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NOAA Technical Report NMFS 27

Proceedings of the Eleventh U.S.-Japan Meeting on Aquaculture, Salmon Enhancement, Tokyo, Japan, October 19-20, 1982

Carl J. Sindermann (Editor)

Under the U.S.-Japan Cooperative Program in Natural Resources (UJNR)

Panel Chairmen:
CONRAD MAHNKEN - United States
NOBUHIKO HANAMURA - Japan

March 1985

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

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U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
National Oceanic and Atmospheric Administration
John V. Byrne, Administrator
National Marine Fisheries Service
William G. Gordon, Assistant Administrator for Fisheries

PREFACE

The United States and Japanese counterpart panels on aquaculture were formed in 1969 under the United States-Japan Cooperative Program in Natural Resources (UJNR). The panels currently include specialists drawn from the federal departments most concerned with aquaculture. Charged with exploring and developing bilateral cooperation, the panels have focused their efforts on exchanging information related to aquaculture which could be of benefit to both countries.

The UJNR was started by a proposal made during the Third Cabinet-Level Meeting of the Joint United States-Japan Committee on Trade and Economic Affairs in January 1964. In addition to aquaculture, current subjects in the program are desalination of seawater, toxic microorganisms, air pollution, energy, forage crops, national park management, mycoplasmosis, wind and seismic effects, protein resources, forestry, and several joint panels and committees in marine resources research, development, and utilization.

Accomplishments include: Increased communications and cooperation among technical specialists; exchanges of information, data, and research findings; annual meetings of the panels, a policy coordinative body; administrative staff meetings; exchanges of equipment, materials, and samples; several major technical conferences; and beneficial effects on international relations.

Conrad Mahnken - United States
Nobuhiko Hanamura - Japan

CONTENTS

Statement of Eleventh Joint Meeting of the UJNR Aquaculture Panel, Salmon Enhancement, Tokyo, Japan, October 19-20, 1982

The Eleventh Joint Meeting of the UJNR Aquaculture Panel was held on October 19-20, 1982, at the Shiba Yayoi Convention Hall in Tokyo, Japan. Dr. Nobuhiko Hanamura, Japanese Panel Chairman, and Mr. Conrad Mahnken, U.S. Panel Chairman, presented welcoming addresses and opening greetings. Panel members, guests, and observers were introduced by the respective chairmen.

The business meeting was chaired by Dr. Hanamura, and symposium moderators were Dr. Hanamura, Mr. Mahnken, and Dr. Fujiya. Rapporteurs for the meeting were Mr. Ben Drucker and Dr. Takeshi Murai.

1. *Scientists Exchange*

The Panel concluded that the scientist exchange program sponsored by the UJNR has been an effective means of advancing aquaculture science and the exchange of information between the two countries. This program was continued between the Tenth and Eleventh UJNR meetings.

During this period:

a). Six members of the U.S. Panel of the UJNR and eleven scientists as observers attended the Eleventh UJNR Meeting.

b). Dr. Hiroshi Motoh, Central Laboratory of Marine Ecology Research Institute, visited the Browns Ferry Biothermal Research Station in Athens, Alabama, the Environmental Protection Agency Laboratory in Duluth, Minnesota, and NOAA's Northwest and Alaska Fisheries Center in Seattle, Washington. He also attended the International Symposium on the genus *Chionecetes* in Anchorage, Alaska.

c). Dr. Susumu Ito, Director of the Aquaculture Center, Aomori Prefecture, visited a variety of laboratories, commercial growers, fish hatcheries, and research organizations in the Pacific Northwest. He also attended the Annual Meeting of the North American Shellfish Association held in Olympia, Washington.

d). Dr. Nagahisa Uki, Tohoku Regional Fisheries Research Laboratory, will visit a variety of research agencies from 19 November to 18 December, 1982, to meet with U.S. scientists and exchange information on molluscan culture in general, but specifically on abalone culture.

e). In 1983, Dr. Isao Yano will visit the U.S. to do research on reproductive physiology of prawns, and arrangements for this visit will be made by the U.S. Panel members.

f). Efforts for Mr. Osamu Fukuhara's visit to the U.S. in 1983 will be made by the Japanese Panel.

g). Arrangement for Dr. William Seaman's visit to Japan in 1983 will be made by the Japanese Panel.

h). Dr. Hanamura expressed his deep appreciation for the kind arrangements provided for the Japanese scientists by the U.S. side at the Tenth Joint Meeting.

2. *Literature Exchange*

For the period 1981-82, the U.S. Panel sent to the Japanese Panel 107 scientific papers. During this same period, the Japanese Panel sent to the U.S. Panel 78 scientific papers.

Proceedings of the symposium "Seaweed Aquaculture," which was held in 1977, was published in 1981 as a Technical Report of the National Marine Fisheries Service, NOAA, and 6 copies were mailed earlier to the Japanese Panel. An additional 20 copies have been sent, and 20 more copies will be sent to the Japanese Panel in the near future.

In the future, 100 copies of each publication will be sent to the Chairman of the Japanese Panel.

Sixteen copies of the Annual Report on Japan's Fisheries (a Summary for Fiscal Year 1981) were presented to the U.S. Panel members.

This program has been very useful for both countries and should be continued.

3. *Cooperative Studies*

The discussion concentrated on two elements: 1) ongoing programs and 2) suggested new programs.

Ongoing Programs

a. Registry of Marine Pathology

By combining the talents of the United States in detection of disease in wild stocks of fishes, with that of the Japanese for recognition of disease in cultured fishes, an opportunity existed for the

UJNR to develop a registry of marine pathology. To that end, a collection of slides from Japan and the United States is being assembled by Drs. Murchelano and Matsusato which will be available to all researchers. The achievement of this goal is nearly complete, and hopefully will be completed by the Twelfth UJNR Meeting.

b. Disease Resistance of U.S. Oysters in Japan

Strains of disease resistant oysters have been sent to Japan and comparisons have been made with cultured populations. The results have been sent to the United States, and the program was terminated with success.

c. Abalone Culture

Dr. Uki, Tohoku Regional Fisheries Research Laboratory, will be visiting the United States during November-December 1982. At that time he will discuss with U.S. workers the status of abalone culture. A determination will be made at the Twelfth UJNR Meeting whether or not to start this cooperative program.

Suggested New Programs

The United States proposed a study entitled "Sea Ranching of Western Pacific Pink and Chum Salmon in the Western Atlantic." The purpose will be to determine the best donor stocks for transplantation to the Western Atlantic (coast of New England). The approach would be to obtain stocks of Asian origin from Japan and North America (controls). These stocks would be reared, released, and recaptured in Maine.

