# PERSPECTIVES OF NORTH PACIFIC SALMON SEA RANCHING

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## ABSTRACT

Public sea ranches have existed in most Pacific rim nations since the late 1800s. In the 1970s, private sea ranches were permitted in some coastal regions of North America (California, Oregon, Alaska). These private sea ranches added substantially to the salmon migrants already being released by public hatcheries in Japan, USSR, USA, and Canada.

Private sea ranching was initially seen as a way to offset the high cost of public hatcheries and to provide fish to the common property fishery as well as to private sea ranchers. However, social, institutional, and biological roadblocks constrain the development of these systems in North America. Paradoxically, some fishermen fear the political power of large corporate sea ranchers and have opposed further development. Over-optimism by corporate planners combined with perceived biological constraints of the freshwater/marine ecosystems have also slowed development of private sea ranching.

This paper examines the status of sea ranching in the context of massive salmon releases now made from public hatcheries. Topics include: historical salmon harvest and the recent dependence on releases from public hatcheries and sea ranches; the possible harmful interaction of wild and hatchery fish; and the perceived problems of ocean carrying capacity.

## INTRODUCTION

> "It was the best of times, it was the worst of times,
> it was the age of wisdom, it was the age of foolishness."

Dr. Peter Larkin chose this appropriate Dickens' quotation to begin his stimulating 1980 lecture series on Pacific salmon. His point is even more pertinent today; it is at once the worst of times and the best of times for Pacific salmon. The management of this valuable resource, the decline of freshwater habitat, and the anarchic nature of the fishery itself make it the worst of times. But the scientific understanding of salmon biology and the ability to enhance the resource through hatcheries create an optimism that make it the best of times.

This paper outlines the development of salmon sea ranching in the North Pacific Ocean. It reviews past and present trends in public salmon ranching and addresses some of the pressing biological problems facing the emerging private sea ranching industry.

Much has been written about the 'recent' development of sea ranching. The fact is that sea ranching was developed in the 19th century and since the late 1950s has played a prominent and important role in the enhancement of the common property salmonid resource in Pacific rim nations. The technology developed at these public sea ranches provided a relatively sophisticated base for the fledgling private sea ranching industry. Without this technological base, the rapid expansion of private sea ranching would not have been possible. Commercial salmon ranching is nothing more than the franchising of hard-learned government hatchery technology. Therefore it is difficult to address private sea ranching outside of the historical context of the public/private chum salmon hatchery systems of Japan or the public enhancement programmes for chinook and coho salmon in the north western USA. Furthermore, it is possible that competition between the emerging private corporate sea ranches and public hatcheries is the major force hindering development of private commercial sea ranching.

Thorpe (1980) defined salmon ranching as, 'An aquaculture system in which juvenile fish are released to grow, unprotected, on natural foods in marine waters from which they are harvested at marketable size'. Sea ranching in the North Pacific includes both public and private facilities for the release of anadromous salmonids. Sea ranches are sometimes defined as private facilities land-based near the ocean and where returning adults can be captured. But most public hatcheries also fit this definition; the major difference is the harvest management. Public hatcheries expect releases to be exploited at a high rate by the fishery sometimes hundreds of miles from that site, for example, the coastal troll fishery of Washington and Oregon. State, federal, provincial, and prefectural agencies programme the smallest possible escapement to meet the egg-take requirements for hatcheries. Private sea ranches strive to return a maximum of bright adults to the land-based release site. However, in the overall context of hatchery technology, stock preservation, and ocean carrying capacity, these differences are minor. In the large picture, the public and private sea ranches should be considered as the same.

## DEVELOPMENT OF ARTIFICIAL PROPAGATION

For salmon, the earliest recorded enhancement efforts were in 18th century Japan when, in 1716, a samurai named Buheji Aoto fenced a stream to protect spawning salmon, a primitive artificial spawning channel (Atkinson, 1976).

Modern scientific fish culture in the Pacific began with the development of commercial salmon fisheries in North America. The first effort in artificial propagation of Pacific salmon in North America was a hatchery on the McCloud River in California in 1872. This hatchery was to obtain chinook salmon eggs for Atlantic Ocean tributaries to establish runs replacing depleted Atlantic salmon. The philosophy of the time was to exchange depleted native species with new species.

As native salmon runs declined under intensive fishing, artificial propagation was invoked to sustain or increase run sizes. Hatcheries were established along the west coast of North America in the 1880s and 90s and in Japan a hatchery opened in 1889. Much of the early propagation was of ova and fry. By the 1920s it was apparent that such hatchery production contributed little to maintaining runs.

In the 1920s-30s, the economic feasibility of hatcheries was questioned, and some hatcheries were closed after production records indicated unacceptable costs per fish returned. From the 1930s to the 1950s, hatcheries were subordinated to the enhancement of natural reproduction through improved fish passage, predator control, and development of spawning channels.

In the 1950s and 60s, advances in the knowledge of feeds, diseases, and the early life history of Pacific salmon led to improved survival of hatchery fish. These improvements increased management's reliance on hatchery fish. Through the 1970s, public sea ranches expanded rapidly, augmented by private corporate sea ranches in Oregon and private non-profit making sea ranches in Alaska.

Pink Salmon (Oncorhynchus gorbuscha)

Pink salmon, the most abundant Pacific salmon species, spawns from Puget Sound to Kotzebue Sound in North America and from Bering Strait to Hokkaido, Japan, in Asia. The harvest of pink salmon in the north western Pacific Ocean where odd-year runs dominate is approximately twice that in North America (Figure 1). In North America, pink salmon are harvested primarily in British Columbia and in central and south eastern Alaska.

The time series of pink salmon catches shows that catches in Asia are much reduced compared to catch levels prior to World War II (Figure 1). In North America, the catch trend has been downward in Alaska and Washington but relatively stable in British Columbia. Catches since the 1970s in Asia and North America increased primarily as a result of increased hatchery production and favourable environmental conditions. Both USSR and Alaskan fisheries are benefiting from sea ranch releases. Benefits are more evident in the USSR where a significant sea ranching system has existed since the 1950s and which now releases an estimated 600 million fry annually. Asian stocks in 1982 were enhanced from USSR releases at a rate of about six fry for each adult caught.

Chum Salmon (Oncorhynchus keta)

The distribution of chum salmon is similar to that of pink salmon except that it extends south to northern California in North America and to central Honshu Island in Asia. The greatest harvest of chum salmon is in the north west Pacific in the Japanese high-seas fishery and in USSR terminal fisheries (Figure 2). In North America, catches are much smaller and mostly from central Alaska to British Columbia.

The Asian harvest of chum salmon is almost three times that in North America. The trend in Asian fisheries is downward in the USSR but upward in Japanese fisheries. In North America, the catch trend has been downward in almost all areas (Figure 2).

Asian chum salmon production was high prior to World War II but dropped during the war years. Following the war the catch increased for a few years, then decreased as stocks were overexploited. In the 1970s the catch of Asian chum salmon stocks rose again. This increase is attributed to massive Japanese releases which accelerated from 400 million fry in the early 1960s to nearly 2 billion in 1982. There has been a steady rise in Asian catch to more than 35 million fish of which 30 million were caught in the Japanese fishery alone (Shirahata, in press). By 1974 the Japanese catch had reached 10 million fish, a particularly noteworthy landmark representing the highest catch attained under the natural spawning conditions of the 1880s. A return of 38.6 million fish is expected from 2.15 billion fry released in 1984 (Shirahata, in press).

From the late 1880s until the expansion of chum salmon ranching in Japan, hatcheries released chum salmon fry from ponds to the stream soon after yolk sac absorption. Egg and fry development was accelerated through the use of constant $8^{o}C$ groundwater on Hokkaido. These conditions allowed releases from early to middle February. These fry were sometimes subjected to severe conditions in the streams and coastal marine waters with temperatures as low as $0$-$5^{o}C$ in February and March. Japanese scientists early recognised that stream survival of liberated hatchery fry was dependent on size and time of release.

In 1962, production-scale hatchery experiments of feeding up to 300 million fry were undertaken to delay release for short periods (Mayama, in press). It was shown that dry diets could increase body weight from 0.6 to 1.0 g in about one month so that fed fry could be released from Hokkaido in May when coastal temperatures exceeded $10^{o}C$. Larger fish, released during high primary and secondary productivity in the coastal waters, survived at a much higher rate (Figure 3). Returns for unfed fry released in 1950-60 averaged 1.2%; returns improved to 2.3% after 1966 as the percentage of fed fish increased.

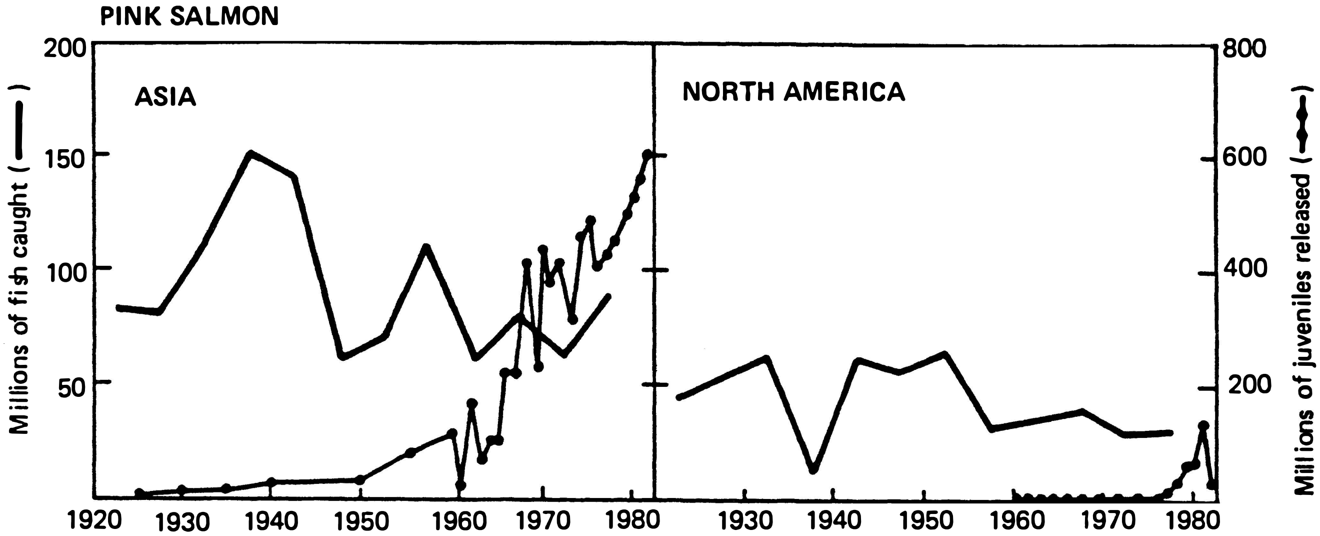


Fig. 1. Catch of pink salmon (5 year means) of Asian and North American origin by fisheries of the USSR, Japan, USA and Canada 1920-82; hatchery releases from Asia and North America 1960-82. USSR release data for 1977-82 are estimated by McNeil (1977a, b).

