Atlantic salmon fisheries has been adopted by NASCO on a preliminary basis. This decision structure is shown in **Figures 6** and **7** for single stock (i.e., exploiting salmon from one river) and mixed stock (i.e., exploiting salmon from more than one river) fisheries, respectively.

In short, salmon fisheries changed greatly in the last four decades of the twentieth century and the development of salmon farming had a marked effect on these fisheries. There is great concern about the future of the wild stocks and the fisheries continue to undergo critical re-examination.

See also

Fishery Management. Fishing Methods and Fishing Fleets. Salmonid Farming. Salmonids.

Further Reading

Anon (1991) *Salmon Net Fisheries: Report of a Review of Salmon Net Fishing in the Areas of the Yorkshire and Northumbria Regions of the National Rivers Authority and the Salmon Fishery Districts from the River Tweed to the River Ugie*. London: HMSO.

Ayton W (1998) *Salmon Fisheries in England and Wales*. Moulin, Pitlochry: Atlantic Salmon Trust.

Barbour A (1992) *Atlantic Salmon, An Illustrated History*. Edinburgh: Canongate Press.

Baum ET (1997) *Maine Atlantic Salmon. A National Treasure*. Herman, ME: Atlantic Salmon Unlimited.

Dunfield RW (1985) *The Atlantic Salmon in the History of North America*. Canadian Special Publication of Fisheries and Aquatic Sciences 80. Ottawa: Department of Fisheries and Oceans.

Hansen LP and Bielby GH (1988) *Salmon in Norway*. Moulin, Pitlochry: Atlantic Salmon Trust.

Jakupsstovu SHi (1988) Exploitation and migration of salmon in Faroese waters. In: Mills D and Piggins D (eds) *Atlantic Salmon: Planning for the Future*, pp. 458–482. Beckenham: Croom Helm.

Mills DH (1983) *Problems and Solutions in the Management of Open Seas Fisheries for Atlantic Salmon*. Moulin, Pitlochry: Atlantic Salmon Trust.

Mills DH (1989) *Ecology and Management of Atlantic Salmon*. London: Chapman and Hall.

Møller Jensen J (1988) Exploitation and migration of salmon on the high seas in relation to Greenland. In: Mills D and Piggins D (eds) *Atlantic Salmon: Planning for the Future*, pp. 438–457. Beckenham: Croom Helm.

NASCO (1991) *Economic Value of Atlantic Salmon*. Council document CNL(91)29. Edinburgh: North Atlantic Salmon Conservation Organization.

Taylor VR (1985) *The Early Atlantic Salmon Fishery in Newfoundland and Labrador*. Canadian Special Publication of Fisheries and Aquatic Sciences 76.

van Brandt A (1964) *Fish Catching Methods of the World*. London: Fishing News (Books) Ltd.

Vickers K (1988) *A Review of Irish Salmon and Salmon Fisheries*. Moulin, Pitlochry: Atlantic Salmon Trust.

Went AEJ (1955) *Irish Salmon and Salmon Fisheries*. The Buckland Lectures. London: Edward Arnold.

Williamson R (1991) *Salmon Fisheries in Scotland*. Moulin, Pitlochry: Atlantic Salmon Trust.

Pacific

R. G. Kope, Northwest Fisheries Science Center, Seattle, WA, USA

doi:10.1006/rwos.2001.0452

Introduction

Pacific salmon comprise six species of anadromous salmonids that spawn in fresh water from central California in North America across the North Pacific Ocean to Korea in Asia: chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), chum salmon (*O. keta*), pink salmon (*O. gorbuscha*), and masu or cherry salmon (*O. masou*). Pacific salmon spawn in rivers, streams, and lakes where they die soon after spawning. Most juveniles migrate to the ocean as smolts, where they spend a significant portion of their life cycle. The length of freshwater and marine residence varies by species and the life span ranges from 2 years for pink salmon to as much as 7 or 8 years for some chinook salmon populations. Spawning runs of adult salmon have contributed an important source of protein for human cultures as well as a large influx of marine nutrients into terrestrial ecosystems. Large runs of mature fish returning from the sea every year have been highly visible to people living near rivers and salmon have historically assumed a role in the lives of people that extends beyond subsistence and commerce. Salmon became part of the social fabric of the cultures with which they interacted, and this significance continues today.

History

Salmon played an important role in the lives of people long before the arrival of Europeans on the

Pacific rim. The predictable appearance of large runs of fish in the rivers emptying into the North Pacific Ocean provided a readily available source of high quality protein that could be harvested in large quantities and preserved for consumption in the winter when other sources of food were scarce. In the coastal areas of Washington, British Columbia, and south-east Alaska, Pacific salmon were a staple in the diets of tribal people and supported a level of human population density, commerce, and art unrivaled elsewhere on the continent. In Asia, salmon were harvested for subsistence by native people in Siberia, and the Japanese have harvested and dry-salted salmon in Kamchatka and Sakhalin at least since the seventeenth century.

When Europeans arrived on the Pacific rim, they were quick to take advantage of the abundant salmon. In the late eighteenth century Russian fur traders in Alaska caught and preserved salmon to provision native trappers. Distant markets developed for fresh, dried, salted, and pickled salmon, but the industry was hampered because the methods of preserving fish were inadequate, and spoilage was a recurrent problem. Commercial fisheries for Pacific salmon did not expand to an industrial scale in North America until the introduction of canning in the 1860s.

Pacific salmon were first canned on the Sacramento River in California in 1864. The canning industry then rapidly spread to the Columbia River, Puget Sound, British Columbia, and Alaska. Within 20 years canneries were established along the entire west coast from Monterey in California to Bristol Bay in Alaska, and commercial fisheries for Pacific salmon were conducted on an industrial scale. By the beginning of the twentieth century a few canneries had also been established in Asia, but the principle product produced in Asian salmon fisheries remained dry-salted salmon preferred by Japanese consumers.

With the advent of powered fishing boats in the early twentieth century, new fishing gears became prevalent and a trend developed to intercept salmon further and further from their natal streams. Two factors contributing to this trend were the possibility of harvesting salmon at times when local stocks were unavailable because of run timing or depletion, and the harvesting of fish before they became available to other fisheries. Off the coast of the United States troll fisheries targeting chinook and coho salmon developed (largely to avoid the closures imposed on river fisheries to protect stocks) and purse seine gear came into use in pink, chum, and sockeye fisheries. The Japanese began using drift gill nets which enabled the development of a high-seas mothership fleet off the coast of Kamchatka, and shore-based fisheries in the Kuril Islands.

Increasing catch of salmon stocks offshore led to a period, in the latter half of the twentieth century, of increasing international collaboration on research and management of Pacific salmon fisheries. One of the underlying principles of international management in the twentieth century has been that salmon belong to the countries in which they originate. Because of this principle, much of the research has focused on the migration and distribution of different stocks, and on methods to determine the origin of salmon encountered on the high seas. This principle of ownership has also encouraged the escalation of hatchery production.

Gear Types

Aboriginal fisheries traditionally used a variety of gear to harvest salmon. Weirs and traps were employed throughout North America and Asia and were probably the most common and efficient means of harvest. Spears and dipnets were also widely used. North American tribal fishermen also used hook and line, bow and arrow, gill nets, seines, and an elaborate gear called a reef net. The reef net was employed in northern Puget Sound to target primarily Fraser River sockeye salmon. It consisted of a rectangular net, suspended between two canoes in shallow water in the path of migrating salmon and was fished on a flood tide. Leads helped to direct fish into the net, which was raised when fish were seen swimming over it.

