INTERNATIONAL NORTH PACIFIC
FISHERIES COMMISSION
Established by Convention between Canada, Japan
and the United States for the Conservation of the
Fisheries Resources of the North Pacific Ocean

BULLETIN NUMBER 35

DISTRIBUTION AND ORIGIN OF CHUM SALMON
IN OFFSHORE WATERS OF THE NORTH
PACIFIC OCEAN
by F. Neave, T. Yonemori and R. G. Bakkala

OFFICES: 6640 Northwest Marine Drive
Vancouver, V6T 1X2
PREFACE

In 1970, the Commission decided to prepare new joint comprehensive reports containing broad syntheses of available information on the distribution and origin of the six species of salmon (genus Oncorhynchus) on the high seas of the North Pacific Ocean, and on the oceanographic conditions which are closely related to these salmon. The Commission has published previously similar joint comprehensive reports which provided information available approximately through 1961 (Bulletin No. 13-oceanography, No. 16-coho, chinook, and masu salmon in offshore waters, No. 20-sockeye salmon in offshore waters, No. 22-pink salmon in offshore waters, and No. 25-chum salmon in offshore waters). These reports were parts of a comprehensive report entitled "Salmon of the North Pacific Ocean", which also provided catch statistics and information on the life history, spawning populations, and offshore distribution of salmon.

The present report, which deals with chum salmon, is the fourth of the new series. The first three in this series concerned coho salmon (Bulletin 31), oceanography (Bulletin 33), and sockeye salmon (Bulletin 34).

Research reports submitted to the Commission for publication in the Bulletin must first receive approval for publication by three scientific referees. At the present time, these referees are: Dr. K. S. Ketchen, Pacific Biological Station, Environment Canada, Nanaimo, B.C.; Mr. Koya Mimura, Research and Development Department, Fishery Agency of Japan, Tokyo; and Dr. F. M. Fukuhara, Northwest Fisheries Center, National Marine Fisheries Service, Seattle, Washington. Following approval for publication by the scientific referees, reports must receive approval for publication by the Commission. Approval for publication by the Commission does not necessarily constitute endorsement of the views of the authors.

Bulletins of the Commission are published separately in English and Japanese and accuracy of translation is the responsibility of the Secretariat. The original language of this Bulletin was English.

INFPC SECRETARIAT
August, 1976
DISTRIBUTION AND ORIGIN OF CHUM SALMON IN OFFSHORE WATERS OF THE NORTH PACIFIC OCEAN

By
Ferris Neave, Pacific Biological Station,
Fisheries and Marine Service, Environment Canada,
Nanaimo, British Columbia
Tamotsu Yonemori, Far Seas Fisheries Research Laboratory,
Fishery Agency of Japan,
Shimizu, Shizuoka, Japan
Richard G. Bakkala, Northwest Fisheries Center,
National Marine Fisheries Service,
Seattle, Washington

TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>23</td>
</tr>
<tr>
<td>31</td>
</tr>
<tr>
<td>33</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>41</td>
</tr>
<tr>
<td>48</td>
</tr>
<tr>
<td>48</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>51</td>
</tr>
<tr>
<td>66</td>
</tr>
</tbody>
</table>

(4) Rates of travel .................................. 69
Other studies .................................. 71
Summary .................................. 71
References .................................. 76

INTRODUCTION

Studies on the offshore distribution of Pacific salmon began prior to World War II (Sato, 1938; Hirano, 1953; Fisheries Agency of Japan 1955; Kasahara, 1961; Barnaby, 1952) but were not fully developed until the advent of the Japanese mothership fishery for salmon in the North Pacific, the Bering Sea, and the Sea of Okhotsk in 1952 (Fisheries Agency of Japan, 1955; Taguchi, 1957; Kasahara, 1961). In 1955 a vast cooperative program was undertaken by member nations—Canada, Japan, and the United States—of the International North Pacific Fisheries Commission to determine the ocean distribution and migrations of the various stocks of Asian and North American salmon in relation to the Japanese fishery. Reviews of these studies, covering data available up to about 1962, were published for each species of Pacific salmon as bulletins of the Commission. Findings relating to chum salmon were reviewed by Shepard et al. (1968)—INPFC Bulletin No. 25. In the years since their publication was prepared many further investigations have been reported. The purpose of the present review is to examine this newer information and, in conjunction with the earlier findings, to summarize our current understanding of the ocean life history of chum salmon. In general, the material treated extends to the end of 1971.

STOCKS AND FISHERIES

The geographical distribution of the spawning grounds of chum salmon has been described in con-
Fig. 1. Coastal distribution (stippled) of chum salmon in the North Pacific Ocean and adjacent seas.

A considerable detail by Sano (1967), Atkinson et al. (1967), and Aro and Shepard (1967). Their findings have been summarized by Shepard et al. (1968). It can be said that all accessible and environmentally suitable streams flowing into the North Pacific Ocean, the Sea of Okhotsk and the Bering Sea, north of about latitude 33°N on the Asian coasts and latitude 43°N on the American side, are visited by the species. Small numbers of chum salmon also penetrate the Arctic Ocean to as far west as the Lena River in the Soviet Union and as far east as the Mackenzie in Canada (Fig. 1).

"Spawning may take place as early as June... or as late as January... In general, the spawning season of northern chums tends to be earlier than that of chums from more southern areas. This tendency is reflected in the times of arrival of the runs in the various coastal fishing areas" (Shepard et al. 1968).

As was pointed out by these authors, catch statistics...
provide the only basis for comparing the abundance of chum salmon stocks throughout most of the North Pacific region inhabited by the species. With the probable exception of certain far-northern populations, however, commercial exploitation is so intensive that it can be assumed to provide a reasonably accurate picture of the relative abundance of the main stocks. Total estimated commercial catches of Asian and North American chums up to 1970 are shown in Fig. 2.

ASIAN STOCKS

The authors cited above reviewed the main historical features of commercial chum salmon fisheries up to 1962. The peak period of the yield in Asian coastal waters was between 1928 and 1941, when the annual catches of Japanese and U.S.S.R. fishermen averaged 33 million fish, weighing about 97,000 metric tons. These fish were taken mainly by traps but also by beach seine and set nets.

During about the same period (1929 to 1945), Japan also operated a mothership drift net fishery on the high seas off the east and west coasts of Kamchatka and a drift net and trap fishery based on the North Kuril Islands. At the peak period of these fisheries (1936 to 1942) the average annual yield amounted to 15.9 million fish, or one-third of the total Asian chum salmon catch.

A major shift in the geographic distribution of salmon catches was initiated in the 1950’s, when a Japanese mothership (driftnet) fishery began to operate in waters far offshore. At the same time the Japanese landbased fishery extended its eastward limit of operation in waters south of 48°N.

A description of the mothership fishery in the 1952 to 1960 period is given by Manzer et al. (1965). Since then, the basic character of the fishery has remained unchanged. Each mothership is accompanied by about 30 catcher boats and four scouting boats equipped with surface gillnets. Fishing by the catcher boats is usually conducted within a radius of about 30 miles (50 km) from the mothership, to which the catches are delivered daily. The scouting boats on the other hand may explore waters up to several hundred miles from the mothership. In 1961 operations were conducted by 12 motherships and 410 catcher and scouting boats. In each year from 1962 to 1971 inclusive, 11 motherships and 369 catcher and scouting boats were reported. As shown in Fig. 3, the mothership fishing area is for the most part bounded by longitude 175°W, longitude 160°E, latitude 46°N, and the Kamchatka Peninsula.

The maximum length of gillnets set daily by a catcher boat is limited by Japan-U.S.S.R. agreement to 12 km in waters west of longitude 170°E and 15 km east of longitude 170°E. In 1963 and subsequent years, the use of gillnets with a mesh size of less than 121 mm (stretched measure) was prohibited, and it was further required that at least 60% of the gear should consist of nets having a minimum size of 130 mm. Monofilament nets first appeared in this fishery in 1962 or 1963, and within a few years entirely supplanted the multifilament gear which had previously been used.

In the years from 1962 to 1971 the mothership fleets left their Hokkaido port on May 15 and terminated their operations on achieving an assigned catch limit (usually in late July), with an ultimate closure on August 10.

The history of the Japanese land-based salmon fisheries before and after World War II is described by Taguchi (1957). Brief reviews are also provided by Manzer et al. (1965) and Kasahara (1963). From 1962 onward, two zones ("A" and "B") have been recognized in the landbased fishery for regulatory purposes (Fig. 3). The northern boundary of Zone B is defined for the most part by latitude 45°N, with an eastward limit of longitude 175°W. Zone A extends from latitude 45°N northward to the mothership fishing area. Zone B is open from April 30 until a quota set for this zone is attained, but with an ultimate closure on June 30. After the quota for Zone B is attained, Zone A is opened for gillnet fishing until a quota allocated to each boat is attained, with an ultimate closure on August 10.

In the landbased gillnet fishery, mesh sizes less than 110 mm are not permitted and sizes from 112 to 117 are usual. The total length of the gillnet string set daily by a boat is limited to 15 km. Introduction of monofilament nets lagged a year or two behind the

---

**Fig. 3.** Fishing areas of Japanese mothership and land-based fisheries (from INPFC Statistical Yearbook 1972).
Fig. 4. Estimated average annual catches of chums in various coastal and high-seas fishing areas for periods shown.
mothership fishery but is now complete.

In 1971 the number of gillnetters operating in offshore waters of the landbased area (those exceeding 30 tons) was limited to 330 vessels by the Minister of Agriculture and Forestry. Many much smaller gillnetters (less than 7 tons) operate in coastal waters. These are licenced by the Governor of Hokkaido Prefecture and amount to about 1,380 boats yearly.

The Japanese longline fishery has operated only in Zone B, with an eastern limit at longitude 160°E until 1968, and at longitude 165°E until 1972 when this fishery was terminated. The longline unit is the "hachi," which has a length of about 135 m and carries 49 hooks on branch lines about 1 m long. Salted anchovy was used for bait. About 369 longline boats were licenced in 1971 by the Minister of Agriculture and Forestry.

The changes in the annual catches reported from various major areas up to 1962 are shown in Fig. 4. (Data for the period up to 1962 are from Fig. 5 of Shepard et al. (1968).)

In the 1963 to 1970 period the annual average of all Asian commercial chum catches was lower than in the 1954 to 1962 period—72,000 metric tons as against 98,000 metric tons in the earlier years. The reduction was especially marked in catches made on the west and east coasts of Kamchatka and along the Okhotsk coast. Mothership catches on the high seas were also reduced (from an average of 26,000 metric tons to 16,000 metric tons) but this was offset by an equivalent increase in the yield of Japanese landbased and freshwater fisheries (from 25,000 metric tons to 35,000 metric tons).

**NORTH AMERICAN STOCKS**

These stocks are exploited by North American fishermen only in coastal and fresh waters. Since the abolition of the extensive Alaska trap fishery in 1959, drift nets and purse seines have been the main instruments employed. (As is evident from data presented later in this report, North American chums are exploited to some degree by the Japanese mothership fishery in the North Pacific Ocean and Bering Sea.)

The distribution and relative magnitude of the major North American chum fisheries in the historical periods previously considered for Asian stocks are indicated in Fig. 4. Since 1962 the average total North American catch has been lower than in the 1954 to 1962 period (28,000 metric tons and 38,000 metric tons respectively). There has been little change, however, in the relative contributions of the various geographic areas.

**RELATIVE ABUNDANCE OF ASIAN AND NORTH AMERICAN STOCKS**

In comparing total Asian and total North American catches, Shepard et al. (1968) showed that "since the peak period of development in Asian fisheries in the late 1920's the yield from North American areas has always been less than that from Asia. In the periods
from 1928 to 1934 and from 1946 to 1953 (periods when exploitation in Asian waters was mainly restricted to coastal areas) the average annual yield on the Asian side was 29.6 million fish, weighing 87.1 thousand metric tons, while that on the North American side averaged 47% of the Asian total in numbers of fish (13.9 million) and 69% of the Asian total by weight (60.1 thousand metric tons). More recently (1954 to 1962) the catch on the Asian side was somewhat higher than the average for the earlier periods (1954 to 1962 average annual catch was 36.7 million chums weighing 97.7 thousand metric tons). During the 1954 to 1962 period the catch on the North American side dropped to an average of 9.2 million fish per year, weighing 38.1 thousand metric tons, only 25% of the Asian catch by numbers and 39% by weight.” As mentioned above, average annual catches have been lower on both sides of the Pacific in the 1963 to 1970 period, but the ratio of American to Asian fish (25% by number and 39% by weight) has been almost exactly maintained.

**OFFSHORE DISTRIBUTION**

**Sources of Data**

Salmon distribution studies in offshore waters have continued in the period since the completion of the previous comprehensive report on the ocean distribution of chum salmon (Shepard et al. 1968). The main effort has continued to be on immature and maturing1 fish of age .12 and older, but important new studies have also been carried out on the distribution and movement of juvenile (age .0) salmon.

Studies on juvenile salmon along the North American coast have been conducted by the Fisheries Research Institute of the University of Washington and by the Auke Bay Laboratory of the National Marine Fisheries Service (Hartt et al. 1966; Hartt, Smith and Dell, 1967; Hartt, Smith, Dell and Kilambi, 1967; Hartt et al. 1969; Hartt et al. 1970; Royce et al. 1968; Straty, 1974). Some preliminary work has also been carried out on juveniles in the Okhotsk Sea by Birman (1969) and Hokkaido University (data provided by Faculty of Fisheries, Hokkaido University, Hakodate). Fine-mesh purse seines were used by the Fisheries Research Institute in their studies along the Washington, British Columbia, and Alaskan coasts, extending into the Bering Sea, while the Auke Bay Laboratory used tow nets, round-haul nets, lampara nets, and purse seines in their studies along the north side of the Alaskan Peninsula. Fine-mesh gillnets were used by the Japanese and U.S.S.R. investigators in the Okhotsk Sea.

Data on the distribution of age .1 and older chums were available from several sources. In the Japanese mothership fishery the species were separated on the catcher boats. The total weight of each species was determined on delivery to the mothership and a random sample of 100–150 fish from five catcher boats were weighed each day to determine average size and total number of fish. Detailed information reported by each catcher boat on effort, catch, and location was summarized by the Japanese Fisheries Agency by 10-day periods and 2°×5° areas. Measurements of length, body weight, and gonad weight, and a scale sample for age determination, were taken daily from 30 fish of each species. Because of the difficulty of gathering biological data from the boats engaged in the Japanese landbased fishery, 10 or more research ships fished and carried out sampling procedures in the areas exploited by the landbased fishery, using gillnets and longlines similar to those employed by the commercial fishermen. Longline catches by Canadian and United States research vessels were also examined but had certain limitations because of their selectivity for older immature and maturing fish.

The data having the greatest continuity from year to year and between seasons, and with the broadest coverage in offshore waters, have been provided by the gillnet catches of the research vessels of the three nations. These catches have been used as the main basis for depicting the offshore distribution of chum salmon by age and maturity, with other catches being used as supporting evidence.

**Limitations of Data**

The gillnets fished by research vessels were made up with a range in mesh sizes designed to catch all available sizes of chum and other species of salmon except for juvenile fish. The method of calculating catch per unit of effort (CPUE) was to sum the average catch per mesh size over all mesh sizes fished, which gave equal weight to each mesh size fished. This procedure has proven satisfactory for comparing relative abundance between fishing locations as long as the number and size of meshes remained the same. Some variation in mesh sizes has occurred in the gillnet strings used by the regular research vessels, particularly in recent years, which has resulted in CPUE values that are not strictly comparable.

The 98 mm mesh was added to the United States
gillnet string in the winter and spring to better sample certain sizes of age .2 fish and the 51 mm mesh was added in winter to sample the small age .1 fish. Japanese research vessels used the 5-mesh gillnet starting in 1965 and the 10-mesh net in 1971 to improve the ability to sample all sizes of salmon with equal efficiency (see above).

Mesh selection curves can be used to equate CPUE values from the various combinations of mesh sizes. Mesh selection studies on the INPCC standard 4-mesh gillnet (Manzer et al. 1965; Peterson, 1966; Ishida, 1969) have shown that this range of mesh sizes adequately covered the size range of salmon available in the spring and summer but was not equally efficient for all sizes of salmon within this range. Corrections applied to catches from the 4-mesh nets proved to be relatively minor, however. In view of these findings and the large number of gillnet sets available for analysis in this report, corrections for mesh selectivity were considered impractical and uncorrected values of CPUE were used.

Some other factors may have been even more significant than mesh selection in their influence on the comparability of indices of abundance derived from research vessels of the three countries. These include the numerous types and sizes of vessels used in the research sampling, differences in colour, fiber types, lengths of nets and direction in which they were set, variation in the body length-weight proportions of the various stocks fished, variation in weather, sea state, tidal, and current conditions between sets, and the variable effects of predators and dropout rates. (Dropouts are fish that become enmeshed in the net but drop out before the net is hauled.)