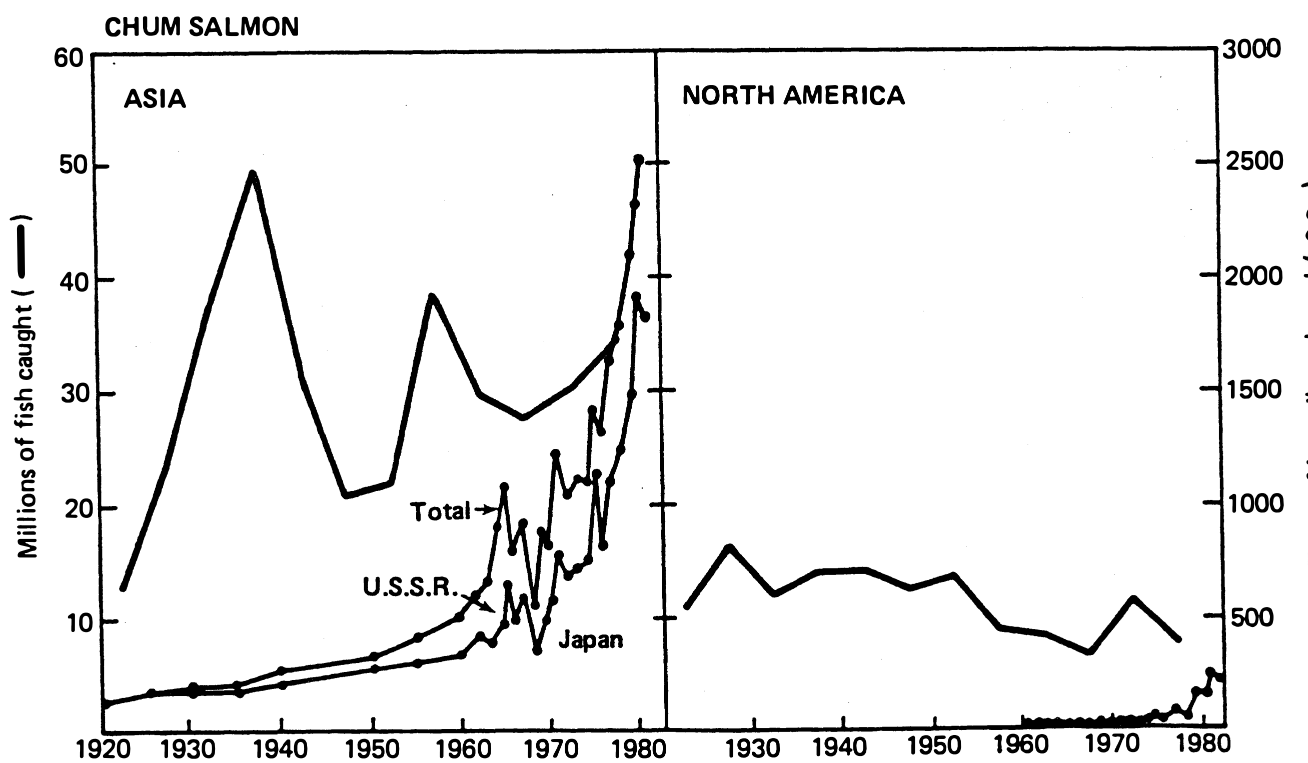


Fig. 2. Catch of chum salmon (5 year means) of Asian and North American origin by fisheries of the USSR, Japan, USA and Canada 1920-82; hatchery releases from Asia and North America 1960-82. USSR release data for 1977-82 are estimated by McNeil (1977a, b).

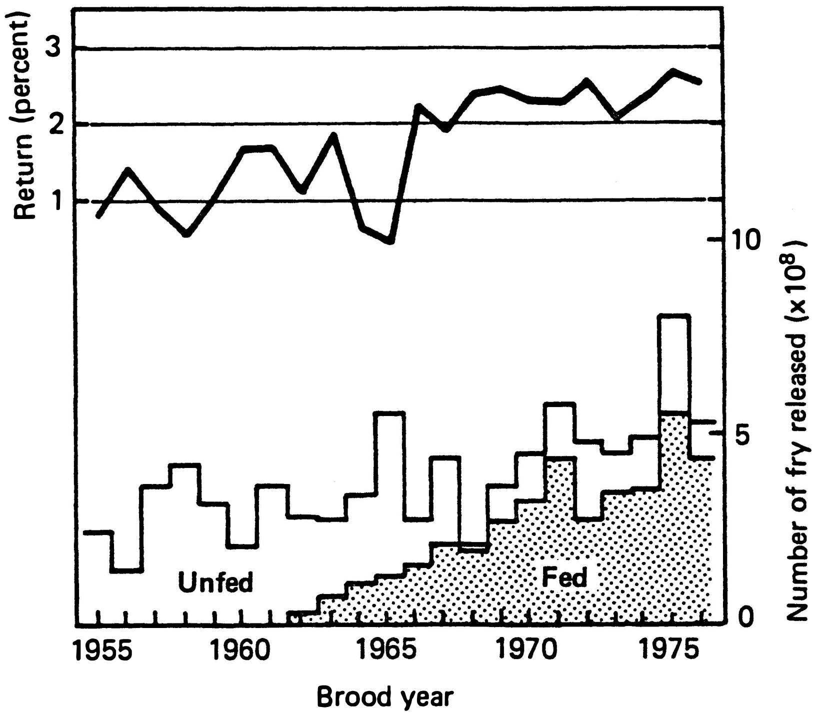


Fig. 3. Chum salmon fry released from Hokkaido sea ranches, 1955-76, and per cent return.

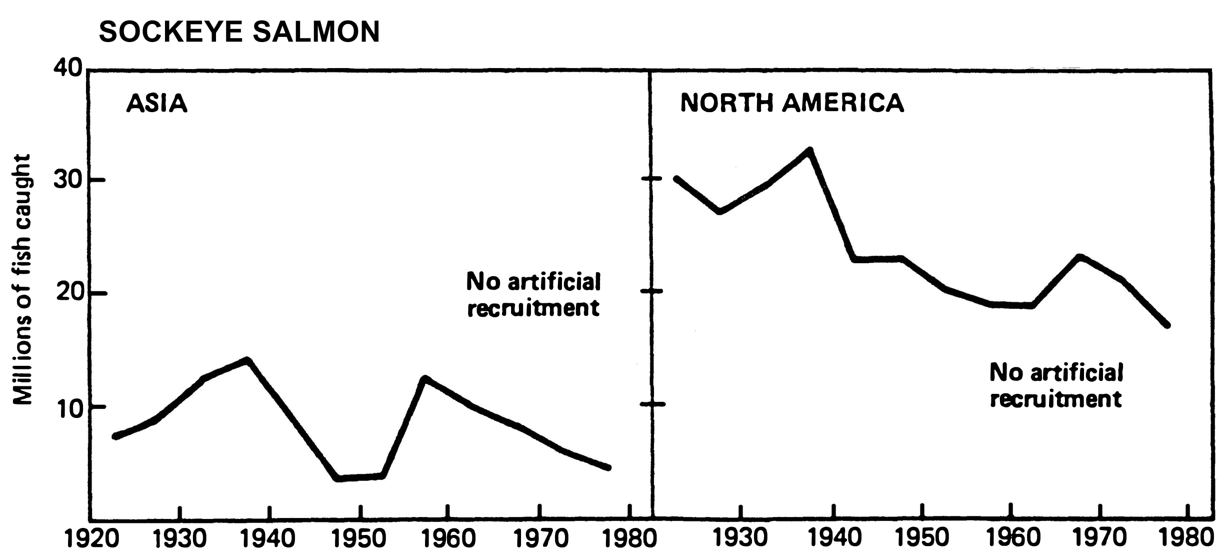


Fig. 4. Catch of sockeye salmon (5 year means) of Asian and North American origin by fisheries of the USSR, Japan, USA and Canada 1920-82.

Two interesting features of Japanese sea ranching are the improved contribution (percent return) from released fry and the shift of chum salmon fishing effort from the high seas to coastal fisheries (Table 1). The advent of 200 mile fishing limits has restricted the Japanese high-seas fishery of chum salmon destined for the USSR and North America. As a result the percentage of catch by coastal fisheries has increased from 15% in 1965 to 72% in 1981.

In the USSR, production of hatchery chum salmon almost doubled between 1973 and 1982. However, Soviet results have not equalled those in Japan, as returns of adults have averaged only 0.3% of fry released (Roukhlov, 1980).

