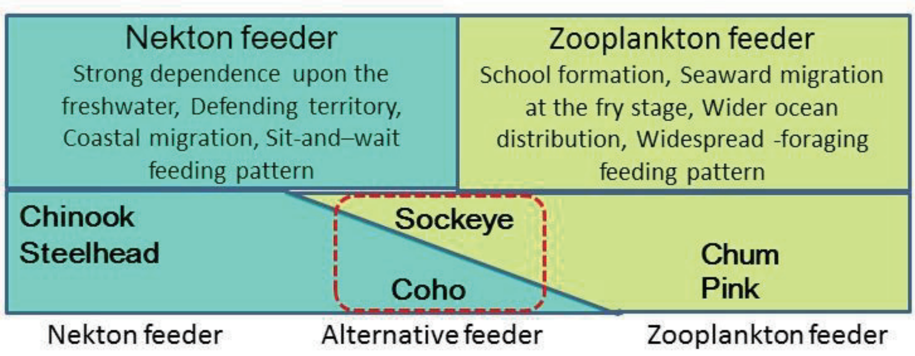

Figure 2. Feeding pattern of Pacific salmon (Qin & Kaeriyama, in press)

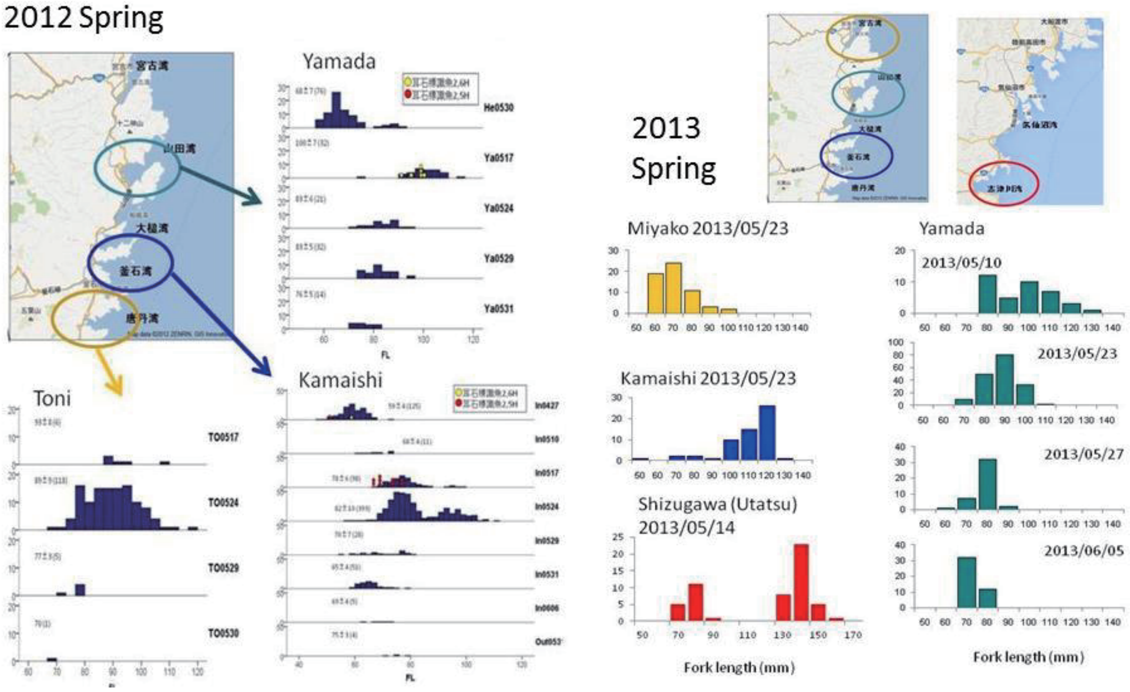

Figure 3. Body size of juvenile chum salmon at the offshore migration during spring of 2012 and 2013 in the Sanriku coast

Paradigm of the fishery science should be shifted from the technology of fish catching, which has introduced the “fishing down marine food webs”, overfishing, biological interaction between wild and hatchery-produced salmon, and aquatic-ecosystem crash, to the sustainability science of ecosystems and organisms in the ocean, in order to achieve the human well-been in the future generation. Educations on dietary and the understanding of symbiosis with the global ecosystem are also the most important issues. We should think about “*The Limits to Growth*” in the earth, and account for future limitations in ocean carrying capacity and for expected fluctuations in the carrying capacity in response to ecosystem changes. Therefore, the framework of ecosystem-based risk management including the adaptive management and the precautionary principle would be extremely important for the conservation of Pacific salmon (Fig. 4).

■ **Will we be able to use the ocean organisms as seafood in the future?**

➢ Carrying capacity in the marine ecosystem →吾唯足知 “More than enough is too much”

➢ Fisheries Industry : Economic efficiency→Ecosystem Approach

■ **What do we need for seafood security and marine ecosystem sustainability in present and future?**

➢ Education

- Paradigm shift from the traditional fisheries science to the new ecological fisheries science
- Dietary education 食育
  → e.g. “local production for local consumption” 地産地消

■ **How do we establish the sustainable management based on the ecosystem approach?**

➢ Adaptive management & Precautionary principle

1) Adaptive learning: Learning by doing, Responsibility of risk exposition

2) Feedback control: Monitorin and Evaluation according to the backcast

- Fisheries: Long-term climate change (e.g., Global warming, Regime shift), Carrying capacity
- Aquaculture: Food security, Conservation of marine ecosystem, Water pollution

Figure 4. Sustainability for Pacific salmon and ocean ecosystem conservation

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Interdisciplinary Learning in Fisheries and Aquaculture

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Keywords: sustainable fisheries, interdisciplinary education, authentic learning, quality human interaction

Introduction

It has been said, “Give a man a fish, and you feed him for a day. But teach a man to fish, and you feed him for life”. That is a nice quote, but the realities of fisheries are a lot more complex than that. Overfishing and unintended consequences on the ecosystem may change fishing habits; it may change who is given access to fisheries; or even if it is possible to still fish. Natural disasters are another example of such game changers. Because of these reasons it may be more correct to say that teaching a man to fish may feed him for a while. However, teach a man or a woman to learn, to question and to think - and they will find new solutions in times of changes or crisis. Such a man will not only feed himself, but nations, and generations to come. In other words, mastering the art of learning is vital because we at all times need to find sustainable solutions. If not, fisheries may decline or even vanish. This presentation addresses how we teach to learn about sustainability.

Sustainability

Sustainability has been defined as *"development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (*World Commission on Environment and Development 1987). Different scientific bodies of literature emphasizes different aspects of the sustainability concept.

Biologically, sustainable fisheries may refer to the maximum level of catch that would allow sustainable exploitation (MSY) (Gulland, 1983), or to biodiversity and the soundness of the ecosystem as a whole.

Economically, sustainability refers to the fisheries´ ability to be competitive as an industry. Maximum sustainable yield (MEY) is calculated based on optimising the difference between the cost of fishing and the income gained, and usually occurs at a lower fishing effort than the fishing effort occurring at MSY (Hersoug, 1996).

Socially, sustainability refers to fisheries´ role in coastal societies, offering livelihoods, food and jobs. The importance of addressing social concerns has been recognized as Maximum Social Yield (MsocY), and the associated reference point varies with the fishery situation (ibid).

Sustainability, then, should be understand at the intersection of these understandings, as illustrated in Fig. 1.

