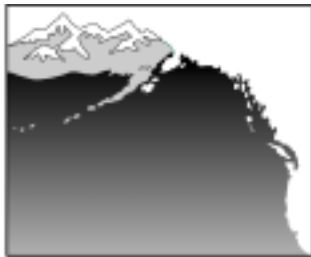


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Abstract

Direct information from high seas tagging studies indicates that Yukon River chinook salmon are concentrated in the Bering Sea. These results are supported by scale pattern analysis (SPA), which estimates that immature western Alaska (particularly Yukon River) chinook salmon are the dominant population in the northwestern and central Bering Sea in summer and in the southeastern Bering Sea (west of 170°W) in winter. SPA indicates that immature Yukon chinook salmon are also distributed well offshore in the central North Pacific Ocean (north of 46°N) in spring-early summer (June). Parasite analysis of chinook salmon continental origins supports scale pattern results for Bering Sea distribution of western Alaska salmon. Existing data are inadequate for inferring the distribution and migration routes of juveniles in their first year at sea and adults in their last spring at sea. New ocean research on salmon distribution, carrying capacity, ecology, run forecasting, response to climate change, and stock and fishery interactions is recommended.

Introduction

In this paper we summarize information on the general state of knowledge and current hypotheses about ocean migration and residency of Yukon River chinook salmon (*Oncorhynchus tshawytscha*), including a brief comparison with what is known about ocean migration and residency of other North Pacific chinook salmon stocks. The first section of our results and discussion is a summary of information from previously published reviews of ocean distribution and migration patterns of chinook salmon, which include data collected from 1955 through 1986. Subsequent sections also include new data from 1987-present and information from other publications and processed reports not covered by the earlier reviews. Information on current and potential future directions for ocean research on Yukon River chinook salmon is also discussed.

Methods

Throughout the paper we assume that data on the distribution of chinook salmon in the Bering Sea and western Alaska chinook salmon in all ocean regions are representative of the distribution of Yukon River chinook salmon. Distribution and relative abundance data were taken from published scientific literature, processed agency reports, and databases maintained and updated annually with new information by the High Seas Salmon Research Program, School of Aquatic and Fishery Sciences, University of Washington. These databases include the high seas tag (1956-present) and coded-wire tag (1981-present) recovery databases and high seas research and fishery catch and effort data files (1955-present). Additional data on high seas salmon research have been provided on different occasions by the Canadian Department of Fisheries and Oceans, the Fisheries Agency of Japan, Russia's Pacific Research Institute of Fisheries and Oceanography, and the U.S. National Marine Fisheries Service. Material has also been extracted from International North Pacific Fisheries Commission (INPFC) and North Pacific Anadromous Fish Commission (NPAFC) documents submitted by the Contracting Parties (Canada, Japan, Russia, and the United States). Methods for the scale pattern analyses are described in cited references. Freshwater and ocean age designation for salmon follows the European formula (Koo 1962). In this notation, a number preceding a dot is the number of years (winters) that the fish spent in freshwater, and a number following a dot is the number of years spent in the ocean. For example, an age-1.4 chinook salmon spent one year in freshwater and four years in the ocean. All salmon in the ocean are assigned the same birthday, that is, all fish become one year older on January 1. We followed the definitions for salmon life-history and maturity stage established in previous reviews, that is, a "juvenile" fish is in its first ocean year (ocean age-.0), an "immature" fish is in its second or subsequent ocean year (ocean age-.1 or older) but not its last ocean year, and a "maturing" fish is in its last ocean year.

Results and Discussion

Summary of information from published reviews of historical data (1955-1986)

Historical research related to high seas salmon driftnet fisheries and various other ocean interception fisheries has yielded data on the ecology and biology of salmon in the North Pacific Ocean since the mid-1950s. Some of the early research in the mid-1950s by INPFC member nations was simply to ascertain the range limits and migration routes of the different species of Pacific salmon (Jackson and Royce 1986). Field investigations of ocean distribution, migration patterns, abundance, and stock origins of chinook salmon have always been limited by the low abundance of this species in research vessel catches. Data acquired over the past 47 years by numerous vessels conducting different lines of research have added more detail, and the data can be combined to show oceanic distribution and relative abundance of chinook salmon. However, these data were collected over many years, and distribution of effort has been spotty. For example, there has been very little research vessel effort south of 50°N between 175°W and 155°W, and most of the Gulf of Alaska data were collected in the 1960s. The great majority of research effort has occurred in summer, and information from other seasons is much less extensive. Additional data are limited to the times and areas of intensive coastal and high seas commercial fisheries for salmon and other species.