Commercial fisheries in Asia have primarily utilized traps in coastal waters, and seines and weirs in the rivers. In the early twentieth century the Japanese began using drift gill nets largely to avoid the uncertainty of retaining access to trap sites in Kamchatka. This allowed the Japanese to harvest salmon stocks originating from Kamchatka and the Sea of Okhotsk outside of Russian territorial waters and ultimately led to the development of the Japanese high-seas mothership fishery. Today traps remain the most prevalent and efficient gear used in Asian coastal fisheries.

In North America, early commercial fisheries primarily used haul seines and gill nets. Traps were employed very effectively in the Columbia River, Puget Sound, and Alaska, and fishwheels were also used on the Columbia River and in Alaska. Traps are no longer permitted in North America, and fishwheels are only used in Alaskan subsistence fisheries and as experimental gear in tribal fisheries in British Columbia. As internal combustion engines came into use by the fishing fleet, troll and purse seine gears were developed to target salmon in coastal waters.

Catch

Since 1950, the catch of Pacific salmon has been dominated by pink and chum salmon, followed by sockeye, coho, and chinook salmon (**Figure 1**). Masu salmon are relatively uncommon, and spawn only in Japan and rivers entering the Seas of Japan and Okhotsk. They account for 1000–3000 tonnes per year, nearly all of that in Japan. Total harvest of Pacific salmon was relatively stable at around 400 000 tonnes during the 1950s, 1960s, and 1970s, but has increased dramatically since the 1970s, reaching a peak of more than 1 million tonnes in 1995. This has been due to increases in harvest of chum salmon in Japan, and in pink and sockeye salmon, primarily in Alaska (**Figure 2**). It is noteworthy that these three species have fundamentally different marine distributions to chinook and coho salmon. Chinook and coho salmon tend to have more coastal distributions while sockeye, pink, and chum undergo extensive marine migrations and have more offshore distributions. These differences in marine distributions have apparently contributed to differences in abundance trends in response to environmental changes like El Niño-Southern Oscillation (ENSO) events and regime shifts occurring on decadal scales.

Chinook Salmon

Harvest of chinook salmon in the North Pacific has been variable but has been relatively stable since 1950, at least until the 1990s (**Figure 3**). Until the last couple of years, total production has varied between 15 000 and 30 000 tonnes with the bulk of production coming from North America. Average annual total harvest from the North Pacific for the 5 years period from 1994 through 1998 has been 18 000 tonnes including production from aquaculture, with approximately 10 000 tonnes coming from capture fisheries.

Chinook salmon originate primarily from large river systems, with the Columbia, Fraser, Sacramento, and Yukon Rivers being the largest producers. Historically the majority of the chinook harvest came from the USA, but recent environmental conditions have impacted southern stocks and the

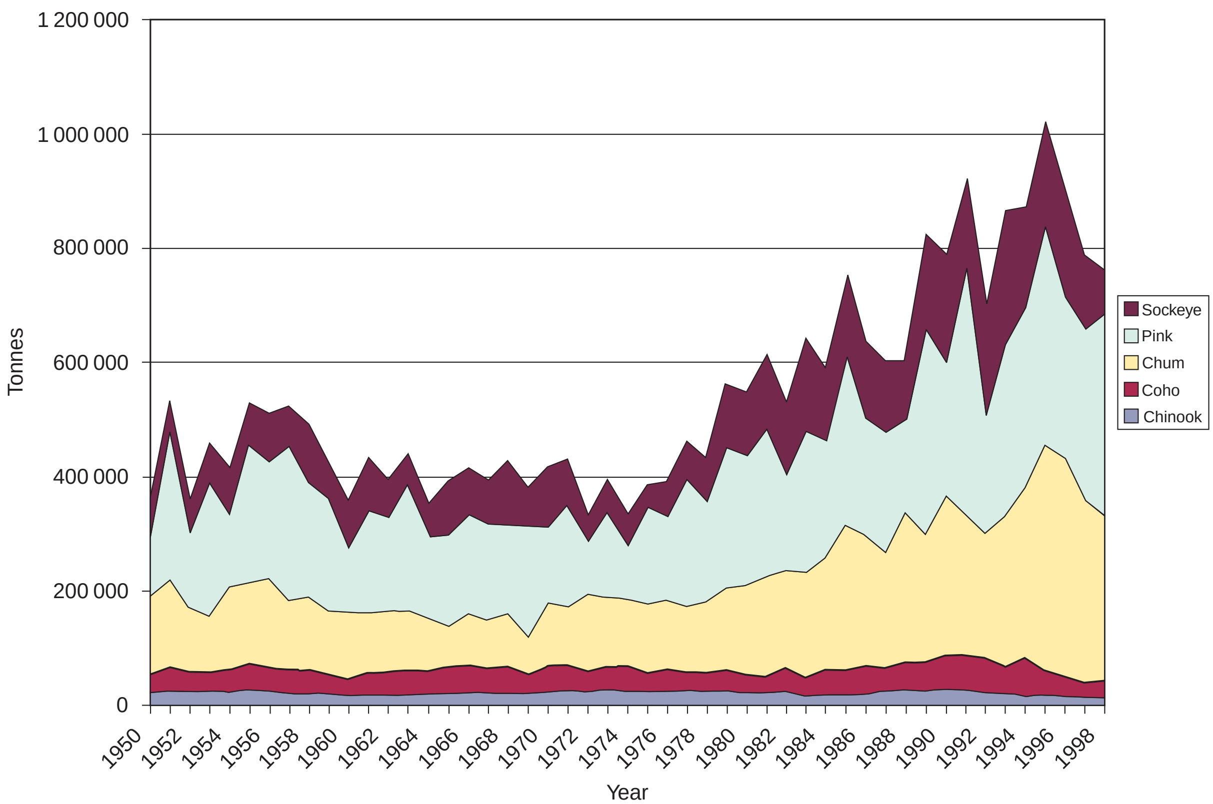

Figure 1 Commercial harvest of Pacific salmon in the North Pacific Ocean by species. Harvest includes both commercial capture fisheries and aquaculture. (Data from FAO Fishstat database.)