Also, Japan is interested in the transplantation of North American stocks and will develop a cooperative study with the United States. Details of the project will be developed between the United States and Japan by the next meeting.

As a test shipment, approximately 350,000 chum salmon eggs from stock in Japan will be shipped in the fall of 1982 to the United States. This transplantation project is being funded by the National Science Foundation which will enhance the credibility of the program and allow the United States to pay all costs of the transplantation experiment in New England.

After consideration of the results of the test shipment and development of a plan, the newly proposed project should be adopted at the Twelfth Meeting.

4. *Second Five-Year Plan*

For the second five-year plan, a modification was proposed and accepted as follows:

Year 2 (1983) U.S.A. Reproduction/Maturation/Seed production
Year 3 (1984) Japan Environmental quality in aquaculture systems
Year 4 (1985) U.S.A. Aquaculture engineering
Year 5 (1986) Japan Marine ranching

5. *Publications*

The slow progress in publishing papers presented at past UJNR meetings is a matter of concern to both the U.S. and Japanese panels. At the Tenth Annual UJNR Meeting in Delaware last October, the panel made two decisions that should speed the process of publication: 1) all manuscripts must be presented to the panel chairman at the time of presentation at the Joint Meeting, and 2) the U.S. side would publish all annual proceeding as NOAA Technical Reports. Progress since last October in publishing the results of past meetings is as follows:

a. Proceedings of the Sixth U.S.-Japan Meeting (1977) have been published.

b. In September, the U.S. Chairman received the four Japanese papers delivered at the Seventh U.S.-Japan Meeting held in Tokyo, Japan, in May 1978 (marine finfish culture). These will be combined with the U.S. papers and submitted to the NOAA editorial office within the next 2 months.

c. Proceedings of the Eighth U.S.-Japan Meeting held in Bellingham, Washington, in October 1979 (freshwater finfish culture) have been edited, galley proofs approved, and will be published as a NOAA Technical Report in November 1982.

d. Papers presented at the Ninth U.S.-Japan Meeting held in Kyoto, Japan, in May 1980 (shrimp culture) were received by the U.S. Panel Chairman in September. These seven papers will be combined with the papers from the Tenth U.S.-Japan Meeting held in Rehoboth, Delaware, in October 1981 (molluscan culture), and will be submitted to NOAA for publication by early spring, 1983.

e. Papers from the Eleventh U.S.-Japan Meeting on Aquaculture, Tokyo, 1982 (salmon enhancement) will be edited and submitted for publication to NOAA by late winter, 1982. Because of the importance of this subject matter, the papers will be published in both Japanese and English, with the U.S. responsible for the English version and the Japanese Panel responsible for publishing the version in Japanese.

6. *Other Matters*

The United States side proposed a study for the "Experimental Transplantation of Japanese Scallops (*Patinopectin yessoensis*) to Puget Sound." The purpose would be to determine growth and survival of scallops. A shipment of a small number of scallops will be made to be brought back to the United States in October 1982 for disease certification. After being certified, additional live scallops will be imported for experimental purposes in the winter of 1982 and placed in a variety of Puget Sound environments to determine their adaptability. The number involved would be about 1,600 scallops at 2.5 g each. The scallops should never have resided on the sea floor.

The Japanese side approved this experimental planting and will have the juveniles and several adults ready to be taken back to the United States at the end of the field trip. It was requested that the Science Counselor/Fisheries Attache of the U.S. Embassy, formally request the subsequent winter shipment from the Japanese Fisheries Agency.

7. *Field Trip*

The schedule of the field trip was announced by Dr. Nose, and Dr. Hanamura thanked Drs. Kobayashi and Koganezawa for their cooperation for the field trip.

8. *Next Joint Meeting*

As the theme of the twelfth Meeting has been changed, details of the schedule for that meeting will be decided in the near future.

Respectfully submitted

Conrad Mahnken - United States
Nobuhiko Hanamura - Japan

Methods of Measuring and Controlling the Parr to Smolt Transformation (Smoltification) of Juvenile Salmon

WALTON W. DICKHOFF,[1] CRAIG SULLIVAN,[2] and CONRAD V. W. MAHNKEN[3]

INTRODUCTION

In net-pen culture and hatchery enhancement of salmonid fishes it is important that reliable methods are available to measure the parr to smolt transformation of anadromous salmonids, since incompletely developed fish may die or not grow when they enter seawater. There are many methods which may be useful for the measurement of smoltification; however, three methods have been used most widely: Seawater challenge, gill Na^+-K^+ adenosinetriphosphatase (ATPase) activity, and plasma levels of the hormone thyroxine (T_4). Smoltification can be divided into two broad physiological processes: Osmo-ionregulation and metamorphic development. Seawater challenge measures osmo-ionregulation, while monitoring plasma levels of T_4 provides information on metamorphic development. Gill ATPase activity measurements may be an indicator of both osmoregulation and development. Studies on smoltification using all three methods simultaneously suggest that smoltification of a population of salmon may be synchronous or asynchronous. For example, maximal osmoregulatory performance as measured by seawater challenge may occur at a time when gill ATPase activity is low. Therefore, measurement of smoltification of salmon in aquaculture operations should use at least two of the methods.

Smoltification is naturally controlled by changes in photoperiod and temperature. Artificial control of these environmental conditions in order to regulate the rate or completeness of smoltification is possible. Alternatively, smoltification may be controlled by treating fish with hormones. Experiments using thyroid hormones in the diet of salmon undergoing smoltification have suggested that some aspects of smoltification may be controlled in this manner. Thyroid hormone in the food stimulates morphological changes and growth, among other aspects; but this hormonal treatment may not increase the fish's ability to regulate its blood ion levels when the fish enters seawater. Hormonal treatment procedures for increasing or accelerating osmoregulatory abilities of smoltifying salmon will not be available until more is known about the physiology of osmoregulation. Additional studies on other methods of hormonal control of smoltification are needed.

METHODS OF MEASURING SMOLTIFICATION

The decision on when to release juvenile salmon from hatcheries or when to transfer them to seawater has often been based on factors other than the physiological readiness of the fish for seaward migration or for seawater entry. In those cases where the development (degree of smoltification) has been considered, the criteria used most often have been body coloration (silvering) or size. Recent studies have indicated that these criteria are imprecise (Gorbman et al. 1982; Folmar et al. 1982). Furthermore, it is evident that smoltification can be abnormal when fish are raised under artificial conditions (Bern 1978; Nishioka et al. 1982). During the last 10 yr, research on developing methods for the precise determination of the progress of smoltification has provided many measurements of physiologic change which could be useful for indicating smolt development (smolt quality). Among these methods three have been applied most widely: Seawater challenge, gill Na^+-K^+ ATPase activity, and plasma thyroxine (T_4) concentration.