Figure 1. Sustainability (Adopted from Charles, 2001)

These dimensions are not always in harmony. One could argue that there is an ongoing “battle” between the different concerns. Different seafood nations find different ways of solving them. Nevertheless, understanding and achieving sustainability is a multidisciplinary and interdisciplinary effort.

An excellent illustration of that was the salmon crisis in Chile in 2010. The locations were very close, so when a virus disease started to spread, it was impossible to keep it away from the neighbor locations, and millions of fish had to be slaughtered. Companies went bankrupt and many people lost their jobs. The key lesson was to integrate ecological, biological knowledge with management regulations and laws.

Another example is from Norway. Salmon production is a growing industry in Norway. It counts for about a third of the total seafood production, but 70 % of the total value. In 2012, an analysis of the marine potential in Norway was carried out. It suggested that the value creation from aquaculture may be multiplied by five in 2050. However, the same analysis says that this growth is not without conditions. It highlighted the vital bottlenecks for further sustainable production, such as sea lice and diseases, escape and environmental impacts, area use and the need for other marine feed resources. These are challenges that require crossovers between different bodies of knowledge.

Marine education

The question is how the marine education systems respond to the sector´s need for interdisciplinary knowledge? Academic disciplines are constituted as discrete discourses. The effect of this is that we produce specialists within our own fields. It is nothing wrong with that. Certainly, we still need disciplinary experts. However, as sustainable seafood production is growing in complexity, we may benefit from also having interdisciplinary minds, whose specialty is to see how things relate. This could be expanded to transdisciplinary knowledge, where also the industry, management and stakeholders are a part of the process of generating new knowledge. Fig. 2 explains and illustrates the differences between different science conceptualizations.

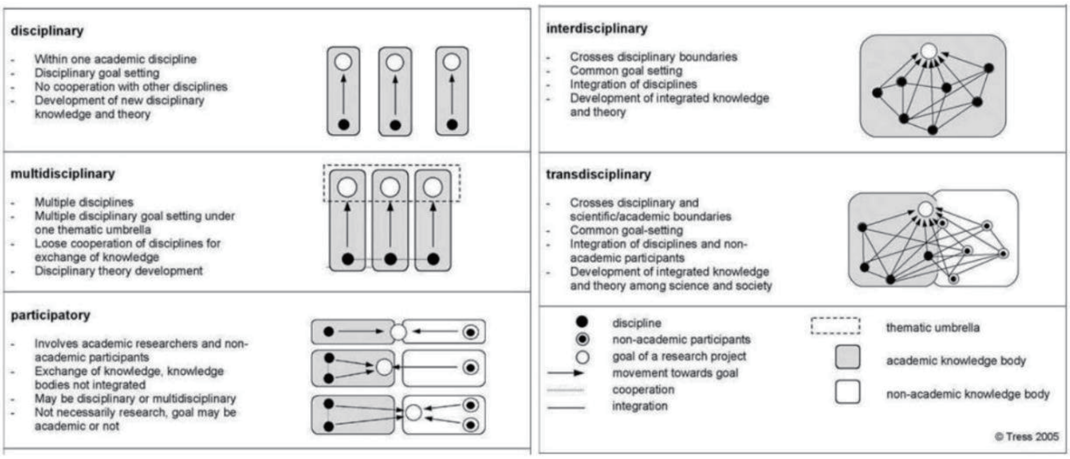

Figure 2. Science Conceptualizations (Tress, Tress and Fry, 2005)

Moving from disciplinary to interdisciplinary education programs is a challenge for the established academic system. The following principles may be applied in order to fulfill such an ambition.

1) Both industry and societal needs must be addressed, with a strong commitment to sustainable development.

In order to reach the potential of value creation in marine indsutries, it is necessary to have the right human capital, the resourceful and talented higher education graduates who can perform effectively in an interdisciplinary context and who have the necessary applied knowledge, skills and competences for the marine sector of the 21st Century. Thus, learning objectives of education programs should reach beyond covering industry needs.

2) Learning must be centred on active students who, through experience, transform information into knowledge that will be successfully transferred from educational settings to the real world.

“Learning methods that are embedded in authentic situations are not merely useful; they are essential” (Brown, Collins and Duguid, 1989). Authentic learning is a pedagogical approach that situates learning tasks in the context of real-world situations, and in doing so, provides opportunities for learning by allowing students to experience the same problem-solving challenges in the curriculum as they do in their daily endeavours (Herrington, Reeves and Oliver, 2013). This may be operationalized through internships, or simulations like role-playing activities (Oberle, 2004).

3) Educational method and content must be research-based and anchored in the principles of responsible research and innovation: public engagement in science, open access to research results and sound ethics.

Students should develop independent research skills in an active way. This means they must be provided with opportunities to put these skills into practice such that at the culmination of the program, students are able to undertake, with supervision, an autonomous piece of research work. A practical way of organizing this is that students are linked to relevant research environments at the faculty and work on contemporary research topics as part of their learning. In that way they will learn to apply knowledge and to create own discoveries, rather than simply learning about existing theories (Healy, 2005). This development must take into consideration the principles of Responsible Research and Innovation (Owen, Macnaghten and Stilgoe, 2012).

4) Students, teachers and administrators should form a community of quality teaching and learning practitioners.

Creating an optimal learning environment is essential for any university program. Nevertheless, a learning community does not just happen; it is created intentionally at every level of an organization. This means that education institutions must strive to develop among academic/teaching and administrative staff a culture of shared responsibility for students, courses, and program. Quality human interaction is crucial in this endeavor.

Concluding remarks

At the Norwegian College of Fishery Science, UiT the Arctic University of Norway, we are currently implementing a project with the ambition of moving our education programs in the direction of interdisciplinary and transdisciplinary learning. We will share our experiences through papers and presentations, and we are very much interested in discussing with other institutions. We are interested in experiences and lessons learned in increasing canditates´ abilities to foster a sustainable development of marine industries, especially in the broad sense of the term.

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Structuring research programs to address industry priorities and ensure technology transfer: the US Western Regional Aquaculture Center program model

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Keywords: regional funding program, end-user engagement, extension specialists, return on investment

Introduction

Research funding programs that have the goal of producing research that will impact commercial development face a number of challenges: first, in ensuring that the research undertaken is relevant to end-users; and second, in effectively transferring knowledge and technology from university and public agency research efforts to end-users. Below, the history of how research, education and outreach to end-users has historically been integrated in the USA is described, with emphasis on the critical role that well-trained and engaged "extension" specialists play. With that background, the challenge of structuring regional funding programs to enhance technology transfer is outlined. More specifically, the organizational structure of a regional aquaculture program will be described, with emphasis on the key roles of industry and extension specialists as research partners.

Integrating research, education and outreach in the USA: a historical perspective

Up until the mid 1880s, higher education in the US was reserved for the wealthy, at universities such as Harvard and Yale. During that time, there was a growing recognition of the need to develop opportunities for ordinary citizens to pursue a tertiary education that an agricultural and rapidly industrializing society required. The US Congress addressed this need through the passing of the Morrill Act of 1862 (and later, the Morrill Act of 1890). The 1862 Act is often referred to as the Land Grant Act, since Congress donated: "Public Lands to the several States and Territories which may Provide Colleges for the Benefit of Agriculture and the Mechanic Arts". This Act required that the proceeds from the sale of this public land given to each state was to be invested and the interest used to endow, support, and maintain at least one Land Grant university in each state. These universities were required to: "….without excluding other scientific and classical studies and including military tactic, to teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the legislatures of the States may respectively prescribe, in order to promote the liberal and practical education…..".