Some adjustment of the Japanese data was necessary, however, in order to equate them as nearly as possible to the United States and Canadian data, particularly in the case of the Japanese research vessel data that were combined with the United States research vessel data. The major adjustment was the conversion of CPUE in tans (one tan is 50 m long for these research vessels) to CPUE in shuckles (one shackle is 91 m). The same adjustment was made to data from the mothership catcher boats where the tan is also 50 m and to data from the Japanese research vessels in the landbased fishing area where the tan is 41 m long. A second adjustment was made to Japanese commercial catches in the mothership fishing area and to catches of research vessels in the landbased area because they used only large mesh nets (121 and 130 mm in the mothership fishery and most commonly from 112 to 117 mm in the landbased fishery). Since all of the nets used by these vessels were efficient for maturing fish but only about one-half of the nets used by the regular Japanese and United States research vessels were efficient for maturing fish, the CPUE values for the mothership and landbased data were reduced by one-half. Although these corrections were intended to make data from the various sources approximately comparable, the fact that mothership and landbased vessels used monofilament gillnets and the regular research vessels multifilament nets tends to negate the comparability. Therefore, CPUE value from the different gear types cannot be directly related and are shown on separate figures. This of course also applied to the Canadian and United States longline data in the northeastern Pacific.

Possibly the severest limitation of the data may result from the behaviour of salmon which in some seasons may place a substantial proportion of the fish at depths not sampled by the surface gear used or for other reasons may limit their encountering the gillnets. The catches of maturing chum salmon in winter and immature chums in winter and spring will be shown later to be unreasonably low in comparison to their abundance in later seasons of the year. Standard gillnets have a depth of only 7 m, while the baited hooks used in longline fishing are suspended only 1 m below the floating mainline. In addition, these methods of fishing are passive and their efficiency depends on the fish actively encountering the gear. The extent of the lack of lengthy directional movements performed by salmon may vary seasonally and thus change the effectiveness of this gear in certain periods of the year.

Some studies on the vertical distribution of salmon have been undertaken but conclusive results have
proven difficult to acquire and this lack of information remains a constraint to a complete understanding of the distribution of salmon, particularly in winter and spring. Comparisons between surface and deeper catches are made dubious by the different procedures entailed in setting sub-surface gear, by the possible differences in mesh shape (and therefore effectiveness) of nets of varying panel depth, and by the possibility that fish might be caught during the descent or ascent of the gear rather than at the level at which fishing was being mainly conducted. The likelihood of daily or seasonal changes in depth preference must also be taken into account. At the present time we can only refer to scattered observations by the three nations.

In 1957, 1959, and 1960, Canadian investigators in the Gulf of Alaska used gillnets (12.2 m deep, 113 mm stretched mesh) which could be suspended at various levels from a floating line. At the deepest level investigated the net occupied approximately the 50-60 m zone. Daytime fishing between mid-May and early June showed that maturing chums were present at all levels investigated. Catches made at night indicated some movement toward the surface but fish were still caught at depths between 10 and 40 m. Very few immature chums were caught during this period. In July immature fish became dominant but no chums were taken below the 30-40 m level (Manzer, 1964).

LeBrasseur and Barner (1964), using a midwater trawl in coastal waters of northern British Columbia in November, 1963, reported the catching of age 0 chums at depths of from 3 to 95 m. On the basis of the condition of stomach contents and comparisons with concurrent catches of juvenile pink salmon, they suggested that the chums were spending most of their time in relatively deep water, visiting the surface at daybreak and nightfall.

In the summers of 1961, 1962, and 1963, Japanese investigators fished gillnets at various depths down to 40±m in the Northwest Pacific Ocean and the Bering Sea (Fisheries Agency of Japan, 1963, 1964; Machidori, 1966). They concluded that immature chums, by day and by night, were present throughout the vertical range investigated, with no tendency to concentrate in a particular layer. Maturing chums tended to be nearer the surface.

In July, 1964, Japanese investigators fished surface and sub-surface longlines at five stations in the northwestern Pacific Ocean, between 163°E and 165°E (Fisheries Agency of Japan, 1966). In each operation, lines were set to fish simultaneously at 0, 20, 40, 60, and 80 m. The combined experiments yielded only 29 chums, only two of which could have been caught at depths below the surface line—one on the 20 m line, and one on the 80 m line. The possibility that these fish might have been caught during the sinking or lifting of the gear cannot be excluded.

In 1968 and 1969 United States research vessels fished sunken gillnets at stations in the western Gulf of Alaska and at 176°W (French et al. 1969; French et al. 1970). The depth intervals examined were: 0-7 m, 8-15 m, 16-23 m. In 1968 a spring cruise (April-June) yielded only 10 chums (none caught in the deepest net). In July and August, 118 chums caught at 176°W showed 52% in the 0-7 m net, 25% in the 8-15 m net, and 23% in the 16-23 m net. In 1969 a winter cruise (January-February) yielded no chums. Sets made between late April and early September showed a higher percentage of chums at the deepest level than was the case with sockeye.

From the scattered observations recorded to date, it is not possible to draw specific conclusions regarding the total vertical range of the species or to demonstrate consistent movements in relation to age, season, or the diurnal cycle. In view of the great mobility of salmon, attempts to demonstrate significant differences between the concentrations of fish in small vertical intervals within a short distance of the surface may well be unrewarding, at least at seasons when near-isothermal conditions prevail. It is evident, however, that a majority of fish are frequently present at depths below the narrow zone which is fished by commercial gear. At some places and times, chum salmon appear to be less closely tied to the surface than sockeye and pinks. This is perhaps consistent with the very broad geographical (horizontal) range of the species and its apparent tolerance of wide variations in temperature.

While the depth distribution of chum salmon evidently exceeds by far the surface layer normally fished by surface gear, the question remains whether a fairly constant proportion of the fish inhabit surface waters so that the measure of relative abundance obtained at the surface represents the abundance of fish in the area. A summary of results from the above studies (Table 1) suggests that this may not be the case. For maturing fish, the proportion of fish taken in the surface net showed wide variation between studies, ranging from 13% to 80%. The studies on immature chums also indicated extreme variation in the proportion of fish in the surface layer (ranging from 38% to 90%). The proportion taken in the surface layer was much less variable in years when sample sizes exceeded 100 fish (ranging from 38% to 52%). The overall results of these studies indicates that indices of abundance derived from fishing the surface layer do not consistently reflect the abundance of the total population of chum salmon between areas and per-
TABLE 1. Vertical distribution of chum salmon.

<table>
<thead>
<tr>
<th>Maturity stage</th>
<th>Area</th>
<th>Months fished</th>
<th>Year</th>
<th>Total fish caught</th>
<th>0-10 m²</th>
<th>More than 10 m</th>
<th>Percentage of catch</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturing</td>
<td>Northeastern</td>
<td>May-June</td>
<td>1959</td>
<td>15</td>
<td>13</td>
<td>87</td>
<td></td>
<td>Manzer (1964)</td>
</tr>
<tr>
<td></td>
<td>Pacific</td>
<td></td>
<td>1960</td>
<td>78</td>
<td>22</td>
<td>78</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aleutian</td>
<td>April, May</td>
<td>1968</td>
<td>10</td>
<td>80</td>
<td>20</td>
<td></td>
<td>French et al. (1969, 1970)</td>
</tr>
<tr>
<td></td>
<td>Island area</td>
<td>June</td>
<td>1969</td>
<td>70</td>
<td>43</td>
<td>57</td>
<td></td>
<td>Machidiri (1966)</td>
</tr>
<tr>
<td></td>
<td>Northwestern</td>
<td>June</td>
<td>1962</td>
<td>21</td>
<td>76</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pacific</td>
<td>June</td>
<td>1963</td>
<td>17</td>
<td>76</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immature</td>
<td></td>
<td>July</td>
<td>1960</td>
<td>38</td>
<td>79</td>
<td>21</td>
<td></td>
<td>Manzer (1964)</td>
</tr>
<tr>
<td></td>
<td>Pacific</td>
<td>August</td>
<td>1969</td>
<td>195</td>
<td>46</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Island area</td>
<td>August</td>
<td>1962</td>
<td>39</td>
<td>90</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Northwestern</td>
<td>August</td>
<td>1963</td>
<td>39</td>
<td>90</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Surface nets used in the three studies varied in depth: 0-12 m in Manzer’s study, 0-10 m in Machidiri’s study, and 0-7 m in the French et al. study.

...happens between years in a single area. This may simply be a function of the small sample sizes, however. The more consistent result shown by the larger samples is more encouraging. Investigation of vertical distribution should receive additional effort in order to resolve this question satisfactorily.

Total Ocean Distribution

As pointed out by Shepard et al. (1968), chum salmon occupy almost all of the subarctic region of the North Pacific Ocean and adjacent seas in various life-history stages. The limits of distribution as illustrated by these earlier authors can now be slightly extended on the basis of research and commercial catches since 1962 (Fig. 3).

The limits of distribution for chum salmon must extend even farther than those shown, at least during the periods when chum salmon are leaving and returning to spawning areas. It can be assumed that in certain time periods, the distribution of the species extends throughout most, if not all, of the Sea of Japan, the Okhotsk Sea, the Chukchi Sea, and at least along coastal areas of the Arctic Ocean, west to the Lena River in the U.S.S.R. and east to the Mackenzie River on the North American continent. The ocean distribution of the chum is probably the broadest of any of the species of Pacific salmon.

Within this total distribution, the location of concentrations of chum salmon and the make-up of the population undergo changes as components of the population return to fresh water to spawn and the new brood years of young fish migrate to sea. Most of these changes take place during the spring and summer and the extensive research effort in this period yields a fairly good description of these changes. Figure 6 serves to summarize and review the general nature of the transition in the population and its distribution during this period. The figure only includes the immature and maturing chum salmon which have spent a year or more at sea (age 1 and older fish). The juvenile age 0 fish will be discussed later in the text along with available information for other periods of the year.

The first major feature of the distribution is the apparent restriction of chum salmon in late April and May to waters mainly south of the Aleutian Islands and in the Gulf of Alaska, although sampling in the Bering Sea is insufficient to confirm this conclusion. A second noticeable feature, during this period, is the predominance of maturing fish in the catches and the lack of immatures in anywhere near the abundance they show in later months. The indicated low abundance of immatures may be due to their location at depths greater than the 7 m sampled by surface gillnets or because of the lack of directional long-range migrations in this period. Maturing chum salmon continue to make up a major share of the catches in most areas in June but immatures begin to appear in greater abundance and predominate in catches from the central Aleutian area southward and in the more southern waters of the northeastern Pacific. By July, immatures generally predominate in offshore catches except in some coastal waters. Maturing fish continue to be found throughout the ocean in the summer but in relatively low abundance.

At the time maturing fish are moving toward coastal areas and the immature fish are becoming more available in surface waters, there is a general shift in the
Fig. 6. Distribution and relative abundance of immature and maturing chum salmon in spring and summer as shown by gillnet catches of research vessels of Canada, Japan and the United States, 1956 to 1971.
population to the north. This movement is initially made by the maturing fish which, by June, are abundant in the Bering Sea and later by the immatures, which begin to occupy waters of the central and western Bering Sea in June. By July it would appear that the majority of immatures previously located in the western Pacific had moved into the western and central Bering Sea. A corresponding northward movement of immatures is also apparent for chum salmon in the eastern Pacific. As will be described later, the immature fish move south in the fall or early winter and return to the more southerly waters they occupy in winter and early spring to complete an annual cycle.

The above description of the general changes in the ocean distribution of chum salmon serves to introduce the following discussion on the distribution of various life history groups from the time chum salmon enter the sea until they return to coastal waters on their spawning migration.

**Distribution by Life History Group**

The ocean life of chum salmon can be separated into several stages according to age and maturity status. The initial stage (juvenile age .0 fish) can be subdivided into two periods; one involves the first few months at sea (generally June-September) when the young chums remain relatively close to shore. The second subdivision includes the fall and early winter period when the juveniles begin to move off-
shore.

After January 1, the fish are considered to be age .1 even though formation of the annulus is not yet completed. The fish are termed immatures from this point until the beginning of the year in which they mature and spawn. Essentially all of the age .1 fish remain immature as do the majority of age .2 fish. Most chum salmon mature at age .3, but some remain immature until age .4 and smaller numbers until age .5. Age .6 fish are rarely encountered.

The distribution of age .1 and older chum salmon varies according to their maturity status rather than their age and the various age groups of immature or maturing fish generally occupy similar areas of the ocean. For this reason, following the discussion of age .0 fish, most age groups (with the exception of age .1 immatures) will be combined and their distribution shown according to their maturity status.

**Juveniles**

Most juvenile chum salmon enter salt water within a period which, in different areas, extends from April to July. The exodus from small British Columbia streams was found to peak in April or May and the fish commonly reached the sea within a few hours following their emergence from the reds (Hunter, 1959; Neave, 1955). Pravdin (1940) reported that in Kamchatkan rivers chum fry migrate to sea in May and June but some remain longer in fresh water. Mihara (1958) found free-swimming fry in Japanese rivers in early May or earlier but many did not reach the river mouth (a distance of up to 120 km) until late June or early July. Evidence from Bristol Bay indicated that few fish reach the sea before late June.

Extensive sampling along the coasts of Washington, British Columbia, and southeastern Alaska has shown that juvenile chum salmon were generally abundant within 20 miles (37 km) of shorelines from at least 48°N to 59°N in July, August, and September. More limited sampling indicated that they were still abundant in the same relationship to land in October. Some juveniles remain in coastal waters even later, since they have been taken within 5 miles (9 km) of shore in November in British Columbia (LeBrasseur and Barner, 1964).

Along the north coast of the Gulf of Alaska and south of the Alaska Peninsula, small intermittent catches of age .0 chum salmon were made in August, whereas catches in September were more frequent and generally larger.

In the Bering Sea, along the north side of the Alaska Peninsula, relatively small catches of juvenile chum salmon were made up to 20 miles (37 km) offshore in July. In August and September catches were larger and the distribution of age .0 fish extended to more than 30 miles (55 km) from shore. The main body of juvenile fish appeared to remain east of 165°W at least through August.

The distribution of age .0 chum salmon during their first summer at sea is illustrated in Fig. 7 for the areas studied. The direction and extent of migrations of juvenile chum salmon was inferred from tagging experiments and the direction in which purse seine was set. The small catches or absence of fish in nets where the purse seine was open to the north in contrast to their presence or higher abundance in sets open to the south strongly suggests that all species of juvenile salmon move northward along the coasts of Washington, British Columbia, and southeastern Alaska in their first summer (Hartt et al. 1970). Six chum salmon were recovered from those tagged at age .0 (Hartt et al. 1974), four of these were recovered as adults near the point of release but two of the returns suggest that chum salmon also move northward with other species during their early months at sea. One of these age .0 fish was tagged in the northern Gulf of Alaska and recovered in the Strait of Juan de Fuca while the other was tagged off southeastern Alaska and recovered off British Columbia.

From the indications provided by the direction of purse seine fishing, juvenile salmon, including chums, taken along the northern coast of the Gulf of Alaska and south of the Alaska Peninsula were probably migrating westward (Hartt et al. 1970). Catches along the north side of the Alaska Peninsula indicate that movements of juvenile salmon in the eastern Bering Sea were not as directional nor as rapid in summer as those along the eastern coast of the Gulf of Alaska. Substantial catches of juvenile salmon were made irrespective of the direction of the set, although larger catches were made when the seine was open to the east. Hartt et al. (1970) concluded from these catches that the young salmon probably shift back and forth with the tides but that the dominant movement was seaward to the southwest.

In Asian waters the distribution of age .0 chum has been studied in parts of the Okhotsk Sea (Fig. 7). Birman (1969) states that prior to August, juveniles were located in coastal waters. By August small schools of juveniles were located 100 miles or more offshore and in September they were distributed across the Sea in the region from Sakhalin Island to the Kamchatka coast. Movement into the Pacific Ocean begins in October and lasts until December.

Samples of juvenile chum salmon generally showed an increase in size throughout the summer but lengths were somewhat variable depending undoubtedly on the length of time they had been at sea. Young chum
Fig. 7. Known distribution and direction of movement of age .0 chum salmon in their first summer at sea.

Fig. 8. Location of catches of immature chum salmon in winter (data from the years 1962 to 1971).
salmon taken prior to moving into the open ocean in July were about 10–12 cm in length according to samples from the Strait of Juan de Fuca (Hart et al. 1970) and off Hokkaido (Sano, 1966). After reaching the open ocean, the size in August and September ranged from 13–20 cm along the British Columbia and Gulf of Alaska coasts and tended to be larger in the north (Shepard et al. 1968). Sizes were similar (13–18 cm) for juveniles taken in the Bering Sea in these same months. Juveniles from the south side of the Alaska Peninsula in late August and early September were larger (20–22 cm) and probably had been at sea longer than fish taken in the other areas. Similar variation was noted for age .0 chums taken in the Okhotsk Sea. One group of juveniles taken in August ranged from about 11 to 18 cm and others taken in late August and September ranged from about 14 to 25 cm (Birman, 1969). In October another group of juveniles were 16 to 24 cm in length.

Immatures

a. Winter. The juvenile chum salmon become age .1 immatures in January. Sometime in winter, juveniles in the Bering Sea move into the North Pacific Ocean and, with fish of the same age already in the North Pacific, continue to move south in apparent response to cooling temperatures or changes in the location of food sources that accompany these cooling trends. At that time they probably join the older immatures (age .2 and .3 fish mainly) which have also moved south from the more northerly waters they occupied the previous summer. The most conclusive evidence of this migration is provided by the location of immatures in spring, but winter data also tend to support a movement of this type.