In North America, enhancement efforts for chum salmon have recently accelerated, but Canadian and American hatcheries still release less than 10% of the numbers released in Asia. More than 50 fry were released in Asia for every adult caught in 1982, compared to about three fry/adult in North America.

Sockeye Salmon (Oncorhynchus nerka)

Sockeye salmon occur from Washington to Kotzebue Sound in North America with centres of abundance in British Columbia and Bristol Bay, Alaska. Asian sockeye salmon occur primarily in river systems on the Kamchatka Peninsula. Sockeye salmon abundance is three times greater in North America than in Asia (Figure 4).

Harvests of Bristol Bay stocks account for about 50% of the North American catch. British Columbian catches are second to those of western Alaska. Significant catches of sockeye salmon also occur in central Alaska.

The general catch of sockeye salmon has declined since the 1930s (Figure 4). In Asia the catch has declined for both the Japanese and Soviet fisheries. North American catches have declined except in western and central Alaska, where runs increased after 1979. These recent increases are perhaps due to favourable climatic conditions and decreased interception by the Japanese high-seas fishery.

TABLE 1

ANNUAL CHANGES OF CATCH IN THE JAPANESE SALMON (Hiroi, in press)

| Year | Coastal catch (% of total catch) |
|---|---|
| 1965 | 15.5 |
| 1966 | 17.9 |
| 1967 | 19.0 |
| 1968 | 15.6 |
| 1969 | 19.7 |
| 1970 | 20.9 |
| 1971 | 26.1 |
| 1972 | 23.3 |
| 1973 | 27.3 |
| 1974 | 32.6 |
| 1975 | 41.3 |
| 1976 | 32.8 |
| 1977 | 44.3 |
| 1978 | 58.2 |
| 1979 | 67.0 |
| 1980 | 64.5 |
| 1981 | 71.6 |

Sockeye salmon are difficult to propagate due to their susceptibility to viral and bacterial infections and their exacting food requirements. The continued decline of this species may be due in part to lack of hatchery enhancement programmes. The only hatchery produced sockeye salmon in the North Pacific in 1982 were about 5 million, grown and released in Washington State. There are enhancement programmes for this species in British Columbia in the form of spawning channels and nursery lake fertilisation programmes, but even here sockeye salmon populations are primarily dependent on natural environmental conditions. Major sockeye salmon producing areas require extensive freshwater lakes and are exemplified by nursery lakes on the Fraser River in British Columbia and in the productive Bristol Bay region of western Alaska.

Coho Salmon (*Oncorhynchus kisutch*)

Coho salmon spawn from central California to Norton Sound in North America. In Asia, coho salmon spawn primarily in streams on the Kamchatka Peninsula and in the northern Sea of Okhotsk.

The North American catch of coho salmon is twice that of the Asian harvest (Figure 5). The Asian catch appears to be generally rising even though no sea ranching of this species occurs there. In North America the greatest harvests are in south eastern Alaska, British Columbia, and Washington (Figure 6). In Alaska the catch for the major areas of coho salmon production has been decreasing, while in British Columbia to California the trend has been toward increasing harvests. Much of the increase south of Alaska is due to hatchery production.

Coho salmon enhancement in North America increased in the 1950s following the initiation of the Columbia River Development Program. Hydroelectric development resulted in the loss of wild runs, and mitigation hatcheries were constructed on the lower river to replace lost fish. Coho salmon sea ranching on the Columbia River accelerated in the 1960s (Figure 5) following a decline in catch in the 1950s. These very large hatcheries elevated coho and chinook salmon to the primary sea ranch species in North America.

Coho salmon smolts have the largest release size requirements of North Pacific oncorhynchids at between 25-30 g each and require 14-16 months of hatchery rearing. Federal, state, and Indian hatcheries in Washington State rear over half of the coho salmon released into North Pacific waters. Ten coho salmon smolts were released from North American hatcheries for each adult caught in 1982.

Although catch remains high, recent trends in yield (adults caught/smolts liberated) in the Oregon Production Index area, which includes the Columbia River, show an alarming decline. This has led to speculation that the ocean carrying capacity of this region has been reached or exceeded (see below).

Chinook Salmon (Oncorhynchus tshawytscha)

Chinook salmon are about five times more numerous in the North American catch than in the Asian salmon catch (Figure 7). In North America the greatest harvest is in British Columbia and off Washington, Oregon, and California. In Asia most of the harvest is in the Japanese high-seas fishery or in Soviet terminal fisheries on the Kamchatka Peninsula.

The Asian catch has moved slightly upward since 1920, while in North America the catch has varied between regions (Figure 8). In western Alaska, increases have occurred through increased harvesting of wild stocks. In central and south eastern Alaska, catches have decreased. Catches in British Columbia have increased dramatically; most of this increase has been attributed to interception of Washington and Oregon hatchery fish. California catches have decreased only slightly since the 1940s; this stability has also been attributed to interception of Washington or Oregon stocks. Washington and Oregon catches severely declined in the 1960s, followed by recovery in the 1970s with increased production of hatchery fish from the Columbia River Development Program (Figure 8).

Numerically, chinook salmon is the major sea ranch species in North America. Of the 260 million smolts released in 1982, 160 million were produced in Washington State. Chinook salmon smolts are the second largest of the oncorhynchids at release, averaging about 11 g. More than 60 smolts were released for every adult caught in North America in 1982.

The recent declines in wild chinook salmon populations in North America have caused concern among fishery managers. Overexploitation and loss of freshwater habitat have been the major causes. Wild stocks of bright chinook salmon that spawn on the upper Columbia and Snake Rivers, above the hydroelectric dams, have shown an especially rapid decline; fishery biologists suggest that restrictions on the coastal fishery be imposed to protect these fish.

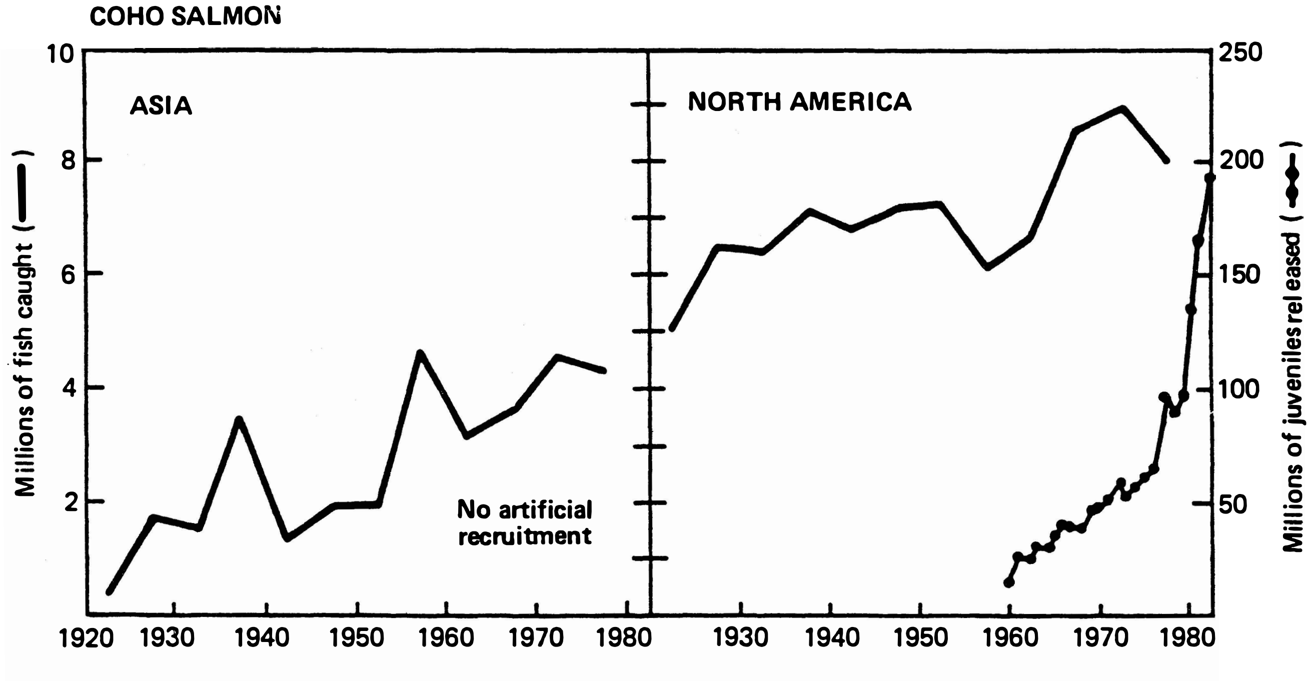


Fig. 5. Catch of coho salmon (5 year means) of Asian and North American origin by fisheries of the USSR, Japan, USA and Canada 1920-82; hatchery releases from North America 1960-82.