Land Grant Universities originally had several missions: providing education and undertaking research that was relevant to the needs of the state's citizens, but also providing practical information that would benefit the wider community and help agricultural economic development. The idea of undertaking research of relevance to rural communities was embodied in the Hatch Act of 1887 which formally added agricultural research to the Land Grant university system through the establishment of state agricultural experimental stations at each Land Grant university. Efforts to transfer new information and technology to the state's citizens were still largely informal, and often depended on giving hands-on experience to farmers at "demonstration" farms based at the Agricultural Experimental Stations. The Smith-Lever Act of 1914 included this language: "…inaugurate, in connection with these colleges, Agriculture Extension work which shall be carried on in cooperation with the United States Department of Agriculture….in order to aid in diffusing among the people of the United States useful and practical information on subjects relating to Agriculture and Home Economics, and to encourage application of the same". The Act established the Cooperative Extension Service, a single, unique nationwide system that eliminated duplication of local, state and national outreach efforts to farmers/community. The Cooperative Extension Service was funded by and coordinated through a national, state and local government partnership that established a network of "extension agents" trained in information and technology transfer who were based at universities and/or in local communities.

Regional research funding programs: improving relevance by including end-users in the research proposal funding process

Many applied research funding programs issue requests for proposals in specific areas of research based on a list of regional research priorities, such as, for example, improving irrigation methods, diagnostics and treatment of specific diseases in farmed animals, or reducing effluent discharge from cattle farms. How do these programs address the key challenges of first, ensuring that the research reflects the needs of end-users, and second providing a mechanism so that research information and technology is efficiently transferred?

First, structuring the funding process (Fig. 1) to ensure end-user input at all stages (development of regional research priorities, involvement in proposal review, reviews of progress of specific research projects) actively engages end-users and encourages industry investment (additional research funds, in-kind contributions).

Perhaps most importantly, end-user engagement from the outset of project development increases potential for industry-relevant research being undertaken. Second, involving well-trained and engaged information/technology transfer specialists (extension specialists in the US) at all stages of a research project, but especially at the proposal preparation stage, increases the potential for that funded research to have impacts on end-users. Third, assessing the long-term impacts of these types of research funding programs can results in improvements to the program. Documenting specific examples of impacts (particularly the economic impact) of targeted research efforts increases advocacy by industry for the program, and is valuable in justifying the continued existence of the program to legislators and funding agencies.

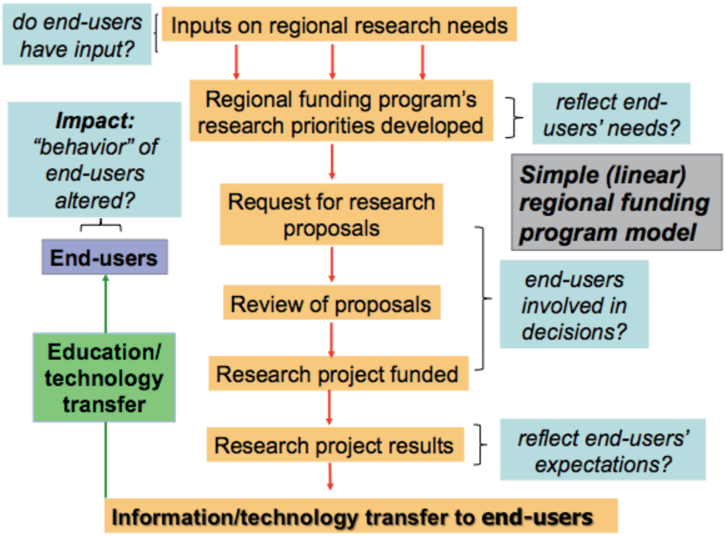

Figure 1. Flow diagram showing inputs and outputs in a hypothetical model of a funding cycle of a regional funding program. Italicized text emphasizes points where end-users could have input into the process. Note that this basic model is linear, without feedback.

Integrating industry and extension with researchers: the Western Regional Aquaculture Center model

The US Regional Aquaculture Center (RAC) program was established in 1987. The five Centers are geographically located such that they represent regional aquaculture opportunities in the United States. The Western RAC (WRAC) serves 12 states in the western region of the USA. The mission of the RACs is to provide regional research, education and technology transfer to sustain and expand each region's aquaculture industry. Funds from US Congress are administered by the USDA-NIF and oversight is provided by USDA-NIFA National Aquaculture Program Leader. Each RAC has considerable autonomy in policy and decision-making - each Center works independently, and coordination between the five Centers is achieved through regular Directors' meetings. Key features of the Centers are: projects reflect industry needs (industry-driven) and are designed to impact commercial development; the funding process encourages region-wide cooperation and team-building, and each project must include researchers in at least two states, and have predicted impact beyond one state; projects are externally and internally peer-reviewed for technical and industrial merit; and projects must involve funded extension specialists whose role is to facilitate information/technology transfer.

The WRAC's Funding Cycle: The funding process is guided by: 1) the Industry Advisory Council which determines and prioritizes needs of the regional industry; 2) the Technical Committee which works with industry to identify priority areas and develop problem statements that are included in the bi-annual request for proposals, and also reviews proposals for scientific merit, potential impact. The Technical Committee is composed of a Research Subcommittee consisting of university, state/federal public agencies, and industry-based researchers in aquaculture-related disciplines, and the Extension Subcommittee, whose members are trained extension specialists appointed by each state's Cooperative Extension Service Director.

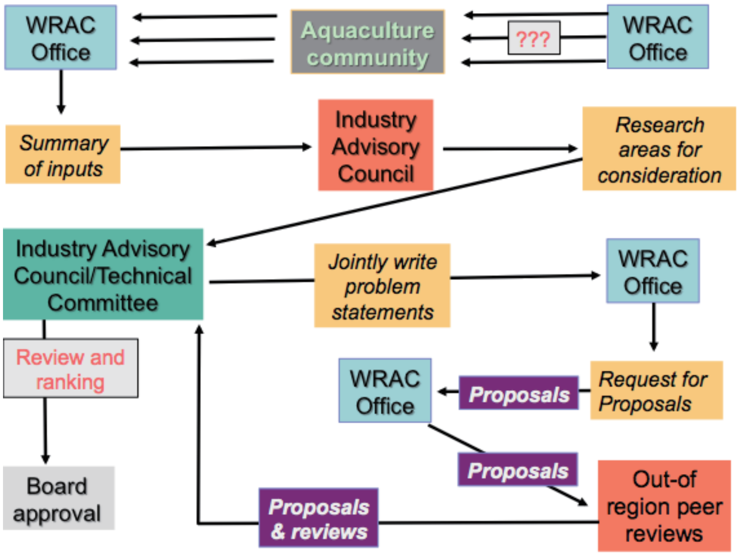

Figure 2. The WRAC's model for determining priority areas of research and for selection of proposals for funding that high potential to impact industry development. The cycle begins with solicitation of opinions from the aquaculture community. The Industry Advisory Council actively participate in all steps of the funding cycle.

The WRAC funding cycle (Fig. 2) is designed to have input from industry throughout each step. The cycle begins with the Center's office soliciting input from the aquaculture community on the key problems in industry. These ideas are then complied into a short list of priority areas for research by the Industry Advisory Council, and jointly with the Technical Committee, specific problem statements are written, and form the basis of the request for proposals. Proposals are subject to external peer review and internal review, and then ranked by the Industry Advisory Council/Technical Committee, and submitted to the WRAC's Board of Directors for approval for funding.

