Introduction

The reports in this Bulletin summarize the studies of the early marine period of the life history of juvenile Pacific salmon. The format and contents of the four papers vary slightly because the reasons for juvenile salmon studies differ among the four countries. The research conducted by each country reflects the relative importance of the various species of salmon as well as the particular management issues. All reports document the history of the early marine studies and all reports provide a comprehensive list of publications. Authors note that not all material has been published in regular publications requiring some recognition of difficult to find reports and even, on occasion, personal communications. The authors of the four reports did not write a critical review, rather they summarized past studies by reporting results identified in the original papers. Not all statements are referenced so that the text is more readable. Readers who require more detail or specific references may need to review the list of references and refer to original papers. It is useful to use this Bulletin in association with the summaries of the life histories of Pacific salmon published in Groot and Margolis (1991. Pacific salmon life histories. UBC Press, Vancouver, Canada). The papers in Groot and Margolis (1991) also provide additional detail about the location of marine rearing areas of Pacific salmon for each country.

This introduction highlights the contributions of each paper by providing a very brief executive summary of each paper along with some commentary on the relationships of the results of the research among the four countries. The authors of each report provided a summary of their expectations of future issues and the reader is encouraged to find these sections in each paper as it is informed speculation that has many common themes among the four countries. The order of papers in the Bulletin is alphabetical and the same order is used in this summary.

Canada

Pacific salmon on the west coast of Canada have been a major focus for human society for thousands of years. Commercial harvests of Pacific salmon began about 1870, but the active management of Pacific salmon did not begin until much later. In fact, it wasn't until the 1990s that coho salmon were managed in a manner similar to the other species of Pacific salmon. In 1937, a formal agreement was ratified with the United Stated of America to establish the International Pacific Salmon Fisheries Commission to manage sockeye salmon in the Fraser River. In 1959, it was agreed to include Fraser River pink salmon in the agreement. In 1953, the International North Pacific Fisheries Commission was established and activities associated with assessing the impact on Canadian salmon of the high seas Pacific salmon fishery consumed much of the Canadian research effort on Pacific salmon. Thus, it was not until 1955 that scientists started their investigations of the early marine phase of Pacific salmon. This early research was carried out to improve the ability to predict the number of returning adults. Underlying this research was a strong belief that abundance could be rebuilt to historic levels, even though the natural factors regulating abundance were completely unknown. One of the first studies by Parker in the mid-1960s remains as one of the best Canadian studies on the timing of early marine mortality. This study concluded that 55–77% of pink salmon died over the first 40 days in the ocean and 78–94% of those surviving, died over the remaining 410 days at sea.

In the early 1970s, the general abundance of all species of Pacific salmon continued to decline despite efforts to control fishing and protect freshwater habitat. A concern was that the rearing areas in estuaries might in some way be associated with the ability for the managed salmon stocks to recover. Emphasis shifted in the 1970s as studies focused on chinook and coho salmon, although chum salmon studies continued. Excellent research was conducted on the linkage between food available to juvenile salmon in the nearshore areas and the survival and behaviour of chinook, coho, and chum salmon. The dependence of juvenile salmon on estuaries was found to be specific with juvenile chinook salmon being most dependent on the estuary. It was about this time that it was discovered that chinook salmon had two distinct life history types. The ocean type juveniles remained in fresh water less than 12 months while the stream type remained in fresh water more than 12 months and entered the ocean at a considerably larger size. It was in the 1970s that Canada started its' Salmonid Enhancement Program that originally was designed to double the production that existed in the early 1970s. Unlike the Japanese hatcheries studies, there was no direct linkage between the Salmonid Enhancement Program and the early marine research studies, perhaps because there was a strong belief that the ocean was not limiting production. However studies on salmon diets continued with results that were similar to the observations reported in the other papers in this Bulletin.