Mason (1965) provided the first comprehensive review of INPFC data (1955-1962) on chinook salmon in offshore waters. Over the entire 8-year period combined research gillnet and

longline catches by Canada, Japan, and the United States in the Bering Sea and North Pacific Ocean were less than 2,000 chinook salmon, illustrating the extremely low abundance of chinook salmon in near-surface research catches. By combining research and Japanese mothership fishery catch data he was able to develop the first relatively complete picture of the broad-scale distribution of chinook salmon in offshore waters. Mason's results indicated that chinook salmon (primarily immature fish) are distributed across the North Pacific Ocean from at least 41°N to the Aleutian Chain, and in the Bering Sea westward from Bristol Bay to Kamchatka and northward from the Aleutian Islands to 60°N. In spring (May) chinook salmon were distributed south of the Aleutians to 42°N latitude in the central North Pacific and to 40°N close to Japan, and the greatest concentrations were south of the Komandorski Islands and east to 175°E, where abundance appeared to increase in June and peak in July concurrently with a westward shift in distribution toward the coast of Kamchatka. In June, the greatest concentrations of immature chinook salmon were in the central Bering Sea, and these concentrations apparently shifted westward of 180° in July, and further westward in August.

Major et al. (1978) updated previous summaries of INPFC data with information collected primarily through 1970, and summarized significant new information as follows:

General distribution of juvenile (ocean age-.0) chinook. In their first summer and fall in the ocean, juvenile (ocean age-.0) chinook salmon tend to be distributed close to shore rather than in offshore waters; by winter (December and January) they also occur in offshore waters.

General distribution of ocean age-.1 chinook. In their second summer and fall in the ocean (ocean age-.1) chinook are distributed over a wide area (coastal Gulf of Alaska, eastern Aleutian Islands, most of the Bering Sea, and the North Pacific Ocean south and eastward from the tip of the Kamchatka Peninsula to the central Aleutian Islands) but have not yet attained their maximum offshore distribution; the only substantial catches in offshore waters were in the central Bering Sea where stocks are primarily of Yukon River, Kuskokwim River, and Bristol Bay origin.

Major distribution area/maturity. Among three offshore regions—the western North Pacific Ocean and the Bering and Okhotsk seas—the greatest concentration of all ocean-age groups (age-.1 and older) is in the Bering Sea. In the western and central Bering Sea in summer (June-July) most chinook salmon are immature and the few maturing fish appear to be bound for Russian (Kamchatka Peninsula) rivers;

Vertical distribution. The vertical distribution of chinook salmon in offshore waters is not well defined, but they frequent greater depths (e.g., depths to 110 m in coastal waters) than other salmon species and are captured in offshore waters in trawls fished on or near the bottom.

Distribution and sea surface temperature. The abundance of chinook salmon appeared to be independent of sea surface temperature at the range where they were encountered (2.0-11.5°C).

Distribution of western Alaska (including Canadian Yukon) chinook from tagging. At the time of Major et al.'s report there were eight coastal recoveries of high seas tagged salmon (3 Yukon R., 1 Kuskokwim R., 2 Bristol Bay, 1 Yakutat, and 1 Columbia R.). These recoveries showed that western Alaskan chinook salmon occurred in the Bering Sea as far west as 172°12'E (at

59°03'N) and in the North Pacific Ocean just south of Adak (as far west as 176°18'W (at 51°36'N), where they mixed with chinook from a wide coastal range (Yakutat to the Columbia R.).

Distribution of western Alaska (including Yukon Territory) chinook from scale analysis. Scale growth patterns showed that western Alaskan-type chinook salmon increased in proportion from west to east within the area of the former Japanese mothership fishery (160°E-175°W), particularly in the Bering Sea in summer where high-seas driftnet catches of immature fish were highest.

Distribution of other N. American stocks. Stocks from N. American streams other than western Alaska were known from tag experiments to occur in the North Pacific Ocean as far west as 176°34'W (at 51°29'N), and were widely scattered in the Gulf of Alaska and farther south, principally close to shore.