The problem statements that are contained within the request for proposals outline a major problem or area for research, describe potential solutions through research, and emphasize the role of the extension specialist and the need to consider information and technology transfer as an integral part of the research proposal.

The requirement for a detailed plan for information and technology transfer: A comprehensive plan for extension/outreach is required for each proposal. This plan is based on the logic model, commonly used by the extension community. For each proposed objective, the following must be answered:

1. Target Audience - who will receive project information for this objective?
2. Intended Learning Outcomes - what will be learned from this objective?
3. Intended Management and/or Behavioral Outcomes - what will be the management or behavioral outcomes of this project objective?
4. Procedures to Achieve Intended Outcomes: i) what are the inputs -who will do what and at what cost, and how will target audience be contacted? ii) what are the outcomes -what products will be developed and at what cost, and What publications, workshops, demonstrations, etc., will be developed?
5. Evaluation Plan -what methods will be used to measure what learning or behavioral changes have occurred?

Documenting "return on investment" is important: Is the regional research program achieving its goals, from the point of view of end users? This is an important question, especially as many small regional research programs are under threat, so demonstrating effectiveness of the program to the US Congress is essential for the long-term viability of these types of programs. The most compelling arguments are based on impacts on industry, as perceived by industry. Critically, assessing the impact of long-term (8 years or more) investment of research funds in a particular area requires the central long-term participation of extension specialists who are able to work with industry and with researchers, often years after a particular research project has finished, to summarize the research and to document its impacts on industry. Statements from individuals in industry that highlight what would have happened if the research has not occurred, and the economic impacts of the research are particularly powerful.

Effective information and technology transfer depends on engaging extension specialists at all stages of project development: The requirement for a funded extension specialist to be a member of the research team from the proposal preparation stage on increases the likelihood of that products of the research will be communicated to end users and encourages researchers to think beyond their specific research publications. Extension specialists facilitate input to the program on critical industry needs, through industry associations and through personal contacts, and their long-term relationship with regional industry is critical in assessing long-term impacts of the program.

Historically, many extension personnel had a background of working with the US Peace Corp. With an increasing need to specialize, numerous undergraduate and graduate training programs exist, usually based at Land Grant universities. These degrees and training programs are multidisciplinary, with a typical undergraduate degree emphasizing subjects such as science, agricultural education, communication, economics and accounting, math and statistics, management, technical writing and marketing. The large extension community offers ongoing training, workshops and conference. Many faculty at Land Grant universities have full- or part-time extension appointments.

Conclusions

This brief overview emphasizes that the impact of regional research and outreach programs whose mission is to support industry can be enhanced through: 1) the engagement of end-users throughout the entire pre-funding and funding process and throughout the life of a specific research project; and 2) the active involvement of well-trained and engaged extension specialists at all stages. Potential criticisms of this approach include the lengthy, deliberative nature of the funding process, and the requirement for regular meetings of large committees, which are time-consuming and costly. Conversely, the working relationships built among committee members offer the less tangible, but important benefit of building the multi-state networks and teams of industry, researchers and extension specialists that a developing regional industry needs.

Using masu salmon to support aquatic marine environmental education for endogenous watershed development

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Keywords: tsunami disaster, masu salmon sushi, ecosystem education, reginal resident reunion

Background

The disaster-affected areas of the Great East Japan Earthquake have numerous problems such as population decline, aging, and the reduction and stagnation of industry and employment from before the earthquake. Through the earthquake experience and its effects, its resolution has become more difficult. The root of the problems is the fragmentation of various social events such as production and consumption, and urban and rural areas by globalization. To eliminate the fragmentation to achieve endogenous development of the region, building up mutual trust of local residents (Kodera 2011), understanding of the value of local resources, and the need for sharing have been pointed out (Shinkai 2013), practicing community planning based on Education for Sustainable Development (Abe 2009). But no specific methodology has yet been shown.

Objectives

This study was conducted to clarify the development of the relationship between watershed residents and urban consumers during ongoing production and consumption of "Natural Miyako Masu Salmon Sushi (NMS)" using masu salmon *Oncorhynchus masou masou* from the Hei River, Miyako city, Iwate Prefecture. Miyako city was heavily damaged by the March 11, 2011 tsunami which struck after the Great East Japan Earthquake. As described in this paper, the contents, development, and sales of “NMS” were examined.

Masu salmon as a special fish for residents

Masu salmon is a special fish for Hei River watershed residents. First, because they are anadromous fish, they require a close connection with the forest, river, and sea, all of which must be in a healthy condition. The Hei River maintains its rich ecosystems through the efforts of watershed residents. A 93-year-old resident reported that the downstream area “Kani-oka fall” was recognized as an outstanding experience zone where masu salmon were captured by his uncle’s small skimming net when he was only 9 years old. He explained that masu salmon had been a valuable source of protein for residents for many years. Anthropologists have found numerous relics related to salmon in the Hokkaido and Tohoku regions. In the

Hei River, many watershed residents appear to have local traditional knowledge about the salmon that has been handed down since the Jomon era.

The “NMS” development process

At "The World Masu Salmon Summit in Iwate" held in May 2013 at the Hei River headwaters, a video presentation educated participants about the ecology of masu salmon, after which a feedback discussion was held (Table1-No.1). Post-questionnaires revealed that many participants regarded the salmon as food. This result motivated us to examine the effective utilization of masu salmon as food.

After the summit, the "NMS" development was conducted with various entities such as watershed and urban area residents, and the university staff. In May 2014, "NMS" development was started (Table1-No.2).

We chose roles related to the “NMS” development and sales plan. In June 2014, the plans were examined (Table1-No.3). Based on the results presented for recipes, we decided to use ingredients produced in Iwate Prefecture such as masu salmon of Miyako Bay landings, along with millet and rice cultivated at Iwate Prefecture, and salt produced from Sanriku ocean water.

In late August 2014, a domestic airline magazine publisher asked us to introduce “NMS” (Table1-No.4). In late October 2014, an article describing how "NMS" was made and activities of environmental education programs was published in the magazine (Table1-No.6)*. Additionally, this article emphasized the importance of learning and understanding of the connections among forests, rivers, the ocean, and human beings through visitation of the Hei River after eating NMS. In addition, it was explained that "NMS" is beneficial not only for regional development, but also for producers and consumers to learn together and create new opportunities for development.

Contents of the brochure as an educational material

We created a brochure as an educational material intended specifically for aquatic marine environmental education (Sasaki 2014). The brochure comprises three parts. The first introduces the relationship among masu salmon, forest, river, the ocean, and human life. The second part explains contents of current studies of masu salmon. The third is an introduction of environmental conservation activities by the "Heigawa Masu Salmon MANABI Project (HSP)."

1) The first part is a text dialog between an elementary school student and a professor who has better understanding of the life history of masu salmon. First, the student asks about the origin of the masu salmon used for "NMS". Then the professor explains that the salmon were caught at Miyako City, Iwate Prefecture, which has an important location that supports a beneficial exchange of resources among the

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* JAL Card, Co. Ltd. 2014. Local Specialties, AGORA, No. 11, pp. 77-78

rich forest, the river, and the sea. The student then becomes interested in the life history and ecology of the masu salmon, specifically with respect to its body changes in response to its life stages. The student comes to understand the importance of the valuable connection of the forest, the river, and the sea. Moreover, from the perspective of the water cycle, the student realizes that human beings are involved in the forest–river–sea connection. The importance of treating domestic sewage is shown to be paramount. Finally, the student reflects on this new knowledge of the inter-relation among the environment and human beings. He expresses his intention of sharing his knowledge with friends.