Seawater Challenge

The seawater (SW) challenge test of Clarke and Blackburn (1977, 1978) measures the hypo-osmoregulatory ability of fish transferred from freshwater (FW) directly into SW. Analysis of the blood plasma Na^+ concentration of the transferred fish indicated that highest Na^+ levels are attained 24 h after SW entry. Thus, in typical application of the test, blood levels of Na^+ are measured at 24 h. Hatchery reared smolts may have plasma Na^+ values in the range of 150 to 160 mmol at the 24-h timepoint (Clarke and Blackburn 1978). Other studies of hatchery smolts have indicated that plasma Na^+ may reach 170 mmol or higher 24 h after SW entry (Folmar and Dickhoff 1981). Perhaps it is best to consider relative differences between control and treated groups of fish subjected to SW challenge rather than assign some absolute 24-h Na^+ value as the criterion for smolt status of individual groups of fish.

The SW challenge test compares the degree to which fish are preadapted to withstand the hyperosmotic stress of direct entry into full-strength (30%) SW. In a sense this test is artificial in that under natural conditions salmonids may spend some time in brackish water in the estuary at the end of their downstream migration. Studies on chum salmon behavior suggest that adaptation to full-strength seawater requires at least one tidal change (6 h) or longer during which the fry remain in the estuarine mixing zone between fresh and saltwater where salinity is approximately one-third that of SW (Iwata et al. 1982). In other studies it is apparent that adaptation to full-strength SW is facilitated if the fish are adapted to dilute SW for differing times (Gould et al. 1985). These results suggest that gradual adaptation to SW is an important component in the development of hypo-osmoregulatory ability in salmonids. Nonetheless, the SW challenge test provides important information about the smolt status of anadromous salmonids.

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Gill ATPase Activity

Measurements of the ouabain-sensitive Na^+-K^+ ATPase of the gill reveal cycles of activity during smoltification in FW and increases in activity 4 to 5 d after the fish enter SW. The point of highest ATPase activity generally coincides with the peak in smoltification. The changes in ATPase activity in FW are potentially of greater value than those in SW because of their predictive value. A significant correlation has been found between peak ATPase activity and the number of returning adult salmon (Wahle and Zaugg 1982). Changes in gill ATPase activity in fish in SW occur after the fish's initial adaptation to SW. Patterns of gill ATPase activity during smoltification are variable among genetic stocks of fish and from year to year in a single stock (Zaugg 1982). These differences in ATPase pattern are probably due to variations in rearing conditions. Some evidence indicates that the greatest degree of smoltification based on survival in SW in a group of fish occurs near the peak of their gill ATPase activity, although sometimes smoltification is greatest during increasing or decreasing ATPase activity (Zaugg 1982; Ewing and Birks 1982; Mahnken et al. 1982).

The functional significance of the gill Na^+-K^+ ATPase activity has not been established clearly. Some have suggested that this enzyme activity represents the "sodium pump" that participates in blood ion regulation. However, the increased activity of this enzyme in FW is not closely associated with changes in blood levels of ions in the fish. The increase in gill ATPase activity in fish shortly after entering SW does not appear to be closely related to the level of the enzyme activity in fish in FW. It is quite possible, then, that ATPase activity measured in FW is associated with an enzyme activity that differs from the ATPase in fish in SW. The direction of sodium transport by the gill in FW is opposite in direction from sodium transport in SW. Most likely the increased ATPase activity measured in gills of fish in FW is a developmental event associated with general changes in metabolic activity of the gill and not the "sodium pump." On the other hand, gill ATPase activity in FW may be an important indicator of iono-osmoregulatory potential of the fish, since the gill is an important regulator of this process.

Thyroxine (T_4 Surge)

The surge in blood plasma concentration of T_4 that occurs in anadromous salmonids is coincident with the time of smoltification. Studies on yearling salmon indicate that smoltification is most complete in a population after about 80% of the T_4 surge has transpired in FW (Folmar and Dickhoff 1981). Studies of T_4 surges during smoltification of salmon at various latitudes suggest that T_4 peaks frequently may be associated with the time of the new moon (Grau et al. 1981). Comparison of the T_4 surge in different genetic stocks during the same year and in the same stocks over several years reveals a large variation in the patterns of change in plasma hormone concentration. This situation is similar to that for gill ATPase changes and suggests that the T_4 surge is subject to many environmental and genetic influences.

The specific functions of thyroid hormones in salmon during smoltification are not completely understood, although thyroid hormones have been implicated in many physiological, morphological, and behavioral processes in juvenile salmonids (Folmar and Dickhoff 1980). Evidence is strongest for a role of the thyroid in integumentary pigmentation (e.g., body silvering), growth, metabolism, and some behavioral aspects such as salinity preference. The importance of thyroid hormones for osmoregulatory adjustments is still unsettled.

COMPARISON OF METHODS

Generalizing from studies on SW challenge, gill ATPase activities, and plasma T_4 surges in coho salmon, a hypothetical pattern of the relationships of these measures can be presented (Fig. 1). The plasma T_4 surge occurs just prior to the highest ATPase values which, in turn, are coincident with the greatest hypo-osmoregulatory ability. Data that support the hypothetical scheme shown in Figure 1 have been presented (Folmar and Dickhoff

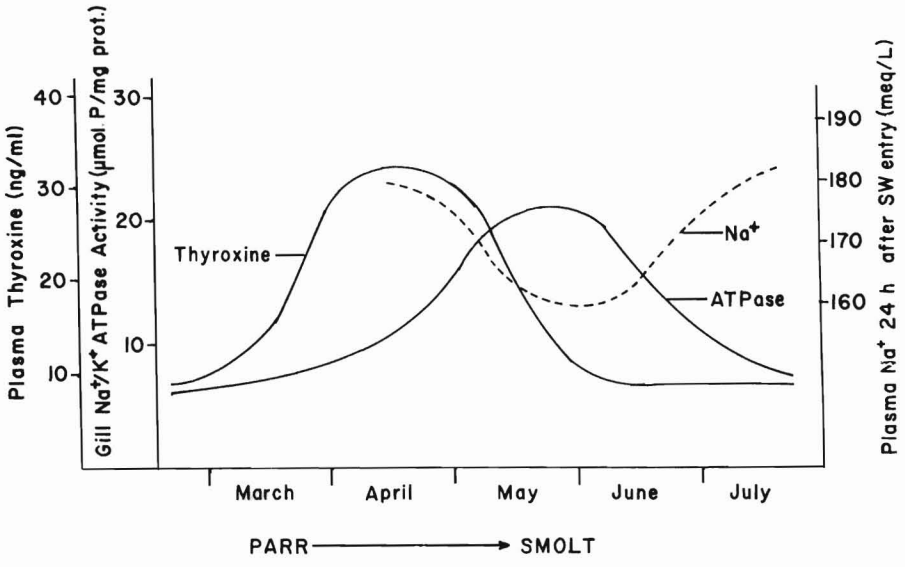

Figure 1.—Typical patterns of change in blood plasma thyroxine (T_4) concentration, gill Na^+/K^+ ATPase activity, and plasma Na^+ levels 24 h after seawater challenge of yearling coho salmon during the parr to smolt transformation.