Distribution of Russian stocks. At the time of Major et al.'s summary there were no reported recoveries of tagged salmon from Russia. Indirect information from scale, maturity, and distribution studies suggested that Russian chinook range as far south in the western North Pacific Ocean as about 40°N and as far east as about 180°, and are widely distributed in the Bering Sea to at least as far west as 160-165°E.

Ocean age composition of chinook in offshore waters. Ocean ages-.2 and -.3 fish dominated in offshore research and commercial driftnet fishery catches, with only small proportions of age-.1, -.4, and -.5 fish, and proportions of age-.2 fish increased in catches over the May-July period regardless of fishing area.

Hartt and Dell (1986) provided some additional information on the distribution of juvenile (age-.0) chinook salmon in the eastern Bering Sea and North Pacific Ocean. Most of their sampling was done in relatively nearshore waters from May to October 1964-1968 with fine-mesh purse seines. In the eastern Bering Sea, juvenile chinook salmon first appeared in their catches in late June, and were caught in all subsequent time periods. The westernmost catches of juvenile chinook were south of the central Aleutian Islands during July. Data were inadequate for inferring migration patterns between juvenile and immature age-.1 stages, but indicated that western Alaskan stocks migrated farther offshore than stocks from other North American production areas to the south. The mixing of juvenile age-.0 and immature age-.1 chinook in both coastal and offshore waters appeared to be unique compared to other Pacific salmon species. There was no evidence of overlap in distribution of Bering Sea and Gulf of Alaska chinook salmon stocks at the juvenile stage. The direction of local movements of juveniles in the eastern Bering Sea was variable, apparently influenced by strong tidal currents and rich feeding conditions.

In the most recent comprehensive review of historical information, Healey (1991) used high seas disk tag data (1956-1984; C. Harris, Fisheries Research Institute, University of Washington, pers. comm.) and coded wire tag recovery data (1980-1986; Dahlberg 1982; Wertheimer and Dahlberg 1983, 1984; Dahlberg and Fowler 1985; Dahlberg et al. 1986) and the results of scale pattern analyses (Major et al. 1978; Myers et al. 1984; Ito et al. 1985, 1986; and Myers 1986) to describe the distribution and relative abundance of regional stock groups of chinook salmon in

the Bering Sea and North Pacific Ocean. Healey concluded that in the Bering Sea western Alaskan chinook salmon (including Canadian Yukon fish) are the most abundant stock group, and Russian and central Alaskan stocks are about half as abundant as western Alaskan chinook salmon. The abundance of the southeast Alaska-British Columbia stock group in the Bering Sea is low. In the western North Pacific Ocean, there is a broad mixture of Russian, western Alaskan, and central Alaskan stocks, and western Alaskan chinook are probably no more abundant than Russian stocks. Central Alaskan stocks are probably less abundant than Russian chinook salmon in the Bering Sea and western North Pacific Ocean. Abundance of southeast Alaska and British Columbia chinook salmon is low in both the Bering Sea and western North Pacific Ocean. These stocks, as well as Washington, Oregon, Idaho, and California stocks, are probably distributed mainly in the eastern North Pacific with the greatest concentrations in coastal waters over the continental shelf. Healey notes that “virtually all chinook captured in the Bering Sea and western North Pacific Ocean are stream-type” (fish that spent one or more winters in freshwater before migrating to the ocean). However, the accuracy of freshwater ages, which were determined from the scales of chinook salmon in high seas mixtures, is not known.

New information (not included in previously published summaries) on the general ocean distribution of chinook salmon

Japanese research gillnet data clearly show the broad ocean distribution of chinook salmon in summer (June-July 1972-1990; Fig. 1; Ishida and Ogura 1992). The nets, constructed of 10 different mesh sizes to reduce size selectivity, are soaked overnight, and sample only surface waters (to about 8-m deep). Chinook salmon are caught in the nets while actively feeding at the surface before sunrise. These data indicate that the highest summer concentrations of chinook salmon are in the central Bering Sea between 170°E and 170°W, where immature Yukon River chinook salmon are estimated by tagging, parasite, and scale pattern studies to be the major stock component.