2) The second part is an introduction to the latest research related to otoliths, analyzing migration routes and spawning areas of masu salmon. This study clarified that the natural environment, which is suitable for masu salmon life and growth, is the same as that needed by humans. Furthermore, the study described that the decline of masu salmon has resulted from environmental problems such as rising sea temperatures caused by global warming and the construction of dams in watersheds, which have been exacerbated by the fragmentation of society.

3) The third part presented activities conducted as aquatic marine environmental education, “HSP”, particularly elucidating the importance of sustainable management of fisheries resources to ensure the continuous future production of salmon.

Evaluation of NMS

In late October 2014, the product “NMS” was produced. The brochure was developed. Questionnaire surveys were conducted (Table1-No.5). In November 2014, the product was first shipped (Table1-No.7). Discussions were held to examine questionnaire responses about the products (Table1-No.8).

Table 1. The “NMS” development process

No.	Year	Date	Contents
1	2013	5/16	"The World Masu Salmon Summit in IWATE"
2	2014	5/17	Consultations on the development of "NMS"
3	2014	6/18	Discussion about recipe of "NMS"
4	2014	8/25	A domestic airline magazine publisher was asked us to introduce "NMS"
5	2014	10/24	Accomplishments of the product, brochure and questionnaires of "NMS"
6	2014	10/28	Publications on the magazine that published the article informing about "NMS"
7	2014	11/11	Start shipping of "NMS"
8			Discussion in reference to the questionnaires about "NMS"
9	2014	11/12	"7th Miyako Seafood Cookery Lessons"
10	2014	11/28	Lunch event for the new products, a tasting of "NMS" was performed

In November, 2014, after development of the “NMS", the residents of the Hei River watershed undertook new activities. First, Miyako Marine Products Commercial Cooperatives conducted the "7th Miyako Seafood Cookery Lessons" (Table1-No.9). At this meeting, the chef who supervised the preparation of “NMS” lectured about French cuisine using marine products including masu salmon. Then they developed the new products of “Heshiko” using masu salmon and “Okiameat” using small shrimp “Isada.” In November, they presented a launch event. A tasting of "NMS" was held (Table1-No.10).

Conclusion

Through "NMS" development, signs of changes in the relation between the watershed residents were observed. Furthermore, they broadened their understanding of linkages among the forest, the river, the sea, and human beings. Such an understanding is expected to engender changes in their new actions for regional development.

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Sustainability of diversification by salmon producing countries in global salmon markets

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Key words: global salmon market, diversification, global divisional cooperation

Abstract

This paper focused on the importance for stabilization of global salmon prices to sustain diversity in salmon production system by medium- or small- scale aquaculture producing countries and natural capture producing countries. The objective of diversification in salmon production system is avoiding economic risk depend on oligopolistic expansion by giant-scale aquaculture production countries influencing global salmon prices. It is important for capture producing countries and medium- or small- scale aquaculture countries not only to make effort to improve stabilization of salmon resources but to promote global divisional cooperation in salmon production system. Japan is not only one of the largest consumer countries of salmon commodities but produces both of natural salmon and farmed salmon. Japan has been using salmon resource variety and sustained diversification of salmon commodities traditionally.

Introduction

Salmon were one of the most popular fish in the subarctic waters and they were economically valuable fish as same as cod and herring traditionally. Their fishery was very important in the northern hemisphere. However, salmon aquaculture has been expanding to the present around the world. Global salmon price has been influenced by salmon aquaculture production. Unstable supply of farmed salmon is afraid of causing economic confusion to global markets. Oligopolistic expansion by giant-scale aquaculture production countries influencing global salmon prices in salmon production system poses potential risks of production and prices. Therefore, this paper focused on the importance for stabilization of production and prices to sustain diversity of salmon production system by medium- or small-scale aquaculture producing countries and natural capture producing countries. In addition, this paper described also sustainability of diversification in global salmon markets by global divisional cooperation.

Methods and Data

The information by country of salmon capture production and salmon aquaculture production was searched for using a FAO FishStat database from 1950 to 2011. The information by country of salmon commodities was searched for using a FAO FishStat database from 1976 to 2009. The interannual variability of salmon production by capture and aquaculture, and salmon commodities was analyzed. Main species of salmonids analyzed in this article were Chinook salmon, Chum salmon, Coho salmon, Masu salmon, Pink salmon, Sockeye salmon, Rainbow trout and Atlantic salmon.

Items and manufacturing process of Japanese domestic salmon commodities were researched by interviews with fisheries cooperatives and fish processing factories in Hokkaido.

Results and Discussion

Development of salmon aquaculture production: Salmon were economic valuable fish as same as cod and herring historically. Salmon fishery was one of the most important fisheries in the northern hemisphere. However, salmon living in the southern hemisphere were transplanted from the northern hemisphere for recreational sport. And then marine aquaculture production of salmon has been increasing in the southern hemisphere. Salmon became one of the most popular fish in the present world.

In the northern hemisphere, main countries of marine capture production of salmon (Pink s., Chum s., Sockeye s. and Coho s.) are Russia, USA, Japan and Canada et al. (Fig.1). Main countries of marine aquaculture production of salmon (Atlantic s. and Rainbow trout) are Norway, UK, Canada and Danish Faeroe Islands et al. (Fig.2). In the southern hemisphere, main countries of marine aquaculture production of salmon (Atlantic s., Rainbow trout, Coho s. and Chinook s.) are Chile, Australia and New Zealand et al. On the other hand, main countries of freshwater capture production of salmon (Pink s. and Chum s.) are Russia and Japan. Main countries of freshwater aquaculture production of salmon (Rainbow trout) are Iran, Turkey, Italy and France et al. (Fig.3).

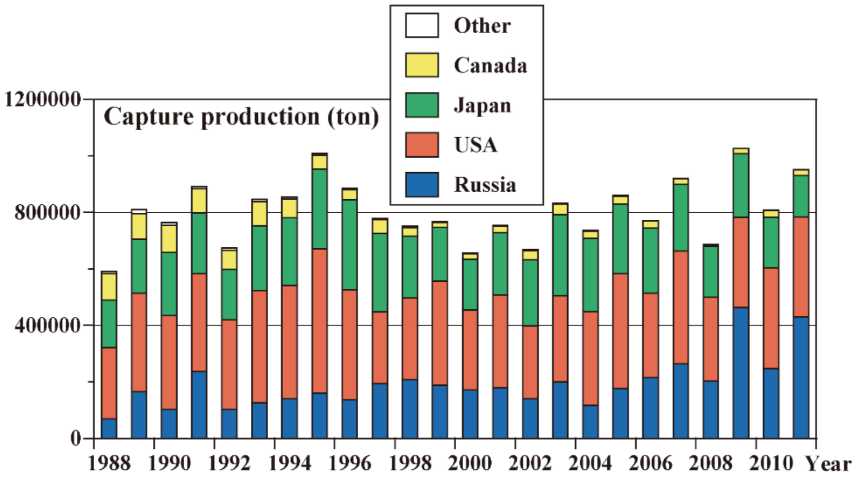

Figure1. Salmon capture production by main countries from 1988 to 2011. Salmon fisheries have been producing more than 800 thousand metric tons recently.

Both salmon produced by aquaculture and natural capture are distributing to global markets. Pink salmon, Chum s., Sockeye s., Coho s. and Chinook s. are produced by natural capture. Atlantic salmon, Rainbow trout, Coho s. and Chinook s. are produced by aquaculture. Giant-scale producing countries by natural capture are Russian and USA. Medium-scale producing countries by natural capture are Japan and

Canada et al. In contrast, giant-scale producing countries by aquaculture are Norway and Chile. Medium-scale producing countries by aquaculture are UK, Iran, Turkey, and so on.