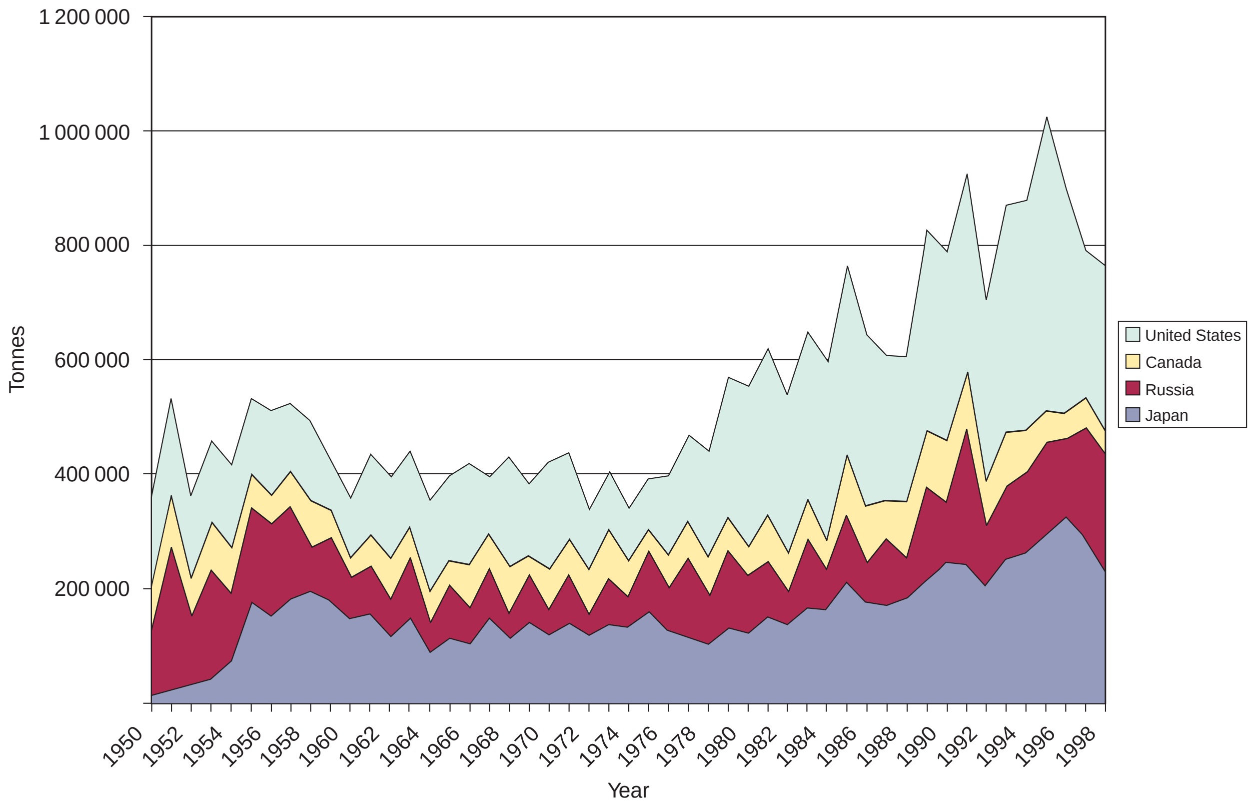

Figure 2 Commercial harvest of Pacific salmon by major fishing nations. (Data from FAO Fishstat database.)

harvest in Canada has surpassed that of the USA. Two pronounced dips in production, in early 1960s and 1980s, immediately followed strong ENSO events in 1959 and in the winter of 1982–83. The decline in production in the 1990s has also been associated with a series of ENSO events.

A trend which is not apparent in **Figure 3** is the shift from natural to hatchery production and aquaculture. During the latter half of the twentieth century there was a transition from predominantly naturally produced chinook salmon to production that is dominated by hatchery fish. Annual releases of hatchery chinook salmon have increased from approximately 50 million juveniles in 1950 to an average of 317 million from 1993 to 1995. The increase in Canadian landings in the late 1980s is coincident with the rapid expansion of a Canadian hatchery program throughout the 1980s. In recent years, poor marine survival, and conservation concerns for natural stocks have led to reductions in harvest in both the USA and Canada.

In the last decade, there has been a rapid increase in production of chinook salmon through aquaculture in net pens (**Figure 4**). While Canada is a major producer of pen-reared chinook salmon, the bulk of this production now comes from the Southern Hemisphere, primarily from Chile and New Zealand.

Coho Salmon

Many aspects of the history of coho salmon production are very similar to that of chinook salmon production. Like chinook salmon, harvest of coho salmon in the North Pacific has been variable, but relatively stable until the last few years, with most of the production coming from North America (**Figure 5**). Production has varied from 30 000 to 60 000 tonnes, dipping below 30 000 tonnes following the strong ENSO events in 1959 and 1982. North American coho stocks have also suffered from poor marine survival in recent years, and conservation concerns have prompted reductions in harvest. Average annual production from the North Pacific from 1994 through 1998 have been 38 000 tonnes, with 24 000 tonnes coming from capture fisheries.

Like chinook there has also been a shift from natural production to hatchery production and aquaculture. Hatchery releases have increased from approximately 20 million juveniles in 1950 to an

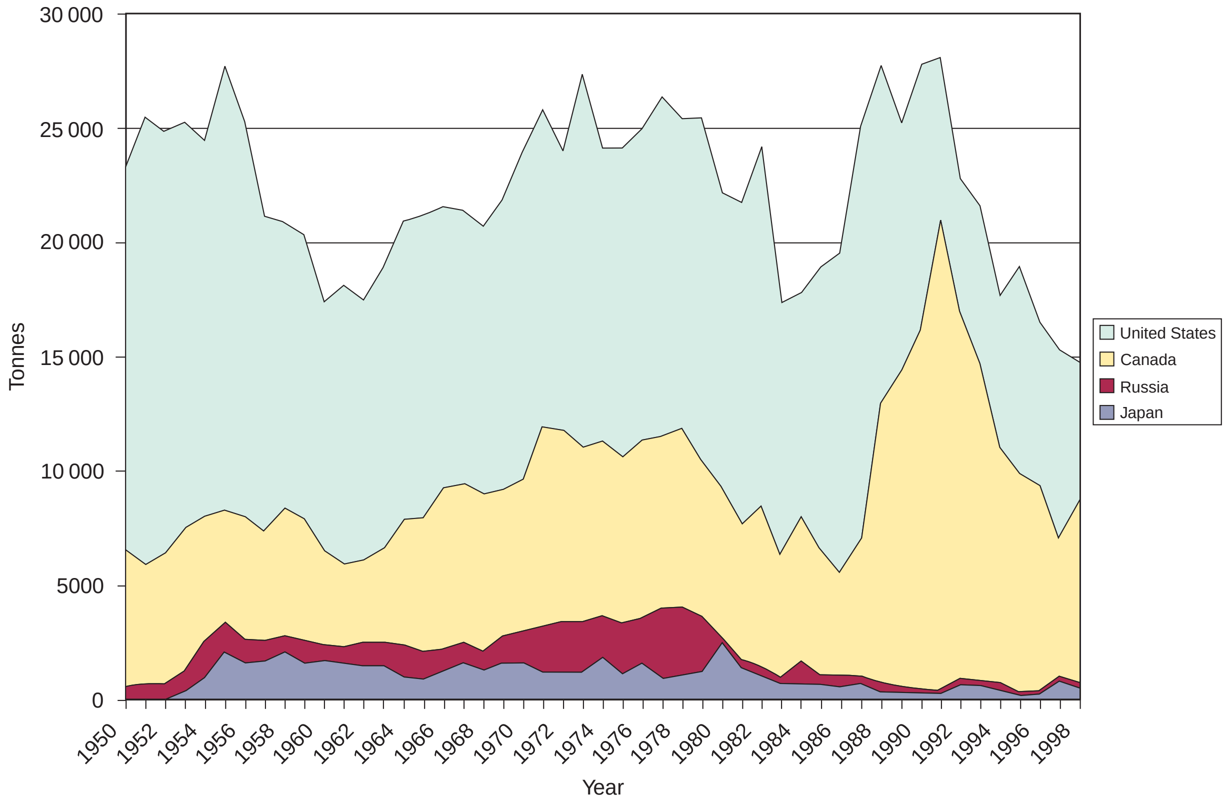

Figure 3 Commercial harvest of chinook salmon by major fishing nations in the North Pacific Ocean. Harvest includes both capture fisheries and aquaculture. (Data from FAO Fishstat database.)

average of 111 million juveniles annually from 1993 to 1995. Much of the increase in production by Japan in the 1980s was from aquaculture. The shift from capture fisheries to aquaculture production has been even more dramatic for coho salmon than for chinook (**Figure 6**). While Japan was the largest producer of pen-reared coho in the late 1980s and early 1990s, Chilean production has rapidly expanded in the 1990s and now exceeds all other production combined.