We examined fall, winter, and spring patterns of distribution and abundance of chinook salmon by combining data from gillnet, longline, and purse seine gear used by Japanese, Canadian, Russian, and U.S. research vessels from 1955 to 1991 (Fig. 2). By autumn chinook salmon seem to have moved to Gulf of Alaska and Kamchatka coastal waters, but there are almost no research vessel data for the western Bering Sea, which is probably the main area of distribution of immature Yukon River chinook salmon in autumn. Very minimal data from winter show a few fish in the central eastern North Pacific, south of the Alaska Peninsula; there is no information from the southern part of their distribution in winter. Research vessel catches in spring show that chinook salmon are distributed well offshore in the North Pacific Ocean along the southern edge of their ranges, south of about 45°N. Clearly, the historical high seas salmon research vessel data are inadequate for showing the autumn, winter, and spring distribution of chinook salmon in the North Pacific Ocean and Bering Sea.

The Japanese high seas salmon driftnet fisheries were terminated in 1991, and since then high seas salmon research programs have been greatly reduced. One research vessel, the *Wakatake maru*, has been used for annual surveys in the central North Pacific and Bering Sea along the 180° longitude in summer (June-July, 1991-2001). The *Wakatake maru* data show the low relative abundance of chinook salmon compared to other species in high seas research gillnet catches, and the higher relative abundance of chinook salmon in the central Bering Sea than in the central North Pacific Ocean (Table 1). In 1998 and 2000, chinook salmon abundance in the

Bering Sea was relatively high, when young ocean age-.1 fish predominated in the catches (Table 2). Immature chinook salmon in the central North Pacific in summer from the Subarctic Current to the Aleutians feed primarily on squid (*Berryteuthis anonychus*), and in the Bering Sea their diets are more diversified, also including fish and euphausiids (Table 3). Another Japanese research vessel, the *Oshoro maru*, has been used for summer salmon surveys the central North Pacific Ocean and Gulf of Alaska, where the few chinook salmon caught by research gillnets were predominantly immature ocean age-.2 fish feeding primarily on squid (Tables 4 -6). Sonic tracking by Japanese scientists of four chinook salmon (probably immature) in the central Bering Sea in summer showed that they swam in or below the thermocline, which was about 20-40 m deep in most areas, with occasional vertical movements toward the surface or deeper layers (Ogura and Ishida 1995). Occasional winter surface-trawl surveys by Japan have shown aggregations of juvenile chinook salmon moving offshore into the western North Pacific Ocean in December-February (Nagasawa et al. 1994; Ueno et al. 1997; Ishida et al. 1999). The February 1998 trawl survey was the only one that included stations in the Bering Sea, where chinook was the only salmon species in the catch (Ishida et al. 1999).

Data from chinook salmon bycatch in commercial trawl fisheries provide a more complete picture of fall, winter, and spring chinook salmon distribution in the eastern Bering Sea than the research vessel data shown in Figure 2. The largest reported catches by foreign and joint-venture groundfish fisheries in the U.S. 200-mile zone in eastern Bering Sea were in 1979 and 1980 (over 100,000 and 201,000), and catches declined after 1980. Incidental chinook salmon catches were usually highest in demersal (4-6 m above the bottom) trawl fisheries operating along the 200-m contour during the late fall, winter, and early spring (Nelson et al. 1978, 1979, 1980, 1981a, 1981b, 1982, 1983; Berger et al. 1984, 1985). Chinook salmon are more closely associated with the bottom than other species of Pacific salmon, and decreased activity of chinook salmon during winter months may cause increased susceptibility to trawls (Natural Resource Consultants 1984). The decline in incidental catches of chinook salmon after 1981 may have been related to an increase in the use of pelagic (mid water) trawls (Nelson et al. 1981a). Analyses of bycatch data from U.S. groundfish fisheries in the eastern Bering Sea indicate that immature chinook salmon enter the eastern Bering Sea in autumn, remain there throughout the winter and spring, and then move to other areas in summer (ADFG/NPFMC 1999). Data from commercial trawl operations off the U.S. west coast (1985-1990) indicated a seasonal shift in abundance and depth distribution of chinook salmon, that is, catches were higher in winter and were dispersed throughout a depth range of 100-482 m, than in summer when catches were low and occurred at shallower depths (less than 220 m, Erickson and Pikitch 1994). Recent U.S. research trawl surveys in the eastern Bering Sea (Bristol Bay) in summer have found juvenile chinook salmon distributed within the coastal domain (Farley et al. 2000).