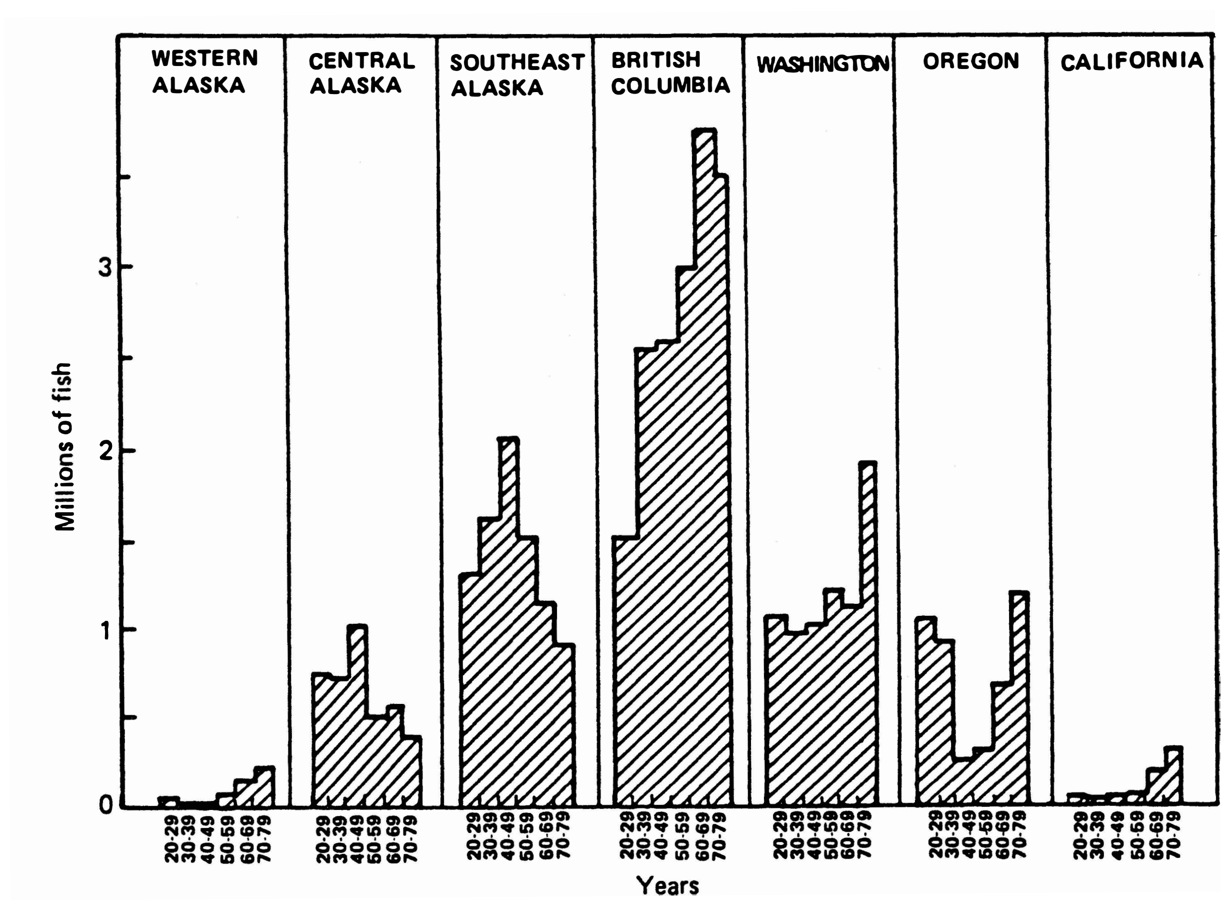


Fig. 6. Average annual commercial catch of North American coho salmon, by region and decade, 1920-77 (Fredin, 1980).

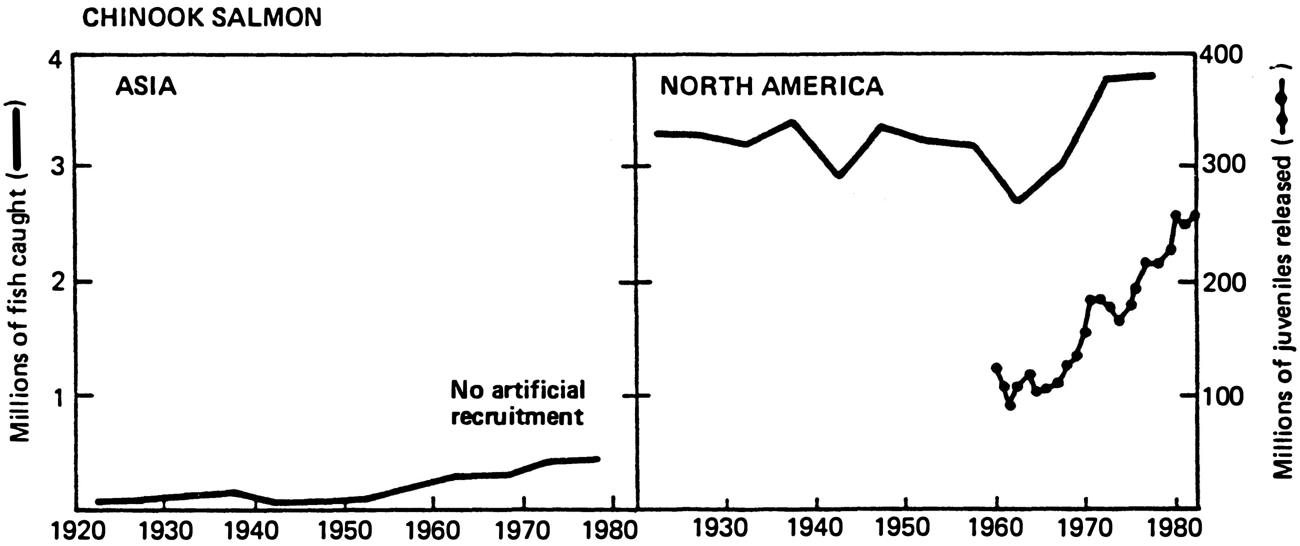


Fig. 7. Catch of chinook salmon (5 year means) of Asian and North American origin by fisheries of the USSR, Japan, USA and Canada 1920-82; hatchery releases from North America 1960-82.

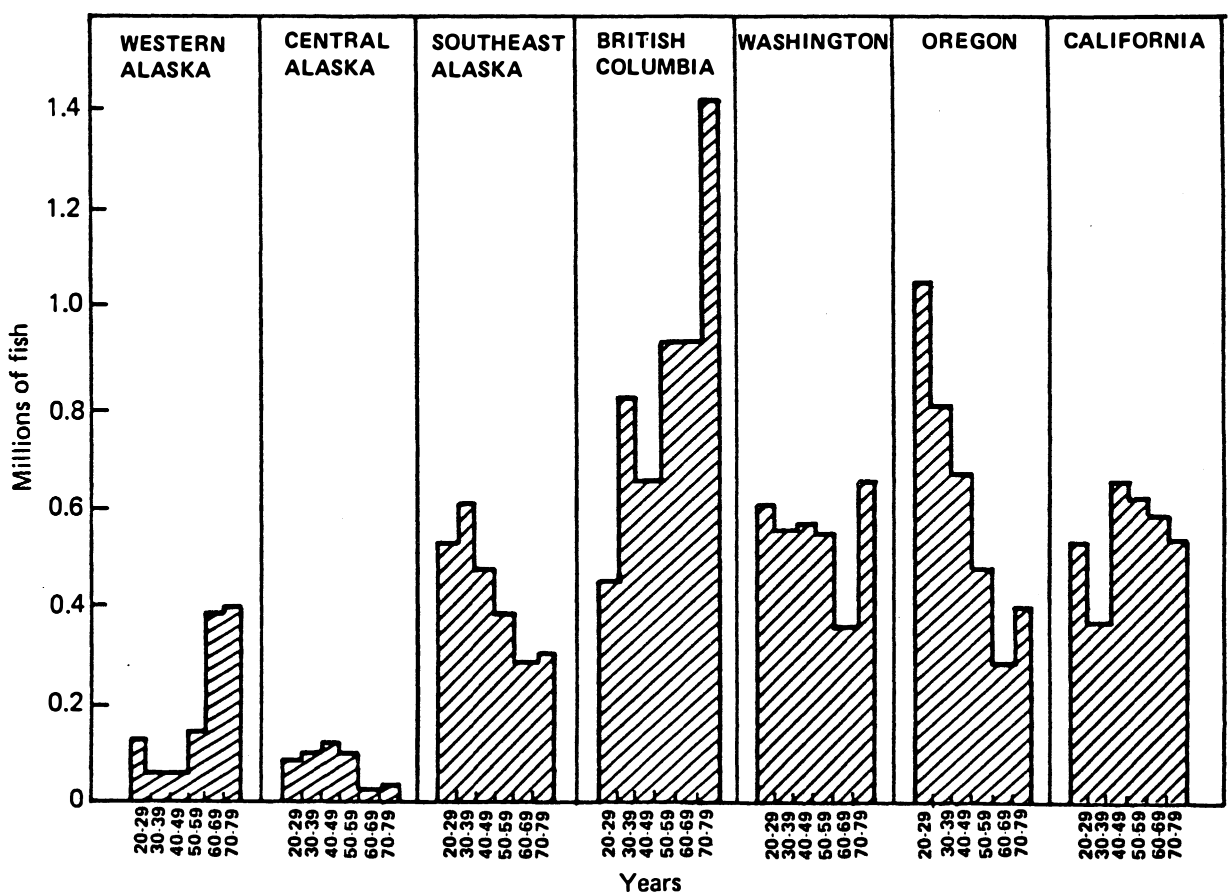


Fig. 8. Average annual commercial catch of North American chinook salmon, by region and decade, 1920-77 (Fredin, 1980).

SUMMARY OF ASIAN AND NORTH AMERICAN RELEASES

Sea ranching is an international undertaking, practised on a massive and expanding scale in the Pacific Ocean by the USA, Canada, USSR, and Japan. Hatchery production from Pacific rim nations is increasing; optimistic forecasts for further expansion have been issued. These nations have taken a biologically optimistic view of sea ranching, but some scientists and fishery managers have come to question the wisdom of continued rapid expansion.

There are signs of stress in heavily enhanced regions and questions are being asked about the ability of the ocean to accommodate these billions of additional fish. Stress has not appeared in all geographic areas; in Japanese chum salmon enhancement, there does not seem to be any limitation to the number of fish produced through enhancement.

It is the desire of fishery managers that sea ranching take advantage of the great natural productivity of the ocean to enhance the resource beyond its historical limits; the Japanese probably have done just that. Historical coastal catch of chum salmon in Hokkaido/Honshu waters never exceeded 10 million fish annually, where 30 million are now produced as a result of massive hatchery releases. The Japan fisheries agency estimates that more than 80% of chum salmon caught either in the coastal or high-seas fishery are of hatchery origin. Canada, Japan, and the USA all plan to increase hatchery releases, the Soviet Union alone to 5 billion by the year 2000 (Roukhlov, 1980).