Sockeye Salmon

Sockeye harvest was relatively stable in the 1950s, varying between 50 000 and 100 000 tonnes, but reached a low point in the 1970s of $<40\,000$ tonnes (**Figure 7**). In the 1980s and 1990s, a combination of favorable marine conditions and harvest management that allowed sufficient spawning escapement led to dramatic increases in sockeye production in Alaska and the Fraser River in British Columbia. This has led to all-time record harvests in Alaska and the highest harvests in British Columbia since a blockage at Hell's Gate on the Fraser River devastated sockeye salmon runs in 1913 and 1914. The peak harvest exceeded 230 000 tonnes in 1993, and the average harvest from 1994 to 1998 was 148 000 tonnes annually.

Sockeye salmon have the most complex life history of any Pacific salmon. Most sockeye salmon rear in lakes for 1–3 years. They then migrate to the ocean where they spend from 1 to 4 years. Despite this variability, most spawning runs are dominated by fish of a single total age, usually either 4 or 5 years. The extended freshwater rearing period allows for interactions between successive year-classes within populations which contribute to cycles with periods of 4–5 years. While there is some evidence of cyclic dominance in the catch record, it is largely masked by aggregation of stocks in the fisheries. Differences in spawner abundance between peak and off-peak years in individual populations can be greater than an order of magnitude, and cycles can persist for decades.

Unlike chinook and coho salmon, most sockeye production is the result of natural spawning. While artificial production from 1993 to 1995 has averaged 326 million juveniles annually, 75% of this artificial production has been from natural spawning in artificial spawning channels.

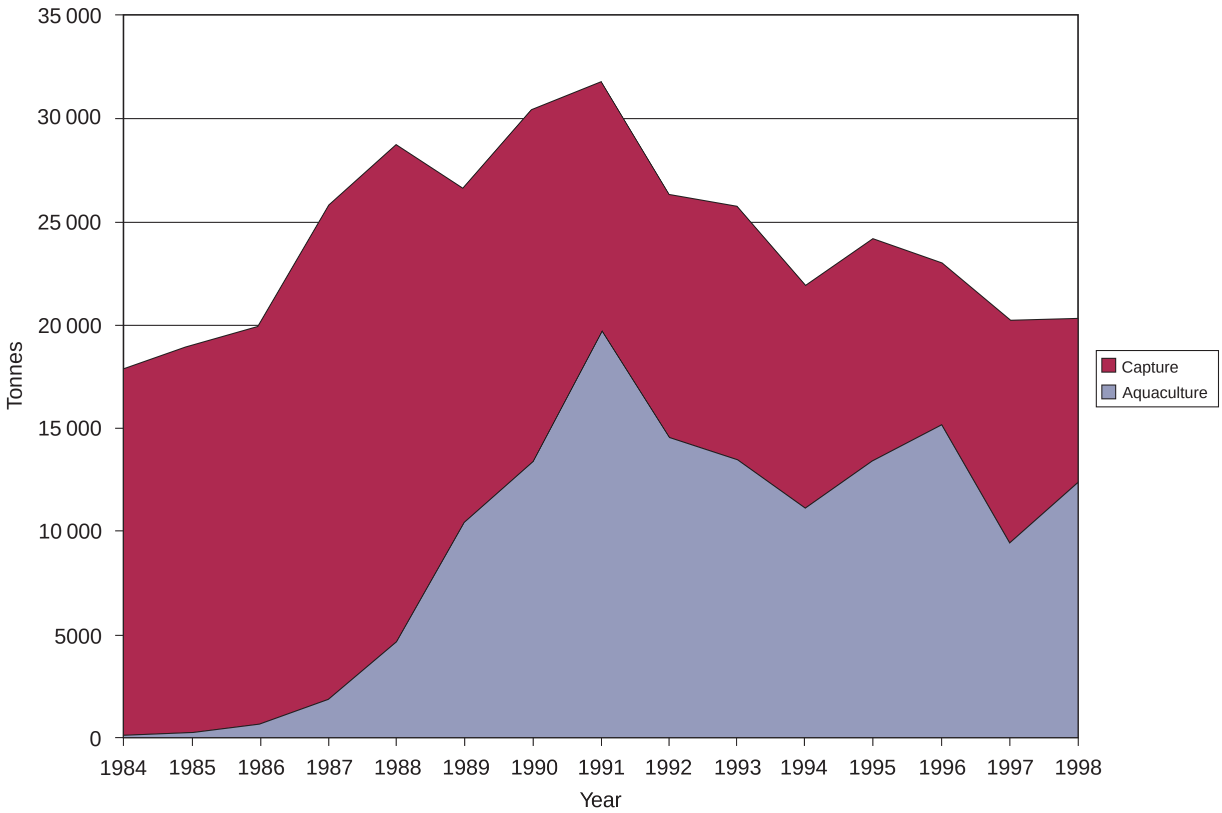

Figure 4 Total commercial production of chinook salmon in the Pacific basin. Most aquaculture production is in the Southern Hemisphere. (Data from FAO Fishstat database.)

Pink Salmon

Pink salmon are the most abundant species of Pacific salmon, but they also have the smallest average body size. Unlike other species of salmon, pink salmon all have a fixed 2 year life span. Because of this, the even-year and odd-year brood lines are genetically and demographically isolated, and tend to fluctuate independently with either the even-year or odd-year being dominant for long periods of time. In some streams only one of the brood lines is present. This is readily apparent in their harvest history (**Figure 8**), especially in Asian stocks where the odd-year brood line has been dominant.

The historical pattern of pink salmon harvest is similar to that of sockeye; landings were relatively stable in the 1950s and 1960s but declined slightly to reach a low in the early 1970s (**Figure 8**). Since the mid-1970s production has increased to recent record levels, reaching a peak harvest of $>430\,000$ tonnes in 1991. This increase has occurred in Russian and Alaskan harvested while Canadian harvest has been stable and Japanese harvest has declined. The average annual harvest of pink salmon from the North Pacific from 1994 through 1998 was 327 000 tonnes.

Russia and Alaska are also where most pink salmon originate. While natural production is the major source of pink salmon, Alaska, Russia, and Japan have significant hatchery programs. Japan has had a long-standing hatchery program that has increased gradually, while Alaska did not begin hatchery production of pink salmon until the 1970s, but has expanded rapidly to surpass all others combined.