In the 1980s there was a strong emphasis on research on the early marine period of Pacific salmon. Juvenile sockeye migrations were monitored to determine if a relationship existed between the route to the high seas taken by juveniles and the route taken by the adults that returned. There was a large-scale study to determine the importance of estuarine rearing for chinook salmon. This study was able to demonstrate that there was an interaction between hatchery and wild chinook salmon in the estuary that needed to be minimized if wild chinook salmon were to be maintained. New gear for capturing juvenile salmon were developed; first using a large beam trawl, then settling on a modified mid-water rope trawl that was capable of fishing on and near the surface. The largest study of the factors affecting the early marine survival of juvenile Pacific salmon, the marine survival of salmon, or MASS program, was conducted from 1987 to 1991. This was a multidisciplinary study involving fisheries and oceans scientists. The results of this large program are reported in the Canadian paper, however more material remains to be published.

One area that has received almost continual research attention is the Strait of Georgia. This is the most important rearing area for juvenile Pacific salmon as the adult returns from the juveniles that enter the Strait can account for up to about 40% of the Canadian Pacific salmon catch. The series of investigations are summarized in the Canadian report, including detail of diets and predation. One study of predators, identified the river lamprey (*Lampetra ayresi*) as a major predator of juvenile Pacific salmon. Although the river lamprey is a different species than the lamprey identified as a major predator in the Russian paper, the impacts were similar. Another study in Masset Inlet clearly showed that coho will eat both pink and chum juveniles, with a preference for pink salmon. A study of smolt size and early ocean growth of coho salmon concluded that large coho size as a juvenile did not give a constant survival advantage, but large smolts did survive better in years when marine survival was relatively poor. Offshore Pacific salmon research started in the 1990s after a pause of almost a quarter century. This work was strongly influenced by a co-operative research cruise on a Russian research vessel in the Gulf of Alaska. The results showed that juvenile Pacific salmon migrated northward along the coast with virtually no juveniles beyond the shelf break.

As hatcheries increased in prominence, several studies researched the potential impact of hatchery fish on wild fish. One study in the Campbell River area in the late 1980s showed that wild chinook fry represented 55% of the total catch of young salmon but consumed only 28% of the total rations available to the young salmon. Coho and chinook hatchery-reared smolts were only 28% of the catch, but consumed 65% of the available rations. Thus there was evidence that the hatchery-reared fish had a higher feeding rate than wild fish. In a Strait of Georgia study, in the 1990s, it was shown that the percentage of hatchery coho had increased from almost zero in the late 1960s to as high as 79% in the mid-1990s without an increase in coho abundance.

In general, the conclusions from the Canadian research are that there are similarities with the observations in the other papers in this Bulletin. Pink salmon prefer to eat small items, chum salmon prefer oikopleura, and coho and chinook salmon consume more fish than the other salmon species. Rates of growth are rapid in the early marine period, but there is considerable uncertainty in the measures of these rates. There is evidence that these early rates of growth are related to marine survival, but the mechanism appears to be more complicated than size related predation. Canadian research showed that the conditions in the ocean can limit survival. In fact, there is solid evidence that the marine survival and resulting adult abundances are related to climate. The Canadian report concludes with a series of questions and recommendations such as why do some stocks of salmon have better marine survival than others and how do juvenile Pacific salmon survive the first marine winter. It is recommended that a plan be developed to adapt to the expected changes in climate. A team of experts is proposed to be the most efficient way of doing this and experts from NPAFC would make a significant contribution.

Japan

Japan may have the longest recorded history of commercial Pacific salmon fishing with records dating back over 400 years. At present, virtually all of the Pacific salmon produced in Japan, are produced artificially in hatcheries. Most of this production is chum salmon (about 90%). The remaining production is pink salmon (5% to 10%), with a small production (less than 1%) of masu salmon (*O. masou*). The artificial production of chum salmon has been very successful as indicated by the maximum return of 89 million fish in 1996 compared to average returns of about 3 million fish between 1900 and 1970. Returns have declined since 1996 for reasons that remained to be explained.