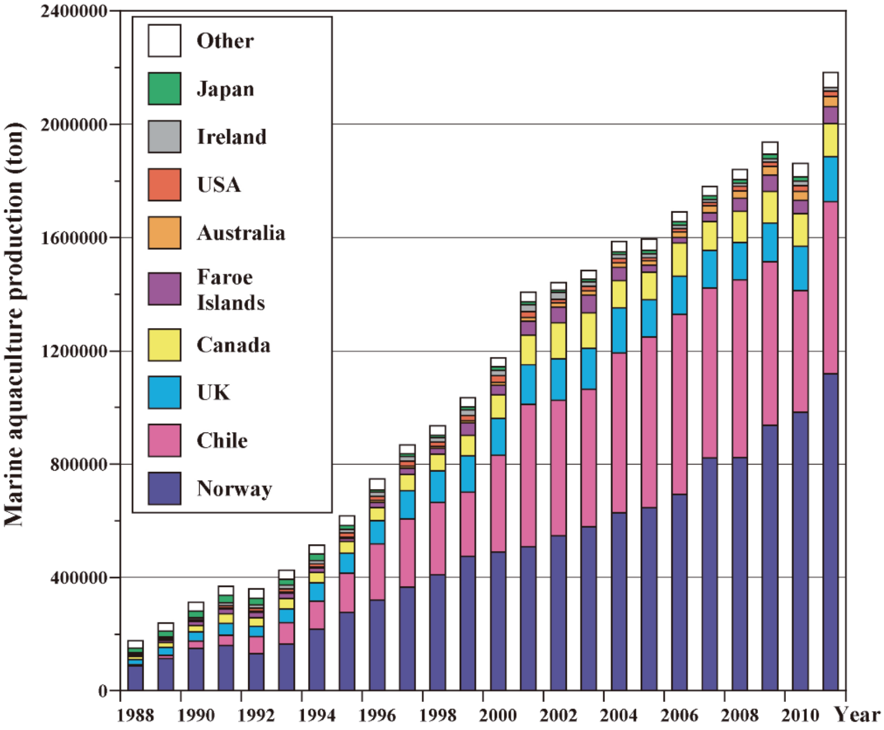

Figure 2. Marine aquaculture production of salmon by main countries from 1988 to 2011. Marine aquaculture produced more than 2 million metric tons of salmon in 2011.

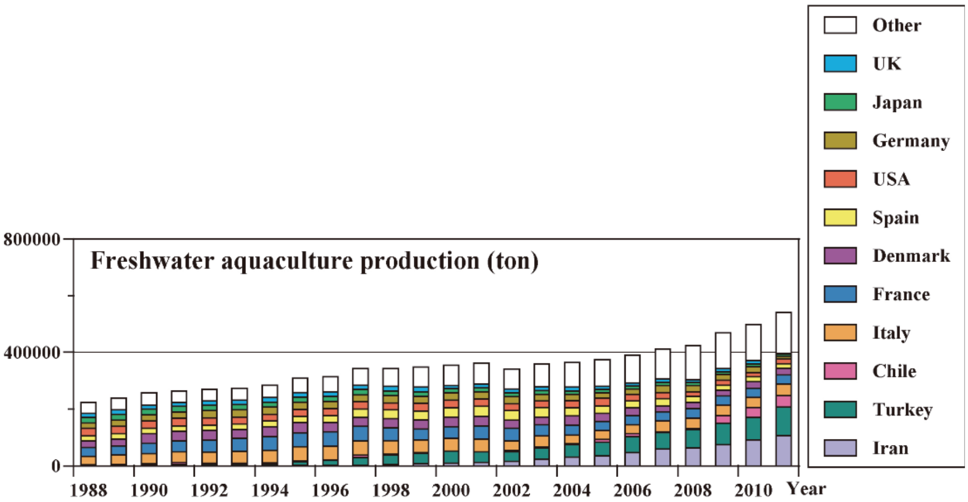

Figure 3. Freshwater aquaculture production of salmon by main countries from 1988 to 2011. Freshwater aquaculture produced more than 500 thousand metric tons in 2011.

Issues of salmon aquaculture production: Though a total production of salmon was about 4 million metric tons (Mt) in the world today, 70 % of the total was produced by aquaculture and 30 % was produced by natural capture. Salmon supply in global markets has been controlled by aquaculture. The reasons why salmon aquaculture production has been increasing were development of farming technology and expanding of management scale and global marketing. Global demand for farmed salmon has been created by marketing strategies and production scale expanding.

Global price of salmon has been influenced by salmon aquaculture production. Farmed salmon by Norway in the northern hemisphere and Chile in the southern hemisphere are distributing to global markets all year around. Accordingly, unstable supply of farmed salmon is afraid of causing economic confusion to global markets. Though salmon aquaculture has developed a necessary industry in global markets, they still have many issues as follows; influence of Peruvian fishmeal price, environmental load, algae bloom (red tide), parasitic salmon lice, diseases (ISA, SRS etc.) and food safety of genetically modified (GM) salmon, and so on.

Influence of global salmon markets on domestic markets: In March of 2011, the great east Japan earthquake and the giant tsunami destroyed almost fish processing factories and salmon stocks in Sanriku coastal area, Tohoku district (Shimizu, 2011; Shimizu et al., 2012). And then large amounts of Chilean Coho salmon were imported to Japan. However, the price of Coho salmon supplied largely to Japanese market slumped and other fishery market prices decreased also by the influence of large amounts (Shimizu, 2013; Shimizu et al., 2015). Meanwhile, the production of Chilean farmed rainbow trout decreased due to disease (SRS) in 2013 and the price of Chilean trout elevated in Japanese market by the decrease of imported amounts (Undercurrentnews, 2014a; Undercurrentnews, 2014b).

Many kinds of salmon and their commodities are distributing in global markets today. The production variability of farmed salmon with a large market share globally has influenced the prices of salmon and other fishery commodities with a small market share domestically. One of the big issues in global markets was current oligopolistic structure by giant-scale salmon aquaculture producing countries.

Necessity of diversification in salmon production system: It is necessary for salmon price stability to control oligopolistic expansion by giant-scale producing countries of farmed salmon (Norway and Chile). It is important for medium- or small- scale producing countries of farmed salmon not only to find solutions of aquaculture issues described above by their cooperation but to promote brands of salmon and sustain production of brand salmon each country. At the same time, it is important for natural salmon producing countries not only to make effort to improve stabilization of salmon resources but to control IUU fishery and promote natural brands of salmon.

In salmon production system, to control oligopolistic expansion by giant-scale producing countries influencing salmon prices, it is important for medium- or small-scale aquaculture producing countries and natural capture producing countries to sustain each production scale and to promote each brand salmon and commodity. Therefore, it is necessary to sustain diversity of salmon production system by aquaculture and capture fisheries.