What do these massive releases mean to North Pacific fishermen? Salmon sea ranching escalated rapidly in the 1970s and it was not until the past decade that the decline in harvests was reversed for the four enhanced species, coho, chinook, chum, and pink salmon. Sockeye salmon, not enhanced through hatcheries, has continued to exhibit declining catch through the 1970s in both Asia and North America.

North Pacific hatcheries released 4.23 billion juvenile salmon in 1982. Hatchery production, all species combined, increased 2.5 times in the decade ending in 1982 (Table 2 and Figure 9). If this expansion continues through the year 2000, more than 10 billion fish will be released annually by Pacific rim nations. This increase of 2.5 times contrasts with other predictions of three to five times (Gordon, 1982) and may be more realistic in light of the recent downturn in the world economy. This has affected the ability of Pacific rim nations to proceed with original enhancement projects.

TABLE 2

MILLIONS OF HATCHERY SALMON RELEASED FROM PACIFIC RIM NATIONS 1973-82

| | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|
| Pink salmon | | | | | |
| Japan | 39.00 | 0 | 0 | 50.00 | 0 |
| USSR[1] | 270.00 | 457.00 | 486.00 | 400.00 | 429.20 |
| Canada | 0 | 0 | 0 | 0 | 1.30 |
| USA | 0 | 1.21 | 0 | 4.85 | 16.89 |
| Total | 309.00 | 458.21 | 486.00 | 454.85 | 447.39 |
| Chum salmon | | | | | |
| Japan | 716.73 | 756.56 | 1,145.98 | 810.54 | 1,105.84 |
| USSR[1] | 407.00 | 337.00 | 294.00 | 500.00 | 536.50 |
| Canada | 0 | 0 | 0 | 0 | 3.10 |
| USA | 6.57 | 10.01 | 29.64 | 23.78 | 69.72 |
| Total | 1,130.30 | 1,103.57 | 1,469.62 | 1,334.32 | 1,715.16 |
| Coho salmon | | | | | |
| Japan | 0 | 0 | 0 | 0 | 0 |
| USSR | 0 | 0 | 0 | 0 | 0 |
| Canada | 0.51 | 0.52 | 1.00 | 2.39 | 2.80 |
| USA | 52.89 | 56.08 | 59.94 | 60.54 | 94.67 |
| Total | 53.40 | 56.60 | 60.94 | 62.93 | 97.47 |
| Chinook salmon | | | | | |
| Japan | 0 | 0 | 0 | 0 | 0 |
| USSR | 0 | 0 | 0 | 0 | 0 |
| Canada | 2.00 | 2.40 | 2.22 | 3.10 | 6.10 |
| USA | 180.43 | 165.28 | 177.00 | 183.35 | 211.34 |
| Total | 182.43 | 167.68 | 179.22 | 186.45 | 217.44 |
| Grand total | 1,675.13 | 1,786.06 | 2,195.78 | 2,038.55 | 2,477.46 |

TABLE 2 (cont.)

| | 1978 | 1979 | 1980 | 1981 | 1982 |
|---|---|---|---|---|---|
| Pink salmon | | | | | |
| Japan | 0 | 0 | 0 | 0 | 0 |
| USSR[1] | 460.53 | 494.15 | 530.02 | 568.93 | 610.46 |
| Canada | No data | 0 | 3.57 | 6.04 | 10.00 |
| USA | 35.89 | 61.90 | 68.17 | 141.45 | 26.78 |
| Total | 496.42 | 556.05 | 601.76 | 716.42 | 647.24 |
| Chum salmon | | | | | |
| Japan | 1,212.44 | 1,463.39 | 1,896.16 | 1,817.76 | 2,150.00 |
| USSR[1] | 575.66 | 617.69 | 662.78 | 711.16 | 763.08 |
| Canada | No data | 49.20 | 75.33 | 93.21 | 120.43 |
| USA | 47.38 | 107.47 | 81.13 | 151.38 | 99.77 |
| Total | 1,835.48 | 2,237.75 | 2,715.40 | 2,773.51 | 3,133.28 |
| Coho salmon | | | | | |
| Japan | 0 | 0 | 0 | 0 | 0 |
| USSR | 0 | 0 | 0 | 0 | 0 |
| Canada | No data | 3.50 | 4.12 | 4.99 | 10.90 |
| USA | 88.41 | 93.76 | 132.51 | 161.27 | 182.56 |
| Total | 88.41 | 97.26 | 136.63 | 166.26 | 193.46 |
| Chinook salmon | | | | | |
| Japan | 0 | 0 | 0 | 0 | 0 |
| USSR | 0 | 0 | 0 | 0 | 0 |
| Canada | No data | 13.60 | 15.45 | 19.03 | 17.30 |
| USA | 218.24 | 212.37 | 245.26 | 231.24 | 242.28 |
| Total | 218.24 | 225.97 | 265.71 | 250.27 | 259.68 |
| Grand total | 2,638.55 | 3,117.03 | 3,719.50 | 3,906.46 | 4,233.66 |

1 Russian data 1976-82 are estimated using 7.3%/annum increase as described by McNeil, 1977a, b.

Data sources: Hiroi in press; Wahle and Smith, 1979; McNeil, 1977a, b; PPR, 1979, 1980, 1981; SBR, 1982; and SBR in press.

Japan's chum salmon releases are half of all the artificially recruited fish in the Pacific. Numerically, chum salmon constitute about 75% of all salmon released into the Pacific (Figure 9). Although fewer coho salmon are released than any other sea ranch species, because of their large size at liberation coho salmon nearly equal chum salmon in total weight (4.4 vs 4.7 million kg). The increase in enhancement (Table 3) has also been greatest for coho (3.6X) and chum (2.8X). The enhancement ratio has been highest for chum salmon, in Asia, and chinook salmon, in North America, at about 52-63 fish released for each adult caught. The enhancement ratio is lowest for pink salmon in North America.

Private sea ranches in Alaska and Oregon released 67% of all pink, 12% of all coho, 8% of all chum, and 0.5% of all chinook salmon in North America. Overall contribution is 9% and, although growing each year, private contributions are still relatively insignificant compared to the total fish released from public sea ranches in North America.

Releases from Pacific rim nations in 1982 indicate the importance of sea ranching in sustaining the salmon resource. Release projections by species, however, suggest the physical resource limitations in different geographic and political regions. For example, low releases of coho salmon in California and chum salmon in Oregon do not indicate high natural abundance but rather that stocks near the southern limit of their ranges are so depleted that egg sources are often unavailable for enhancement programmes. In contrast, low production of chinook salmon in Alaskan hatcheries reflects the high abundance of wild populations. However, reliance on natural production has often resulted in drastic annual fluctuations, a serious difficulty with managing wild runs and a situation that is less likely to occur with artificial recruitment.

High releases, such as chum salmon in Japan or coho salmon in the Columbia River, almost always reflect an inability of the freshwater habitat to support sufficient juvenile fish, usually a result of environmental deterioration. The Japanese example represents a case where artificial recruitment probably exceeds anything that the natural system ever produced.

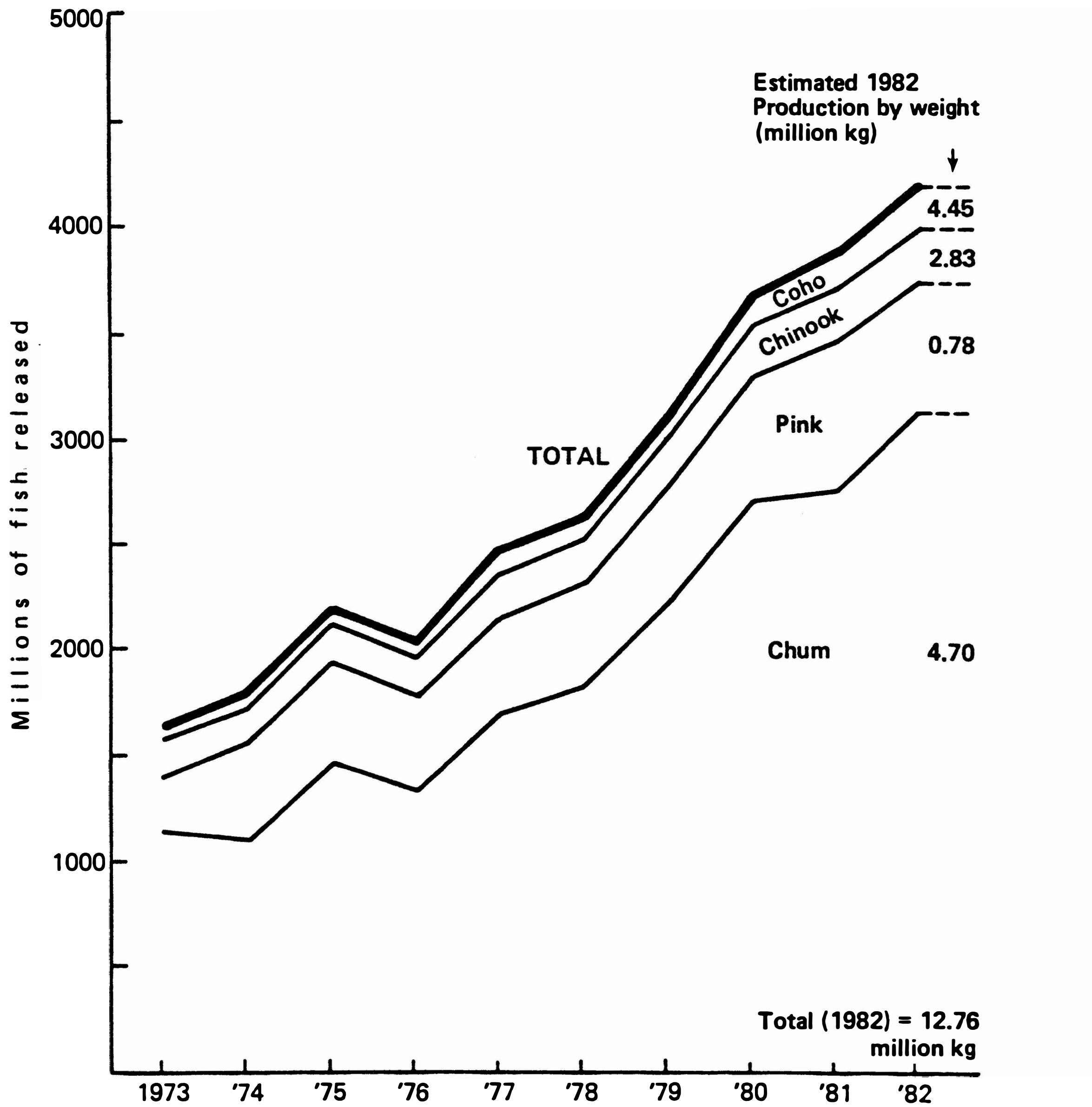


Fig. 9. Hatchery salmon released from Pacific rim nations 1973-82.