Chum Salmon

Like pink and sockeye salmon, the harvest of chum salmon declined in the 1950s and 1960s, and has increased to record levels in the 1990s (**Figure 9**). However, there is a fundamental difference between the production history of chum salmon and those of pink and sockeye salmon. North American production has been relatively stable and natural production in Asia has declined while there has been a large increase in Japanese hatchery production. The decline in Asian natural production is greater than is apparent from the catch history of Russian fisheries because the Japanese catch in

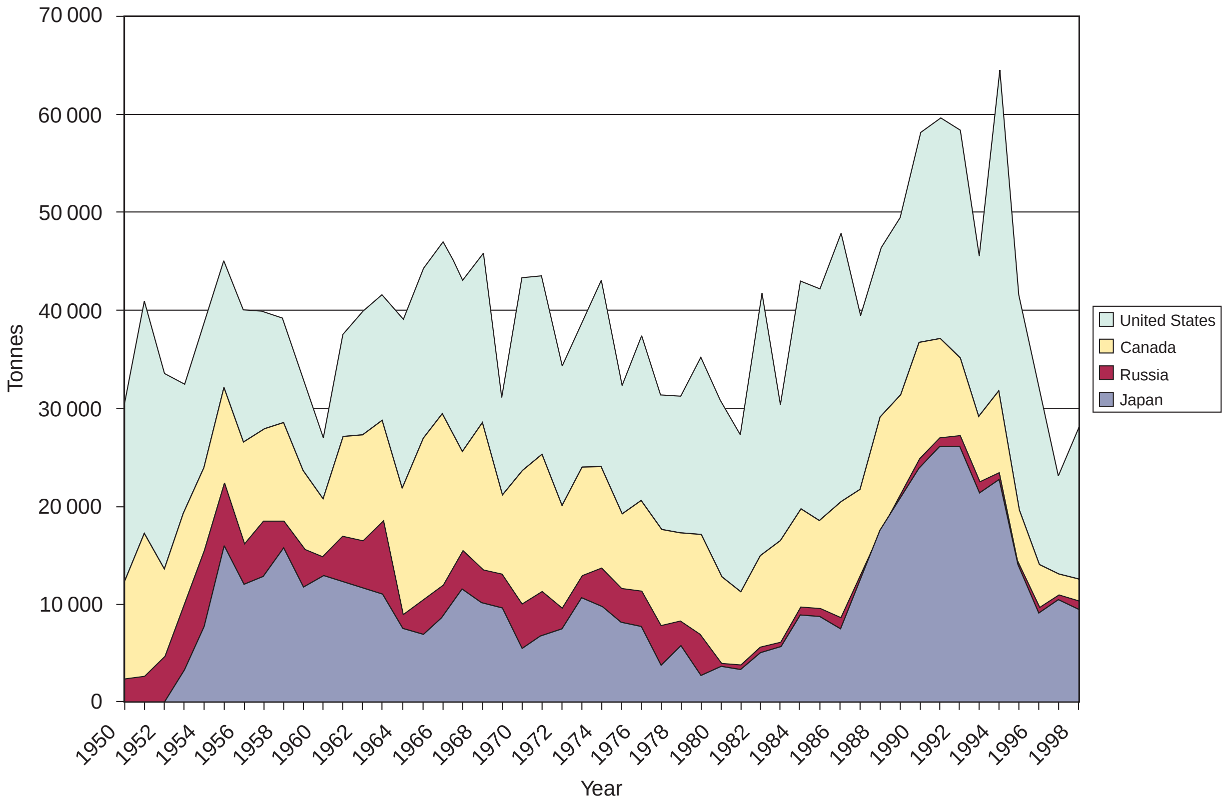

Figure 5 Commercial harvest of coho salmon by major fishing nations in the North Pacific Ocean. Harvest includes both capture fisheries and aquaculture. (Data from FAO Fishstat database.)

the 1950s and 1960s was primarily from high-seas fisheries, while the recent Japanese catch has been predominantly from coastal fisheries targeting returning hatchery fish from Hokkaido and northern Honshu.

Issues

Hatcheries

Pacific salmon fisheries are unique among marine commercial and recreational fisheries in the scale of their dependence on artificial propagation. Because freshwater habitat is often the factor most limiting to salmon production, massive artificial propagation programs have been implemented for all species of Pacific salmon to enhance fisheries, and as mitigation for freshwater habitat losses.

While hatcheries have augmented the abundance of salmon, there is increasing concern over potentially deleterious effects of hatcheries on natural salmon populations. Mixed stock fisheries targeting abundant hatchery stocks can overharvest less productive natural stocks that are intermingled with the hatchery fish. Hatchery stocks often differ genetically from the local natural stocks because the original broodstock for the hatchery may have been obtained from a nonlocal population or hatchery, hatchery breeding practices which unintentionally exert selection pressure for particular traits, and because of domestication through adaptation to hatchery rearing conditions. Stray spawners from the hatcheries can make natural stocks appear more productive than they really are, and interbreeding between natural and hatchery stocks can further reduce the productivity of natural stocks through outbreeding depression.

While artificial propagation is widespread, the focus has been on different species in different areas.

In the contiguous United States, the focus of artificial propagation has been on chinook and coho salmon. Hatchery programs exist in most rivers that support chinook and coho populations, and hatchery releases from 1993 through 1995 have averaged approximately 71 million coho and 252 million chinook annually. Alaska and Canada also have hatchery programs, but their combined releases in the same period have averaged about 38 million coho salmon and 64 million chinook salmon annually. Hatchery fish account for the majority of the harvest of these two species in the contiguous United States.

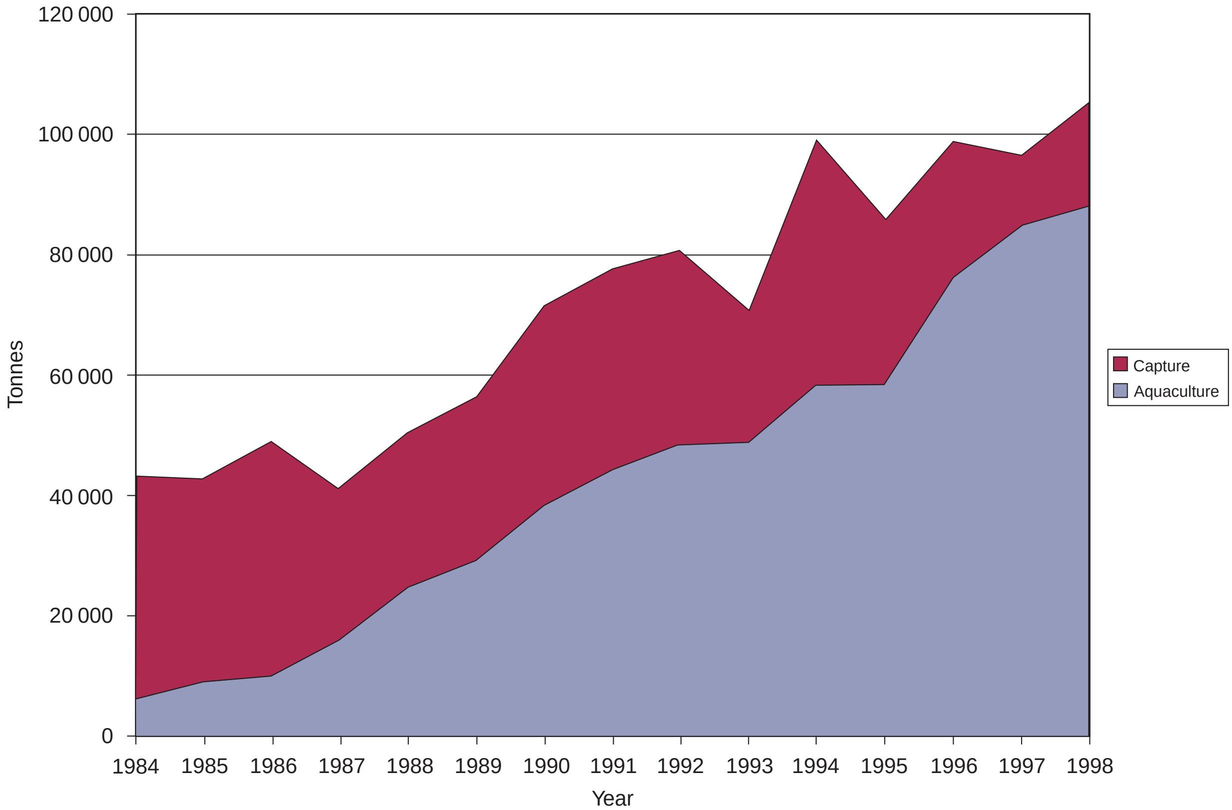

Figure 6 Total commercial production of coho salmon in the Pacific basin. Most aquaculture production is in the Southern Hemisphere. (Data from FAO Fishstat database.)