Although the winter sampling (mainly by United States research vessels) has been rather widespread, catches of immature chums have been very small and intermittent (Fig. 8). It would appear that sampling was extensive enough to cover any likely distribution that immatures might have in this period and it is assumed that they were largely unavailable to surface gillnets. Experimental fishing to a depth of 23 m was carried out by a United States vessel in the northeastern Pacific (mainly along 155°W and 165°W) on one winter cruise, but no chum salmon were taken (French et al. 1971). The latitudes fished, however, were probably north of the main concentrations of immatures since the operations were restricted to waters from 50°N northward except for one set at 49°N. Of interest here is the observation of Le-Brasseur and Barner (1964) in coastal waters of British Columbia, which indicated that age .0 chums in November were spending most of their time in relatively deep waters that extended to depths of 95 m. Thus, even though direct evidence is lacking in offshore waters to support the contention that immature chums generally occupy deeper waters in winter, the lack of catches in surface waters over broad areas of the ocean would strongly suggest this as a possibility.

The location of the relatively few immatures taken (Fig. 8) indicates that in the central and western Pacific they mainly occupy waters south of 50°N in mid and late winter. The numbers of fish taken in waters south of 50°N ranged from only one to four and were mostly age .2 and .3 immatures; catches of age .1 fish south of 50°N were made in only three locations and in each instance were represented by only one fish.

Four catches of immatures were also made from 53°N to 57°N in the area south of Kodiak Island; all of these were age .1 fish taken in January 1969. It can be speculated that these fish (recent graduates from the "juvenile" category) were belated members of a southward migration. Their location may illustrate one route of migration used by the young fish to move from coastal waters into more southern waters. This southward movement need not be restricted to narrow routes, but could occur over broad fronts based on the extensive coastal waters they inhabited earlier.

b. Spring and Summer. Research vessel fishing was much more comprehensive in spring and summer than in winter and provided enough data to illustrate by time period the areas of main concentrations of immatures and changes in their distribution through the seasons. To demonstrate these changes the main research vessel catches were grouped by 15-day periods in most cases and CPUE shown to the nearest 1° of latitude and 5° of longitude. The CPUE values were also divided to show the abundance of age .1 and age .2 and older immatures separately since the distribution of these age groups differed quite markedly in certain periods. Catch data from other sources—the Japanese mothership vessels, Japanese research vessels in the landbased fishing area and Canadian and United States longline fishing—were used in support of the main research vessel data and were grouped by monthly periods, since these data, except for longline catches, were not available in the standard format used. In addition, catches of age .1 fish were not shown separately for the mothership and landbased areas, since catches of these small fish were insignificant due to the large mesh gillnets used.

—April-May

The limited research vessel fishing in winter sug-
Fig. 9. Distribution and relative abundance of immature chum salmon in April and May as shown by gillnet and longline catches. Canadian, Japanese and United States research gillnet data from 1956 to 1971, commercial mothership gillnet data from 1961 to 1970, landbased research gillnet data from 1964 to 1971, and Canadian and United States longline data from 1961 to 1970.
gested that immatures were mainly located between 45°N and 50°N in that season. The research vessel catches by gillnets in late April and early May showed immatures at these same latitudes but also extending farther south (Fig. 9). Abundance of immatures in gillnet catches was relatively low in contrast to their abundance in later time periods, indicating that they were not fully available to surface gillnets in spring, although to a greater degree than in winter.

Immatures appeared to be taken in greater numbers by longlines (Fig. 9) than by gillnets in early spring although relative abundance values from the two gear-types probably are not comparable. Takagi and Osako (1967) reported on the greater effectiveness of longlines as compared with gillnets for pink salmon in early spring. They suggested that salmon

Fig. 10. Distribution and relative abundance of immature chum salmon in June as shown by gillnet and longline catches (see Fig. 9 for years covered by the various sources of data).
actively search out food in spring, when it is scarce, and thus readily take longline bait. In addition, salmon are probably not undergoing lengthy directional migrations at this time as they do in later spring and summer, when gillnets become more effective.

In the latter half of May and through June and July, rather dramatic changes in the distribution of immatures occurred. The initial stages of this change were noted in late May as immatures began to shift northward and appeared in catches north to the Aleutian Islands (Fig. 9). Catches in the more northern waters were all of age .2 and older fish indicating that the migration to the north was initially made by the older immatures. Catches by the Japanese mothership fishery in late May also showed immatures ranging north to the Aleutian and Komandorskii Islands in the western Pacific. Age .1 fish were usually not taken in May but the few catches of this age group suggest that they remained well south of 50°N through May in the western and central Pacific.

In the northeastern Pacific no change in the distribution was apparent from April to May, indicating that a northward movement of immatures had not yet started in this region.

The combined evidence from the various data sources demonstrates that immatures are found across the Pacific Ocean in April and exhibit a cline in their distribution. In the western Pacific they were located south to near 40°N but in the eastern Pacific only to about 45°N. Their distribution extended farthest north in eastern waters with some immatures located to near 55°N in the far northeastern Pacific.

Fig. 11. Northward movement of immature chum salmon in June and early July as illustrated by gillnet catches of the Japanese mothership fishery (1961 to 1970).
June

A continuation of the northward shift in distribution of immatures was shown by catches in June (Fig. 10). In early June age 2 and older immatures were taken in the Bering Sea north to about 55°N and in the latter half of June to near 60°N. Abundance of the older immatures in the Bering Sea was low in June in relation to their abundance in July-August and these earlier arrivals may represent similar stocks or may simply be the forerunners of the general ocean population. A similar migration of the older immatures was also found in the northeastern Pacific but did not begin there until later. Additional evidence of the movement of immatures was shown by gillnet and longline catches (see Fig. 9 for years covered by the various sources of data).
into the Bering Sea in June was furnished by catches of the Japanese mothership fishery (Fig. 11) which show a gradual northward extension in the distribution of immatures in each succeeding 10-day period of June and early July. While the range of immatures continues to expand northward, some still occupy waters south to near 40°N in the western Pacific and to near 46°N in the eastern Pacific.

Another feature of the late June period was the first substantial catches of age 0.1 fish in the central North Pacific and their initial appearance in the Bering Sea. These catches apparently represent the first stages of the northward movement of the younger age group—a movement which began for the older immatures approximately 1 month earlier. Some age 0.1 fish were taken by longline gear in the northeast Pacific throughout the spring; their abundance was usually very low with the exception of some larger

![Diagram](image-url)
catches from 46°N to 48°N in May and June.

—July

After the initial appearance of significant numbers of age .1 fish in gillnet catches in late June in the North Pacific there was a rapid movement into the Bering Sea. By early July (Fig. 12) large catches of this age group were made by research vessels in the central Bering Sea north to about 57°N. The age .1 chum salmon were apparently also accompanied by large numbers of age .2 and older immatures since the abundance of these also increased over that shown in June.

A more comprehensive picture of the distribution of immatures is provided by the broader coverage of research vessel fishing in late July (Fig. 12). From east to west the distribution extended from about 135°W in the east across the North Pacific and into the Okhotsk Sea. Immatures were also found throughout the western Bering Sea north to approximately 65°N but not in the northern part of the eastern Bering Sea. Intermittent small catches in the southeastern Bering Sea show the presence of some immatures in these waters but their numbers seem insignificant in contrast to catches in the western Bering Sea. Immatures were abundant along 175°W in the Bering Sea in early July but seemed to be located mainly west of this longitude in late July. This suggests that immatures may use Amukta and adjoining passes in the Aleutians and waters in the vicinity of 175°W as one route to reach their summer feeding areas in the western Bering Sea.

With the increase in abundance of immatures in the Bering Sea there is an apparent corresponding decline in abundance of immature chums south of the central and western Aleutians through July and early August. These changes suggest that the major proportion of immatures move from the central and western Pacific into the western Bering Sea in summer. Catches of immatures by the Japanese mothership fishery also support this conclusion by showing greater abundance of immatures in the Bering Sea than in the North Pacific in July (Fig. 11).

In the northeastern Pacific there is also a major shift of immatures to the north in July (Fig. 12). As in the central and western Pacific the northward movement is initially made by the older immatures. The large group of immatures located from south of the eastern Aleutian Islands to the central Gulf of Alaska represent these older, earlier arrivals. Although some age .1 fish also occupy these more northern waters in July, their main concentration was located to the south and east of the main concentration of older immatures.

—August

By August the age .1 and older immatures appear to become generally intermixed (Fig. 13). Abundance of immatures in the central and western Pacific remains relatively low in contrast to abundance in the Bering Sea, again demonstrating that most chum salmon in this region of the ocean are located in the Bering Sea in summer. The presence of the second large group of immatures south of the eastern Aleutians and Alaska Peninsula was still evident in early August but was not as distinct in late August, perhaps because of westward movement of some of this group as is implied by an apparent increase in abundance of immatures south of the central Aleutians in August. The age .1 chums that were concentrated to the south and east in the northeastern Pacific in late July were now distributed throughout the northeastern Pacific north of about 49°N but seemed most abundant in the Gulf of Alaska.

The distribution of immatures probably reaches its most northern location in late August. Its southern boundary appears to be about 48°N or 49°N over most of the North Pacific but near 50°N or 51°N in the far eastern Pacific. Immatures did not occupy waters eastward from 140°W to any degree in August.

—September

Sampling in September was much less comprehensive than in July and August and adds little to our understanding of the distribution of chum salmon in summer. The immatures still appeared to occupy the same waters they inhabited in August (Fig. 14). They still were found in the western Bering Sea and in waters of the North Pacific near the Asian coast to about 145°W in the eastern Pacific. There seemed to be some increase in abundance of immatures in the vicinity of 50°N, perhaps indicating the beginning of a southward shift in the distribution of immatures. Evidence of this is quite vague, however.

In describing the distribution of immatures during the spring and summer, two major concentrations of fish were noted which appeared to migrate independently and to maintain, to a large degree, their separate identity through the spring and summer. The larger of these two concentrations was made up of Asian fish and was initially located in the central and western Pacific. As described earlier most of this group moved into the Bering Sea in summer. The second concentration, consisting mainly of North American chums, was located in the northeastern Pacific throughout the spring and summer and did not enter the Bering Sea. Although the main body of these two groups remained separated, some overlap
occurred and was probably more pronounced in the case of the age .2 and older fish than for the age .1 fish. Some indication of areas of intermingling were provided by tagging data.5

Sixteen tag recoveries have been made inshore of chum salmon tagged in offshore waters as age .1 immatures. Ten of these were Asian recoveries and all were tagged in the central and western Pacific in an area bounded by 174°W and 170°E and 49°N and 53°N in the period from June 21 to August 13. The eastward limit for age .1 fish of Asian origin from tagging data corresponds to the eastward boundary of the group of age .1 fish located in the central and western Pacific as shown by distribution studies. This evidence suggests that at the end of their first year at sea most if not all Asian chum salmon become distributed only as far east as the central Aleutians and do not enter the northeastern Pacific nor intermingle to any significant degree with age .1 fish of North American origin. The main body of age .1 Asian fish was shown to move into the Bering Sea in the summer and to maintain their separation from the North American immatures in the northeastern Pacific. Some of the age .1 fish of Asian origin remain in the North Pacific through the summer. A single recovery from western Alaska of an age .1 fish tagged in the central Aleutians in August shows that some overlap in the distribution of age .1 fish from Asia and North America occurs in the central Aleu-
tians later in the summer. This probably results from a westerly shift in the distribution of North American fish in July and August.

Six chum salmon tagged as age .1 fish have been recovered in North America. Five of these were tagged in the area of concentrations of age .1 fish in the northeastern Pacific between 150°W and 165°W. Returns came from western Alaska (4) and Kodiak Island (1). As mentioned above, the sixth age .1 fish from North America was tagged near Adak Island and was recovered in the Kotzebue Sound area.

The age .2 and older chum salmon of Asian and North American origin appear to be distributed similarly to the age .1 fish but with a greater overlap of stocks from the two continents. These older fish have spent an additional year or more at sea and in their second and third winters at sea the Asian chums probably move east or southeast into the northeastern Pacific where they intermingle with North American chum salmon.

All inshore recoveries of immature age .2 and older chums tagged from the western and central North Pacific and Bering Sea east to 160° came from Asia. No recoveries were made in North America from immatures tagged in the Bering Sea. In the area of the North Pacific from 180° to 175°W tag recoveries of age .2 and older chums were mainly from Asia (59) but also from North America (12). The Asian recoveries from this area were from tagging in the period of mid-June to mid-August whereas North American recoveries were tagged from mid-July to mid-August. Some of the Asian fish were undoubtedly part of the group that moved north into the Bering Sea while others probably represented the group of Asian immatures that remained in the North Pacific through the summer. The North American recoveries, which were tagged from mid-July to mid-August were probably fish that earlier were located to the east and had moved into the central Aleutian area in late July and August.

Additional recoveries in Asia of age .2 and older immatures tagged east of 175°W illustrate the eastward extent in distribution of these older Asian immatures in spring and early summer. Two Asian immatures were located as far east as 155°W and 156°W in spring (tagged in early April and early May). Twelve other recoveries were made in Asia from tagging in June and July in the North Pacific between 170°W and 160°W. Two age .2 immatures tagged in the northeastern Pacific in spring and recovered at sea in the summer of the same year may illustrate the migration of Asian fish from these waters during the summer. One fish tagged in April near 45°N and 167°W was recaptured south of Adak Island near 49°N and 177°W while the other was tagged near 53°N and 168°W and recaptured in the northern Bering Sea near 58°N and 177°W.

Thus, the distribution of age .2 and older immatures of Asian origin extends eastward into the northeastern Pacific to at least 155°W in spring but, on the basis of tagging data, they probably move westward out of the northeastern Pacific by early summer. North American immatures, while mainly located in the northeastern Pacific, extend westward in the North Pacific to intermingle with Asian immatures south of the central Aleutians. The lack of any tag recoveries in North America from immatures occupying the central and western Bering Sea suggests that North American immatures do not enter the Bering Sea in summer but tagging effort there may not be adequate to justify this conclusion.

c. Fall and Early Winter. Catch data for the October-December period are available only for some locations south of the western Aleutian Islands and in the northeastern Pacific. The data fail to demonstrate the overall distribution of immature chum salmon in this period except for their presence in certain areas of the western and northeastern Pacific (Fig. 14). The most important contribution, particularly from the data in the western Pacific, was to illustrate a return southward movement of immature fish in late fall and winter. Catches along 175°E in October and November extended south to 46°N which was 3° farther south than catches along this longitude in late August. A southward shift in the distribution of immatures would be expected in this period since, as shown earlier, all immatures were located south of 50°N by January (Fig. 8).

Transition from Immature to Maturing Fish

In the next year at sea some of the immatures mature and leave offshore waters for spawning streams while others remain immature an additional year or more. For those fish that mature, the maturation process begins prior to the end of the calendar year but it has been customary to recognize their status as of January of the new year. The maturing component is made up of age groups .2 to .5 (immatures of ages .1 to .5 in the previous year). Essentially all of the age .5 and .6 fish and most of the age .3 and .4 fish will be maturing while a much smaller proportion of the age .2 fish will mature.

Those chum salmon that remain immature another year repeat the migrations already described. The distribution and movements of the maturing fish are discussed in the following section.

Maturing Fish

a. Winter. As noted earlier, the catches of im-
mature chum salmon in winter were extremely small and scattered and the fish appeared not to be generally available to the surface gillnet and longline gear used. The maturing fish, however, were taken more consistently and in greater abundance than the immatures. These catches were essentially all made in the North Pacific Ocean and mainly south of 50°N (Fig. 15). Two maturing fish were taken in the southern Bering Sea near Attu Island in early February. The north-south range of maturing chums varied in different regions. In the western Pacific (west of 175°E) catches were restricted to waters south of 47°N, but they extended to near the Aleutian Islands in the central region, to near 52°N south of the Alaska Peninsula and to at least 56°N in the Gulf of Alaska. The southern limit of catches also shifted northward from west to east, being located well south of 45°N in the western Pacific but apparently only extending to about 46°N or 47°N in the eastern Pacific. These changes in the north-south range of maturing fish appeared to be related to surface water temperatures as will be discussed in the section on "Environmental features associated with distribution."

b. Spring and Summer

April and May

In spring maturing chum salmon were taken more consistently in the North Pacific than in winter. Their distribution extended from near the Asian coast to near the North American coast and northward to near inshore waters of the Northern Gulf of Alaska, the Alaska Peninsula, and the Aleutian Islands (Fig. 16). They extended southward to about 40°N in the western and central Pacific and to about 45°N or 44°N in the eastern Pacific.

Thus, in the spring, the distribution of maturing fish was much wider from north to south than that of immatures. The maturing fish were found farther north than the immatures but extended as far south as the immatures. Main concentrations of maturing fish were somewhat north of main concentrations of immatures.

The northern limit of maturing fish west of about 155°W is undefined in early spring due to the lack of sampling in the Bering Sea in late April and early May. The available evidence, however, indicates that most, if not all, maturing chums were located south of the Aleutians in early spring. This conclusion is based on the lack of chums in the Bering Sea in winter, at least in surface waters, and the small catches in the southern Bering Sea in late May, which suggests that movement into the Bering Sea was just starting in this time period. Evidence from tagging shows that many chum salmon destined for streams throughout coastal areas of the Bering Sea were locat-
Fig. 16. Distribution and relative abundance of maturing chum salmon in April and May as shown by gillnet and longline catches. Canadian, Japanese and United States research gillnet data from 1956 to 1971, commercial mothership gillnet data from 1961 to 1970, landbased research gillnet data from 1964 to 1971, and Canadian and United States longline data from 1961 to 1970.
ed south of the Aleutian Islands and Alaska Peninsula from April to June (see section on origin of high seas chums) and also supports the conclusion that chums from even the most northerly spawning areas were located in the North Pacific in winter and early spring.