Artificial rearing of Pacific salmon started in 1876 but did not reach a large scale until 1888. At present there are 21 national, 13 prefectural, and 269 private hatcheries in Japan. The number of juveniles produced in these hatcheries increased from 800 million in the early 1970s to 2 billion in 1982. Production has remained at about 2 billion since 1982. The return rate, or marine survival, increased from 2% in the mid-1960s to over 3% after the 1984 brood year. The increase in return rate is believed to result from improved hatchery practices and improved ocean conditions. A return rate of about 3% means that 97% of the juveniles that entered the ocean died. A change in marine survival of only 1% makes a tremendous change in the number of adult fish that return. It is remarkable that the marine survival has been rather constant around the 2% to 3% rate.

The rivers that naturally produce chum salmon in Japan are almost all small, and without estuaries. Thus, the focus for Japanese research on the early marine period was in the near shore area in the early years and offshore areas in recent years. The objective of the research has been to optimize the timing of the release of juveniles from hatcheries and to maximize the production from hatcheries. Most of this research has been on chum salmon, which are at the southern limit of their geographical range in Japan.

Japanese research has shown that juvenile chum salmon are in low abundance in the near shore areas in April. Their abundance increases rapidly from late May to early June and decreases rapidly by mid-June. The timing of the rapid decrease in abundance appears to be consistent among years. A decrease in the abundance of food organisms appeared to be the main stimulus for juvenile chum salmon to move offshore. However, offshore migrating chum salmon were concentrated in areas with a surface temperature from 9°to 13°C and a surface salinity from 31.0 to 33.9 pus. There were size-related distribution patterns that fell into size ranges of about 30–50 mm, 50–80 mm, 80–120 mm, and larger than 120 mm. Juveniles, 80–120 mm were in the process of migrating offshore.

Feeding of juvenile chum salmon was found to be very selective as observed in the studies of all countries. Japanese studies showed that the diet of juvenile chum salmon does not usually correlate well with zooplankton composition collected in the same area. It is clear that juvenile chum salmon actively searched for their prey. Harpacticoid and calanoid copepods were the most important prey items of juvenile chum salmon. Prey size was an important factor. As chum size exceeded 55 mm, diet changed to larger copepods and euphausiids. Studies using RNA-DNA ratios and triglyceride contents suggested that pink salmon and chum salmon differed in their early growth strategies. Chum salmon had faster growth rates and less energy storage in the early stages, but decreased growth rate and increased energy storage as growth progressed. Pink salmon had low energy and slow growth rates at first, but both increased as they grew.

Recent research has been through cooperative studies with Russian scientists. These studies found that juvenile chum salmon rear mainly in the southern and central Okhotsk Sea from summer through to November. They migrated out of this area through the Kuril Islands and into the western North Pacific Ocean in the late autumn and early winter. One study showed that 90% of the juvenile salmon were shallower than 40 m during this migration. A small percent (2.8%) were detected in water deeper than 70 m. In 1993 and 1996, the abundance of juvenile chum salmon in one area of the Okhotsk Sea was estimated to be 60–100 million fish and 200–334 million fish respectively. Chum salmon of Japanese and Russian origin reared in this area, thus this abundance estimate provided a general indication of the dominance of chum salmon in the surface waters in this area. Both the Japanese and Russian studies clearly showed that the Okhotsk Sea is a major rearing area for chum salmon as well as for pink salmon. Pink salmon juveniles appeared to have migration patterns similar to chum salmon. Large concentrations of juvenile pink salmon were observed in the southern Okhotsk Sea in October and November. Movement offshore occurs late in the year. In general, little is known about the winter distributions of the juveniles and about the factors that affected their survival during the first marine winter.

Studies of early marine mortality identified relatively few predators. In a review paper, 90 fish species were recorded to occur in the same habitat as juvenile chum salmon, but only 9 were identified as predators of chum salmon in the near shore area. Predation was recognized as a major cause of mortality immediately after chum were released from the hatchery, but rates of predation by some species declined after a few weeks. Studies of predation by sea birds suggested that they might cause more mortality than fish predators. Japanese studies can be summarized as identifying five species of sea birds and 9 species of fish as major predators of chum salmon. However, there have been no quantitative studies of the impact of predation on the early marine survival of juvenile chum salmon.