Russian research trawl surveys have provided new information on chinook salmon distribution and migration patterns in the western Bering Sea (Radchenko and Chigirinsky 1995, Radchenko and Glebov 1998, Smorodin et al. 2001). Concentrations of chinook salmon smolts are found on the Korfa-Karaginsky shelf in early October (Radchenko and Chigirinsky 1995). Most juvenile (ocean age-.0) chinook salmon off eastern Kamchatka leave coastal waters and move offshore into the Bering Sea by late September-early October (Smorodin et al. 2001). The general seasonal movements of all other age groups (age-.1 and older) of chinook salmon appear to be similar, that is, distribution shifts southeastward in fall-winter and northwestward in spring-summer. In spring (May) maturing chinook salmon are distributed in the western Bering Sea,

and by late June-early July they are finishing the ocean phase of their return migration. In summer and autumn, immature chinook salmon move from the eastern Bering Sea into the western Bering Sea, where their distribution appears to shift from the eastern part of the Russian EEZ in late June to the western Aleutian Basin and shelf and continental slope of the Navarin region by early October (Fig. 3; Radchenko and Chigirinsky 1995). Immature age-.1 chinook salmon are distributed mainly in pelagic waters, where they feed on juvenile squid and euphausiids, and older, larger immatures (ocean age-.2 and older) tend to be distributed at or near the bottom (180 m and above) along the outer shelf, where they feed on adult squid (*Berryteuthis magister*) (Radchenko and Glebov 1998). In November-December immature chinook salmon begin to leave the western Bering Sea (Fig. 3; Radchenko and Chigirinsky 1995). In winter ocean age-.2 or older chinook salmon are distributed in near-bottom layers of the northern and western Bering Sea shelf and along the entire 200-m contour of the eastern Bering Sea shelf, where they continue to feed mainly on gonatid squids (Fig. 3; Radchenko and Glebov 1998).

Information from tagging studies

Much of the INPFC-related salmon research was directed at the stock composition of salmon caught in the salmon fisheries and the delineation of ranges of stocks in relation to the fisheries areas (Jackson and Royce 1986). To this end, extensive tagging programs were implemented, and tags have been applied to fish on the high seas for recovery inshore since 1955. After the end of the high seas salmon driftnet fisheries in 1991, the high seas tagging program was greatly reduced, and at present the only high seas salmon tagging operations in the Bering Sea, which is the main area of ocean distribution of Yukon chinook salmon, are done by scientists aboard the Japanese research vessel *Wakatake maru* in July. Since 1980 the catches of high seas research vessels and commercial groundfish (trawl) vessels in the U.S. 200-mile zone have been examined for salmon and steelhead with missing adipose fins to recover coded-wire tags (CWTs).

Western Alaska chinook salmon. All western Alaska recoveries of chinook salmon tagged and released during high seas salmon investigations by Japan, Russia, and the United States (1955-2000) have come from fish tagged in the Bering Sea or just south of the Aleutians (Fig. 4, Table 7). One tag was recovered in the Canadian Yukon and the remainder were recovered in western Alaska (8 Yukon fish, 4 Bristol Bay fish, and 2 Kuskokwim fish). All but one of these tagged fish were released west of 179°W in June and July. These data show that immature Yukon, Kuskokwim, and Bristol Bay chinook salmon mix in offshore waters of the Bering Sea in summer, and suggest that Yukon River chinook salmon are the predominant stock of western Alaskan salmon in the central and northwestern Bering Sea in summer. The release locations of two maturing fish recovered in Bristol Bay suggest a possible spring migration corridor running northeastward from the south-central Aleutians and along the north side of the Alaskan Peninsula to Bristol Bay. Although there are no returns of tagged salmon to the Yukon River from the North Pacific, a reasonable assumption is that Yukon chinook salmon are also distributed well offshore south of the Aleutian Islands and perhaps into the Gulf of Alaska (Rogers 1987).

All nine ocean recoveries of CWT western Alaskan chinook salmon are from Canadian Yukon (Whitehorse Hatchery) fish in the bycatch of trawl fisheries in the eastern Bering Sea (Fig. 5, Table 8). We think it is reasonable to assume, however, that wild Yukon fish would have distribution patterns similar to hatchery fish. One recovery on the eastern Bering Sea shelf

in June was probably a maturing fish, and suggests that Yukon fish may approach the river mouth from the south. The other recoveries were from fish caught in winter (December-March) along the eastern Bering Sea shelf break (200-m depth contour) northwestward from Unimak Pass to the international boundary.