Some changes can be noted in the distribution of maturing fish from winter to spring and from early May to late May. An obvious change is the apparent increasing abundance of fish through these periods, reflecting their increasing availability to surface gillnets as the season advances. Another change in the central and western Pacific was a northward shift in the distribution. In winter most maturing chums were located south of 50°N in the Aleutian area and this was still the case in late April and early May although they were taken more consistently between 50°N and the Aleutian Islands in the later period. This probably indicates some northward movement of maturing chums as early as mid-spring. The greater abundance of fish in these more northerly waters in late May suggests that this movement becomes intensified later in the month. The relatively high abundance of maturing fish between 180° and 165°E in late May represents the onshore movement of some Asian stocks of chums (Fig. 16). Catches by research vessels in the landbased fishing area show that these stocks were mainly located south of 50°N in April.

The distribution of maturing fish in the northeastern Pacific, as shown by longline catches, extended farther north than in the central and western Pacific (Fig. 16). As early as April maturing fish were located near coastal waters of the northern Gulf of Alaska and the greatest proportion of maturing fish was located north of 50°N. These differences in distribution may be due to the differences in temperature regimes in the two regions. As shown by long-term means (Fig. 17) surface temperatures exceed 5°C throughout much of the northeastern Pacific in May whereas such temperatures are restricted to waters south of 50°N in the western Pacific. The warmer waters of the northeastern Pacific may allow chum salmon to occupy more northerly waters in an earlier time period in this region than in regions to the west.

—June

Maturing fish are active in June, as they accelerate their shorward migration. This is evidenced by data which show a rapid movement of maturing fish into the Bering Sea and a decline in abundance of fish in the central Pacific south of 50°N (Fig. 18). This movement was also evident from research vessel catches in the landbased fishing area, where abundance declined at offshore stations in June compared to levels in April and May (Figs. 16 and 18). Catches remained relatively high in waters near the Kuril Islands and fish located farther offshore in April and May move through the Kurils into the Okhotsk Sea in June. This group of fish represents the earlier summer runs of chum salmon destined for the Amur River and streams flowing into the northern Okhotsk Sea (Kondo et al. 1965). Other maturing fish, previously located in the landbased fishing area, move north into the waters fished by the Japanese mothership fishery in June. Catches by the mothership fishery show maturing fish rather uniformly abundant over large areas of the western North Pacific Ocean and Bering Sea in this period.

The rapid and extensive changes in distribution shown by maturing fish in the western and central Pacific were not evident for fish in the northeastern Pacific (Fig. 18). This was undoubtedly due to differences in the environment between the regions which allowed fish in the eastern Pacific to occupy more northerly waters prior to June and to the close proximity of spawning areas for many of the stocks located in these waters. Some of the populations inhabiting the northeastern Pacific, however, such as those from Asia and northern Alaska, undoubtedly move out of this region in June or earlier. Some evidence of this movement is shown by the declining abundance of fish from April to June in the area south of 50°N and westward from 145°W. Results of tagging studies, discussed later, will show this to be an area of concentration of Asian maturing chums in early spring.

—July

The continued advance of maturing fish towards coastal areas can be noted from distribution data in July (Fig. 19). Catches by research vessels throughout many areas of the North Pacific, including the landbased fishing area, were generally small. The distribution of maturing fish, however, still extended across the entire North Pacific. The southern boundary of the distribution shifted farther north from June to July as shown by the predominantly blank catches in waters south of 50°N in the eastern and central Pacific. In the western Pacific catches still extended to about 45°N.

The onshore movement of maturing fish in the northeastern Pacific was also quite pronounced from June to July (Figs. 18 and 19). The body of maturing fish still remaining in these waters was now located mainly north of 55°N.

The abundance of maturing chums was greater in offshore waters of the Bering Sea than in the Pacific. Research vessel catches showed large numbers of
Fig. 17. Long-term mean surface isotherms in the North Pacific Ocean for representative months of winter, spring, and summer (from Lavolette and Seim, 1969). Temperatures have been converted to centigrade from the Fahrenheit values given in the above source.
maturing fish in the far northern Bering Sea and in some areas of the western Bering Sea and Okhotsk Sea. The more comprehensive coverage provided by the mothership fleet demonstrated the presence of large numbers of maturing fish throughout the western Bering Sea in July. Catches by the mothership fleet also indicated substantial numbers of maturing fish southeast of the Kamchatka Peninsula in the Pacific although abundance was lower than in the Bering Sea.

—August-September

Some maturing chum salmon continue to maintain a wide distribution at sea in August although in low abundance (Fig. 20). Most fishing locations throughout the western Bering Sea and western North Pacific south to about 45°N produced small catches of maturing fish as did fishing locations from the central Aleutians to the Gulf of Alaska in waters from approximately 50°N to the Aleutian Islands and Alaska Peninsula. The largest CPUE values were from fishing locations nearer coastal areas such as the northern Bering Sea and near the Kamchatka Peninsula.

Sampling by research vessels in September was much less comprehensive than in August but again demonstrated the presence of some maturing chums over broad areas of the ocean (Fig. 21). Catches were more intermittent in September than in August, probably illustrating the final evacuation of offshore waters by the few remaining fish.

The ocean distribution of maturing chum salmon in spring and summer had certain characteristics that
Fig. 18. Distribution and relative abundance of maturing chum salmon in June as shown by gillnet and longline catches (see Fig. 16 for years covered by the various sources of data).

differed in some respects from other species. These included the relatively uniform abundance of the maturing fish over broad areas of the ocean, the rather gradual decline in abundance of maturing fish through the spring and summer, the prolonged period over which maturing fish continued to occupy offshore waters, and the apparent lack of large local concentrations of fish that would demonstrate well-defined inshore migration routes of major stocks. In contrast to chum salmon, maturing sockeye salmon, particularly the Bristol Bay stock, leave offshore waters rather quickly in June and July and through heavy concentrations in certain areas demonstrate specific routes used to reach Bristol Bay (French and Bakkala, 197-)

The special characteristics of the chum salmon ocean distribution can undoubtedly be attributed
certain features of their freshwater life history including the broad geographical range of spawning streams, the many individual spawning stocks that make up the population, and the lengthy period over which spawning of the various stocks occurs. The range and abundance of individual stocks has been described earlier in this paper. Shepard et al. (1968) discussed the time of spawning of stocks and pointed out that it extended from June in some northern streams such as in Norton Sound, Alaska, to as late as January in some Japanese streams. Major groups of chums spawned at intervening times between these extremes. These
Fig. 20. Distribution and relative abundance of maturing chum salmon in August as shown by gillnet and longline catches (see Fig. 16 for years covered by the various sources of data).

Fig. 21. Distribution and relative abundance of maturing chum salmon in September as shown by gillnet catches of research vessels from Japan and the United States, 1956 to 1971.
authors used the times of arrival of the runs in coastal fishing areas to indicate differences in periods of spawning. Peak commercial catches in central and western Alaska and along the east coast of Kamchatka were generally made during July, while in southeastern Alaska, northern British Columbia, and on the west coast of Kamchatka and the northern Okhotsk Sea coast, they were made in July and August. The Amur River and Sakhalin regions show peak catches in September while largest catches in Hokkaido and southern British Columbia occur in October. The southernmost runs of commercial importance in Honshu and Washington-Oregon peak latest, in November or December.

This extended spawning period in combination with the many spawning populations and coastal areas inhabited by the species explains the gradual evacuation of offshore waters that extends over prolonged periods of the spring and summer as the populations depart from high seas areas to meet their various spawning schedules. In addition, the numerous individual populations migrating in various directions to reach spawning streams would account for the generally uniform distribution of maturing chums and the failure of distribution studies to clearly illustrate specific routes and timing of inshore movements for individual stocks.

AGE COMPOSITION IN OFFSHORE WATERS

The number of winters spent by chum salmon in the sea before attaining maturity varies from one to six, but fish maturing at less than age .2 or more than age .4 are insignificant in number.

The age composition of salmon at sea is difficult to determine because of the large areas of the ocean inhabited by the total population at any given time. the rapid movement of the fish in certain seasons, the selectivity of most gear types used, and the unavailability of some age groups to surface gear in winter and spring. Thus the measures of age composition obtained in any one year come from segments of the population and may not accurately reflect the age composition of the total population. For these reasons data for illustrating age composition were selected from whichever source sampled a particular maturity group most effectively.

In the case of maturing fish the most comprehensive and systematic sampling was provided by the Japanese mothership fishery in the western Pacific and Bering Sea and by the Canadian and United States longline catches in the eastern Pacific. Mothership catches should be representative of the age composition of Asian stocks and the longline catches representative of North American stocks. As discussed earlier, some Asian fish also occupy the eastern Pacific in spring and they make up some proportion of the longline catches. Recoveries of fish tagged in waters east of 165° W were 13% Asian in April and May and 1% Asian in June.

Age composition from the two areas is shown in Table 2 by 10- or 15-day time periods in the spring and summer and by year. Changes in the age composition of samples by time period are immediately apparent and these changes were similar in each region of the ocean. The proportion of age .3 and .4 fish decreased through the season while the proportion of age .2 fish increased. These changes parallel those observed as the maturing fish reach inshore waters, where the older fish appear earlier and the younger fish later (Marr, 1943; Semko, 1954; Thorsteinson et al. 1963). Age .3 fish predominated in samples in all time periods in the western Pacific and in most time periods in the eastern Pacific except for July, when age .2 fish predominated. The data also indicate that age .2 fish were more prevalent in the eastern Pacific, making up 26% of the catches in this region but only 8% of the catches in the western Pacific. A relatively high proportion of age .2 fish is characteristic of stocks of chum salmon originating from the more southerly areas of their inshore distribution (Bakkala, 1970). The high percentage of this age group in offshore waters of the eastern Pacific, particularly in June and July, evidently means that the more northerly stocks had largely left these waters by June and the catches in June and July were primarily made up of stocks originating in more southerly coastal areas.

Yearly variation in age make-up of the population sampled is shown in the lower half of Table 2. With the exception of samples in the western Pacific in 1961, age .3 fish predominated in each area and year. The proportion of age .3 fish varied considerably between years, ranging from 40 to 91% in the western Pacific and 49 to 83% in the eastern Pacific. The usual predominance and wide variation in proportion of age .3 fish in offshore samples is also characteristic of stocks of maturing fish in coastal waters (Bakkala, 1970). It is also of interest that in 1961 when samples in the western Pacific indicated a predominance of age .4 fish, this same age group predominated in coastal waters of the Okhotsk Sea and west Kamchatka (Kondo et al. 1965). The contribution of age .2 fish to catches was greater in each year, and of age .4 fish less, in the eastern Pacific than in the western Pacific. This parallels findings from coastal sampling which show that stocks spawning in Gulf
of Alaska streams contain a greater proportion of younger fish than do stocks originating in Asian rivers.

Because of the selectivity for larger older fish by the large mesh nets used by the Japanese mothership fishery and longline gear, these sources of data could not be used to demonstrate age composition of immature fish. Gillnet catches of research vessels were a better source. Because of the few vessels involved, however, the amount of effort in a given year and time period was very small in relation to the large areas of ocean inhabited by immature chums, the changes that take place in the distribution in spring and summer, and the poor availability of immatures to surface gear in winter and spring. These problems are obvious from data in Fig. 22 where the lack of immatures in catches can be noted up to late June. The changes in distribution of the immatures is also apparent from this figure. In the western Pacific age .2 and .3 fish predominated in catches until late

Fig. 22. Average CPUE of age groups of immature chum salmon by time period and ocean region. Data from Canadian, Japanese, and United States research gillnet catches, 1956 to 1971.
June, when age .1 fish predominated. They remained the dominant age group until late July, after which age .2 fish predominated. These changes reflect the movement of age .1 fish through the waters south of the Aleutians in this period, as already described. The movement of age .1 and age .2 fish into the Bering Sea is illustrated by the increasing abundance of these two age groups in June and July. Age .1 fish usually predominated in Bering Sea catches after June. Thus the limited research vessel sampling in the central and western Pacific may poorly reflect the age composition of immatures in any one year because of the lack of coverage of broad areas of the ocean in a limited time interval. Combined data from the years 1956 to 1970 and for the time period of mid-July through August show the following age composition for immatures in the central and western Pacific (west of 170°W) and in the Bering Sea:

<table>
<thead>
<tr>
<th>Age area</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bering Sea</td>
<td>53.1%</td>
<td>35.0%</td>
<td>11.6%</td>
<td>0.3%</td>
<td>---</td>
</tr>
<tr>
<td>Central and western Pacific</td>
<td>37.6</td>
<td>51.2</td>
<td>10.4</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>46.4</td>
<td>41.9</td>
<td>11.1</td>
<td>0.5</td>
<td>&lt;0.1</td>
</tr>
</tbody>
</table>

In the eastern Pacific age .2 fish predominated throughout most of the spring and summer (Fig. 22). The high proportion of age .2 fish in the samples was probably due to poor sampling in areas of concentrations of age .1 fish by research vessels using gillnets.

Combining data as described above, the age composition of samples of immatures in the eastern Pacific was as follows:

<table>
<thead>
<tr>
<th>Age</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent</td>
<td>31.0</td>
<td>54.9</td>
<td>13.9</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**SIZE AND GROWTH**

The average lengths of chum salmon in offshore waters for various life history stages are given in Table 3. As pointed out by LaLanne (1971) these data indicate that for the same sex, age, and maturity group, fish of presumed Asian origin (caught west of 180°) averaged 47 mm smaller than those of presumed North American origin (caught east of 165°W). The smaller size of Asian chum salmon relative to North American fish is also reflected by length data from United States research vessels summarized from the years 1956 to 1970 (Fig. 23). When lengths were averaged by 5° of longitude across the North Pacific Ocean the size of fish was shown to increase from west to east. This trend was consistent for each of the life-history groups and time periods for which adequate data were available. As demonstrated by tagging data in this and earlier reports, Asian fish
occupy the western Pacific and North American fish the eastern Pacific with fish from the two continents intermingling in the central regions of the Pacific.

Of interest is another feature of the size distribution of chum salmon exhibited by maturing fish prior to their movement inshore for spawning (Fig. 24). When the lengths of fish were averaged by 2° of latitude within the area between 165°E and 175°W, the sizes were seen to increase from south to north for both age .2 and .3 fish. This trend was apparent for each 10-day period of sampling from late May to late June. By July the relationship had broken down, probably due to the changing make-up of the population as the earlier maturing chums departed for inshore waters and as later maturing fish replaced them in the area of sampling. The reason for this size distribution of maturing fish just before their migration to spawning areas is unknown and seems contrary to the size distribution one might expect assuming that stocks originating from the more northerly land areas also occupied the more northerly offshore waters. It has been shown that within age groups, chum salmon sampled inshore decrease in size from south to north (Gilbert, 1922; Marr, 1943; Henry, 1954; Sano, 1966). This distribution may be related to the general principle that larger fish typically precede smaller fish into spawning streams.

Although Asian chum salmon are smaller than North American chums, their growth rate during summer months is greater than that of North American fish as shown by LaLanne (1971). Instantaneous growth rates in weight per month during the summer were as follows:

<table>
<thead>
<tr>
<th>Maturity status</th>
<th>Origin</th>
<th>Age (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North American</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Asian</td>
<td>0.225</td>
</tr>
<tr>
<td></td>
<td>North American</td>
<td>0.153</td>
</tr>
<tr>
<td></td>
<td>Asian</td>
<td>0.180</td>
</tr>
</tbody>
</table>

These monthly rates averaged 62% greater for immature and maturing stages of chum salmon of Asian origin than for fish originating from North America. LaLanne (1971) suggested that a shorter growing season for Asian chum salmon may explain their more rapid growth in summer but smaller size relative to
North American fish. Evidence from scale studies indicates that new growth begins as early as February or March for chums from the Gulf of Alaska (Bilton and Ludwig, 1966) but begins about May 1 for chum salmon in the western Pacific (Kobayashi, 1959).

Also contributing to the lack of growth of Asian chum salmon in winter may be the substantial reduction of habitable water in the western Pacific due to the intrusion of cold water from the north (see section on influence of environmental factors). It is conceivable that these conditions may create a high degree of interspecies competition for food during the winter and severely limit or prevent growth. North American chum salmon do not experience such severe winter conditions in the eastern Pacific and can maintain a broad distribution throughout the year.

The movement of many Asian chum salmon into the Bering Sea in summer may provide the basis for the rapid growth observed for these stocks at this season by reducing the density of the population per unit area. Further, some evidence would suggest (Motoda, 1972) that food organisms may be more abundant in the Bering Sea in summer than in the North Pacific Ocean.

ENVIRONMENTAL FEATURES ASSOCIATED WITH DISTRIBUTION

Environmental features which have been examined for their possible influence on the distribution of salmon in the high seas include salinity, currents, temperature, thermocline, and food supplies. As previously discussed, variation in time of spawning of the various stocks and the extensive geographical distribution of spawning streams occupied by the species are also involved.