In the studies of juvenile rearing areas in the Okhotsk Sea and in the western North Pacific Ocean off Kuril Islands, 24 species of fishes and two species of squid were observed in a common habitat. Juvenile salmon were the most abundance; followed by myctophids, arabesque greenling, squids, and the deep sea smelt (*Leuroglossas schmidti*). It is apparent that this is an important summer feeding and rearing area. It could be hypothesized that juvenile salmon are not experiencing heavy predation at this time as major predators were not identified.

It is in the Okhotsk Sea where there will be an interaction between hatchery-reared and wild chum and pink salmon, however, there has been limited research to study interactions. All Pacific salmon producing countries now recognize the importance of studying the relationship between the two rearing types. Japan proposes to study where and when the predominately wild, Russian chum stocks mix with Japanese stocks in the Okhotsk Sea. Japan proposes to continue to improve the understanding of the mechanisms that regulate the marine survival of hatchery-reared chum salmon once they enter the ocean. A priority for Japanese research to improve the forecasts of the recruitment of returning adults is similar to the priority of Russian research. The decline in marine survival after 1996 does not appear random, although it does appear to be natural. A better understanding of where, when, and how much mortality occurs in the various seasons of the first ocean year, will help explain the mechanisms that caused the decline and thus will help optimize hatchery production. We can assume that the biological basis for chum behaviour and survival is similar for all stocks. Thus, the detailed investigations of Japanese scientists should provide insights on issues such as the importance of estuaries, the importance of growth in the first four weeks in the ocean, and the role of predators in recruitment, that will improve the management of all chum stocks in all countries.

Russia

The first extensive studies of the early marine period of Pacific salmon were carried out by Russian scientists beginning in the 1960s. Pacific salmon are an important part of the commerce and culture of Russians living along their Pacific coast as indicated by the establishment of research laboratories in Khabarovsk, Vladivostok, Yuzhno-Sakhalinsk, Petropavlovsk-Kamchatsky, and Magadan. Over the past decades, literally thousands of scientists and support staff have studied the ecology of juvenile salmon in the early marine period with an emphasis on assessing the abundance of the returning adult pink, chum, and sockeye salmon. Significant advances occurred in their research when small pelagic trawls were developed in 1981 and perfected for assessment use by the mid-1980s. Forecasts of returning abundances using estimates of spawning escapements were adjusted using information from abundances estimated both inshore and offshore and from growth. No other country uses information from juvenile surveys to compliment their forecasts of the number of returning adults.

Russian studies emphasized related feeding to the availability of food. All juvenile Pacific salmon were found to exhibit selective feeding, but their food preferences became even more selective after their seaward migration. There results of the Russian studies were consistent with the observations in the other countries of feeding habits and migratory behaviour. For example, when chum salmon first enter the ocean, they feed extensively on harpacticoid copepods. These preferences changed to calanoid copepods and then to euphausiids as the juveniles grew. The Russian studies also showed that chum salmon remain in the near shore areas longer than pink salmon juveniles.

Hatcheries are a common approach for the management of Pacific salmon in Russia, as they are in Canada, Japan, and the United States. Hatcheries are used more extensively in the Sakhalin Islands than in any other region of the Russian Far East. There have been a number of studies in Russia that have attempted to assess the marine carrying capacity for juvenile Pacific salmon so that there is optimal use of both hatchery and wild production. There also were studies of the potential interaction between hatchery produced juveniles and wild juveniles in the juvenile rearing areas. These are difficult studies and they represent a challenge for future research by Russian scientists.