Canada has the largest program for artificial production of sockeye salmon, but the majority of this is in the form of artificial spawning channels in the Fraser River system. In these artificial channels adults spawn naturally and juveniles emigrate to lakes for rearing without being artificially fed. This program has developed rapidly since 1960 and the 1993–95 average annual production was approximately 244 million fry. Alaska has the largest hatchery program for sockeye smolts with annual production that has averaged approximately 69 million.

Alaska also has the largest hatchery program for pink salmon. This program has expanded rapidly since the 1970s. Annual releases of hatchery fry averaged 843 million from 1993 to 1995, and returns from this program have contributed substantially to the increases in landings of pink salmon in recent years. Over the same period, Japanese hatcheries have released an annual average of 132 million, and Russian hatcheries, 264 million pink salmon fry.

The largest Pacific salmon hatchery program is operated by the Japanese for chum salmon. Japan's chum salmon hatchery program dates back to 1888 when the national salmon hatchery was built in Chitose on Hokkaido. This program released 200 000–500 000 juveniles annually in the 1950s, but expanded rapidly in the 1970s. From 1993 to 1995 Japanese hatcheries released an average of more than 2 billion chum salmon fry annually. During the same period, Canada and the Russian Federation each released an average of 220 million hatchery chum salmon annually, and annual releases from US hatcheries have averaged more than 500 million hatchery chum salmon fry. Combined, these programs have been releasing nearly 3 billion chum salmon juveniles per year, nearly 60% of the hatchery production of all Pacific salmon combined.

The recent and rapid increase in hatchery production of salmon, coupled with the increase in total landings and a concurrent decline in the average size of individuals of all salmon species has raised concerns, and prompted research into the possibility that ocean carrying capacity is currently limiting production of salmon in the North Pacific Ocean.

International Management

One of the challenges in management of Pacific salmon fisheries is the direct result of their

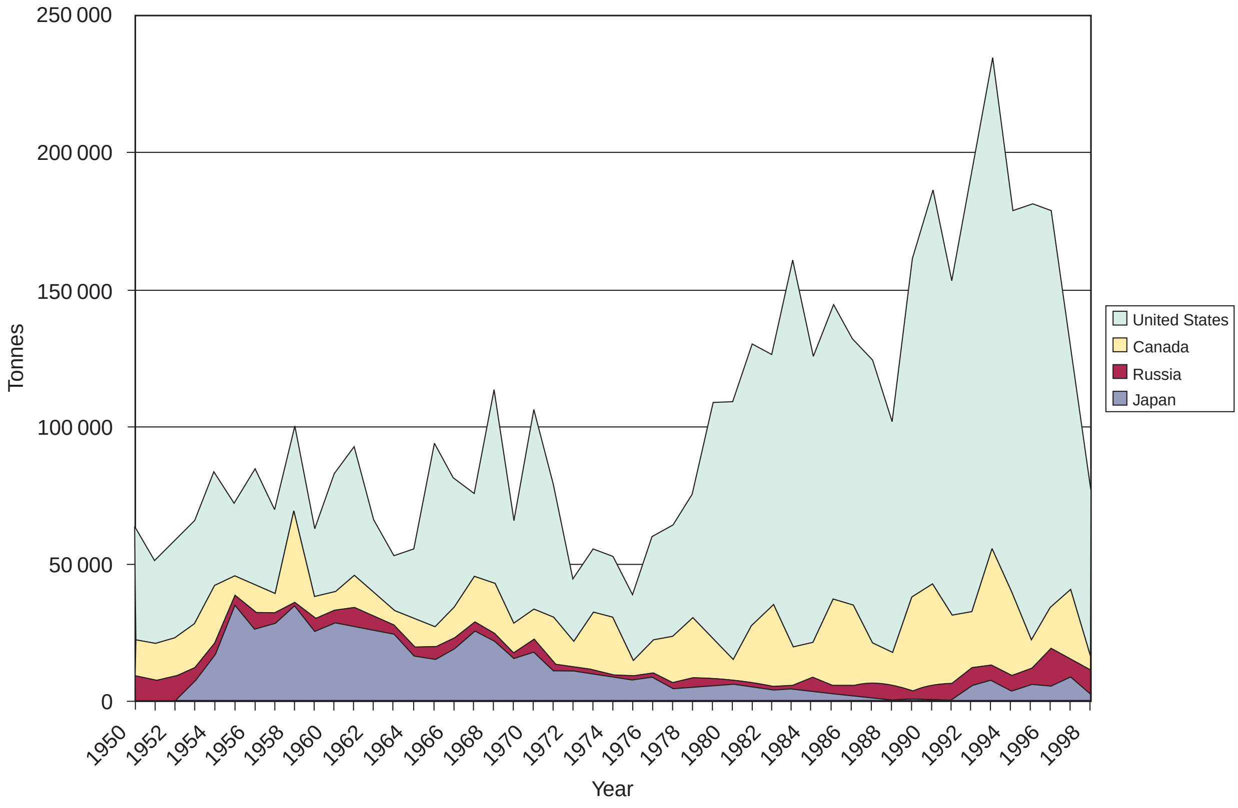

Figure 7 Commercial harvest of sockeye salmon by major fishing nations. (Data from FAO Fishstat database.)

anadromous life history. Although stocks are genetically distinct, and segregate at spawning, they undergo extensive marine migrations and co-mingle in the ocean. This characteristic makes stocks vulnerable to interception in foreign fisheries. Countries harvesting Pacific salmon have long recognized the need for international coordination of harvest management, but cooperation has been an ongoing challenge complicated by international relationships that have been less than cordial at times.

Japanese have fished for salmon along the coasts of Sakhalin, Kamchatka, and the Kuril Islands at least since the early seventeenth century. In the early nineteenth century, Russia levied a tariff on salmon exported to Japan, and in the 1890s Russia began to restrict Japanese access to trap sites. Through the early part of the twentieth century relations between Japan and Russia became increasingly strained and the Japanese fishing industry generally had increasing difficulty accessing traditional shore-based trap sites in Russia. This encouraged the development and expansion of Japanese high-seas drift gill net fisheries in the western Bering Sea and southern Sea of Okhotsk and of shore-based trap and gill net fisheries in the Kuril Islands targeting salmon stocks originating primarily from the Sea of Okhotsk. During World War II Japan lost all access to trap sites in the Soviet Union, and the Japanese high-seas fishery ceased. At the end of the war, the Soviet Union took possession of the Kuril Islands and Japanese fisheries based in the Kuril Islands ceased as well.