1981). On the other hand, different relative patterns of the three measured parameters have been observed. In other words, the peak level of gill ATPase activity may occur at the same time or even before the T_4 surge. Furthermore, the timing of these two events (T_4, ATPase) may appear to be unrelated to the development of hypo-osmoregulatory ability. Thus, the normal or appropriate pattern of T_4, ATPase, and osmoregulatory performance remains open to question. Perhaps the occasional disparity in the relative patterns of the three indices of smoltification may be explained by the possibility that smolt development in a population may not be synchronous. In other words, gill ATPase, T_4 changes, and hypo-osmoregulatory development may be controlled independently and may not be coordinated. The basis for asynchronous smoltification is not known at this time; however, it is probably due to some aspects of artificial conditions for rearing salmonids in hatcheries. The effects of particular hatchery practices on various indices of the parr-smolt transformation are areas for future studies.

A common assumption in studies of smoltification is that this biological transformation may come to completion within the confines of a hatchery. There are several indications that downstream migration to the estuary and entry into seawater may be important elements which complete the development of a true smolt. We have already discussed the behavior of salmon fry in osmotic gradients in the estuary and the beneficial effects of adapting fish to dilute seawater (see above). Additional examples of modification of smolt indices after the fish's release from the hatchery but while still in the river may be given.

Gill ATPase activities of migrating coho salmon captured in the estuary have been shown to be higher than the values obtained from the same population of fish maintained in the hatchery (Zaugg 1982). In chinook salmon migrating in an artificial stream, gill ATPase levels may occur earlier and reach values that are higher than those obtained from the same stock of fish retained in the hatchery (Hart et al. 1981). These observations suggest that maximal development of gill ATPase activity cannot be realized in fish maintained in a hatchery. The mechanism responsible for the elevated ATPase of migrating fish is not known but may be related to reduced rearing density, better water quality, or swimming exercise.

Similar studies of T_4 levels in migrating fish have shown that increases or decreases in blood hormone concentration can occur after the fish are released from the hatchery (Dickhoff, unpublished). There is some basis for speculation on the mechanisms responsible for modification of plasma T_4 levels in migrating fish. Coho salmon which are forced to swim at speeds up to two body lengths per second show elevated plasma T_4 levels within 90 min of forced exercise. Increased swimming in rapidly flowing streams may be responsible for increases in T_4 levels in migrating fish. Another factor which may influence plasma T_4 levels in migrant fish is the effect of novel freshwater (Dickhoff et al. 1982). When salmon are exposed to freshwater which differs from that in which they are reared, a transient rise in plasma T_4 occurs. This response is seen only during smoltification and is due presumably to some as yet undefined chemical factor or balance of factors in the new freshwater. Since thyroid hormones may be involved in homing imprinting, this response to different freshwater may be a part of the homing imprinting mechanism operative in downstream migrating fish.

The modification in gill ATPase activity and plasma T_4 levels in migrating fish are relatively less important in hatchery-reared fish which are released into streams compared with fish which are transferred directly into seawater net-pens. It may be advantageous to mimic some aspects of downstream migration in a hatchery by exercising fish or exposing them to alternative sources of freshwater when possible.

METHODS FOR CONTROLLING SMOLTIFICATION

Smoltification is a developmental process which is the expression of an endogenous rhythm synchronized by photoperiod and affected by temperature (Wagner 1974; Hoar 1976; Wedemeyer et al. 1980; Eriksson and Lundqvist 1982). Methods for controlling or increasing smoltification would involve optimizing photoperiodic events and increasing temperature. While these methods are simple and cost effective, alternative ways of controlling and enhancing smoltification are possible. The natural endogenous cycle and the photoperiodic influence on that cycle undoubtedly involve neuroendocrine and endocrine pathways. Other potentially effective, low cost methods for artificial control of smoltification would involve the use of those hormones which respond to photoperiodic information to direct the physiological transformation of salmonid parr. Thyroid hormone administration would appear to be an attractive method in this regard considering the relation between thyroid hormone surges and smoltification.

The most expedient method for administration of thyroid hormones to large numbers of salmon is incorporation of triiodothyronine (T_3) into the diet. Several studies on the effectiveness of thyroid hormones for stimulation of growth of fish in general and smoltification of salmonids in particular have been published (see recent reviews by Donaldson et al. 1979; Higgs et al. 1982; McBride et al. 1982). The dosage of thyroid hormone is important, since large doses can cause growth anomalies or inhibition of growth. The most effective dosages incorporated into the diet which do not produce undesirable side effects range from 4 to 20 mg/kg of T_3. The optimal dose is dependent on several factors including age of the fish, rearing temperature, ration, and species (Higgs et al. 1982).

In a study on the effectiveness of dietary T_3 (12 mg/kg and 4 mg/kg) for stimulating smoltification of coho salmon, we were able to control the proportion of smolts as determined by morphological criteria by regulating the dose of T_3 (Fig. 2). In this study of yearling coho salmon, T_3 treatment was initiated on 10 January, 4 mo prior to the period of smoltification. Treatment with T_3 was continued throughout the experiment. Plasma levels of T_4 increased earlier in the group treated with the highest dose of T_3 (Fig. 3). Although these findings suggest stimulation of smoltification by T_3, the results of a seawater challenge test revealed no significant increase in hypo-osmoregulatory performance of the treated fish (Table 1). The results of this experiment indicate that some, but perhaps not all, aspects of smoltification may be stimulated by exogenously administered thyroid hormone. The development of methods for artificial control of some aspects of smoltification (e.g., hypo-osmoregulatory ability) must await a better understanding of the basic biological mechanisms regulating the parr to smolt transformation.