A common source of investigation among the four papers in this Bulletin has been the determination of the factors that cause the very large early marine mortality. In general, only a very small percentage (2% to 5%) of the juvenile salmon that enter the ocean, survive to return as adults. It is believed that predation causes most of this mortality shortly after the juvenile salmon enter the ocean. Another way of looking at this problem would be to determine why there are returns from virtually all stocks when the early marine mortality is so large. Why, for example, in some years would the mortality not be 100%; in such cases the stock would be lost if it were pink salmon, or a brood year could be lost if it were a chum salmon.

Russian studies identified a relatively small number of predators of juvenile salmon in different areas that accounted for reductions in abundance ranging from 2% to 96%. The most important predator identified was the Arctic lamprey (*Lampetra japonica*), which consumed, up to 93% to 96% of the juvenile population in some years. Lamprey were considered to be a major predator because salmon were in contact with lamprey for 1.5 to 3.0 months, compared to shorter exposures for other predators such as Arctic smelt (*Osmerus mordax dentex*) and Ussuri whitefish (*Coregonus* ussuriensis). Lamprey predation was considered to affect juvenile salmon in the Sea of Okhotsk and north Sakhalin Island because the migration paths of the lamprey and salmon were similar. In the South-west Sakhalin, West and East Kamchatka, the main predators were Artic smelt, Artic char (*Salvelinus alpinus*), Siberian char (*Salvelinus leucomaenis*), where they consumed up to 70% of pink and chum juveniles. Russian studies clearly showed that significant amounts of mortality occurred later in the first marine year. Methods used to estimate the mortality of pink salmon, for example, showed that the mortality in some broods changed from 55% to 96% after migration offshore late in the first marine year.

Future research in Russia will emphasize the need to understand the interaction between hatchery and wild fish. It is no longer believed that the carrying capacity in the ocean is limitless. Thus, it is important to determine a rational combination of the two rearing types. The assessment of recruitment remains as the highest priority in Russian research. Although Russian forecasts have been very good, there is the expectation of improvement through the use of surveys before and after the offshore migration of juveniles. All countries are beginning to manage fisheries on an ecosystem basis and Russia will carry out early marine studies that investigate the impacts of fishing on the interrelationships among species.

United States

Research on the early marine period of Pacific salmon by United States has been distributed among 7 species including steelhead trout (*O. mykiss*) and the coastal cutthroat trout (*O. clarki clarki*). The investigations in the United States tend to be associated with two geographical areas; the area off the West Coast (Washington, Oregon and California); and the area off Alaska. Most studies off the West Coast have been on coho, chinook, and steelhead. Studies off Alaska have researched pink, sockeye, and chum, more than the other species. The objectives of the research have changed over the years. The original research tended to be associated with defining the distributions of Pacific salmon of United States origin. Understanding where Pacific salmon produced in United States migrated and reared was important for the protection of Pacific salmon on the high seas and for cooperative management of stocks from Canada and the United States that were jointly fished. More recently, in addition to these international considerations, there was regional interest based on the insatiable curiosity of biologists to understand the biology and behaviour of Pacific salmon.

Off California, chinook salmon are the most abundant species. They are at the southern limit of their distribution and historically were relatively abundant. At present, the various stocks appear to be at record low levels or extinct. Chinook are virtually all the ocean type, spending about 40 days in estuaries or close to shore before moving off shore. In recent years, large numbers of juvenile chinook salmon have been released from hatcheries in California. In Oregon and Washington, the two most abundant species are chinook and coho salmon, but steelhead trout are a species of major interest. The total catches of Pacific salmon off California, Oregon, and Washington are only about 5% of the total catch in the United States in the last decade, but there is exceptional interest in the health and management of Pacific salmon in this area. There is a diversity of issues related to Pacific salmon produced in the Columbia River and in Puget Sound. A number of stocks have been identified as requiring special protection and there is growing concern about the interaction between wild and hatchery-produced salmon. Washington hatcheries produced large numbers of chinook, coho, and chum salmon, which some believe affect the abundance of wild salmon and others believe, are essential to support the important commercial and recreational fisheries. The research carried out on these "southern" stocks has identified a diversity of behaviours and even life history strategies. For example, the direction of coastal migrations of juvenile chinook salmon from Washington and Oregon is stock specific, with some moving north to waters off Canada and Alaska and some moving south to waters off Oregon and California. Juvenile steelhead trout were reported to move directly offshore soon after they enter the ocean early in the spring or summer.