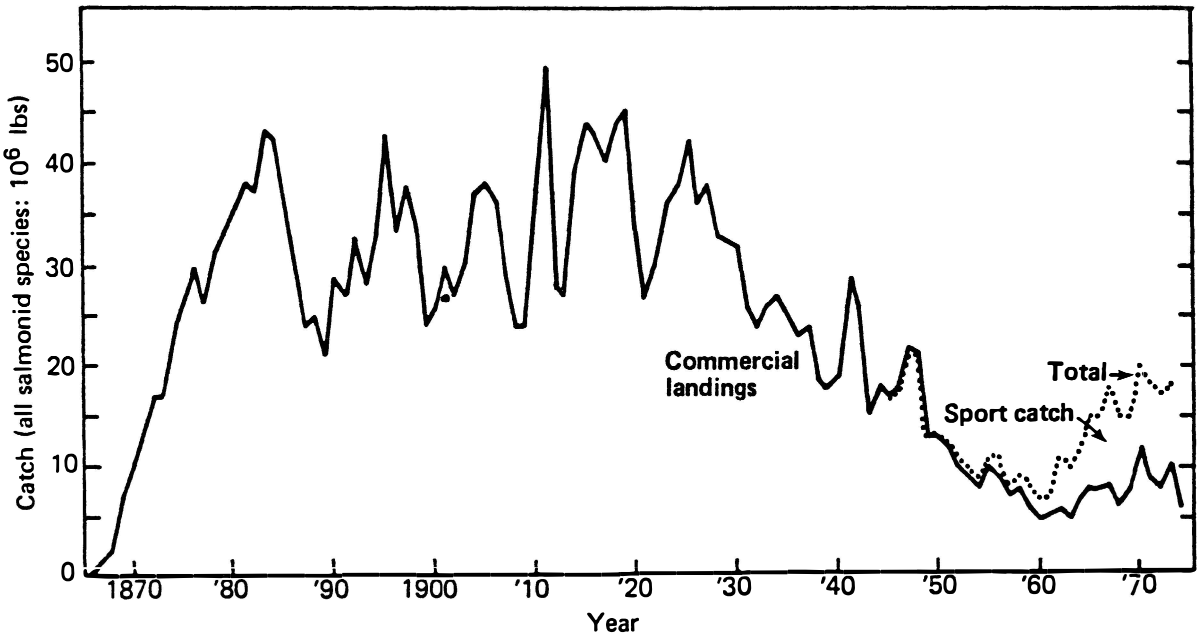


Fig. 10. Columbia River commercial salmonid landings 1866-1938 (Salo and Stober, 1977).

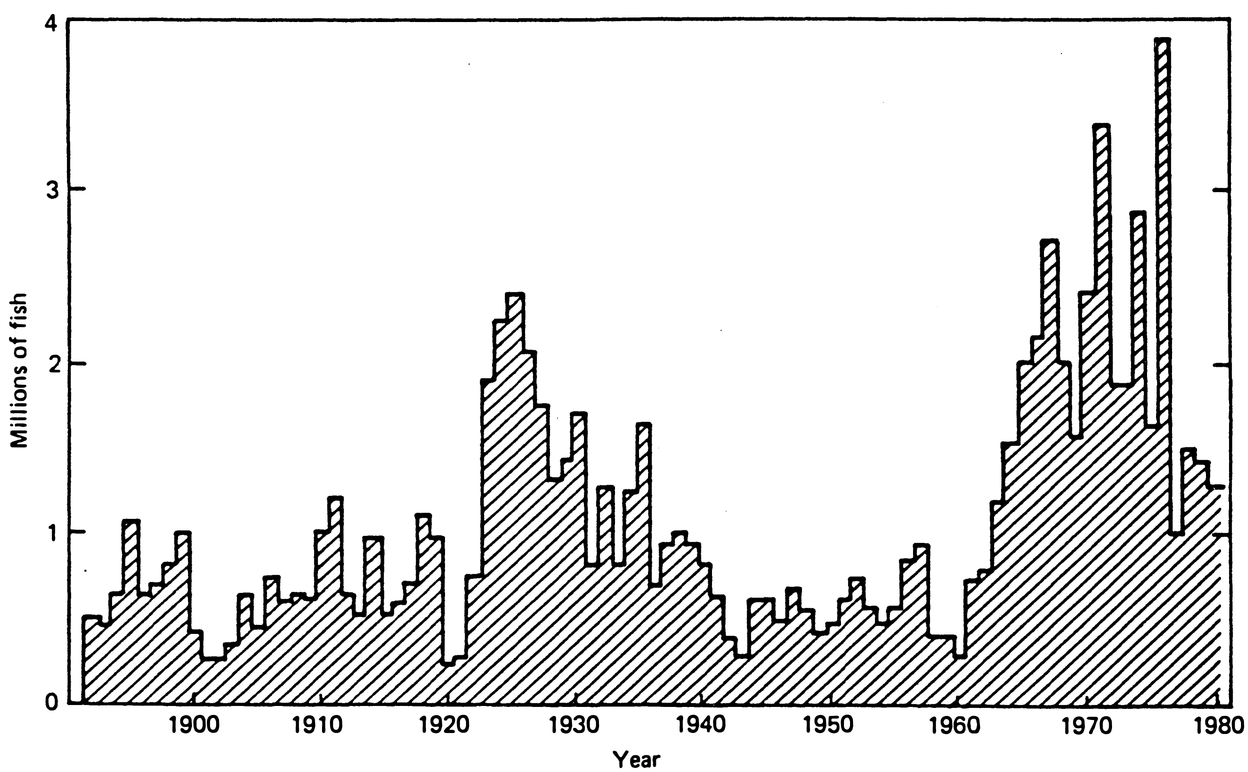


Fig. 11. Coho salmon catch in the Oregon Production Index area, 1892-1979 (ODFW, 1982).

TABLE 3

INCREASE IN RELEASES (1973-82) AND ENHANCEMENT RATIO FOR FOUR SPECIES OF SALMON IN THE NORTH PACIFIC

| | Factor comparing juveniles released in 1982 and 1973 | Enhancement ratio (Migrants released per adult caught) | |
|---|---|---|---|
| | | North America | Asia |
| Pink | 2.4 | 0.9 | 5.5 |
| Chum | 2.8 | 3.4 | 51.8 |
| Coho | 3.6 | 10.2 | - |
| Chinook | 1.4 | 63.4 | - |

PROGNOSIS: PROMISE OR PROBLEM?

A complex of social, political, and biological issues affects North Pacific enhancement programmes. These issues have so complicated the harvest management of Pacific salmon that at times it is difficult to discern the impact of enhancement programmes. Several notable successes are evident: the expansion of sea ranching of chum salmon in Japan and the harvest of nearly 30 million hatchery-produced fish in 1981; the rapid expansion of pink salmon hatchery production by private non-profit making sea ranchers in Alaska and the concomitant increase in local catches; and finally, the near extinction of wild stocks of coho and chinook salmon in the Columbia River as a result of hydroelectric development, and the replacement of these species in the ocean fisheries from lower river mitigation hatcheries.

From an inclusive view of the impact of sea ranching on North Pacific salmon catch, it can be seen that hatchery releases have countered the general decline for some salmon stocks. But hatchery production has not yet returned catches to their pre-1920 levels. A good example is the historical catch of salmon species in the Columbia River/coastal fishery (Figure 10). The decline is due primarily to the loss of unenhanced species like sockeye salmon which have all but disappeared from this fishery. At the same time, coho salmon have been returned to their historical catch level through lower river hatcheries (Figure 11).

But what of the future? What do these massive artificial recruitment programmes mean to fishermen and the commercial sea ranchers of the North Pacific? Will sea ranches continue to build the salmon fisheries? What views are held by salmon biologists for future management of this common property fishery? And finally, how do harvest management plans for public sea ranch programmes impact the profitability of private sea ranches?

Many problems not in evidence even ten years ago are coming to the forefront in the 1980s, forced by the pressures of ever increasing enhancement efforts and the intensive competition for a smaller and smaller piece of the salmon pie by ever increasing user groups. Space does not permit a discussion of social, political, and legal problems which can be more serious than the biological constraints. Four issues seem to generate the most controversy: 1) interception of sea ranch fish by foreign jurisdictions; 2) degradation of freshwater habitat; 3) loss of wild stocks and resultant loss of genetic diversity; and 4) ocean carrying capacity.