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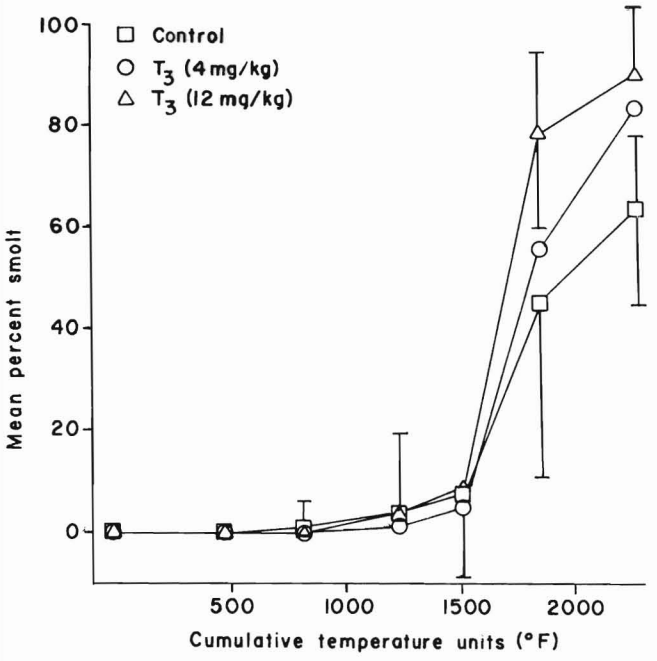

Figure 2.—Mean percent of the population which were smolts (as determined by morphological criteria) during the parr to smolt transformation of coho salmon. A greater proportion of smolts were observed in groups treated with dietary triiodothyronine (T_3) at concentrations of 4 mg/kg and 12 mg/kg.

Table 1.—Plasma sodium of control- or triiodothyronine (T_3)-treated coho salmon 24 h after entry into seawater. Treated fish received T_3 in the diet at 4 and 12 mg/kg for 3 mo prior to seawater challenge.

Group (N=17)	Average plasma sodium	95% confidence interval
Control	174	169-179
T_3 (4 mg/kg)	170	165-175
T_3 (12 mg/kg)	169	165-173

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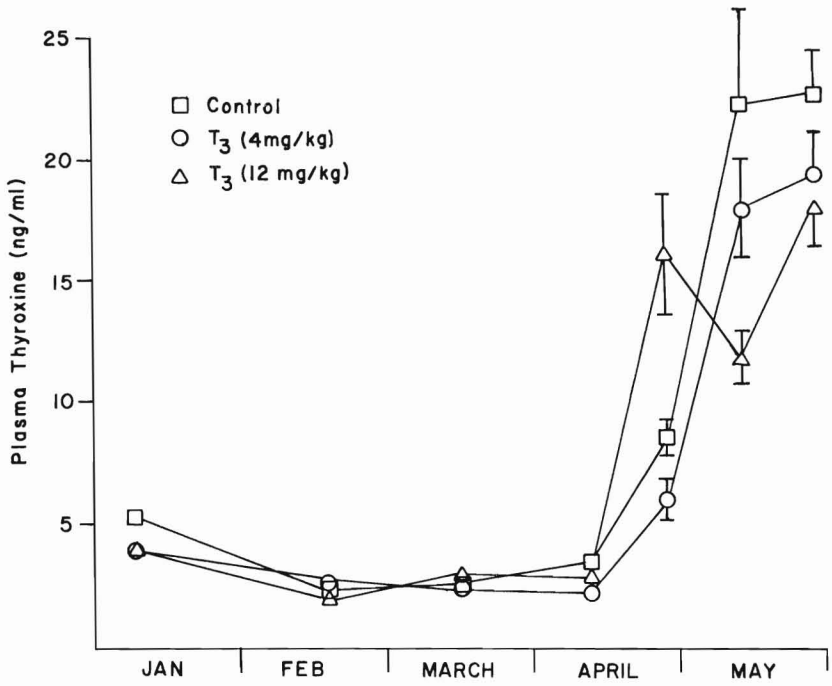

Figure 3.—Blood plasma thyroxine (T_4) concentration in coho salmon during smoltification. An earlier increase in plasma T_4 occurred in fish treated with 12 mg/kg triiodothyronine (T_3) in the diet for 3 mo.

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The Importance of the Environment, Stress, and Disease Relationship in Aquaculture

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A necessary starting place in understanding the physiology of fish in intensive culture is a consideration of normal conditions in the aquatic environment itself. Fishes commonly live under somewhat demanding chemical and physical conditions, many of which have no analogue in the terrestrial environment. It is true that they are physiologically adapted to these conditions, but adaptation does not imply the absence of an energy cost (Lugo 1978). First, fishes must expend a significant number of calories (from the diet) to overcome frictional drag during swimming and to move water over the gills to obtain oxygen. Second, the amount of dissolved oxygen available for respiration is quite limited; it is normally only about 10-12 mg/l, is frequently much less, and can fluctuate widely. The respiratory medium (water) also acts as a dialyzing medium for the blood. Thus, when additional oxygen is needed, the increased gill circulation results, as well, in an increased water influx. The blood electrolyte loss during the resulting diuresis can be life-threatening (Hunn 1982).

Thus, fishes are continually challenged by the normal physiochemical demands of the aquatic environment itself. Added to this may be stress from habitat alterations, and intra- and interspecific interactions such as social hierarchies (Schreck 1981).

Fish in aquacultural facilities are usually under some degree of additional stress because of required operating procedures such as handling, crowding, hauling, drug treatments, and (particularly during stocking) unfavorable or fluctuating temperatures and water chemistry (Piper 1982). This stress is superimposed on that due to the previously mentioned "normal" conditions in the aquatic environment. When recirculation systems are in use, unique conditions of water chemistry occur that can cause an additional metabolic load. These include chronic exposure to low or fluctuating levels of un-ionized ammonia, nitrite, nitrate, carbon dioxide, and gas supersaturation; frequently accompanied by elevated water temperatures (to accelerate growth). Furthermore, environmental conditions and population densities are often dictated more by economic than biological considerations. All of these conditions, together with any fright response that accompanies them, can impose a considerable load, or stress, on the normal metabolism of fish. Although individual stress factors in aquacultural systems are usually sublethal in themselves, stressors are more commonly multiple and the resulting physiological load can reduce growth, impair fish health and quality, and result in decreased survival and increased costs.

A fish's survival in the face of environmental stress depends upon its ability to regulate physiological processes so as to achieve compensation. Any stress requiring an adjustment in excess of ability to accommodate will eventually become lethal; either directly or indirectly as a result of disease. An understanding of the mechanism of response to environmental changes and the degree of stress to which fish can adapt through these mechanisms is important to a definition of the environmental quality required for optimum fish health for hatchery and wild populations. Although fishes can usually physically survive unfavorable environmental conditions for limited periods because of their homeostatic capabilities, these should not be used as an excuse for operating aquacultural systems under marginal conditions. Instead, these abilities should be used to help set priorities and limits for the environmental conditions that will promote optimal fish health and quality.