The overall pattern of all recoveries of tagged Yukon chinook salmon suggests seasonal movement of immature Yukon chinook salmon between summer feeding grounds in the central and northwestern Bering Sea and wintering areas in the southeastern Bering Sea. There are not enough tag recoveries to make quantitative estimates of stock composition of chinook salmon in the Bering Sea and North Pacific Ocean.

Other North American chinook salmon. There are recoveries of CWT central and southeastern Alaska, British Columbia, Washington, Oregon, and California chinook salmon from trawl fisheries in the southeastern Bering Sea (Figs. 6-12, Tables 9-10). The relatively low number of recoveries from Alaskan stocks reflects the pattern of coded-wire tag releases rather than the relative abundance of the stocks. Coded-wire tagged fish are released primarily from North American hatcheries south of the Alaska Peninsula, and provide little or no information on Russian and western and central Alaskan stocks. Canada does not report recoveries of CWT chinook salmon from their research or commercial trawl fisheries.

The number of CWT recoveries from all release locations except the Yukon and Central Alaska (Cook Inlet, Kodiak) were substantially higher in the Gulf of Alaska or the U.S. West Coast than in the Bering Sea. Most Bering Sea recoveries of CWT Alaska chinook salmon were in September-November, suggesting fall movements of immature chinook salmon from pelagic summer feeding areas in the Bering Sea to wintering areas in the Aleutians, North Pacific Ocean, and Gulf of Alaska. However, a few December-March recoveries of CWT Alaska, British Columbia, Washington, and Oregon chinook salmon in the Bering Sea indicates that some fish from these regions may overwinter in the southeastern Bering Sea.

One chinook salmon recovered in a troll fishery off Yakutat, Alaska, and one Columbia River chinook salmon (returning to the Salmon R., Idaho) were recovered from high seas releases of immature chinook salmon caught south of Adak Island in the central Aleutians (Fig. 4). One high seas research vessel recovery of a CWT Columbia River chinook salmon (age 1.1) at 43°30'N, 173°30'W in June is a southwestern range limit for North American chinook salmon in the North Pacific Ocean. These few recoveries suggest that the distribution of North American chinook salmon in the North Pacific Ocean is much broader than indicated by Gulf of Alaska and U.S. West Coast recoveries of tagged chinook salmon.

Asian chinook salmon. There are only two Asian recoveries of chinook tagged on the high seas, one tagged off Hokkaido and one south of the central Aleutians (Fig. 4).

Information from scale pattern analysis

Given the nature of sampling opportunities from the fisheries and the accessibility of known-origin reference materials from Asia and North America, scale pattern analysis (SPA) has proved to be the most useful approach for estimates of stock mixtures of salmon on the high seas.

SPA shows western Alaska (particularly Yukon River) chinook salmon predominate in the Bering Sea. There is a mix of Asian and North American (western and south central Alaskan) stocks from south of the Aleutians down to 46°N, with wide variations in estimated proportions between years. South of 46°N, in the landbased salmon fishery area, the chinook are estimated to be predominately Asian (Myers et al. 1984, 1987; Myers and Rogers 1988; Davis 1990, 1991).

Chinook salmon in the 1979, 1981, and 1982 catches by groundfish fisheries in the eastern Bering Sea were predominantly ages 1.2 (56%) and 1.3 (26%). Regional stock proportion estimates indicated that western Alaska, which included Canadian Yukon fish, was the predominant regional stock of ages 1.2 and 1.3 fish. The proportions of the three western Alaskan subregional stocks (Yukon, Kuskokwim, and Bristol Bay) varied considerably with such factors as brood year, time, and area (Table 11). Bristol Bay and central Alaska (primarily Cook Inlet) stocks predominated in fall (October-November) catches in the eastern portion of the fishery area (east of 170°W), and Yukon fish predominated in winter (January-February) catches in the western portion (west of 170°W).