SALINITY

At a very early age chum salmon show sensitivity to variations in salinity. McInerney (1964) found that seaward migrating fry at first preferred fresh water but that during the summer the preference changed gradually in the direction of increasing seawater concentration, with a terminal preference for water of open ocean concentration. When fish were held in fresh water beyond the usual period of their residence therein, a partial sequence of preference changes occurred, followed by a reversion to fresh water. McInerney (1964) concluded that responses to salinity play a part in guiding the migrants through estuarial areas and thence to the open ocean.

At sea, chum and other species of salmon inhabit the subarctic region of the North Pacific Ocean. This region, defined by its salinity structure, has a permanent halocline maintained by an excess of precipitation over evaporation, with a brackish upper zone above the halocline and a saline lower zone below (Dodimead et al. 1963). The southern boundary of the subarctic region is located at about 40°N. The ocean regions occupied by chum salmon have a relatively low salinity. There is at present no evidence that the distribution of the species is influenced by the rather small variations of salinity within these regions.

OCEAN CURRENTS

The oceanographic features of the subarctic Pacific region were reviewed comprehensively by Dodimead et al. (1963). The pattern of surface circulation in the high seas areas frequented by salmon was well established. The dominant feature is an easterly flow along the southern border of the subarctic region and a return westerly flow to the north. Gyres are recognized in the Gulf of Alaska, in the Bering Sea, in the western subarctic, and in the Sea of Okhotsk (Fig. 25).

It is indisputable, of course, that currents play a major role in creating an environment and a climate in which salmon can live. Within this environment, however, there is little evidence that the general distribution of salmon in the high seas is determined by strict adherence to, or avoidance of, particular ocean currents. The extensive intermingling of stocks from many widely separated spawning areas (discussed elsewhere in this report) could not be achieved by reliance on known ocean currents (Neave, 1964). Dunn (1969) concluded that "the distribution of immature chum salmon... suggests that although these fish may be associated with certain water masses or currents at certain times of the year, they are not restricted to these areas. That is, they are found throughout a broad range of latitude."

TEMPERATURE

Manzer et al. (1965) discussed at some length the association of Pacific salmon catches with surface water temperatures. They concluded that chum salmon have a "tolerable range" between at least 1°C and 15°C and a "preferred range" from 2°C or 3°C to 11°C—the latter being the widest range shown for any of the five species examined. Evidence for the influence of temperature in determining the distribution of chums was found in apparent seasonal shifting of the ocean regions occupied by the species in general conformity with warming and cooling of the water. Shepard et al. (1968) summarize prevailing views as follows: "Kaganovski's descriptions
[based primarily on pink salmon stocks of the Okhotsk Sea] have led to the theory that salmon, in general, avoid waters of near-freezing surface temperatures. Temperatures in the western and northern parts of the subarctic region are considerably colder than in the southern and eastern parts; at the peak of winter cooling (March), ice usually forms on the surface of the Sea of Okhotsk and in the northern and sometimes southwestern parts of the Bering Sea. At the same time, in the western North Pacific, the northern boundary of the warm subtropical waters (apparently unsuitable for chums) lies very close to the near-freezing waters off northern Japan and the Kurils. Assuming that salmon avoid very cold waters, the area of suitable water for chums is very limited in the western half of the subarctic region. On the other hand, temperatures in the area south of the mid-Aleutians and throughout the Gulf of Alaska are moderate, usually above 3°C, and the area of "habitable" waters north of the subarctic boundary is relatively great. Under these conditions stocks originating in most Asian and northern Alaskan areas would be forced to move to the south and the east, whereas stocks originating in rivers tributary to the Gulf of Alaska would not be forced to move away from the general area of their origin. Although data on catches in the colder areas during the winter months are too sparse to permit assessment of the hypothesis of exclusion of chums from northern and western waters, the numerous observations of northward return migrations coinciding with spring warming of the seas lend credence to the theories."

The distribution data presented here illustrate obvious seasonal movements of chum salmon that support the above hypothesis. During the period of maximum cooling in winter and early spring the distribution of chum salmon occupies its most southerly location. Figure 26 shows the location of catches of immature and maturing chum salmon in winter along with certain isotherms that appear to conform with their distribution. The isotherms shown were constructed from temperature readings taken aboard research vessels at the time fishing sets were made. Since most of the temperature readings represented a single measurement from various years, the resulting isotherms may not be typical for all years nor represent average conditions adequately.

The data indicate that chum salmon in winter avoid surface water with temperatures of 3°C or less. One exception was a catch of a single maturing fish at about 46°N and 168°40'E where a temperature reading of 2.4°C was recorded. Temperature conditions of less than 3°C prevail over much of the Bering Sea and parts of the western Pacific in February as shown by long-term mean conditions (Fig. 17). These cooler surface waters probably account for the more south-
tery distribution of chums in the western Pacific in winter and their absence in the Bering Sea. Surface waters from the central Aleutians and eastward in the North Pacific Ocean were characterized by temperatures greater than 3°C and chum salmon ranged farther north in these regions than in the western Pacific. The temperature range in which catches were made varied from just over 3°C to 8°C (with the one exception previously noted) but the preferred range appeared to be from 5°C to 8°C as shown below by the frequency of catches at various temperature ranges.

Factors other than water temperature may also influence the distribution of chum salmon in winter since in many instances fishing in waters with apparently favourable temperatures was unproductive.

Sampling in winter, 1963, south of the central Aleutians (surface temperature 3.8°C to 7.2°C) produced 46 chums in seven sets whereas fishing along 165°W in waters of a similar temperature range yielded no chums (French and Mason, 1964). Winter fishing elsewhere, notably in the Gulf of Alaska, has often
produced few or no chums in areas where surface temperatures cannot be suspected of being unfavourable (Fisheries Research Board of Canada, 1964, 1966, 1967, 1969; French, 1964, 1966; French and Mason, 1964; French et al. 1971; French, Craddock and Dunn, 1967; French, Craddock, Bakkala, Dunn and Thorsen, 1967). A factor that might influence distribution in winter is the need to locate areas where sources of food are available in adequate quantities.

The broad distribution of chum salmon in spring results in their occupying waters of a wide temperature range and surface temperatures do not appear to restrict distribution as much in spring as in winter. Catches were essentially limited to surface waters of 3°C to 8°C in winter whereas in spring chums were taken in temperatures from less than 1°C to 11°C. Manzer et al. (1965) reported catches at temperatures as high as 13°C in June. Some differences in the surface temperatures accepted by immature and maturing chums were apparent from the average CPUE values and the proportion of gillnet sets that successfully caught chum salmon at various temperature intervals (Fig. 27). Immature fish were taken over the range from 3°C to 11°C while maturing fish were taken from less than 1°C to 10°C. Over the

temperature range occupied by maturing fish, the proportion of research vessel gillnet sets that successfully caught maturing fish was uniformly high, ranging from 75% to 100%. In addition, the average CPUE was fairly uniform throughout the range. No maturing fish were taken in five gillnet sets at temperatures of 11°C and 12°C, which may exceed the preferred levels in spring. The southern boundary of good commercial catches was reported by Shepard et al. (1968) to be at about the 10°C surface isotherm.

The average CPUE and percentage of sets with catches was not as uniform over the temperature range occupied by immature fish as it was for maturing chums. The highest CPUE value was at 7°C and values declined at higher and lower temperatures, suggesting that 7°C may be the best liked temperature in spring. The proportion of sets that successfully took immatures, however, was fairly high (65–72%) from 5°C to 10°C.

The main difference in the temperatures inhabited by immature and maturing fish occurred in the lower part of the range. Maturing fish were relatively abundant and taken consistently in temperatures from 1°C to 4°C, whereas immatures were not taken in 1°C and 2°C water and their abundance and frequency in catches was relatively low in 3°C and 4°C water. This relationship agrees with differences in distribution of the two groups. Maturing fish generally extended as far south as the immatures in spring but preceded the immatures in moving into more northerly and cooler waters.

Shepard et al. (1968), using information from Taguchi (1957) and Birman (1958), indicated that main concentrations of maturing chum salmon moved northwestward in the North Pacific Ocean and Bering Sea in spring following the northward extension of the 3°C to 4°C surface isotherms. This appears to be a valid conclusion for most stocks of chum salmon. The more recent data presented here, however, show some substantial catches by research vessels from waters of the northern Bering Sea with temperatures of 1°C and 2°C. These catches probably represent stocks destined for more northerly streams of Alaska and the U.S.S.R. Possibly these more northerly stocks have become genetically adapted to very low temperatures through the necessity of reaching spawning streams in early summer.

Manzer et al. (1965) noted that chum and other species of salmon were associated with a slightly higher temperature regime with each successive month in the period from May to August. This change was attributed to seasonal warming of surface waters. Data presented by the above authors show catches at temperatures ranging from 5°C to 15°C in July
and 6°C to 15°C in August.

Certain seasonal features of chum salmon distribution are observed regularly each year such as the low catches of fish in surface waters in spring, high level of immature catches in mid-summer, and an apparent decline in catches of immatures in autumn. Another prominent feature is the north-south shift in the distribution of immatures which reaches its most northerly limit in mid-summer and its most southerly location in late winter or early spring. These recurrent changes in distribution can be expected to be governed by seasonal changes of the environment.

Features of the heating and cooling cycle in the subarctic region (Figs. 28 and 29) seem to coincide with these changes in distribution. Although the data is from a single location in the eastern Pacific (50°N, 145°W) and details of the cycle may vary by area, the basic characteristics of the cycle remain the same throughout the region (Tabata and Giovando, 1963). The temperature cycle in surface waters reaches its lowest point in March which represents the end of the cooling season (Fig. 28). April marks the beginning of the heating season which continues until August when the peak temperatures of the cycle are recorded. The cooling phase begins in September and ends in March to complete the cycle. Associated with these seasonal changes in surface waters is a secondary cycle in deeper waters featured by the growth and decay of a marked negative thermocline (Fig. 29). Seasonal variation in temperature in these deeper waters is confined to layers above the halocline which is a permanent feature of the central and eastern subarctic region between about 100 and 200 m (Dodimead, 1961). In winter the thermocline is very deep or nonexistent and waters are virtually isothermal from the surface to the top of the halocline (Tabata and Giovando, 1963). With the beginning of the heating season in April, the thermocline is formed, is strengthened and becomes shallower through the period until August. Following August the thermocline increases in depth and decays.

In winter when the thermocline is very deep or nonexistent the abundance of chum salmon in catches has been unreasonably low in view of the much higher levels of abundance observed in spring and summer. Although sampling in winter has not been comprehensive in any one year, rather broad areas of the ocean have been covered over several years and large concentrations of chums should have been encountered in some areas if they were fully available in surface waters. We have suggested here, as have earlier authors, that chum and other species of salmon may inhabit depths below the surface waters sampled by gillnets and longlines in winter. The isothermal conditions existing in waters above the halocline would not appear to form a barrier to such a depth distribution. The extent of the depth distribution might only be limited by the location of the halocline.

During the heating phase of the temperature cycle, chum salmon become more abundant in surface waters and the abundance of immature fish reach their highest levels in mid-summer at the peak of the heating cycle. This trend in availability might con-
ceivably be related to the movement of the thermocline toward the surface which could reduce the depth of favourable water conditions and produce increasing densities of salmon at the surface.

The possibility of such a relationship has been investigated for the period of May to September when the thermocline develops and reaches its maximum strength and minimum depth. Paired observations of catches of immature chum salmon and temperature profiles from 480 gillnet sets in 1967 to 1970 were used. The location of the thermocline was defined as the point where the temperature decreased by more than 0.5°C in 10 m. The area of coverage extended from about 40°N to 64°N and between 165°W and 165°E.

A comparison of the paired CPUE and thermocline depth values, averaged by month, supports in general the assumption that abundance of immatures increases at the surface as the thermocline strengthens and becomes shallower.

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean depth of thermocline (m)</th>
<th>Mean CPUE of immatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>weak or none</td>
<td>0.3</td>
</tr>
<tr>
<td>June</td>
<td>32</td>
<td>2.2</td>
</tr>
<tr>
<td>July</td>
<td>24</td>
<td>4.0</td>
</tr>
<tr>
<td>August</td>
<td>23</td>
<td>5.3</td>
</tr>
<tr>
<td>September</td>
<td>34</td>
<td>4.4</td>
</tr>
</tbody>
</table>

There is also a decrease in CPUE in September as the thermocline begins to decay.

Closer examination of the data demonstrates, however, that the relationship is not as straightforward as the above summary would imply (Table 4). Considerable variation in thermocline depth was observed at fishing stations in the area within months. In May a high proportion of the observations showed a weak or nonexistent thermocline. From June to September a well-developed thermocline was evident at 15, 25 or 40 m with the mode of observation shifting from 40 m in June to 25 m in July and August and back to 40 m in September. This trend undoubtedly resulted from the normal warming and cooling cycle for this period of the year. The frequent changes in depth of the thermocline or mixed layer within months were probably due to local wind stress conditions in the area prior to the time the fishing sets and temperature profiles were made.

Catches of immature chums in the 0–7 m surface layer did not show a direct relation to the thermocline depth, since maximum abundance levels did not coincide with the minimum thermocline depths (Table 4). This indicates that the fish were not forced to the surface by the thermocline as the mixed layer became shallower. It appears that good catches of immatures were not made in surface waters until the thermocline became well established in June at 40 m or less. From June to August mean catches were consistently highest with a thermocline depth of 25 m and consistently next highest with a thermocline depth of 40 m. In September, when the mixed layer became deeper, the higher catches were associated with thermocline depths of 40 m and 60 m. These data suggest that the frequency of occurrence of immature chum salmon in surface waters is not solely dependent and may have no dependence on the depth of the thermocline. It can be noted that when the thermocline depth is very shallow the surface temperature is often higher than is considered favourable for habitation by chum salmon.

Other data bearing on this point are available from studies of the vertical distribution of chum salmon. These studies (previously described in the section “Limitations of Data”) have demonstrated that immature chums inhabit vertical depth ranges from the surface to at least 30 m or 40 m. If the depth of the thermocline influenced the vertical distribution then it should be reflected in the proportion of fish at various depth levels in these studies. Shown below are the percentage of the catch of immature chums taken at each depth level fished by United States research vessels in the summers of 1968 and 1969 together with corresponding thermocline depths at

---

**Table 4. Average catch per-unit-effort of immature chum salmon (that were taken in the upper 7 m of water) in relation to the depth of the thermocline. (The number of observations at each thermocline depth is given in parentheses.)**

<table>
<thead>
<tr>
<th>Thermocline depth (m)</th>
<th>15</th>
<th>25</th>
<th>40</th>
<th>60</th>
<th>85</th>
<th>None</th>
<th>Average CPUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>0.2 (3)</td>
<td>0 (2)</td>
<td>0.1 (7)</td>
<td>0.4 (10)</td>
<td>1.2 (1)</td>
<td>0.3 (91)</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>1.1 (13)</td>
<td>1.1 (11)</td>
<td>2.1 (34)</td>
<td>0 (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>3.2 (38)</td>
<td>4.9 (47)</td>
<td>3.4 (66)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>4.3 (64)</td>
<td>6.2 (69)</td>
<td>5.1 (21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>2.5 (9)</td>
<td>3.8 (11)</td>
<td>4.9 (17)</td>
<td>7.1 (46)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the time of fishing.

<table>
<thead>
<tr>
<th>Thermocline depth (m)</th>
<th>Number of sets</th>
<th>Number of fish taken</th>
<th>Percentage of catch at 0-7 m</th>
<th>8-15 m</th>
<th>16-23 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>14</td>
<td>28</td>
<td>50</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>25</td>
<td>21</td>
<td>249</td>
<td>43</td>
<td>24</td>
<td>33</td>
</tr>
<tr>
<td>40</td>
<td>8</td>
<td>45</td>
<td>49</td>
<td>29</td>
<td>22</td>
</tr>
</tbody>
</table>

Catches in the surface layer were relatively constant (43–50%) regardless of the depth of the thermocline. There appeared to be some tendency for the portion of the catch to increase in the 8–15 m layer as the thermocline deepened but this was not the case in the 16–23 m layer where the percentage of the catch was smallest when the thermocline depth was at a maximum. These results support the earlier conclusion that the depth of the thermocline had little or no influence on the catches of immatures in the surface layer. Other environmental factors that are associated with the annual heat cycle in the North Pacific may be the main cause of the observed seasonal changes in relative abundance of chum salmon. One such factor may be the abundance, location, and depth distribution of food items which could seasonally alter the behaviour of salmon and thus their vulnerability to surface fishing gear.

Also corresponding to the heating and cooling cycle in the subarctic region is the timing of the north-south shift in distribution of immature chum salmon. Their distribution is located farthest south in early spring at about the time surface temperatures reach their minimum in March. The northward shift in the distribution occurs during the middle of the heating phase of the cycle in June and early July and reaches its most northerly location in July and August during the peak of the warming cycle. There is a return southward movement in fall and winter coinciding with the cooling phase of the cycle.

It is entirely reasonable to believe that limitations on the total distribution of chum salmon are imposed directly by certain minimum and maximum temperatures. Between these values, however, the effects of the annual temperature cycle may be indirect—possibly through control of the location and abundance of food organisms.

**Food**

The food of juvenile chum salmon in the weeks immediately following their entry into salt water has been investigated in several Asian and North American areas.

At two Hokkaido localities, in late May and June, the stomachs of fish ranging in length from 3.9 cm to 10.1 cm were found to contain copepods, amphipods, euphausiids, decapod crustacean larvae, insects, and fish larvae (Okada and Taniguchi, 1971).