Because of the many physiological, chemical, and behavioral factors which affect a fish's response to stressors, it is difficult to devise a detailed list of environmental conditions, temperatures, water flows, etc., which would minimize stress and promote fish health under all conditions. Unfortunately, most of the water chemistry information available concerns fish toxicity rather than fish health.

The synergistic effects of dissolved minerals on fish health offer a promising avenue of approach. For example, work at the Seattle National Fishery Research Center with nitrite toxicity has demonstrated than increasing the water hardness to above 50 mg/l, or adding calcium chloride or sodium chloride to increase the chloride level to 50 mg/l will protect steelhead trout against up to 2 mg/l of nitrite. This has important implications for reuse hatcheries using soft water where chronic low level nitrite exposure is frequently a fish health problem.

Another aspect of water chemistry for disease control which has received attention at the Seattle National Fishery Research Center is ozonation—both for pathogen removal and in terms of its fish toxicity. The ozone dosage to destroy enteric redmouth (*Yersinia ruckeri*), furunculosis (*Aeromonas salmonicida*), and the IPN and IHN viruses is substantially less than the chlorine that would be required, and persistent residuals are less of a problem. In addition, ozone shows considerable promise as a replacement fungicide for malachite green in the control of fungus (*Saprolegnia*) during egg incubation.

One of the most insidious effects of stress in aquaculture (and one that is also receiving serious attention as a method of biological monitoring for environmental quality) is increased susceptibility to fish diseases (Esch and Hazen 1980; Walters and Plumb 1980; Ellis 1981). Experience has shown that the mere presence of most fish pathogens, unless present in overwhelming numbers, will not result in epizootics unless unfavorable environmental conditions also exist that have compromised the fish's defense system (Walters and Plumb 1980).

Thus, infectious fish diseases are not single-caused events, but are one outcome of the continuing interactions between the aquatic environment, the fish, and their pathogens. If the host-environment-pathogen relationship is balanced, the result will be good fish health, growth, and survival. If it is marginal, disease problems will begin to become evident and reduced fish condition, growth, and survival will result. If it is unbalanced, chronic

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disease problems can be expected. Examples of fish diseases that are stress-mediated in freshwater aquaculture are those due to facultative bacterial fish pathogens such as aeromonads, pseudomonads, and the myxobacteria, which are continuously present in most natural waters. A classic example is bacterial gill disease, which frequently can be treated successfully by simply reducing the fish population density. Other infectious fish diseases which indicate that tolerance limits to stress are being exceeded include vibriosis (*Vibrio anguillarum*), bacterial hemorrhagic septicemia (*Aeromonas* and *Pseudomonas* spp.), and protozoan parasite and fungus infestations such as costiasis (*Costia necatrix*) and *Saprolegnia* (Wedemeyer et al. 1976). As judged by its physiological consequences, viral erythrocytic necrosis may be a potentially useful indicator disease in the the estuarine environment (MacMillan et al. 1980). Fish disease incidence can, of course, be most easily used as an index of unfavorable conditions in aquacultural facilities which have relatively controlled environmental conditions.

Certain stress-mediated fish diseases have now also been identified as offering particular promise (in biological monitoring) as indicators of unfavorable conditions in the marine environment. These include chromosomal and morphological abnormalities of eggs and larvae, skeletal anomalies, neoplasms, fin erosion, and epidermal ulceration (Malins et al. 1980; Sindermann 1980). A more detailed discussion of stress-mediated diseases, together with a description of the stress factors implicated in their occurrence, is presented in Wedemeyer et al. (1980).

In the special case of anadromous species, a fish health problem of particular significance is the impact of stress on the parr-smolt transformation. A discussion of the physiological changes occurring during smoltification, of particular relevance to aquaculture, is given by Folmar et al. (1982) and Mahnken et al. (1982). Environmental factors such as changes in water chemistry, temperature, or photoperiod may result in inhibition of the development of one or more of these physiological functions (Wedemeyer et al. 1980). For example, the normal development pattern of the gill ATPase enzyme system of coho salmon, *Oncorhynchus kisutch*, parr is affected both by water temperature and by otherwise sublethal amounts of dissolved heavy metals. Chronic exposure to copper at only 20-30 μg/l partly or completely inactivates gill ATPase function (Lorz and McPherson 1976). The consequence is reduced seawater tolerance and, thus, survival. An equally significant behavioral consequence is that normal migratory behavior is inhibited.

In addition to trace heavy metals, anadromous salmonid parr are also affected by contaminants such as the herbicides and nitrates now increasingly common in surface waters as the result of intensive forest and range management, and agricultural practices. For example, both picloram and the dimethylamine salt of 2,4-D used for weed control on noncrop lands inhibit the migratory behavior of juvenile coho salmon (Lorz et al. 1978). Other formulations, such as Endothal and the 2,4-D esters used to control Eurasian water milfoil, may also inhibit seawater tolerance and migratory behavior of smolts (Liguori et al. 1983). Such effects, which are otherwise sublethal at the individual fish level, may have serious consequences in terms of seawater survival (Mahnken et al. 1982).

In the case of water temperature, the effects can be to suppress the onset of smoltification, or to accelerate both smolting and parr reversion. The development of smoltification in anadromous rainbow trout (steelhead) is particularly sensitive to water temperature—which thus provides a useful sublethal index for biological monitoring. Gill ATPase development is essentially blocked at temperatures above 13°C while other physiological parameters, such as growth, can be enhanced (Zaugg and McLain 1972). Coho salmon suffer a retarded pattern of ATPase development at 6°C, and a premature development pattern at 20°C (Zaugg and McLain 1972). Temperatures up to 15°C do not adversely affect smoltification and accelerate growth sufficiently so that minimum size requirements can be met in one rearing season. However, parr-reversion is also accelerated which shortens the time period during which the smolts can successfully convert to seawater. The parr reversion of juvenile chinook salmon due to elevated water temperatures can be substantially reduced if they are reared at salinities of up to 20 ppt (Clarke et al. 1981).

A final aquaculture stress factor to consider that adversely affects smolt performance capability, is crowding and handling (Specker and Schreck 1980; Fagerlund et al. 1981; Sandercock and Stone 1982). The population level effect of significance is reduced seawater survival which renders it of particular importance in ocean ranching.