Diversification by global divisional cooperation of salmon: Global divisional cooperation has been developing in global salmon production system from a trading point of view. Salmon export from Norway expanded from 96,000 Mt in 1990 and 300,000 Mt in 2000 to 640,000 Mt in 2009. On the other hand, salmon import from Denmark increased from 19,000 Mt in 1990 to 140,000 Mt in 2009. Salmon import from Sweden increased from 60,000 Mt in 2000 to 270,000 Mt in 2009. In contrast, salmon export from Denmark increased from 37,000 Mt in 1990 to 120,000 Mt in 2009. Salmon export from Sweden increased from 46,000 Mt in 2000 to 250,000 Mt in 2009. That is to say, Denmark and Sweden imported raw materials of farmed salmon from Norway and exported salmon commodities. It suggests divisional cooperation that Norway supplies raw materials to EU nations and EU nations supplies processed commodities of salmon to consumer countries. Fig. 4 showed relationship of main countries in global divisional cooperation. Salmon supply system has been constructed by global divisional cooperation between producing countries and processing countries. Nowadays, diversification of global salmon production system is sustained by global divisional cooperation.

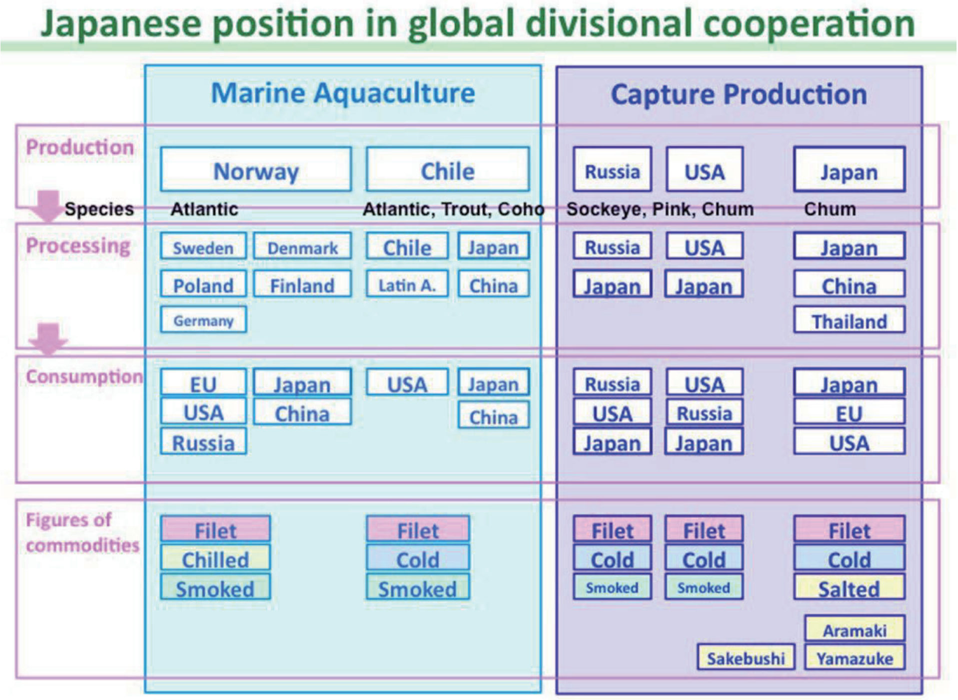

Figure 4. Relationship of main countries in global divisional cooperation. Japan produces Chum salmon by capture and processes salmon commodities from a variety of raw materials. Figures of salmon commodities in Japan are fresh-filet, cold-filet, salted-filet and Japanese original commodities (Aramaki-sake, yamazuke-sake, sakebushi, and so on).

Japanese original commodities of domestic salmon: Salmon have been producing by capture fisheries (set net fishery, gillnet fishery) and marine aquaculture and freshwater aquaculture in Japan. However, other countries have producing salmon through either capture fisheries or aquaculture. Japan has operated diversified fisheries of salmon. In other countries in the world, main salmon products were fresh- or frozen- commodities and few products were salted ones. In contrast, Japanese salmon processing factories have produced not only fresh- or frozen- commodities but salmon brands of salted ones such as “Aramaki sake” and “Yamaduke sake” et al (Shimizu, 2014). Salted salmon commodities are one of the traditional seafood that has supported Japanese food culture (Fig.4).

“Sake-bushi” commodities have been developed recently by seafood factories or fisheries cooperatives in Hokkaido (Shimizu, 2016). They are made from Japanese domestic matured salmon. “Umami” is condensed in “Sake-bushi” commodities. That is to say, “umami” is one of the five basic senses of taste. Japan has created diversified salmon commodities, too. I believe that it is very important for salmon producing countries to create diversified commodities from diversified salmon materials.

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Searching for new market strategy for Iwate Chum Salmon

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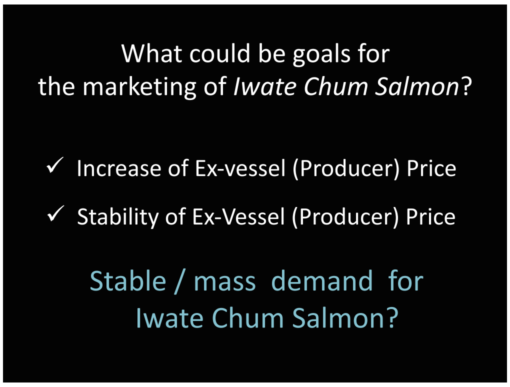
Keywords: decreased salmon production, regional market, meal program development

This presentation explores the market strategy of chum salmon (*Oncorhynchus keta*) landings in Iwate by aiming to achieve the locally-grown and locally-consumed principle. As the most dominated salmon species in landing in Iwate region, with the dramatically decreased in landings and “low price equilibrium” due to substitutions in the market from oversea, the development of new market strategy for chum salmon from Iwate is one of the key issues for the region. We describe unique possibilities of Iwate Chum Salmon for the meal programs for schools and local elder care facilities, and argue the new market strategy for Iwate Chum Salmon as shown in the figures below.



What could be goals for
the marketing of *Iwate Chum Salmon*?

- ✓ Increase of Ex-vessel (Producer) Price
- ✓ Stability of Ex-Vessel (Producer) Price

Stable / mass demand for
Iwate Chum Salmon?

~~Global Market for Salmon~~

⇩

SANRIKU Market for Salmon

- Low Price Equilibrium (低価格均衡) with saturated market
- Immediate introduction of substitutions

School Meals?

Meals for **Senior Citizens' home** ?

Synopsis

The present workshop covered a wide field of topics related to salmon production, biological research and fisheries education. A brief summary of the workshop presentations from oral and poster sessions may help readers to understand the contents of extended abstracts compiled in this report.

Plenary lecture: Dr. Beamish well summarized production trends of Pacific salmon species under on-going global climate change, and emphasized the necessity of developing a reliable model to forecast salmon production either in the short term or long term by a coordinated, international research effort.

Salmon production session: For the short term salmon harvest forecasting, Dr. Gray introduced a carefully planned project to provide annual harvest forecasts of pink and chinook salmon to stakeholders in Alaska relying on marine ecosystem metrices. For effective salmon fisheries management in Alaska, Dr. Jim Seeb reported a successful novel genetic approach for species identification, country of origin determination, and identification of major harvesting stocks in migrating mixture. Understanding the mechanisms that regulate salmon marine survival is actually crucial for optimizing future salmon production in western North Pacific, as Dr. Beamish exemplified for the case of Russian and Japanese salmon fisheries. In fact, Dr. Zavolokin outlined favorable conditions of Russian salmon fisheries for the past three decades, while Drs. Urawa, Miyakoshi and Ogawa reported the recent drastic decrease of, particularly, chum salmon production in northern Japan. Although Japanese salmon enhancement has long been sustained by hatchery operations, the analysis of the production mechanism to solve the significant decline of chum salmon returns to Japan, especially in the Pacific coast, has just began with early marine life analysis to improve juvenile salmon survival (Dr. Urawa) and reconsideration of hatchery operations (Dr. Miyakoshi). In connection with hatchery program renovation, Dr. Kasugai reported a preliminary evaluation of net pen release of chum salmon fry, and Dr. Kishi suggested the negative effect of rearing water turbidity on the hatching rate and emergence of chum salmon fry in a hatchery. In addition, identification of the factors influencing salmon homing behavior is another important issue in salmon fisheries. Dr. Matsubayashi presented a possible correlation of river mouth clogging and salmon run. Dr. Nobata suggested a complicated chum salmon homing behavior, i.e. try and error, in searching their natal rivers to spawn in the Sanriku-region, using an acoustic remote sensing approach. As the final presenter of this session, Dr. Davis summarized successful NPAFC coordination for fisheries enforcement and scientific research on Pacific salmon in the North Pacific.