Manzer (1969) reported on the stomach contents of juvenile chums taken in shoreline waters of northern British Columbia from early June to late August with a length range from 3.2 cm to 10.6 cm. Small tunicates (Larvaea) accounted for 51% of the total volume of the contents. Copepods constituted 19%. Other categories, each contributing 5% or less included decapod larvae, euphausiids, amphipods, insects, and fish.

Foskett (1951) found crustaceans, insects, and fish (herring) in juvenile chums caught on the east coast of Vancouver Island in July and August with a length range of 6.9 cm to 18.6 cm.

LeBrasseur (1969) found that juvenile chums of an average initial length of 4.1 cm, subjected to various feeding regimes, preferred prey in a length range of 1.6 mm to 4.5 mm. It appeared that prey smaller than 1.6 mm required longer hours of feeding, whereas organisms more than 4.5 mm long were less easily caught, these factors being reflected in the growth rate of the predator. In these experiments the chief contributor in the preferred size range was the copepod Callanclus plumchrus. The author adds that “the early sea life of juvenile salmon usually coincides with the period of maximum C. plumchrus biomass in the coastal waters of British Columbia.”

Little is known of the feeding habits of chum salmon between the time when they leave inshore waters and the time when they appear, at a much larger size, in the high-seas catches of commercial and research vessels. Examination of juvenile salmon (including chum salmon) in the eastern Bering Sea in August and September revealed larval fish (especially Mallotus, Ammodites and Clupea) and euphausiids (Thysanoessa) as the chief food items in most of the samples (Hartt et al. 1970).

For larger fish caught in offshore waters the findings of certain investigators are indicated below. Additional references are given by Takeuchi (1972).

In the stomachs of 250 chum salmon caught by gillnet in the northwestern Pacific Ocean in June and July, 1955, Andrievskaya (1957) identified more than 40 kinds of organisms. Many of these were present in very small quantity or in very low frequency of occurrence. In general, investigators of the diet of salmon in offshore waters have found that the main constituents of stomach contents can be grouped in the following categories: euphausiids, amphipods, copepods, decapod larvae, pteropods, squid, and fish.

Andrievskaya (1957) found that pteropod molluscs made the greatest overall contribution to the weight
of stomach contents (40%), followed by euphausiids (16%), tunicsates (16%), fish (8%), copepods (6%), amphipods (5%), and holothurians (5%). The relative proportions, however, were different in different areas. For example, euphausiids were absent in fish taken in the Kamchatka Gulf area but accounted for 47% of the contents of fish in the Aleutian area.

Allen and Aron (1958) examined 156 chum salmon caught between May 18 and August 10, 1955, in three western areas, viz., near the west and east coasts of Kamchatka and south of the western Aleutians. In the latter area, euphausiids constituted 50% of the volume of identifiable material, but fish, pteropods and copepods each contributed more than 10%.

Off the east coast of Kamchatka the rankings were: amphipods (30%), squid (23%), euphausiids (16%), fish (12%), and pteropods (9%). Off the west coast of Kamchatka (Okhotsk Sea), euphausiids were of little importance but crustacean larvae, pteropods, squid, amphipods, and fish all exceeded 10%.

Ito (1964) reported on the stomach contents of chum salmon taken during the summers of 1956 to 1963 in high-seas waters west of 175°W. He found that pteropods and euphausiids were the largest overall contributors by weight to the identifiable material, with amphipods, fish and copepods at times assuming levels of importance.

Takeuchi (1972) examined the stomach contents of 1,128 chum salmon taken in spring and summer, 1964–1966, in the northwest Pacific Ocean and in the Bering Sea and Okhotsk Sea. In the total wet weight of identified material, euphausiids and pteropods were major constituents in chum caught in the northwest Pacific in April to July. Small fish were also of considerable importance in the diet. Lesser amounts were contributed by amphipods and copepods. In samples from the Sea of Okhotsk (June and July) euphausiids were virtually absent and the main contribution was from squid. In the Bering Sea samples (June and July) euphausiids were again nearly absent. Squid, fish and pteropods were the main groups encountered. Comparison of stomach contents with surface plankton hauls made in these regions in 1961–1966 suggested that "there is no strong indication of selective feeding."

In the northeast Pacific, LeBrasseur (1966) reported results from the examination of 361 chum salmon caught by gillnet in the Gulf of Alaska in May and June, 1958. LeBrasseur and Doidge (1966a, b, c, d) also recorded the individual stomach contents of salmon caught in the same general region in 1956 to 1960 and 1962 to 1963. A gross comparison between these findings and those reported by Ito (1964) for approximately the same period in the northwestern Pacific is made in Table 5. In general, the incidence of pteropods was much higher in the western region. However, the proportions of various food organisms varied greatly between samples taken in different years as well as between areas and individuals within a single season. LeBrasseur (1966) found no significant differences in chum stomach contents that could be related to size or state of maturity of the fish. He suggested that "feeding is associated more with availability rather than with preferences for specific organisms." He and other investigators, however, have noted that chum salmon stomachs, in comparison with other species, commonly contain a high proportion of material in an advanced stage of digestion.

### Table 5. Stomach contents of chum salmon caught in the North Pacific in spring and summer, 1956–1963.

<table>
<thead>
<tr>
<th>Year</th>
<th>Region</th>
<th>No. of fish</th>
<th>Total wet contents (g)</th>
<th>Av. contents/</th>
<th>Percent identified</th>
<th>Amphipod</th>
<th>Copepod</th>
<th>Euphausid</th>
<th>Squid</th>
<th>Pteropod</th>
<th>Fish</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>N.E. Pacific</td>
<td>262</td>
<td>1,081</td>
<td>4.1</td>
<td>47</td>
<td>13</td>
<td>100</td>
<td>43</td>
<td>15</td>
<td>16</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>1957</td>
<td>N.W. Pacific</td>
<td>2,215</td>
<td>33,207</td>
<td>15.0</td>
<td>100</td>
<td>13</td>
<td>13</td>
<td>4</td>
<td>4</td>
<td>14</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>1958</td>
<td>N.E. Pacific</td>
<td>575</td>
<td>2,153</td>
<td>3.7</td>
<td>65</td>
<td>19</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>1959</td>
<td>N.W. Pacific</td>
<td>154</td>
<td>1,081</td>
<td>7.0</td>
<td>55</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>1960</td>
<td>N.W. Pacific</td>
<td>453</td>
<td>2,537</td>
<td>5.6</td>
<td>17</td>
<td>6</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>1961</td>
<td>N.W. Pacific</td>
<td>384</td>
<td>4,398</td>
<td>11.4</td>
<td>51</td>
<td>6</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>1962</td>
<td>N.W. Pacific</td>
<td>336</td>
<td>1,243</td>
<td>3.5</td>
<td>45</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>1963</td>
<td>N.W. Pacific</td>
<td>261</td>
<td>2,241</td>
<td>8.6</td>
<td>55</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>N.W. Pacific</td>
<td>74</td>
<td>1,325</td>
<td>17.9</td>
<td>98</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>N.W. Pacific</td>
<td>265</td>
<td>1,969</td>
<td>7.4</td>
<td>73</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>N.W. Pacific</td>
<td>217</td>
<td>1,614</td>
<td>7.4</td>
<td>60</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>N.W. Pacific</td>
<td>353</td>
<td>1,589</td>
<td>4.5</td>
<td>54</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>N.W. Pacific</td>
<td>199</td>
<td>1,599</td>
<td>8.0</td>
<td>46</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>N.W. Pacific</td>
<td>237</td>
<td>678</td>
<td>2.9</td>
<td>35</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>N.W. Pacific</td>
<td>194</td>
<td>2,655</td>
<td>13.7</td>
<td>73</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
</tbody>
</table>
From Table 5 it can be seen that up to 80% of the total weight of contents is sometimes unidentifiable for this reason. Japanese investigators (Fisheries Agency of Japan, 1964) stated that "The stomachs of chum salmon contain mostly unidentifiable material or pteropods, being quite different from the stomach contents of other species." A suggestion that the digestive process may be different in chums is contained in the further remark that "Chum salmon stomachs themselves differ from those of other species in form, size, and in the fact that an appendix exists inside the esophageal orifice." Another possibility
is that the chum may tend to feed at depths or times of day which establish a different relationship between the fish and the gear with which they are sampled.

While the presence of large amounts of unidentifiable material may well affect the proportions that should be assigned to different kinds of food organisms, it is unlikely that it represents an unknown, stable, homogeneous food supply. On occasion, considerable numbers of chum stomachs have yielded almost completely identifiable contents without dis-

![Maps showing distribution of chum salmon](image)

**Fig. 92.** Numbers of chum salmon tagged by Canada, Japan, and the United States in 2° x 5° areas, by seasons, 1956 to 1971.
closing wide departure from menus inferred from small fractions of the total material present.

In general, it is concluded that chum salmon feed on a wide variety of organisms, of which any one of a half dozen types may be of major importance at a given place or time. Growth of the fish may well be affected by annual variations in the total food supply, as is suggested (more especially for pink salmon) by Ito (1964).

The location of abundant sources of the types of

*Fig. 32 (cont.)*
Fig. 33. Destination of maturing chum salmon tagged in 2° × 5° high-seas areas as shown by tag recoveries from major coastal areas in the year of tagging. Within each 2° × 5° area, numerals in upper left, lower left, upper right and lower right show recoveries made respectively in Asian waters from the Amur River northward; from Asian waters south of the Amur River; from Alaska north of the Alaska Peninsula and from North America waters south of the Alaska Peninsula.
Fig. 33 (cont.)
zooplankton shown to contribute heavily to the diet of chum salmon might conceivably play an important role in the distribution of the species. A direct relationship between salmon distribution and abundance of zooplankton has not been established but available information from studies of this type can be mentioned.

United States oceanographers have studied the seasonal abundance of zooplankton along 176°W between the Aleutians and 41°N. The predominant organisms in samples taken from this area were euphausiids and copepods which also were frequently the most abundant organisms in the stomach contents of chum salmon as discussed above. The mean wet weight per 30 minute oblique tow was lowest in winter (14 g in January and February and 12 g in March) much higher in June (47 g) and somewhat reduced from June levels in August (42 g) and September (39 g) (McAlister et al. 1969, 1970). From north to south along longitude 176°W in winter, the highest abundance of zooplankton was between about 49°N and 46°N. These were also the latitudes where most of the immature and maturing chum salmon were taken in winter (see section on "Distribution"). In June zooplankton abundance was highest near 50°N in both 1966 and 1967. This latitude corresponds to the vicinity of relatively large catches of immatures in late June and early July. In August and September, peak catches of zooplankton were located at much the same latitude (50°N–51°N) but large catches of chum salmon in these months were made farther north in the Bering Sea.

Data from vertical plankton tows taken by Japanese research vessels in the years 1956 to 1970 as summarized by Motoda (1972) indicated that zooplankton abundance west of 170°W was higher in the Bering Sea than in the North Pacific in summer (Fig. 30). These findings suggest a basis for the movement of a large proportion of the Asian chum salmon into the Bering Sea in summer, although the plankton organisms taken in the studies discussed by Motoda (1972) were, in part, of a lower form than the main constituents—squid, fish, pteropods—of stomach contents of chum salmon from the Bering Sea (Takeuchi, 1972).

The seasonal changes in location of major concentrations of immature chum salmon appear to coincide rather well with the seasonal and spatial changes in the abundance of zooplankton in the central and western Pacific. Although such a relationship has not been established it may be a primary factor in the observed seasonal movements of chum salmon.

**ORIGIN OF HIGH-SEAS CHUMS**

**TAGGING STUDIES**

The long-standing and well-founded belief that Pacific salmon have a very strong tendency to return to the particular freshwater areas in which they originated has led to the acceptance of the results of tagging operations as the most reliable indicator of the dispersal and movements of chum salmon stocks in the high seas.

Tagging of chum salmon by Japanese and North American investigators prior to the establishment of the International North Pacific Fisheries Commission program in 1953 was mainly carried out within coastal waters on fish which were in the late stages of their spawning migrations. The relatively few experiments which revealed long journeys in offshore waters, were summarized briefly by Shepard et al. (1968). These

![Fig. 34. General release areas for tagging experiments by Canada, Japan, and the United States during 1956 to 1971.](image-url)
Table 6. Coastal and high seas recovery areas for chum salmon tagged in various offshore regions (see Fig. 34 for the location of release areas 1-6).

<table>
<thead>
<tr>
<th>Recovery area -</th>
<th>Number tagged (mature and immature)</th>
<th>Recoveries in year of tagging</th>
<th>Recoveries in subsequent years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Hokkaido and Honshu Islands</td>
<td>1,654</td>
<td>8,274</td>
<td>1,902</td>
</tr>
<tr>
<td>South Sakhalin—Kuril Islands</td>
<td>1</td>
<td>---</td>
<td>2</td>
</tr>
<tr>
<td>North Sakhalin—Amur River</td>
<td>6</td>
<td>1</td>
<td>---</td>
</tr>
<tr>
<td>North coast Okhotsk Sea</td>
<td>19</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>West Kamchatka</td>
<td>3</td>
<td>6</td>
<td>---</td>
</tr>
<tr>
<td>East Kamchatka</td>
<td>---</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Anadyr River</td>
<td>---</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Total Asian Coastal Returns</strong></td>
<td>31</td>
<td>47</td>
<td>18</td>
</tr>
</tbody>
</table>

**High Seas**

| Okhotsk Sea                | 2    | ---  | ---  | ---  | 1    | 3    | 6     | --- | --- | --- | --- | --- | --- | --- |
| Bering Sea west of 175°W   | ---  | 28   | 11   | 13   | 93   | 2    | 147   | --- | --- | --- | --- | --- | --- | 29  |
| Bering Sea east of 175°W   | ---  | ---  | ---  | ---  | ---  | ---  | ---   | --- | --- | --- | --- | --- | --- | 2   |
| Gulf of Alaska east of 160°W| ---  | ---  | ---  | ---  | ---  | ---  | ---   | --- | --- | --- | --- | --- | --- | 1   |
| Central North Pacific (170°E-160°W) | --- | --- | --- | --- | 5    | 118  | 12    | 135 | --- | 21 | --- | --- | 58  | 1   |
| Western North Pacific (west of 170°E) | --- | 7   | 1    | 11   | 128  | 255  | 402   | 6  | 14 | --- | --- | 119 | 36  | 175 |
| Unknown                    | ---  | 1    | 1    | 4    | 22   | 28   | ---   | --- | --- | --- | --- | --- | 6   | 3   |
| **Total High Seas Returns** | 2    | 36   | 13   | 29   | 344  | 294  | 718   | 6  | 38 | --- | --- | 4  | 208 | 40  |

**North American Coastal**

| Western Alaska             | 1    | 32   | ---  | 185  | 167  | ---  | 385   | --- | --- | 19 | 15 | --- | --- | 34  |
| Central and Southeastern Alaska | --- | ---  | ---  | 294  | 1    | ---  | 295   | --- | --- | 9  | 6  | --- | --- | 15  |
| British Columbia, Washington and Oregon | --- | ---  | ---  | 118  | 2    | ---  | 120   | --- | --- | 5  | --- | --- | --- | 5   |
| **Total North American Coastal Returns** | 1    | 32   | 597  | 170  | 800  | ---  | 800   | --- | --- | 33 | 21 | --- | --- | 54  |

**Total Returns**

| 33   | 84   | 63   | 662  | 799  | 468  | 2,109 | 8  | 45 | 3  | 40 | 327 | 57  | 480 |
authors then examined the data resulting from the high-seas tagging of 60,000 chums by the United States, Japan, and Canada in the 1956 to 1962 period. In the next 9 years (1963 through 1971), a further 40,000 chums were tagged on the high seas by the three nations. The combined data from the two periods are reviewed in the following pages.

a. Distribution of Tagging

The total numbers of chums tagged in $2^\circ \times 5^\circ$ areas of the North Pacific Ocean and adjacent seas in 1956 to 1971 are shown in Fig. 31 and the numbers tagged by month in Fig. 32. As was noted in the earlier report, the impossibility of giving equal coverage to all parts of this vast region is quite evident. A further limitation of the data is imposed by the scarcity of tagging experiments at seasons other than from April to August. It can also be mentioned that the gear used for catching fish for tagging was not uniform throughout the program. With few exceptions, chums tagged west of 170$^\circ$E were caught by longlines. In the Aleutian region the great majority were tagged from purse seine. In the Gulf of Alaska both longlines and purse seines were used extensively. Variations in the type, size, and color of the tags used, and in the magnitude of the effort expended on their recovery, have been reported in the annual reports of the Commission. A great majority of the taggings were made with disc tags (described by Hartt, 1962, 1966). In the present report no attempt is made to evaluate the possible effects of differences in tools and techniques.

b. Tag Returns

Of a total of 101,685 released, 2,589 tags (2.5%) were returned up to the end of 1971. These included 2,109 which were recovered within the year in which they were tagged and 480 which were recovered in subsequent years. The fish constituting the latter group were obviously immature at the time of their tagging. Those fish of the first group which were recovered in inshore or fresh waters were regarded as maturing when tagged. However, the tagged chums recovered on the high seas within the tagging year (718 in number) presumably included both immature and maturing fish. Furthermore, the high-seas recoveries, while frequently giving useful information on the direction of movement, usually do not provide acceptable evidence regarding the ultimate destinations of these fish.