Of all the environmental stress factors predisposing salmonid fishes to disease problems in intensive culture, crowding, i.e., approaching or exceeding the maximum carrying capacity of the water, is probably one of the most important. The number of fish which can successfully live and grow in a given water supply depends on its pathogen load, the dissolved oxygen level, metabolic rate of the fish, feeding rate, and how fast the water is being exchanged, which in turn governs the rate at which metabolic wastes accumulate. In a recirculating system, nitrate accumulation must also be considered. This would be a function of the efficiency of the biological filter. The fish pathogen load is a usually neglected, but very important, factor affecting both the carrying capacity and the health of the fish being reared. In recirculating systems, pathogens can be controlled by water sterilization devices using ozone or ultraviolet light, but in the usual hatchery situation, pathogen loads are frequently only indirectly under the control of the fish culturist.

As an additional complication, fish loadings also should be evaluated in terms of the stress they cause. For example, moving juvenile coho salmon held in soft, 10°C water from the relatively light loading of 8.0 kg/m^3 (0.5 lb/ft^3) (density index 0.1) to either 96 or 192 kg/m^3 (6 or 12 lb/ft^3) causes acute stress which can last up to 10 d. A loading of 64 kg/m^3 (4 lb/ft^3) (density index 0.8) causes only minimal blood chemistry disturbances. For fish distribution trucks, this would correspond to about 0.06 kg/l (0.5 lb/gal) of water. However, moving smolting coho salmon at population densities greater than about 16 kg/m^3 (1 lb/ft^3) or 0.01 kg/l (0.1 lb/gal) in hauling trucks causes severe stress and can activate latent kidney disease.

A critical consideration in any discussion involving fish diseases is recognizing that there are still problems in being able to adequately recognize good fish health when it is achieved. Obviously, fish health is far more than the mere absence of fish disease. Growth and survival are also frequently used as measures of health but they are satisfactory only as a first approximation. The problem is especially difficult in the ocean ranching of anadromous fishes because producing smolts of maximum health and quality is critical to maximizing ocean survival and thus returns to the hatchery.

In conclusion, better information on the physiology of fish in intensive culture would assist in mitigating stress, improve fish health and quality, and improve overall survival through disease prevention. The following is recommended:

1) Maintain water quality within recommended guidelines for the species of interest.
2) Regulate population density to prevent crowding stress.
3) Recognize that multiple stress from crowding, handling, and disease treatments is additive or synergistic.
4) When multiple stress is unavoidable, allow an adequate recovery time based on the species, and severity of the resulting physiological disturbances.
5) Use the occurrence of stress-mediated fish diseases as an indicator of adverse conditions and take corrective action.

A better understanding of the physiology of fish in intensive culture, including disease as one physiological consequence of an unfavorable aquatic environment, would provide the factual foundation required for improving efficiency in aquaculture as it has in other branches of animal husbandry. Specifically:

1) Species-specific tolerance limits to multiple environmental alterations are needed (e.g., salinity, oxygen, temperature). For example, at what point do otherwise sublethal temperature increases become stressful when dissolved oxygen is also unfavorable?
2) Improved hatchery procedures to mitigate stress, particularly for Atlantic salmon, striped bass, and intermediate temperature fishes, are needed.
3) Performance challenge tests are needed to allow a more efficient assessment of the impacts of stress, evaluate genetic strains, and allow a more rapid assessment of overall fish health and quality.

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Seawater Acclimation of Premigratory (Presmolt) Fall Chinook Salmon: A Possible New Management Strategy?

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ABSTRACT

At selected points in their life history, juvenile fall chinook salmon, *Oncorhynchus tshawytscha*, were acclimated in diluted seawater, 15 ppt salinity, for different times before they were challenged with undiluted seawater. In successive months, the weight and length of the fish and percent mortality after acclimation in diluted seawater for 0, 6, 24, and 168 hours were as follows: February (1.2 g, 51 mm), 97, 90, 71, and 15; March (2.1 g, 59 mm), 77, 67, 46, and 5; April (3.7 g, 70 mm; Na^+-K^+ ATPase levels rising) <7 in all groups. In July (well after normal April hatchery release) when fish averaged 20 g and 115 mm, mortality after seawater challenge was 25% after 0 or 6 hours acclimation, 8% after 24 hours acclimation, and nil after 168 hours acclimation. For the population of juvenile fall chinook salmon used in these experiments, ability to withstand direct seawater exposure corresponded to levels of gill Na^+-K^+ ATPase.

Growth in seawater was monitored for survivors of each treatment group from the March and April seawater challenges. After 4 months, no significant differences in fish length and weight were observed.

INTRODUCTION

Public and private anadromous salmonid aquaculture in America, especially sea ranching, has reached a significant crossroad insofar as further expansion is concerned. Several economic and environmental factors limit growth of the industry. In the last 5 yr, maintenance, building, and operation costs have soared, all in direct conflict with demands for production of greater numbers of low-cost smolts. Coupled with increased commercial and recreational demand for publicly and privately reared fish, a limit is being approached to the number of adult salmon that originate from hatcheries, at least in the states of Washington, Oregon, Idaho, and California.

Environmental factors play an important role in production of healthy smolts. Supplies of high quality freshwater, already oversubscribed, are used at unrealistic carrying capacities, resulting in overcrowding and disease. New sources of suitable freshwater are increasingly difficult to locate and appear to be the single, most important biological variable limiting salmonid aquaculture.

Man's manipulation of the environment is also a limiting factor. Multiuse of existing water supplies has adversely affected migrations of both smolts and adults. Dams, water removal, and pollution are the primary causes of mortality. These problems are potentially devastating for all fish, particularly poor-quality hatchery fish.

New salmonid-rearing strategies are needed to improve efficiency, increase operational flexibility, allow for multiple-species rearing, and optimize use of existing freshwater. One strategy, early seawater acclimation of small, presmolted, and premigratory fall chinook salmon, *Oncorhynchus tshawytscha*, is the subject of this paper. Other investigators have determined that gradual acclimation to low salinities results in early tolerance to full-strength seawater. Wagner et al. (1968) gradually acclimated Bonneville-stock, fall chinook salmon, using 5-d, 5 ppt salinity increments up to 30 ppt salinity to realize > 80% survival of juveniles 100 d old. Nonacclimated fish were reared 140 d before survival exceeded 80%. Similar results were observed in spring chinook salmon. Kepshire and McNeil (1972), who acclimated 66-d old fall chinook salmon to seawater by incremental salinity increases, each lasting 18 d, before transfer to undiluted seawater, reported a slight reduction in growth of saltwater-adapted fish compared with that of control fish held in freshwater.