Other scale pattern studies have shown western Alaska to be the predominant regional stock in May-June samples of immature chinook salmon in the Bering Sea west of 180° (Major et al. 1975, 1977a, 1977b; Ito et al. 1986; Myers et al. 1987, Davis 1990). Myers et al. (1987) also noted considerable annual variability in estimated proportions of age-1.2 Yukon, Kuskokwim, and Bristol Bay chinook salmon in the central Bering Sea in July, 1975-1981 (Table 12). In June, Yukon chinook were the predominant stock in catches in the central North Pacific Ocean between 170°E and 175°E and in the central Bering Sea between 175°E and 180°. In July 1979-1981, proportions of Yukon chinook were higher in catches from the western portion of the fishery area (175°E-180°) than in the eastern portion (180°-175°W). Rogers (1987) used these estimates to calculate interceptions of Yukon River chinook salmon by the Japanese high seas driftnet fisheries, and found that these interceptions often amounted to over 20% of the domestic catch in the 1970s and even in 1986.

Information from parasites

Parasites acquired in freshwater and found only in one region or on one continent have also been used to determine the freshwater origin of chinook caught on the high seas. Japanese scientists examined two myxosporean brain parasites, *Myxobolus arcticus* and *M. neurobius*, in adult head and smolt samples from two Asian rivers and from North American rivers from the Yukon to the Sacramento (Urawa et al. 1990; Urawa and Nagasawa 1991). *Myxobolus arcticus*, the "Asian" indicator parasite, is also found in some North American chinook (as well as in other species) from British Columbia and southeastern Alaska. We used the interpretation of Urawa et al. (1998) regarding the continent of origin of chinook salmon with parasite "tags," but consider their data to be indirect evidence (not proof of origin) for Russian salmon. In the Bering Sea and the central and western North Pacific, parasite data generally agree with SPA estimates: there are few infected chinook in the Bering Sea (indicating mostly North American origins), and much higher infection rates south of the Aleutians (presumably indicating Asian fish; Fig. 13). *Myxobolus neurobius* has been found only in Columbia River chinook and so far has not been detected in high seas samples.

Summary of Ocean Distribution and Migration Patterns of Yukon Chinook

Data are inadequate for inferring the migration patterns of juvenile (ocean age-.0) Yukon River chinook salmon. If their behavior is similar to other juvenile chinook salmon, then in summer they are probably distributed in the coastal domain rather than in offshore waters, and by winter (December and January) they also occur in offshore waters. Between juvenile and age-.1 stages they probably migrate farther offshore than most other North American chinook salmon stocks. By their second fall in the ocean (ocean age-.1) Yukon chinook salmon may range over a broad area, including most of the Bering Sea and the North Pacific Ocean, north of 46°N and south and eastward from the western Aleutians, where they are distributed in pelagic waters.

The maximum offshore distribution of Yukon chinook salmon is apparently reached in their third and fourth years in the ocean (immature ocean ages-.2 and -.3), when they migrate between summer-fall feeding areas in the central, western, and northwestern Bering Sea to winter-spring feeding areas in the southeastern Bering Sea, Aleutians, and North Pacific Ocean. In spring (May) immature (ages-.1, -.2, and .3) Yukon chinook salmon are probably distributed in the central North Pacific and Bering Sea earlier than other salmon species and stocks. In June-early July immature Yukon chinook salmon move from the eastern Bering Sea and central North Pacific into the central Bering Sea, where in late June they are distributed in international waters (Donut Hole) and in the eastern part of the Russian EEZ. From mid July to September their distribution shifts north and westward, and by early October their northwestward distribution extends to the western Aleutian Basin and shelf and continental slope of the Navarin region (Siberian Coast), where larger, immature (ocean age-.2 and -.3) chinook salmon are distributed mainly at or near the bottom (180 m and above) along the outer shelf.

The highest summertime concentrations of chinook salmon are in the central Bering Sea between 170°E and 170°W, where immature Yukon River chinook salmon are the major component in mixtures of Russian, western Alaska, and central Alaska (primarily Cook Inlet) chinook stocks. These concentrations of Yukon chinook shift westward of 180° in July. Limited data from sonic tracking indicates that immature chinook salmon in this area swim in or below the thermocline (about 20-40 m deep) with occasional vertical movements toward the surface or deeper layers.