<u>Interception of Sea Ranch Fish in Foreign Mixed-Stock Fisheries</u>

Adult salmon migrate through distant coastal fisheries and are harvested together with the wild and hatchery stocks of that area. Whenever stocks are intercepted beyond the political or geographic jurisdiction of origin, there will be controversy. Interception is an unattractive feature of the salmon fishery. Nowhere is this more focussed than in the chinook salmon harvest where it is known that more than one third of the fall chinook salmon bound for Columbia River hatcheries in the US are harvested by Canada (Table 4). Likewise, a large percentage of sockeye salmon destined for the Fraser River in Canada are caught by US fishermen.

Arguments between Canada and the United States on the question of interception of each others' salmon stocks have reached a pitched debate, with neither being able to agree on their 'share' of the resource. Meanwhile, the resource continues to dwindle, some salmon races have all but disappeared, and hatchery enhancement programmes are held in abeyance pending final 'settlement' of a treaty, a treaty that has been in the offing during most of this controversy. The question is not whether sea ranchers or political jurisdictions should have the right to harvest hatchery stocks originating in their waters, the controversy is in how to allocate the remaining portion. That issue is dependent on the ability of salmon managers to develop a harvest management system that treats each population as a separate unit. Until recently that has been accomplished using coded wire tagging, migration patterns and timing, and scale analyses, all time consuming and costly processes.

Recently the use of electrophoresis to identify racial components of mixed fisheries has come into its own. This biochemical technique identifies genetically controlled differences in protein structures between stocks and can rapidly (2-3 days) and with good precision identify the proportional composition of various stocks in mixed fisheries. By applying the biochemical-genetic approach, fisheries agencies could regulate the harvest as a known stock fishery, and could allow specific depleted wild stocks to escape by using effective open/close practices.

TABLE 4

DISTRIBUTION OF CATCH OF COHO AND CHINOOK SALMON STOCKS FROM COLUMBIA RIVER HATCHERIES

| Fisheries | Coho salmon (%) | Fall chinook salmon (%) |
|---|---|---|
| South east Alaska | 0.0 | 0.2 |
| British Columbia | 6.0 | 33.7 |
| Washington | 33.0 | 38.0 |
| Oregon | 39.0 | 4.5 |
| California | 10.0 | 0.4 |
| Columbia River | 12.0 | 23.2 |

Data source: personal communication R. Koski, NMFS, Portland, Oregon.

## Degradation of Freshwater Habitat

Loss of freshwater habitat has caused the decline of wild stocks. There is little doubt that North Pacific freshwater habitats have rapidly declined in water quality and availability since the turn of the century. Development has led to extensive logging, farming, and hydroelectric impacts. Urban and industrial wastes have polluted streams and rivers and led to further loss of spawning and rearing habitat. The result has been an increasing dependence on artificial propagation. The Columbia River affords the ultimate example, where about half of the habitat available to anadromous salmonids has been permanently lost or adversely altered. Twenty-one federally supported hatcheries are maintained on the lower Columbia River below the dams to mitigate for loss of upstream populations. However, wild populations still exist in small numbers and attempts are being made to enhance these. It is the loss of these and other wild stocks through human intervention that has generated so much controversy in North America. Some salmon biologists fear that sea ranching has become a panacea, justifying further loss of the natural habitat supporting our remaining wild stocks.

Interaction of Wild and Hatchery Stocks

Fishery agencies in North America view wild fish stocks as their most valuable resource. Unlike Japan, where wild populations are now gone, North America still has large populations of wild, naturally spawning fish, especially in British Columbia and Alaska. Proponents of wild fish preservation are concerned that expanded artificial propagation will decrease wild stocks, as has been the case in Washington, Oregon, and California. They argue, and rightfully so, that artificial propagation should never be thought of as a substitute for natural production until all opportunities for wild stock maintenance are examined. To them, sea ranching is a rehabilitative, perhaps supplementative, tool in fishery management. This policy generates considerable controversy between sea ranching and wild stock proponents and is a significant deterrent to the development of new sea ranches.

The controversy centres around the wild stocks being overwhelmed by sea-ranch programmes and the heavy exploitation of both in the mixed stock fishery. Wild stocks cannot withstand as heavy an exploitation as the more abundant sea-ranch stocks and are in danger of being overfished.

The assumed result of this loss would be reduced genetic diversity either through outright loss of the wild stocks or through inbreeding of severely depleted wild stocks. Dilution or contamination of gene pools can also take place when straying adults from abundant hatchery stocks interbreed with residual wild fish. The assumption is that interbreeding of hatchery and wild fish could transmit less fit characteristics to wild populations, which are highly adapted genetically to their respective habitats. The tendency then would be toward genetic monoculture, and genetic options for future enhancement programmes would be reduced.

Gordon (1982) noted that the hypothesis of genetic contamination has serious implications in the already widespread introduction and transplantation of Pacific salmon. He also remarked that it is extremely difficult to confirm such hypotheses; despite evidence for genotypic differences between populations, there has been no concerted effort to compare the fitness of one population's genotype with another. Counter theories of genetic contamination regard straying of spawners as a natural phenomenon which enriches the gene pool of populations, that this has always been so, and that unfit characteristics will be ruthlessly culled through natural selection.

In a practical sense, it is difficult to ensure that enough wild spawners will return to their home streams with the present system of managing mixed stock fisheries of wild and hatchery fish. Given present harvest demands, most managers agree that it would be hazardous to rely heavily on wild stocks even if they could be successfully rehabilitated. Proponents of commercial sea ranching point out that changing from an oceanic to a land based harvest would concentrate harvest on hatchery stocks while allowing sufficient escapement of wild stocks to their spawning grounds.

## Ocean Carrying Capacity as a Limiting Factor for Artificially Propagated Salmon

Those involved in management, propagation, and harvest of North Pacific anadromous salmonids generally assume that the quality and quantity of freshwater habitat are the factors which limit the abundance of the resource. The ocean, where these salmonids spend one to four years and achieve most growth, is considered nearly limitless in its productive capacity. Recently, however, this long held and seldom questioned belief has been attacked. Could the North Pacific Ocean have a limited capacity for the production of salmonids? If so, is that capacity being approached?

Unless some serious ecological changes have reduced its carrying capacity, we intuitively suspect that the ocean could support at least as many salmon as it has historically. Although some areas in the North Pacific may be producing fish at or near their observed maximum levels, the ocean as a whole is not producing as many salmonids as it has in the past. Certain runs, in particular those associated with the Columbia and Sacramento Rivers, are producing fish far below historically observed levels (Figure 10). It seems reasonable to assume that resources formerly utilised by these stocks are currently available. Walters et al. (1978) believe that the ocean has returned at least twice as many salmon per year as it now does, and that there is potential for considerable new production. Certainly the Japanese experience with chum salmon substantiates this belief.

These observations do not preclude the possibility that density dependent mortalities and density dependent growth reductions occur in localised portions of the ocean. In fact, several specific examples of density dependent mortality have been reported in North Pacific salmonid populations. Krogius (1965) observed a strong interspecific interaction between Lake Ozernaya sockeye salmon and Kamchatka pink salmon populations; sockeye salmon growth and survival were inversely related to pink salmon abundance. Rogers (1980) demonstrated reduced growth in Asiatic chum salmon and Bristol Bay sockeye salmon in Alaska. Takagi et al. (1981) reported smaller individual pink salmon during years of high abundance. Peterman (1978) searched for density dependent growth or mortality in North Pacific salmonid populations, but found few examples. These observations suggest isolated density dependent like phenomena, but do not prove that ocean capacity has been reached.

The most thoroughly investigated example of suspected density dependent mortality involving sea ranch fish is the case of fluctuating abundance of coho salmon in the Oregon Production Index (OPI) area. The OPI area includes the coastal habitat of coho salmon from southern Washington to northern California, including the Columbia River. This area is a relatively small zone at the southern edge of coho salmon distribution in the eastern Pacific. It is south of the centre of abundance in British Columbia and south eastern Alaska. It is one of the most intensively sea ranched areas of the North Pacific, and each year accepts more than 80% of the released chinook and coho salmon.

The OPI was developed to indicate the annual abundance of adult, three year old coho salmon produced in Columbia River and Oregon coastal hatcheries and streams. The number of three year old adult coho salmon in the OPI area is predicted one year in advance of their harvest on the basis of the number of two year old precocious males (jacks) returning to index hatcheries and dams. The accuracy of this predictor has been very good; the stock sizes from 1972 through 1979 deviated at most only ± 16% from predicted values (ODFW 1982).

Great enthusiasm for sea ranching was generated in the 1960s as the coho salmon catch rose dramatically with increasing hatchery production. Hatchery production rose from 7.5 million fish in 1960 to more than 60 million in 1982, and adult coho salmon production during the early-to-mid seventies was as high as any historical records. But even by 1968 some disturbing trends were evident; adult production wavered and extreme fluctuations in annual catch began to occur in the OPI area (Figure 11). The record high 4.1 million adult fish in 1976 was followed by a record low of 1.1 million fish; since 1977 the average has been less than 2.0 million. This downward trend in adult coho salmon occurred in spite of an increase in smolts released from hatcheries (Figure 12). In the decade prior to this decline in adults, coho salmon catch had met or exceeded past catch levels. Therefore, the argument that harvests had been greater and that there is unused ocean capacity, at least for OPI coho salmon, is not supported.