(1) Coastal recoveries from tagging in ocean regions

Figure 33 shows the number of coastal returns received from each of the contributing $2^\circ \times 5^\circ$ areas and the broad Asian and North American regions to which these fish travelled. In Table 6 the tagging areas are grouped into six main regions (Fig. 34) and the destinations are defined more narrowly.

—Recoveries from tagging in the Sea of Okhotsk (Area 1 in Fig. 34)

From 1,654 fish released there were 33 coastal recoveries—31 in the year of release, two in subsequent years—all from localities within the Sea. The data now available support the earlier tentative conclusion that “maturing chums in the Sea of Okhotsk during late spring and summer months are destined for streams within the Sea and not for areas outside in the North Pacific” (Shepard et al. 1968).

—Recoveries from tagging in the western Bering Sea (Area 2 in Fig. 34)

The release of 8,274 fish yielded 55 coastal returns—48 in the year of tagging, seven in subsequent years. Thirty-three returns came from Japan, 21 from U.S.S.R. localities both within and outside the Sea of Okhotsk, and one from the Yukon River, Alaska. The data are consistent with the opinion expressed in the 1968 report that the three main stocks in the western half of the Bering Sea are those destined for east Kamchatka, west Kamchatka, and Hokkaido.

—Recoveries from tagging in the eastern Bering Sea (Area 3 in Fig. 34)

The release of 1,902 fish provided 53 coastal returns, of which 50 were in the year of tagging and three in subsequent years. Twenty-one recoveries were made in Asian localities (including 10 in Japan) and 32 in western Alaska. As noted by Shepard et al. (1968) the relatively large number of North American returns is in marked contrast to the pattern shown by tagging in the western Bering Sea.

—Recoveries from tagging in the Gulf of Alaska (Area 4 in Fig. 34)

The release of 21,728 fish resulted in 669 coastal recoveries, of which 633 were maturing when tagged and 36 were immature. The 39 Asian returns were distributed from Japan to Anadyr but did not include representatives from the Amur and northwest Okhotsk coastal areas. (An additional 29 fish were recaptured on the high seas, far to the west of the tagging area.) North American coastal recoveries totalled 630 (western Alaska, 204; central and southeastern Alaska, 303; British Columbia and Washington, 123).

These figures (which include data derived from the tagging of some 14,000 chums subsequent to the preparation of the Shepard et al. (1968) report) confirm
the previous conclusion that this region is occupied not only by maturing fish which proceed to adjacent coasts but also receives a heavy influx from western Alaskan sources and other chums with destinations in various Asian areas.

—Recoveries from tagging in the central North Pacific Ocean (Area 5 in Fig. 34)

In this relatively intensively examined region, 53,242 chums were tagged in the 1956 to 1971 period. Coastal returns numbered 574 of which 455 were recaptured in the year of tagging and 119 in subsequent years. In addition, 552 recoveries were made on the high seas, reflecting the intensive fishery which is prosecuted annually in the western part of this region and in Area 6. The coastal returns included 383 distributed throughout all the major Asian areas (about 57% from Japan) and 191 from North American sources, of which 182 were attributed to western Alaska. Taking the region as a whole, the presence of many North American chums in these waters is evident but, as is shown in Fig. 33 only 10 maturing and 13 additional immatures of the North American fish had been tagged west of 175°W.

—Recoveries from tagging in the western North Pacific Ocean (Area 6 in Fig. 34)

The 14,885 fish released yielded 191 coastal returns —174 in the year of tagging, 17 in subsequent years. These were distributed among all the major Asian coastal areas except Anadyr. In addition, 334 tags were recovered in high-seas areas west of 175°W (294 in year of tagging, 40 in later years). No returns were received from North American sources.

(2) Ocean distribution and migration of major stocks as shown by inshore recoveries

Figures 35 to 45 show the high-seas localities from which tagged chum salmon migrated to major inshore areas. In the following paragraphs conclusions reached by Shepard et al. (1968) are indicated together with comments which take account of the additional data now available.

"Chum salmon bound for Japan are widely distributed throughout much of the North Pacific and Bering Sea as far east as the western Gulf of Alaska. Maturing individuals are present offshore south of the Alaska Peninsula during April, May and June... Returns from tagging of immature fish show a more restricted distribution, extending only to the eastern Aleutians." (Addenda to the text noted the occurrence of a maturing chum as far east as 140°W and an immature at 156°W.)

The recovery of more than 100 additional tags in the Japanese area fully confirms the distribution indicated above. A northward extension of the previously known range is provided by recoveries of maturing fish tagged north of 60°N in the western and central Bering Sea.

From the time and space distribution of taggings of chum salmon bound for the Japanese area, as shown in Fig. 35, the following migration pattern is derived.

Maturing fish returning to Japan are distributed mainly in the northeastern Pacific Ocean in April and May, some of them wandering as far as 140°W in the Gulf of Alaska. In June and July these fish proceed northward or westward in the region around the eastern part of the Aleutian Chain. They seem to stay longer in the vicinity of the Chain than the maturing chums bound for east Kamchatka and western Alaska. In late July, at least part of the stock reaches as far north as 64°N in the Bering Sea. In August and September most fish migrate to the waters off the east coast of the Kamchatka Peninsula and then head southward to Japan, where the peak of the run occurs in October and November. The southward migration seems to take place along the Kuril Islands.

Immature Japanese chums (at least of age .2 and older) also appear to be mainly located in the northeastern Pacific Ocean in spring and early summer. They are widely distributed along the Aleutian Chain in July and August. That some of them migrate as far north as 58°N is shown by a 1972 recovery on the Hokkaido coast (not shown in Fig. 33). Tagging studies have failed to demonstrate the presence of either immature or maturing Japanese fish in the Bering Sea before June.

Chum salmon bound for the Kuril Islands and southern Sakhalin Island were located as far east as 141°W, this being the farthest known penetration of the Gulf of Alaska by fish originating in U.S.S.R. areas (as shown by tagging). The four returns from chums tagged east of 165°W were all from early-season taggings (April and May). Recoveries of fish tagged as immature, although scanty, showed a distribution similar to that of adult fish.

The general picture of tag returns suggests that the migration pattern of these fish is very similar to that of Japanese stocks (Fig. 36).

Shepard et al. (1968) found that "chum salmon bound for the Amur River remain relatively close to the Asian coast. The distribution of both matures and immatures is in marked contrast to that of chums from Japan despite the facts that the two areas are relatively close together and that the time of spawning of the stocks from the two areas is not very different."
Fig. 35. Ocean migration of chinook salmon stocks from Japan as indicated by tagging. Numbers (circled for immature and non-circled for maturing fish) show the month and location of tagging.
Fig. 36: Ocean migration of chum salmon stocks from Kuril Islands and southern Sakhalin as indicated by tagging. The numbers (circled or immature and not circled for mature fish) show the month and location of tagging.
Fig. 37. Ocean migration of chum salmon stocks from the Amur River and northern Sakhalin as indicated by tagging. The numerals (circled for immature and noncircled for maturing fish) show the month and location of tagging.
Fig. 38. Ocean migration of chum salmon stocks from the Okhotsk coast as indicated by tagging. The numbers (circled for immature and non-circled for maturing fish) show the month and location of tagging.
Fig. 40. Ocean migration of chum salmon stocks from east Kamchatka as indicated by tagging. The numerals (circled for immature and non-circled for maturing fish) show the month and location of tagging.
In the present account Amur River recoveries are combined with recoveries from northern Sakhalin Island.

Most of the maturing chums of these stocks are in the northwestern Pacific Ocean, principally west of 165°E, in spring and early summer. Although their northward migration seems to be slow, the main body of these fish is in the Okhotsk Sea by July. Since the peak run in the mouth of the Amur River and in northern Sakhalin does not occur before August, the migrants must spend one or two additional months in the offshore waters of the Okhotsk Sea.

In contrast to the maturing chums, immatures are found in more easterly waters, principally in the Pacific Ocean east of 160°E. They move to the north as the summer advances and they must return to the south in autumn and winter (Fig. 37).

Maturing chum salmon bound for the northern coasts of the Okhotsk Sea seem to be distributed densely in the northwestern Pacific Ocean close to the Kamchatka Peninsula in April to June. The main concentration is somewhat farther east than that of the Amur River stock. The peak of the migration into the Okhotsk Sea seems to occur in June. The fish remain there until early August, when the peak of the inshore run occurs on the Okhotsk coast. There is no evidence of penetration of the Bering Sea by maturing fish.

Some immatures are distributed along with the maturing fish in the northwestern part of the Pacific in early summer, but their range of distribution in July and August extends much farther east in the Pacific Ocean and much farther north in the Bering Sea (Fig. 38).

The distribution of maturing chum salmon bound for western Kamchatka, in spring and summer, seems to extend to waters farther east than those frequented by the maturing northern Okhotsk fish. The main body moves westward along the Aleutians in June and some fish travel through the southern Bering Sea. The peak migration into the Okhotsk Sea occurs in July or later and apparently later than the runs to the northern Okhotsk coast and the Amur River.

Immatures of this stock were recovered only from taggings around the western Aleutians (west of 175°W). However, they may migrate farther eastward, since maturing fish of this stock occur even in the Gulf of Alaska in spring (Fig. 39).

"Chum salmon bound for east Kamchatka are distributed generally to the north and east of those destined for the tributaries of the Okhotsk Sea (including the Amur River). A single specimen tagged off Hokkaido seems not to fit the pattern, and such a migration is probably uncommon. East Kamchatkan stocks also apparently penetrate far into the Gulf of Alaska. Immatures show a more restricted distribution, in keeping with the more restricted tagging of immatures." (Shepard et al. 1968).

Maturing fish of this stock occur almost all over the North Pacific Ocean in April and May. The majority, however, are in northeastern waters, including the Gulf of Alaska. More detailed examination of the data indicates that the maturing fish that are present in the northwestern Pacific in May and June (such as the "single specimen" mentioned by Shepard et al. (1968)) are a fragment bound for the southern part of east Kamchatka (south of the Kamchatka River). The main body of east Kamchatka fish apparently spend their last winter in the northeastern Pacific Ocean and migrate westward or northwestern in April and May. Most of them pass through the eastern part of the Aleutian Chain into the Bering Sea in June and approach the coast in July. The timing of their entrance into the Bering Sea is earlier and their migration rate therein seems to be much faster than is the case with Japanese stocks which follow the same route to eastern Kamchatka waters. The maturing fish which occur in the northwestern Pacific in May and June have a shorter distance to cover and their rate of travel must be slower.

Immatures spend the summer months around the Aleutian Chain and in the central Bering Sea, moving south in autumn and winter (Fig. 40).

Maturing Anadyr River chums were tagged in April and May throughout a wide part of the Gulf of Alaska west of 149°W. In May and June they were found just south of the Aleutians and in the Bering Sea. The few records from north of the Aleutians suggest that they did not enter the Bering Sea in force until June. The direction of movement in the earlier stages of the homeward journey is similar to that of eastern Kamchatka fish.

Only two recoveries of immatures were reported. These were tagged on the south side of the Aleutians in June and August (Fig. 41).

As noted by Shepard et al. (1968), chums bound for western Alaska (from Bristol Bay north to the Arctic Ocean) are present in the eastern half of the Bering Sea and in the North Pacific from the central Aleutian area to the central Gulf of Alaska. Maturing individuals are particularly abundant south of the eastern Aleutians in May and June."

Since the above was written, 156 additional tags (140 maturing, 16 immature) have been returned from western Alaska localities. In the North Pacific the known distribution of maturing tagged fish now extends from 179°E to 132°W and from the northern
Fig. 41. Ocean migration of chum salmon stocks from the Anadyr River as indicated by tagging. The numerals (circled for immature and non-circled for maturing fish) show the month and location of tagging.
Fig. 42: Ocean migration of chinook salmon stocks from western Alaska as indicated by tagging. The numbers (circled for immature and non-circled for mature fish) show the month and location of tagging.
Figure 45: Ocean migration of chum salmon stocks from British Columbia, Washington and Oregon as indicated by tagging. The numerals (circled for immature and non-circled for mature fish) show the month and location of tagging.
Fig. 46. Migrations of maturing chum salmon in offshore waters as indicated by high-seas tag recoveries. Numerals show month and location of recoveries. Maturity status was determined by gonad weight at time of recovery. Data pooled from 1956 to 1969.
coast of the Gulf of Alaska south to 44°N, thus encompassing the entire Gulf region (Fig. 42). Some of these Gulf-tagged fish travelled through Bering Strait to Kotzebue Sound, thus penetrating the Arctic Ocean. In the Bering Sea a tagging made near the U.S.S.R. coast (latitude 60°09'N, longitude 174°30'E) produced a single recovery from western Alaska (Yukon River), this being the western-most tagging record of any North American chum salmon. Other Alaska recoveries were confined to chums tagged in the eastern half of the Sea. As in the case of the Anadyr stocks, there was no tagging evidence of the presence of Alaskan chums in the Bering Sea before June.

Maturing fish of these stocks migrate westward in the Gulf of Alaska from April to June and most of them pass through the eastern part of the Aleutian Chain in June. They do not seem to stay long near the islands and their northward migration in the Bering Sea is quite rapid. This migration originates from areas in the Gulf of Alaska, including the northern part of the Gulf which is occupied as early as April. In contrast, the main body of Gulf coastal stocks (central and southeastern Alaska, British Columbia, Washington, and Oregon) do not seem to occupy the northern part of the Gulf until later in the season, suggesting some difference in the wintering areas of Gulf and western Alaska stocks.

No extensive penetration of the Bering Sea by immature fish was disclosed (Fig. 42).

Chum salmon bound for central and southeastern Alaska (i.e., coastal areas from the south side of the Alaska Peninsula to the northern boundary of British Columbia) are thoroughly mixed throughout the entire Gulf, and only rarely are found as far west as the eastern Aleutians. Immature chums from the Gulf production areas were found farther westward than the matures; two were tagged in August south of Adak and one in July and one in August south of the eastern Aleutians.” (Shepard et al. 1968).

The recovery of an additional 138 tags since 1962 has not changed the picture except for the recovery of a single mature chum tagged as far west as Adak (177°W). Two additional immatures had also been tagged in this area. However, the general scarcity of Gulf fish (mature and immature) in waters west of about 153°W is confirmed. There was no significant penetration of the Bering Sea by maturing or immature fish.

The maturing fish of these stocks seem to migrate northward in the Gulf of Alaska from May to July after most of the western Alaskan maturing chums have withdrawn westward from these waters. Central Alaskan matures seem to migrate directly to their coastal areas, whereas southeastern Alaskan matures must turn eastward or even southeastward after reaching the northern Gulf in July.

Immatures of both central and southeastern Alaska migrate northward a little later than the maturing fish. Some of them move westward in the Alaskan stream to at least 177°W (Figs. 43 and 44).

“Chums bound for British Columbia, Washington, and Oregon occupy wide areas throughout the Gulf of Alaska, intermingling extensively with the northern Gulf stocks. The apparently more limited distribution to the south may be a reflection of the smaller number of returns” (Shepard et al. 1968).

Additional tag recoveries have emphasized the mingling of these stocks not only with the northern Gulf fish but also with fish of western Alaskan origin (Fig. 45). The anomaly referred to above (i.e., the finding of northern fish farther south than those of British Columbia and Washington) has been somewhat reduced by a few recoveries of chums tagged south of 50°N. The complete absence of recoveries in this region from the intensive taggings carried out west of 170°W is noteworthy.

The general migration pattern of maturing fish is similar to that of southeastern Alaska stocks.

A feature of taggings made in the Gulf of Alaska is the scarcity of recoveries of fish which were immature when tagged. In British Columbia-Washington, only five out of 125 recoveries were of fish which had been “out” for a year or more. It is therefore not possible to describe the distribution of the immature chums of this region on the basis of tag recoveries.

(3) High-seas recoveries from tagging in ocean regions

The absence of a high-seas fishery in the eastern regions of the North Pacific Ocean and the Bering Sea precludes the recovery of tagged fish in these waters. Hence, movements from tagging localities toward North American coasts can only be demonstrated by coastal recoveries. On the other hand, the many high-seas recoveries made by Japanese fishermen in western regions provide information on the movements of chum salmon in these waters. Figures 46 to 49 show some of these movements. The many recoveries made within a short distance or time interval from the tagging points, or for which maturity data were lacking, have been omitted from these figures.

Migration of maturing chums as indicated by high-seas tag recoveries

From tagging made in April and May in the north-
eastern Pacific Ocean, extensive westward movements of maturing chum salmon are shown (Fig. 46). Some of these fish seem to proceed westward along the southern side of the Aleutians, while others enter the Bering Sea through the eastern or central passes of the Aleutian Islands. On the other hand, fish tagged in the northwestern Pacific Ocean at the same season (April and May) seem to move much more slowly than those tagged in the northeastern Pacific and their movements are more random.

Recoveries from taggings made in June and July demonstrate more clearly the northwestward migration of maturing chums in the Bering Sea and the westward migration in the northwestern Pacific (Fig. 46).

Figure 47 shows the high-seas recovery distribution of maturing chums tagged in the mid-Aleutian area (2°×5° area 8050) in summer. This figure indicates that of the maturing chums migrating from this area, large components move northward into the Bering Sea as well as westward into the western North Pacific.