In 1952, the governments of Canada, Japan, and the USA signed the International Convention for the High-Seas Fisheries of the North Pacific Ocean which established the International North Pacific Commission (INPFC). Under the terms of this Convention, Japan resumed and rapidly expanded their high-seas salmon fishery in the northern Pacific Ocean, Bering Sea, and the southern portion of the Sea of Okhotsk. The primary management action of the INPFC was to set an eastern limit on the extent of high-seas fishing, but it also embarked on a large-scale research program directed at addressing issues relevant to the Commission with much of the focus on stock identification, distribution, and migration patterns. Because the Japanese high-seas fishery targeted Asian stocks, mostly from the Soviet Union, the Soviet Union responded by excluding the Japanese high-seas fishery from the Sea of Okhotsk and a large portion of the western Bering Sea. This action led to the negotiation of a Convention between Japan and the USSR in 1957 which

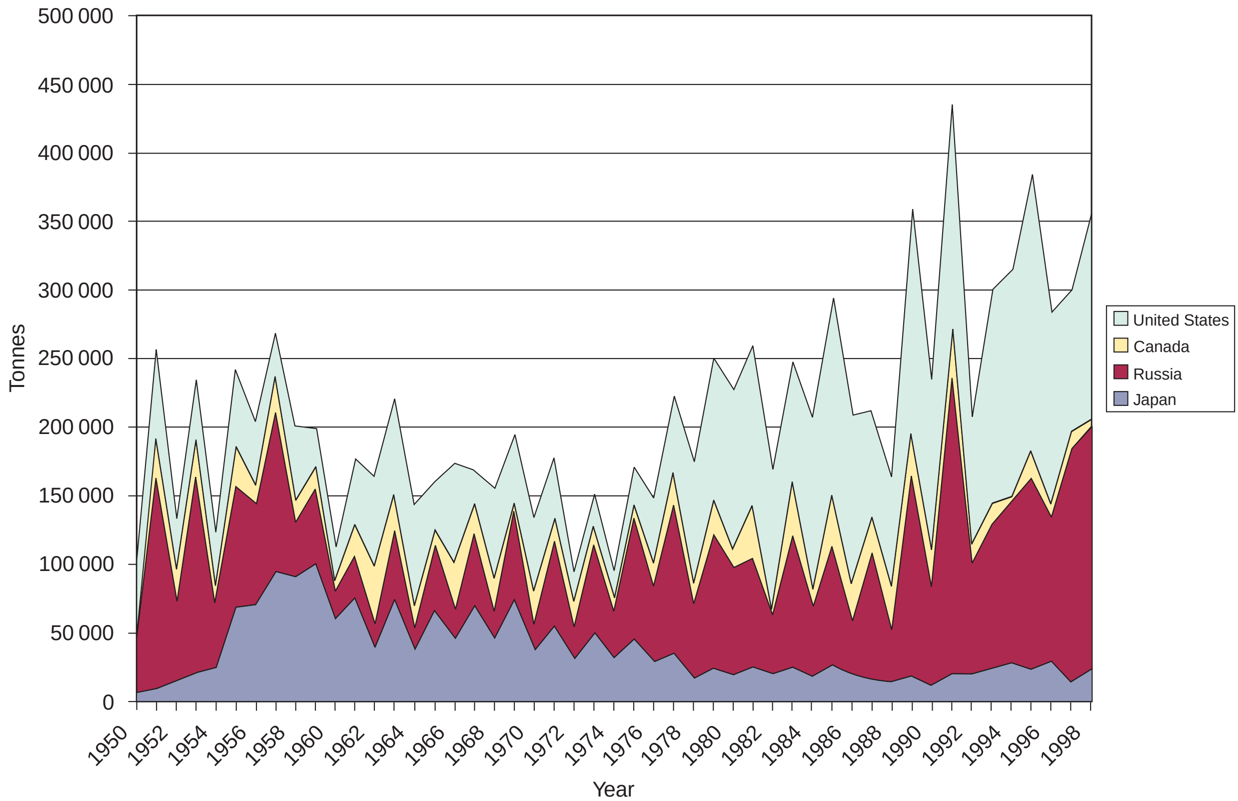

Figure 8 Commercial harvest of pink salmon by major fishing nations. (Data from FAO Fishstat database.)

established the Soviet–Japan Fisheries Commission to regulate the harvest of Asian salmon stocks on the high-seas.

In the late 1970s, leading up to adoption of the United Nations Convention of Law of the Sea in 1982, the USA, Canada, and the Soviet Union established 200 mile fishery zones off their coasts. This further reduced the areas accessible to high-seas fisheries. In 1993 the North Pacific Anadromous Fisheries Commission (NPAFC) replaced the INPFC with Japan, the Russian Federation, Canada, and the USA as members. Between the NPAFC Convention, which prohibits high-seas salmon fishing and trafficking in illegally caught salmon, and the United Nations General Assembly Resolution 46/215, prohibiting large-scale pelagic drift gill netting, high-seas fisheries for Pacific salmon have been eliminated except for illegal fishing.

In North America, much of the focus of international management has been on the Fraser River run of sockeye salmon. This was the largest run of sockeye in North America, and one of the most profitable for the canning industry in the late nineteenth century and early twentieth century. Returning adult Fraser River sockeye have two migratory approaches to the Fraser River: the southern approach through the Strait of Juna de Fuca of the south of Vancouver Island where they are vulnerable to American fisheries, and the northern approach through the Johnstone and Georgia Straits which lies entirely within Canadian waters. In most years the majority of the run has taken the southern approach where it was intercepted by US fisheries, causing persistent friction between the two countries.

The need for cooperative management of the fisheries in these southern boundary waters was recognized by both countries. Beginning in the 1890s, a series of commissions were formed to study the problem and make recommendations. In 1913 the Fraser River was obstructed by debris from railroad construction at Hell's Gate in the Fraser River Canyon. This passage problem was exacerbated by a rock slide caused by the construction in 1914 which effectively destroyed the largest, most productive sockeye run in North America. This had devastating impacts on inland native tribes who depended on salmon as a dietary staple, and had lasting impacts on the commercial fisheries as well. The desire to restore Fraser River sockeye production increased the incentive for cooperation, but it has been a long and difficult process.