A task force of fishery experts and oceanographers was assembled in Oregon to consider the possible causes of this decline (Gunsolus, 1978; ODFW, 1982). The cause of the reduced adult catch in the OPI area was not readily apparent, and numerous speculative, but interesting, explanations were offered. The problem is complex because the adult decline was accompanied by changing ocean conditions, increased fishing effort, and increased hatchery production, including that from the newly

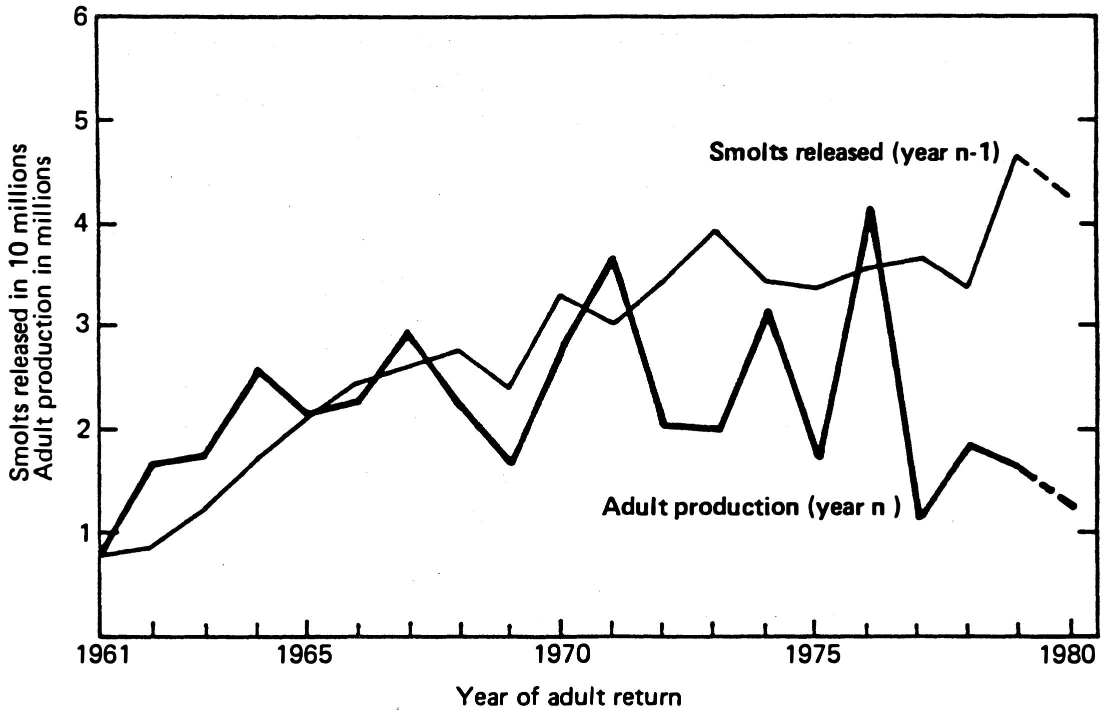


Fig. 12. Coho salmon smolts released and adults produced in the Oregon Production Index area, 1961-80 (ODFW, 1982).

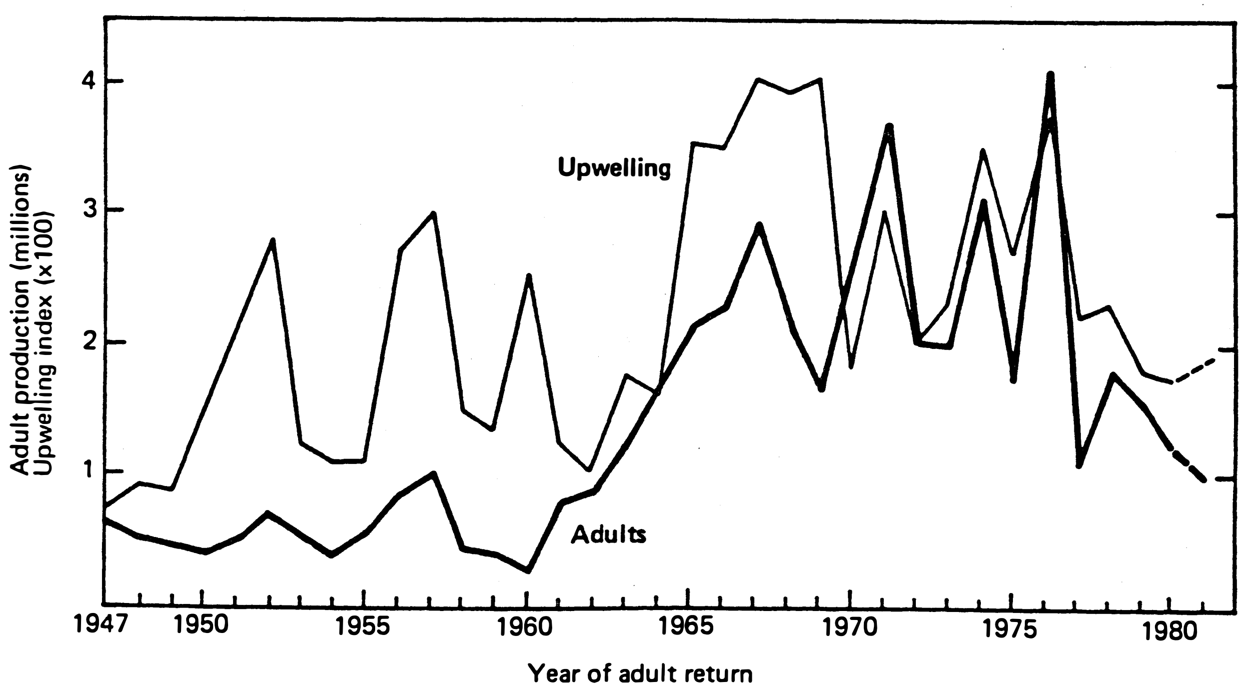


Fig. 13. Adult coho salmon and upwelling in the Oregon Production Index area; dashed lines for 1981 are estimates (ODFW, 1982).

created commercial sea ranches in Oregon. Much evidence, both supporting and discrediting the idea of density dependent or other causes of mortality in the ocean, is given by ODFW (1982).

It has been suggested that the problem may be a freshwater or estuarine phenomenon, for example, the decline in the quality of hatchery smolts after the headlong rush to produce more and more smolts in a system designed to produce far fewer fish. Disease, rearing density, nutrition, and/or genetic changes may be factors causing a general decline in the quality of smolts released from hatcheries. Other freshwater-related explanations are: 1) adult production from hatchery smolts may have only partially replaced lost natural production; 2) too many smolts in freshwater or estuaries, with density dependent mortality in both wild and hatchery stocks; or 3) the problem may be confined to the Columbia River which is by far the largest producer of smolts in the OPI area. With respect to these explanations, the data indicate that coho salmon production declined in both wild and hatchery stocks in Oregon coastal rivers as well as in the Columbia River. Futhermore, the 1976-77 production minimum occurred to a lesser degree from Alaska to California, suggesting a widespread oceanic cause. It is difficult to argue that some freshwater mortality factor would become coincidentally dominant over the entire North American range of coho, especially since artificial recruitment exceeds wild fish production and is constant throughout the OPI area.

Another proposed explanation of the decline in adult abundance is that the annual variation in a population size increases as the mean population size increases (Figure 11). Such variation is seen with OPI coho salmon and is believed to be associated with environmental factors rather than density dependent mortality. Oregon is near the southern limit of the coho salmon range, and the abundance of species at the extremes of their range can also be expected to be more variable.

The most plausible explanation for the recent decline in adult coho salmon may be that the OPI ocean carrying capacity has been exceeded. A significant positive correlation between adult production and the coastal upwelling of the previous summer has been shown (Figure 13). Adult returns from smolts released in 1970 and 1975 are unusually high compared with other years. These smolt releases coincided with periods of intensive upwelling. Summer upwelling off Oregon plays a major role in enriching the habitat for juvenile coho salmon. A shift from south west winds in winter to north west winds in summer occurs in the spring when coho salmon are moving out of the rivers. The resulting summer upwelling can dramatically alter salinity and temperature, and the abundance of food and predators. These fluctuations may enhance or depress growth and survival depending on the intensity and duration of upwelling. Many biologists believe that survival of juvenile coho salmon is determined during the first 2-3 months at sea. Adding credence to this belief is that the number of precocious males returning after their first summer in the ocean accurately predicts three year old adult survival.

Proponents of density dependent mortality point out that correlations between the upwelling index and adult production were low (r=0.58) from the mid 1940s through 1960s when coho stocks were low. Correlations were high (r=0.89) during the 1970s and early 1980s when coho smolts, at least, were relatively abundant. When abundance was low, it is argued, the carrying capacity of the ocean was seldom approached even in weak upwelling years. As abundance increased, however, upwelling determined carrying capacity was frequently challenged.

Years of strong upwelling (above 300 units) seem to produce about a million more adults the following year than years of weaker upwelling. For the years of weak upwelling, density dependent models predict that the highest number of returning adults (about 2 million) will be produced when total smolt production is limited to around 40-45 million. Releases beyond this (such as the 62 million released in 1982) will, according to these models, produce fewer returning adults, and in addition will be devastating to wild smolts forced to compete. Optimum smolt levels may be much higher in strong upwelling years, but since this occurs only about 25% of the time it might be futile to manage on this expectation. The record run of 4.1 million in 1976 occurred when only 36 million hatchery smolts were released with strong upwelling in 1975.

The concept that ocean carrying capacity has been reached for coho salmon in the OPI area remains controversial. Populations cannot indefinitely sustain the growth exemplified by coho smolt production in the OPI area. At some abundance the ecosystem will become limiting and a decline is inevitable if these limits are exceeded. We may never be able fully to understand or predict the carrying capacity of the oceans because of the extensive salmon migration, the complex and interacting food chains, and the variable environmental conditions. But we surely will understand this better in the future as methods are found to maintain or increase salmon production. Whatever the outcome, it is certain that the decline in OPI coho salmon production will generate questions regarding our expectations for increased hatchery production and the long term development of private sea ranching in North America. As McNeil (1980) stated, "The allocation of grazing rights for artificially propagated salmon is likely to become a critical issue".

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