In November-December immature Yukon chinook salmon begin to leave the western Bering Sea. Groundfish research and commercial trawl data show that in winter (December-March) ocean age-.2 or older chinook salmon are distributed in near-bottom layers of the northern and western Bering Sea shelf and along the entire 200-m contour of the eastern Bering Sea shelf. Scale pattern estimates indicate that the greatest winter concentrations of Yukon chinook salmon in the eastern Bering Sea are west of 170°W. In their last spring (June), adult Yukon River chinook salmon are distributed on the eastern Bering Sea shelf, but data are inadequate for inferring their return migration routes.

Current YR DFA analysis

The only stock mixing-proportion estimates for chinook salmon in the eastern Bering Sea are from a period of relatively high abundance of Yukon chinook salmon in the late 1970s and early 1980s (Myers and Rogers 1988). The large incidental catches of chinook salmon in eastern

Bering Sea trawl fisheries in 1979-1980 preceded large runs to the Yukon River in 1980-1981, so the effect of the interceptions was probably not significant. The current Yukon River Drainage Fisheries Association (YRDFA) analysis of chinook scale samples, including the final analysis to be conducted in FY 2002, will provide mixing-proportion estimates for chinook salmon in eastern Bering Sea trawl fisheries in 1997-1999, a period of relatively low abundance of Yukon chinook salmon. If the major component stocks of western and central Alaska chinook salmon can be accurately identified, then the analysis will provide information on possible shifts from the previous period in distribution and relative abundance of Yukon R. chinook salmon, as well as new estimates of the stock composition and distribution patterns among various year classes and age groups of chinook salmon within the times and areas of the fishery.

Research Recommendations

We recommend new ocean research on Yukon River chinook salmon carrying capacity, growth, and stock and fishery interactions. There are many important questions that should be addressed, for example:

1. What is the range of interannual variation in seasonal distribution and migration patterns of Yukon River chinook salmon at each ocean life-history stage? Where are their critical habitats and foraging areas? What are the boundaries of these areas, the conditions that define the boundaries (spatial, temporal), and their residence times in these areas?
2. What are the primary ocean prey, predators, and competitors of Yukon River chinook? What is the range of variation in spatial and temporal overlap of salmon and their predators and prey, and how do changes in ocean conditions affect predator-prey-competitor relations?
3. What and where are the best habitats for promoting summer growth and winter survival of Yukon River chinook salmon? How does environment and body condition (e.g., temperature, photoperiod, lipid content) influence their winter survival and age at maturity?
4. What role does vertical distribution and migration play in growth, bioenergetics, and survival of Yukon River salmon in different seasons?
5. Is there any evidence for competition or density-dependent growth or mortality between Yukon River chinook salmon and Asian salmon stocks in the Bering Sea (e.g., Russian pink salmon, Hokkaido chum salmon)?
6. How do short-term climate change (e.g., warm winters vs. cold winters, El Niño vs. La Niña) and longer-term climate change (e.g., Arctic Oscillation, Pacific Decadal Oscillation) affect salmon distribution, migration, and foraging patterns?
7. Can research trawl data be used to accurately estimate salmon abundance? How are salmon behavior (distribution, migration, and feeding patterns) and environmental conditions related to their abundance and survival, and can fishery managers use this information to accurately forecast adult returns?
8. When and where do stock-specific aggregations of Yukon River chinook salmon form in the ocean? When and where are they most susceptible to interception fisheries? What are the catches and bycatches of Yukon River chinook salmon in coastal and offshore fisheries outside the US EEZ?
9. Are large releases of hatchery salmon affecting the carrying capacity of wild Yukon River chinook salmon in the Bering Sea?

The best approach to resolving these issues is a long-term, multidisciplinary research and monitoring effort to provide data for ocean assessment, management, and conservation of Yukon River chinook salmon stocks. A directed research effort on juvenile Yukon River chinook salmon in the coastal domain is essential to understanding the causes of short- and long-term variation in ocean survival. Given their low abundance relative to other salmon species in research catches, however, a directed high seas research effort on chinook salmon is not practical. We recommend developing a program of high seas research on Yukon chinook in conjunction with ongoing research on other salmon species, as well as by making better use of opportunities to collect samples and data from chinook salmon bycatch in large-scale commercial trawl fisheries. Because Yukon chinook salmon migrate across international boundaries and in the international waters of the Bering Sea and North Pacific Ocean, this research effort should be closely coordinated with Canada, Russia, and Japan under the auspices of the NPAFC. At present, the NPAFC is actively developing and implementing a new cooperative program of research on salmon in the Bering Sea.

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