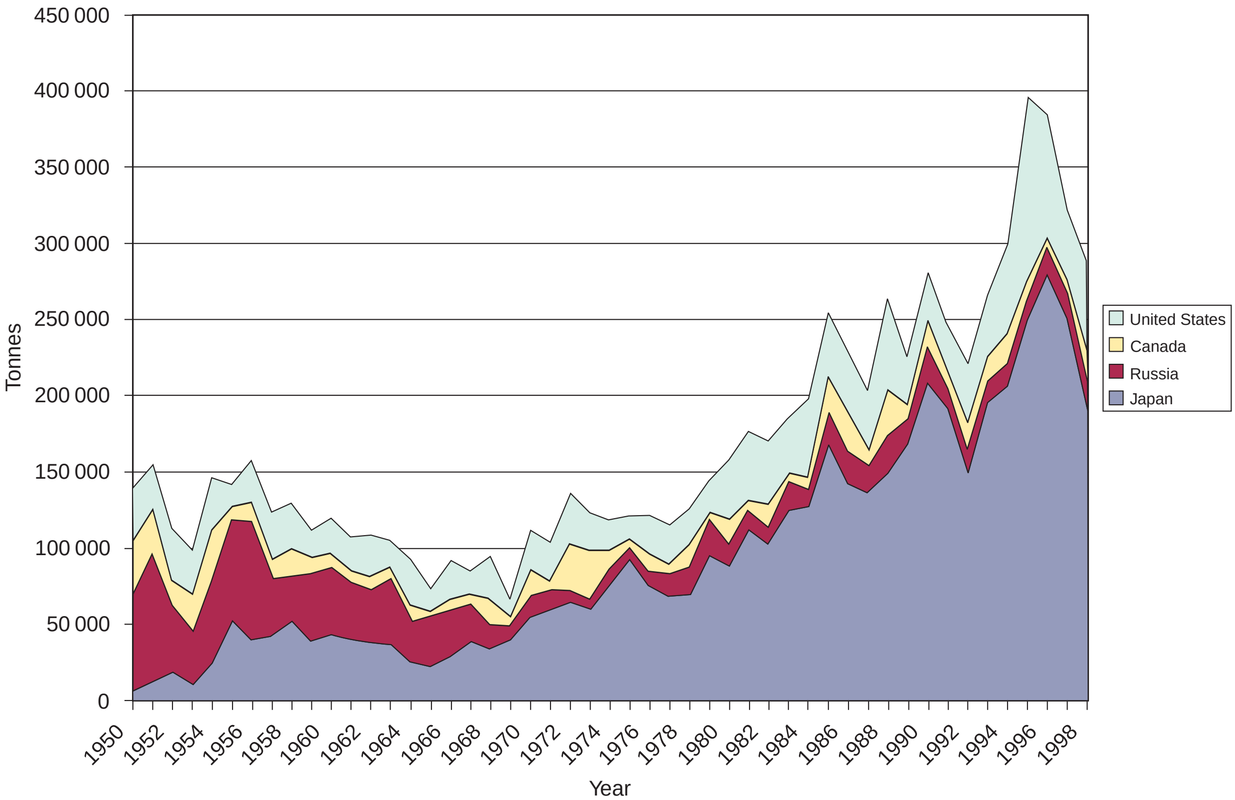

Figure 9 Commercial harvest of chum salmon by major fishing nations. (Data from FAO Fishstat database.)

Bilateral treaties were signed in 1908, 1919, and 1929, but enabling legislation was never passed by the US Congress. The 1929 treaty was amended and again signed in 1930 but was not ratified until 1937, 45 years after negotiations had started. The treaty established the International Pacific Salmon Fisheries Commission (IPSFC) to study and restore Fraser River sockeye salmon, and manage sockeye fisheries in Convention waters of the southern approach to the Fraser River, but postponed any regulatory authority for another 8 years. The IPSFC constructed many fish passage structures in the Fraser River basin, and its authority was extended to include pink salmon with the addition of a pink salmon protocol in 1957.

In 1985 a new treaty was signed and ratified that replaced the IPSFC with the Pacific Salmon Commission (PSC). The PSC has expanded authority, which includes all five species of Pacific salmon harvested in North America, and encompasses marine boundary waters of the northern and southern Canada–US borders, and transboundary rivers passing through Canada and south-east Alaska. However, the effectiveness of the PSC has been hampered by the inability to come to unanimous agreement on allocation issues in some years.

Endangered Species

Because of their dependence on freshwater habitat, anadromous fish are vulnerable to habitat degradation resulting from human activities in inland areas. The requirements of Pacific salmon for spawning gravel free of fine sediments and cold oxygenated water for spawning and juvenile rearing make them particularly vulnerable to habitat loss and degradation from nearly all human activities where salmon and people co-occur. Construction of impassable dams for flood control, hydropower, and irrigation has eliminated access to much historic habitat. Stream channelization and levee construction for flood control has reduced habitat availability and complexity. Logging has resulted in scoured stream channels, increased runoff and sediment loads, and has diminished the availability of shade and large woody debris which provides rearing habitat. Mining has directly destroyed stream channels and choked streams with sediment, as well as contaminating the water with heavy metals. Water diversions for agricultural, industrial, and domestic use have reduced the water available and directly removed juvenile salmon. Grazing has increased sedimentation and destroyed streamside vegetation.

Home construction and urbanization have contributed to sedimentation and chemical pollution, and have increased the amount of impervious surface, increasing the variability in stream flow.

Collectively these impacts have eliminated many populations of Pacific salmon and have compromised the productivity of many remaining ones. Reduced productivity of natural stocks has increased their susceptibility to overharvest, and the construction of hatcheries to mitigate the impacts of water development projects and enhance fisheries has often exacerbated the problem by increasing competition between natural and hatchery fish and increasing the harvest pressure on all fish in the attempt to harvest hatchery fish. As a result, many natural populations are at critically low abundance where they are at higher risk of extirpation from random environmental and demographic variability or from catastrophic events. As a result, a number of distinct population segments of Pacific salmon and steelhead trout in the contiguous United States have been listed as threatened or endangered under the US Endangered Species Act. At the time of writing (2000) the listings include 17 distinct population segments of chinook, coho, chum, and sockeye salmon, and another 10 distinct population segments of steelhead trout. The additional regulatory complexities of dealing with listed species has greatly complicated the management of Pacific salmon fisheries in the USA.

In response to these listings, and critically low abundance of some Canadian stocks, harvest impacts on depressed stocks have been substantially reduced in the contiguous United States and British Columbia. Efforts are being made to reduce the combined negative impacts of habitat loss and degradation, overharvest, and the negative impacts of hatchery production. Fishery scientists and managers are exploring changes in harvest practices to allow more selective harvest of hatchery stocks and healthy natural stocks while reducing impacts on listed stocks.

See also

El Niño Southern Oscillation (ENSO). Fishing Methods and Fishing Fleets. International Organizations. Law of the Sea. Ocean Ranching. Salmonid Farming. Salmonids.

Further Reading

Cobb JN (1917) *Pacific Salmon Fisheries*. Bureau of Fisheries Document No. 839. Washington, DC: Government Printing Office.

Groot C and Margolis L (eds) (1991) *Pacific Salmon Life Histories*. Vancouver, BC: UBC Press.

McNeil WJ (ed.) (1988) *Salmon Production, Management and Allocation*. Corvallis, OR: Oregon State University Press.

NMFS (1999) *Our Living Oceans. Report on the Status of US Living Marine Resources, 1999*. US Department of Commerce, NOAA Technical Memo. NMFS-F/SPO-41.

Shepard MP, Shepard CD and Argue AW (1985) *Historic Statistics of Salmon Production Around the Pacific Rim*. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1819, 297 pages.

SALMONIDS

D. Mills, Atlantic Salmon Trust, UK

doi:10.1006/rwos.2001.0018

Introduction

The Atlantic and Pacific salmon and related members of the Salmonidae are anadromous fish, breeding in fresh water and migrating to sea as juveniles at various ages where they feed voraciously and grow fast. Survival at sea is dependent on exploitation, sea surface temperature, ocean climate and predation. Their return migration to breed reveals a remarkable homing instinct based on various guidance mechanisms. Some members of the family, however, are either not anadromous or have both anadromous and nonanadromous forms.

Taxonomy

The Atlantic salmon (*Salmo salar*) and the seven species of Pacific salmon (*Oncorhynchus*) are members of one of the most primitive superorders of the teleosts, namely the Protacanthopterygii. The family Salmonidae includes the Atlantic and Pacific salmon, the trout (*Salmo* spp.), the charr (*Salvelinus* spp.) and huchen (*Hucho* spp.). The anatomical features that separate the genera *Salmo* and *Oncorhynchus* from the genus *Salvelinus* are the positioning of the teeth. In the former two genera the teeth form a double or zigzag series over the whole of the