Salmon biology session: Selected topics of genetic, physiological and ecological research for salmon fisheries were presented in this session. Dr. Lisa Seeb emphasized application of genetic and genomic tools for stock identification and fisheries management, after reviewing a rapid development of sequencing technology representing by next-generation sequencing (NGS) methods and the expansion of analytical techniques such as parental-based tagging and individual assignment. Dr. Sato argued the use of competent SNP markers in genetic stock identification and ocean distribution analysis of immature chum salmon in the summer Bering Sea, suggesting nonrandom distribution of Japanese stocks in survey area and the influence of ocean conditions on the observed distribution patterns. Application of molecular genetic approaches is progressing for genetic characterization of Pacific salmon in Tohoku, northern Honshu, where no systematic population genetic analysis of salmon species has been attempted to-date. Dr. Kudo preliminarily reported no significant effect of 2011 tsunami disaster on the genetic diversity of the river populations in southern coast of Tohoku region. Dr. Tsukagoshi and his colleagues including Ms. Terui developed many novel competent DNA markers for population genetics of Sanriku salmon species using NGS approach, and applied them for estimation of the fine genetic population structure in local populations of chum and masu salmon (Dr. Tsukagoshi) and the genetic diversity of coastal pink salmon populations in the Sanriku-region (Ms. Terui).

Integration of genetic and genomic technologies into physiological research of salmon actually extends mechanism consideration in their reproduction, growth, maturation, homing behavior, and so on. Dr. Norberg and her colleagues emphasized the potential of reproductive physiology coupled with genomic tools, e.g. identification of responsible genes, to flourish Norwegian salmon aquaculture production, besides their continuous efforts to renovate hatchery technologies. Dr. Swanson also introduced the attempts of modifying hatchery rearing program to improve the effectiveness of supplementation and conservation hatcheries for Pacific salmon. In relation to reconsideration of salmon hatchery program, Dr. Keiko Shimizu reported differential species composition of intestinal microflora between healthy and unhealthy chum salmon fry revealed by molecular genetic approaches, suggesting an influence of hatchery rearing conditions on the health of juvenile salmon. In fact, Dr. Moriyama reported differential somatic growth and activation of hepatic IGF-I gene of chum salmon fry fed or not isada krill extracts. Physiological aspect of anadromous life history of salmon remains mostly unanswered. Dr. Ueda summarized his challenge to elucidate the underlying olfactory mechanism for salmon spawning migration and natal river homing by analyzing endocrine hormone gene expression, such as activation of sGnRHI/II and upregulation of NRI, in chum salmon. Dr. Satoh presented the results of his preliminary proteomic analysis of thermal tolerance mechanism in salmon, in an attempt to verify a correlation of salmon homing migration and coastal water temperature and to create a salmon strain with high temperature tolerance. Dr. Kawajiri reported an unusually yellow homing chum salmon with probable jaundice captured in Iwate coast, although its physiological evidence remained to be accumulated.

Ecological understanding of the ocean migration history of Pacific salmon under ongoing climate change is indeed critical to forecast salmon returns and to set scientific basis for resource management. Dr. Trudel and his colleague gave an overview of their ecological approach to understand the impact of climate conditions on the marine survival of juvenile chinook salmon in the west coast of North America. He suggested a close correlation of juvenile chinook salmon survival and the Pacific Decadal Oscillation, but the mortality agents remained unknown. Dr. Ariga reported preliminary results of migration history analysis of masu salmon in Iwate coast using otolith microchemistry relying on a change of Sr:Ca ratios reflecting fresh water to sea water entry and *vice versa*.

Salmon and fisheries education session: This session included educational topics of ecosystem, socio-economics, regional program, and fisheries marketing. Dr. Kaeriyama gave an overview of his ecological and ecosystem researches on Pacific salmon, emphasizing the necessity of paradigm shift in fisheries science, dietary education, and ecosystem-based risk management/conservation practice for sustainable salmon fisheries under a changing climate. Learning and teaching about sustainability actually is not easy for students and teaching staff as well, since a number of sustainability concepts have been developed for different stakeholders with different purposes. Dr. Tveiterås well summarized the sustainability concept for salmon and fisheries science, i.e. a compound discipline of social, ecological and economic issues, and gave an emphasis for the importance of interdisciplinary education program for sustainability learning in marine education systems through her experience at the Norwegian College of Fishery Science, UiT the Arctic University of Norway, Tromsø. Regional program is also important for bridging different economic, scientific and social considerations related to fisheries science. Dr. Young introduced a regional funding program integrating research, education and outreach in aquaculture, which is conducting at the Western Regional Aquaculture Center, University of Washington, and emphasized the importance of end-user engagement and active involvement of extension specialists for successful program proposal and its fruitful outreach, i.e. technology transfer to end-users. Dr. Mizutani reported an attempt to reconstruct a watershed community declined after 2011 tsunami in Iwate coast by aquatic environmental education with masu salmon, a popular, symbolic fish in the region.

Marketing and related research and education are underdeveloped in Japan, as the development of production technology has been the primary interest in fisheries science. However, the continuous decline of Japanese fisheries resources makes the people focus much attention to create high quality, safe aquatic products and to develop a competent marketing strategy for selling such product domestically and globally. Dr. Ikutaro Shimizu summarized the current situation of global vs. local salmon markets, in connection with rapid increase of aquaculture production over capture fisheries production, and suggested the necessity of stabilizing production and prices, as well as diversification in producing system by a global divisional cooperation, for sustainable global salmon markets. Dr. Ishimura proposed a new marketing strategy for chum salmon from Iwate, i.e. meal programs for local school and elder care facilities in the Sanriku-region.

Panel discussion: On the first day of the workshop, the panelists including Drs. Trudel, Zavolokin, Urawa, Lisa Seeb, Swanson, and Ueda discussed the issues and measures associated with sustainable salmon production and resource management under a changing climate, by ecological, genetic and physiological approaches. On the second day, the panelists including Drs. Beamish, Nagasawa, Norberg, Ishimura, Tveiterås, Urano, and Young discussed the issues of the current and future salmon research and education, in connection with Iwate University's endeavor to establish a new graduate school and undergraduate course of fisheries science, and wrapped up the workshop with consensus of the participants for exchanging mutual scientific interest and future collaboration in salmon research.

List of Participants

Canada

- Richard J. Beamish
- Nancy Davis
- Marc Trudel

USA

- Andrew Gray
- James E. Seeb
- Lisa W. Seeb
- Penny Swanson
- Graham Young

Norway

- Birgitta Norberg
- Kathrine Tveiterås

Russia

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Japan

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- Keisaku Ariga
- Gakushi Ishimura
- Masahide Kaeriyama
- Kiyoshi Kasugai
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