Alaska is the world's largest producer of sockeye salmon and has the largest spawning population in Bristol Bay. Thus, a focus for research has been on the factors that affect the marine survival of juvenile sockeye salmon. Studies have concentrated on the variety of stock specific behaviours that may contribute to specific marine distributions and even subsequent recruitment. Sockeye salmon smolts enter Bristol Bay from May to mid-July and remain inshore until the fall when they move into the Bering Sea. The northwest extent of their distribution in the Bering Sea in the fall and winter remains to be determined. The area where juvenile sockeye salmon are distributed at the end of their first marine winter may be different for individual stocks or stock aggregates.

Alaska is also a major producer of pink and chum salmon. Catches of Pacific salmon in the Alaskan fishery increased to historic levels in recent years. Associated with these increases has been a well-organized attempt to understand the mechanisms that caused the increases and the occasional unexpected decrease. Current research is multi-disciplinary and is well-positioned to solve some problems common to all Pacific salmon management. In recent years, there has been a large production in hatcheries and the impact of hatchery-reared pink salmon on wild stocks has become an important area of research.

Studies of juvenile salmon during the first marine winter is one of the current priorities of the North Pacific Anadromous Fish Commission. Research reported in the paper from the United States identifies observations similar to research results in Asia. Most research in United States is now conducted using pelagic trawls. Although the size of the trawls differ among investigations, there has been considerable progress towards standardizing sampling methods. Observations, to date, indicate that pink and chum fry remain inshore longer than coho, sockeye and chinook juveniles which move into open water sooner. Faster growing individuals may move into open waters sooner. One difference between research in United States and in Asia is the emphasis on the importance of estuaries as rearing areas for juvenile salmon. The role of estuaries has been of general interest and thus their importance for salmon has received considerable attention in United States and in Canada.

Diets of juvenile Pacific salmon have been fairly well documented in the research in United States. There was a similarity in the types of prey consumed by the various salmon species with Asian studies, as was the selectivity in the feeding of pink and chum salmon. Coho and chinook salmon were reported to be more piscivorous and more opportunistic than pink, chum, and sockeye. Predation studies also produced common observations common to Asian studies. Despite some extensive studies that examined potential predators of juvenile salmon, studies within United States waters have found relatively few documented examples of large numbers of juveniles being consumed in the marine environment. In the most extensive study, nine fish and seabird predators were identified that apparently consumed about one half of the pink salmon juveniles in the study area. This is identical to the number of fish and sea bird predators identified in a Japanese study.

The report by the United States also contains some and concerns common to all countries. Current programs are assessing how the ocean environment affects not only Pacific salmon growth, bioenergetics, health, condition, feeding, but the role that juvenile salmon play in the ecosystem. There are cooperative programs in the Bering Sea with Japan and Russia, and also with Canada in the coastal waters shared by the salmon produced in Canada and the United States. There is a requirement to determine the timing of juvenile salmon movement from the coast waters to the high seas, beyond territorial limits.

Priorities for future research in the United States also share common themes among all countries. Interactions between hatchery and wild juveniles need to be determined. More information on the biology and behaviours during the first winter is a common priority as there is a possibility that this is an important period of early marine mortality. There is a common concern about the impacts of a changing climate. The general recognition of greenhouse gas induced climate change means that it is unlikely that there will be the kind of steady states and random variability that is often proposed to affect the dynamics of Pacific salmon populations. Because the effects of global climate change on Pacific salmon will differ between oceanic regions, as well as among salmon species and stocks, future research by the United States is proposed to examine both regional and basin-wide factors that affect early marine survival.

Richard J. Beamish
Chairman of the NPAFC Committee
on Scientific Research and Statistics