—Migration of immature chums in summer, as indicated by high-seas tag recoveries

Tag recoveries of immature chums from early season taggings (in April and May) are too few to provide much information. The general pattern of summer migration of immature chums can be said to be northward (Fig. 48). However, the northward migration in the northwest Pacific Ocean, is not well defined and there is no evidence (from tagging) that immature chums penetrate the Bering Sea. On the other hand, most of the recoveries of immatures tagged in the central Aleutians in June were made in the northwestern Bering Sea in mid-summer (Fig. 48). This suggests that the immature fish which
winter in the central Pacific Ocean enter the Bering Sea and reach its northern parts in mid-summer.

—Migration of immature chum salmon in autumn and winter, as indicated by high-seas tag recoveries.

Autumn and winter movements of immature chums can be inferred from high-seas recoveries of fish tagged in mid-summer of a preceding year. Figure 49 shows that immature fish which had been in the Okhotsk Sea in a previous mid-summer (July) migrated southward as far as near 40°N in the northwestern Pacific within the autumn to spring period prior to their recovery. Similarly, Fig. 49 also shows that immature fish distributed in the western Bering Sea and northern northwestern Pacific in the preceding mid-summer (July and August) migrated southward during autumn or winter. These findings strongly support the conclusion reached elsewhere in this report that immature chums perform strong seasonal north-south migrations.

An unexpected feature of the results from high-seas recoveries is the lack of evidence of northward movement from the western Pacific to the Bering Sea (Fig. 48). Even though the overall migration picture is undoubtedly distorted by the uneven distribution of tagging effort (very heavy south of Adak Island and much lighter in other areas) the amount of effort in the western Pacific would seem sufficient to produce at least a few returns in the Bering Sea if the movement between those areas was as extensive as the examination of gillnet catches implied. Evidence of the reverse migration, however, is available from data in Fig. 49 which demonstrates that immatures tagged in the Bering Sea in mid-summer, move south into

Fig. 48. Migration of immature chum salmon in offshore waters, as indicated by high-seas tag recoveries. Numerals show month and location of recoveries. Maturity status was determined by gonad weight at time of recovery. Data pooled from 1956 to 1969.
the western Pacific by the following spring and summer. The results of tagging south of the central Aleutians in summer indicates that many of these immatures move into the Bering Sea (Fig. 48). By the following spring and summer these had also returned to the western Pacific (Fig. 49). The overall picture then offers rather substantial evidence of north-south migrations between the western Pacific Ocean and Bering Sea. The reason for the lack of direct evidence of northward movement by immatures from high-seas recoveries (Fig. 48) is difficult to explain. It may simply be that tagging effort in the western Pacific or recovery effort in the Bering Sea was inadequate at the proper time and area to detect this movement.

(4) Rates of travel
Previous studies (Hart 1962, 1966; Kondo et al. 1965; Yonemori, 1971) have revealed that the rate of travel of chum salmon was generally less than that of sockeye and pink salmon, due probably to the chum salmon's protracted spawning season which on the average would require slower rates of travel. These authors concluded that the average rate of travel for chum salmon was about 25 nautical miles (46 km) per day with an approximate range of 1 to 40 miles (2 to 74 km) per day.

Rates of travel for maturing chum salmon may be quite variable depending on the offshore distribution of stocks in relation to the location of their spawning rivers. For example, maturing Asian stocks that begin their homeward migration from the central or northeastern Pacific might require relatively fast and
continuous migration to meet spawning schedules. On the other hand, Asian stocks originating their shoreward migration in the western Pacific may be able to move at a more leisurely pace. The rates of travel calculated from tagging to recovery locations for these two types of Asian stocks demonstrate this to be the case. For those stocks requiring lengthy westward migrations, the maturing fish averaged about 21 nautical miles (38 km) per day (using a straight line distance from the point of release to the point of recovery) with a range of 11 to 36 miles (21 to 66 km) per day. An obviously slower pace of travel is indicated for stocks located in the northwestern Pacific in early spring by the much shorter distances travelled in approximately the same time interval in which other Asian stocks span much of the North Pacific Ocean or Bering Sea.

Rate of travel for immatures is probably also variable depending on the length of their feeding migration. Immatures tagged near Adak Island and recovered in the northern Bering Sea—representative of stocks undertaking lengthy feeding migrations—averaged about 15 miles (24 km) per day and ranged from 7 to 24 miles (12 to 44 km) per day. This rate is somewhat less than that of maturing fish tagged at Adak Island and recovered in the Bering Sea (average 19 miles (30 km) and range of 9 to 36 miles (15 to 66 km) per day).

Rate of travel for immatures that remain in the western North Pacific through the summer but also move northward from more southerly waters is much less than for those stocks described above. Rates averaged about 5 miles (9 km) per day and ranged from 1 to 10 miles (2 to 19 km) per day.
Because of the absence of a high-seas fishery for salmon in the eastern North Pacific Ocean, high-seas recoveries of immature salmon in this area are not available and information on their rates of travel is lacking.

**Other Studies**

Attempts to determine the places of origin of chum salmon found in offshore waters (with special reference to distinguishing Asian from North American fish) by means other than tagging were summarized by Shepard et al. (1968). These investigations included examination of the parasitic fauna harbored by the salmon, morphological studies, and studies of blood chemistry. Although certain differences between fish of different stocks were disclosed, the results did not provide satisfactory criteria for separating Asian and North American chums. No recent advances in these fields have been reported.

It has long been known that there are small differences in the scale patterns of salmon of different coastal regions. These differences are expressed in the number and spacing of the ridges (circuli) that are laid down during the growth of the scale. Shepard et al. (1968) and Tanaka et al. (1969) described a massive application of such features to the problem of determining the places of origin of chum salmon inhabiting the high seas. A total of 13,289 scale samples taken in 1956 to 1959 from various Asian and North American coastal areas were examined and scale patterns characteristic of four broad geographical regions (British Columbia/southeastern Alaska, northern Alaska, U.S.S.R., Japan) were established. In testing the distinctiveness of these patterns it was found that the percentage of identifiable fish varied between regions and between brood years. An overall average of 33.5% of the coastal samples could be correctly assigned to one of the four regions. A further 10.2% were correctly assigned to the continent of origin (Asia or North America) but not to a particular region. Fish which could not be assigned to any region or continent amounted to 54.6%. Of the fish definitely classified, less than 2% were assigned to the wrong continent.

A total of 16,763 scale samples taken from chums caught on the high seas were classified according to their resemblance to the scales of the respective coastal regions. The results led to the conclusion that fish of Asian origin predominated in waters west of 175°W. Eastward from 175°W, in the Bering Sea, North American chums became increasingly important and the representation of Asian chums declined. In the North Pacific, from around 165°W eastward, there was a strong preponderance of American-type fish.

These broad findings are in fairly good agreement with the results obtained from tagging experiments. A discrepancy was noted in that the scale studies failed to reveal the widespread distribution of Japanese chums that has been demonstrated by tagging. On the other hand, the indications from scale studies that North American chums occur in the far western North Pacific, and even in the Sea of Okhotsk, and that the distribution of Asian fish extends almost to the British Columbia coast, have not been verified by the many tagging experiments performed up to the present time. Tagging has also failed to demonstrate the presence of immature North American chums in the Bering Sea.

No further extensive application of scale studies to determine the origin of chum salmon in high-seas waters has been reported since the comprehensive treatment of the problem by the investigators cited above.

**Summary**

Chum salmon spawn in streams distributed along the Asian coasts from Japan and Korea to the Lena River on the Arctic Ocean and, on the North American side, in watersheds from Oregon to the Mackenzie River in the Arctic Ocean. Their offshore distribution extends (although not necessarily at all seasons) throughout all waters lying within the latitudes represented by the spawning places.

Main contributors to the total annual commercial catch of chum salmon are: (a) Asian coastal fisheries, with major areas of production centering on the Amur River, northern Okhotsk Sea, and west and east coasts of Kamchatka; (b) North American coastal fisheries distributed relatively evenly from Washington to Bristol Bay; (c) high-seas fisheries conducted by Japanese mothership fleets and landbased vessels in open ocean areas of the North Pacific Ocean and the Bering Sea, west of latitude 175°W.

Throughout the history of the commercial fisheries the yield from Asian areas has always been greater than that from North America. In recent years (1963-1970) the total commercial chum salmon catch has averaged 100,000 metric tons, of which 72% has been harvested by Asian fishermen.

Juvenile chum salmon (age .0) enter the sea in April-July and remain in inshore waters for many weeks. Extensive movements along and seaward from coastlines take place in late summer and throughout the autumn. In winter these fish (termed "age .1" after January 1) move southward and, in company with older immature chums (age .2 and .3), vacate the Bering Sea and other northern portions.
of the range occupied in summer and autumn. A reversal of movement by immature chums, led by the older fish of this category, begins in late May and June and the northward expansion reaches its maximum in or near late August.

While movements of immature chums in winter and spring can be inferred from prior and subsequent distribution of the fish, catches per unit of effort at this season have consistently been extremely small in comparison to the populations which must be present and in relation to the concurrent catches of maturing chums. Presumably the habits of the immatures render them less vulnerable to surface fishing gear at this time of year.

Maturing chums, in winter and early spring, are present throughout most of the Gulf of Alaska but farther west are largely restricted to waters south of the Aleutians. A rapid invasion of the Bering Sea occurs in June, preceding to some degree the migration of immatures into this region. Onshore movements toward Asian and North American spawning areas continue until September or later.

The number of winters spent in the sea by chum salmon varies from one to six, but fish maturing at less than age .2 or more than age .4 are insignificant in number. In catches of maturing chums, fish of age .3 are usually in a majority in both the western and the eastern Pacific Ocean but the proportion of age .2 fish is lower and the proportion of age .4 fish is higher in the western region. In both regions the proportion of age .3 fish declined and the proportion of age .2 fish increased as the season progressed from May to July, due to the tendency of the older fish to depart earlier from the high-seas feeding grounds. The data available do not permit firm conclusions regarding the relative contributions made by the

Fig. 49. Distribution of high-seas recoveries from tagging in mid-summer (July and August) of the preceding year. Main tagging areas shaded. Data pooled from 1956 to 1969.
various age classes of immature chums.

Chums of Asian origin are smaller, on average, than North American chums of corresponding sex, age and maturity status.

Although chum salmon are sensitive to small differences in salinity during the period of their transition from a freshwater to an open ocean habitat, there is at present no evidence that their subsequent distribution in the high seas is influenced by this factor.

While ocean currents must affect the direction, speed, or effort expended in movements (or in resistance to movement) of the fish, they do not account for the observed distribution and migration of the various stocks.

Seasonal shifts in the boundaries of the ocean regions occupied by chum salmon agree in general with the changing positions of surface isotherms. The total known range of surface temperatures associated with the presence of chum salmon extends from 1°C to 15°C. In spring the recorded range was from 1°C to 11°C. Greatest overall frequency of catches occurred within the 3°C to 11°C range. Temperatures below 3°C were avoided by immature fish and by maturing fish except for stocks in the northern Bering Sea. A relation could not be established between the abundance of chum salmon in surface waters and the depth of the thermocline.

During their first summer in the sea chum salmon juveniles feed on a wide variety of inshore organisms which include copepods, other small crustaceans, tunicates, and fish larvae. The stomachs of older fish, taken by commercial and research vessels on the high seas, contain pteropods, euphausiids, copepods, amphipods, crab larvae, squid, fish, and other organisms. The relative importance of these categories varies

---

**Fig. 49 (cont.)**
widely and appears to be governed to a large extent by availability. Certain instances of the concurrence of large numbers of growing chums and abundant zooplankton have been observed but comprehensive information on the relationship between food supplies and chum salmon distribution is lacking.

The ocean distribution and migrations of chum salmon originating in particular areas, as indicated by tagging, are summarized in the following paragraphs.

Maturing chum salmon bound for Japan occur as far east as 140°W in the Gulf of Alaska in spring. During their return journey to the spawning areas some fish travel as far north as 64°N in the Bering Sea. Immature fish are widely distributed in the North Pacific to at least as far east as 157°W. In summer some of them accompany the maturing fish northward to 58°N in the Bering Sea.

Chum salmon originating in the Kuril Islands and southern Sakhalin Island have a distribution and migration pattern similar to Japanese chums.

Maturing chum salmon originating in the Amur River and northern Sakhalin Island are principally found west of 165°E in spring and early summer. They spend a month or more in the Okhotsk Sea before approaching fresh water. The known range of immatures extends to 165°W.

Maturing chums bound for the northern Okhotsk coast in April-June were most numerous in waters near or south of the Kamchatka Peninsula. There is no evidence of their extensive presence in the Bering Sea. The peak of their migration into the Okhotsk Sea is in June. The main inshore migration is delayed until early August. Immature fish, in early summer, inhabit many of the areas occupied by maturing chums but in July and August showed a much more extensive
distribution eastward (to 163°W) and northward (to 59°N).

The distribution of maturing chums bound for western Kamchatka seems to extend to waters farther east than those frequented by the maturing northern Okhotsk fish (to at least 153°W). A westward movement takes place along the Aleutians in June and some fish travel through the southern Bering Sea. Entrance into the Okhotsk Sea is mainly in July or later. Immature fish were recovered only from taggings around the western Aleutians.

Maturing chums of eastern Kamchatka origin are very widely distributed across the North Pacific Ocean in spring (to at least as far east as 145°W). A majority of these fish seem to spend their last winter in the northeastern part of the North Pacific from which they migrate westward or northwestward, entering the Bering Sea in June and approaching the east Kamchatka coast in July and August. Their passage through the Bering Sea is more rapid than that of Japanese stocks which follow the same route. Immature fish were found mainly near the Aleutians in July and August.

Maturing Anadyr River chums were found in the Gulf of Alaska, eastward to 149°W, in April and May and in the Bering Sea in June and July. Their direction of movement in the earlier stages of their homeward journey is similar to that of east Kamchatka fish. Only two recoveries of immatures were recorded.

Maturing chums of western Alaskan origin occupy the entire Gulf of Alaska in spring and were found westward along the Aleutians to 179°E. There was no tagging evidence of the presence of Alaskan chums in the Bering Sea before June. The recovery in the Yukon River of a maturing fish tagged in July at

![Diagram of tagging in the Okhotsk Sea]
60°N, 174°E, not far from the U.S.S.R. coast, constitutes the westernmost record of a North American chum salmon, as revealed by tagging. Other chums, tagged in the Gulf of Alaska, were found to travel as far north as the Arctic Ocean. The direction of movement in the Gulf of Alaska is westward in April-June. In the latter month most of the fish pass through the eastern part of the Aleutian Chain and migrate rapidly northward in the Bering Sea. No significant penetration of the Bering Sea by immature fish was disclosed.

Maturing chum salmon originating in central and southeastern Alaska occupy a large part of the Gulf of Alaska in spring but were rarely found west of 155°W. From May to July the fish tend to shift northward into waters from which western Alaska chums have largely withdrawn. Some immature fish move westward along the Aleutians to at least 177°W. No significant penetration of the Bering Sea by immature or maturing fish was indicated.

Maturing chums originating in British Columbia, Washington and Oregon occupy wide areas throughout the Gulf of Alaska, mingling extensively with the northern Gulf stocks and, to a lesser degree, with fish of western Alaskan origin. No recoveries were obtained from fish tagged west of 169°W. Only five recoveries of fish tagged as immatures were reported.

From a conceptual viewpoint the data derived from tagging and other studies indicate that:

There is little or no intermingling of Asian and North American chum salmon during their first year at sea.

The distribution of older Asian fish extends far eastward (to at least 140°W), resulting in extensive intermingling in waters extending from the central Aleutians to the central or even the eastern part of the Gulf of Alaska, especially in winter and spring. In summer, maturing Asian fish and at least some immatures evacuate the Gulf, many of them migrating into the Bering Sea and thus reducing the degree of intermingling with North American stocks.

The summer invasion of the Bering Sea by immature Asian chums permits these fish to exploit the food resources of a vast area which is apparently denied to them at other seasons by reason of low temperature. Presumably the dispersion also reduces the pressure of inter- and intra-species competition.

North American stocks, including those originating in western Alaska, spend most of their ocean life in the Gulf of Alaska and were seldom found west of 180°. Although western Alaska chums must necessarily pass through the Bering Sea at the beginning and end of their ocean life, there is as yet no evidence from tagging experiments that they visit this body of water during the intervening years.

As was pointed out by Shepard et al. (1968), the very lengthy migrations performed by Asian chums, as compared with most North American stocks, can be plausibly ascribed to the severe winter conditions that prevail near the Asian coasts.

Certain features of the distribution and movements of chum salmon in offshore waters remain undisclosed:

While data have been presented indicating a northward and westward migration of North American juvenile fish in their first summer at sea, paralleling the coastline of the Gulf of Alaska, fall and winter observations are lacking to determine the routes followed by these fish in reaching the waters south of 50°N that they occupy by the following spring. Even less is known of the routes whereby Asian and western Alaska juveniles reach far-distant localities within a year from the time of their entry into the sea.

The extreme scarcity of immature chums in catches made in winter and early spring invites further investigation. A major part of such a study would obviously be concerned with the vertical distribution of the fish.

Confirmation or disproof of the apparent absence of North American immature chums in the Bering Sea would require further tagging in this body of water.

The relationship between food supplies and the movements and distribution of chum salmon has received little attention and should be a fruitful line of study.

A long-standing problem which still awaits clarification concerns the means whereby salmon navigate during their prolonged residence in offshore waters.

REFERENCES


Okada, S., and A. Taniguchi. 1971. Size relationship be-


Tabata, S., and L. F. Giovando. 1963. The seasonal thermo...