The objective of our work was to determine how soon fall chinook salmon can adapt to seawater after acclimation in diluted seawater (15 ppt salinity) and the length of time required for adaptation. At the same time, we compared seawater growth of small, saltwater preadapted fish to seawater growth of fish naturally acquiring seawater tolerance. This effort is the first step in assessing the value of presmolt seawater adaptation as a management tool.

MATERIALS AND METHODS

On 22 October 1981, fall chinook salmon at the eyed egg stage were obtained from production lots at Spring Creek National Fish Hatchery, and transported to Marrowstone Field Station, Seattle National Fishery Research Center, located on Puget Sound near Port Townsend, Wash. Eggs were disinfected in 100 ppm Argentine[4] solution (pH 7) for 10 min, and placed in Heath-Techna Incubator trays (about 3,000 eggs per tray). Each tray received freshwater at the rate of 10 l/min. All fish were hatched by 16 November 1981, and were moved on 8 December 1981 to 12, 80 l troughs each receiving 4 l/min freshwater. On 5 February 1982, random samples of 50 fish each were placed in 68 l glass aquaria

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each receiving 2 l/min freshwater. Each aquarium received either freshwater or seawater treated with ultraviolet light, pumped from Puget Sound, or mixtures of both. Freshwater and seawater temperatures as well as seawater salinity were monitored daily (Fig. 1). Salinity was measured with a YSI Model 33 S-C-T meter. Fish were fed Oregon Moist Pellet "ad libitum."

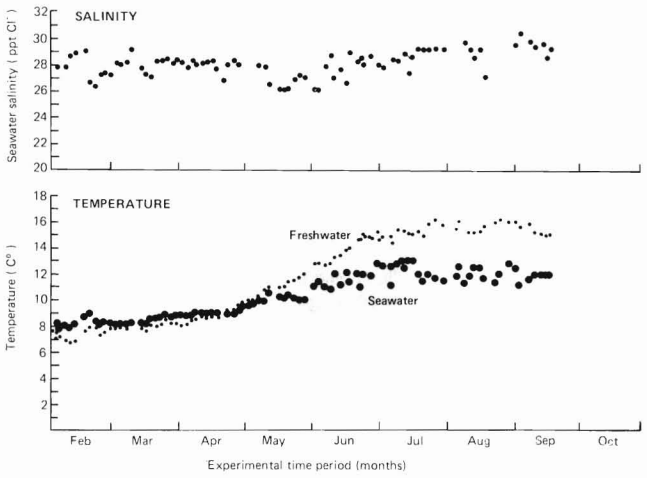

Figure 1.—Seawater salinity, seawater temperature, and freshwater temperature at Marrowstone Field Station from 1 February 1982 to 1 October 1982.

ATPase Determinations

Sixteen aquaria containing 50 fish each and receiving only freshwater were sampled for gill Na^+-K^+ ATPase enzyme activity to measure timing of smoltification. At about 2-wk intervals, 10-30 fish from one aquarium were removed and gill filament tissue was excised. Each sample consisted of tissue from 1 to 3 fish, resulting in 10 replicated samples for each time period. All fish tested for gill Na^+-K^+ ATPase activity were weighed to the nearest 0.1 g and measured (fork length) to the nearest millimeter. Sampling and gill Na^+-K^+ ATPase determinations were according to Zaugg (1982).

Pre-exposure Study

We used 48 aquaria—12 aquaria for each of four seawater challenge experiments—each containing 50 juvenile fall chinook salmon in the pre-exposure study. During each challenge, three tanks were converted directly to seawater. Three tanks were changed to diluted seawater (salinity about 15 ppt) for one of three acclimation periods—6, 24, or 168 h—followed by conversion to full-strength seawater. The experimental procedure was begun on each of the following dates in 1982: 23 February, 23 March, 20 April, and 20 July. Specific exposure salinities for each seawater challenge are summarized in Table 1.

Numbers of dead fish in experimental tanks were recorded daily until mortality subsided (a minimum of 10 d). Kidney samples from about 25% of the dead fish were cultured for bacterial infection on Brain Heart Infusion Agar (Difco). Resulting bacterial cultures were identified by using the API-20E (Analytical Products Industries, Plainview, N.Y.) bacterial identification system, and following the manufacturer's recommended procedures.

Growth Experiment

From the 23 March challenge, two lots of 15 fish each were formed from survivors of each treatment group. More fish survived the 20 April challenge, allowing selection of four 15-fish lots from each treatment group. Each lot was moved to a 68 l aquarium receiving 2 l/min undiluted seawater. Fish were fed Oregon Moist Pellets at a percentage of their body weight based on manufacturer's recommendations and temperature. Growth was monitored monthly for 5 mo. Fish were weighed to the nearest 0.1 g and fork lengths measured to the nearest millimeter.

RESULTS

Gill Na^+-K^+ ATPase Determinations

Gill Na^+-K^+ ATPase activity for fall chinook salmon under the given experimental conditions was low through February and March, averaging below 10 μmol Pi/mg Prot per h (Fig. 2). Activity began to increase in April and continued upward until about 1 July, when it declined precipitously to nearly pre-April values, only to quickly rise again in late July. The first two seawater challenges came before ATPase activity increased and the third as ATPase activity was increasing (Fig. 2). Gill Na^+-K^+ ATPase activity in late June—32 μmol Pi/mg Prot per h—was high compared with values observed in several related studies at other locations on the same brood of fish. The 20 July challenge began at a point when freshwater gill Na^+-K^+ ATPase levels were depressed; however, after 168 h, the activity was nearly equal to that observed during the third challenge. The bimodal nature of ATPase activity for our experimental stock has been observed in past years, but the duration of increased activity from April through June and the subsequent decline had not been previously noted.

Table 1.—Mean salinity during experimental seawater challenges. Also included are salinities of seawater used to acclimate fall chinook salmon before seawater challenge.

	Date (1982)							
	23 February		23 March		20 April		20 July	
Acclimation time (h)	Mean salinity (ppt)	95% confidence interval	Mean salinity (ppt)	95% confidence interval	Mean salinity (ppt)	95% confidence interval	Mean salinity (ppt)	95% confidence interval
0 (undiluted seawater)	27.2	±0.2	27.6	±0.5	26.9	±1.0	29.1	±0.6
6	16.0	±3.0	14.8	±0.8	17.6	±1.8	14.9	±4.0
24	13.5	±1.4	16.3	±1.1	15.8	±3.1	14.1	±1.6
168	14.5	±0.7	14.4	±0.6	15.4	±1.6	15.2	±1.5

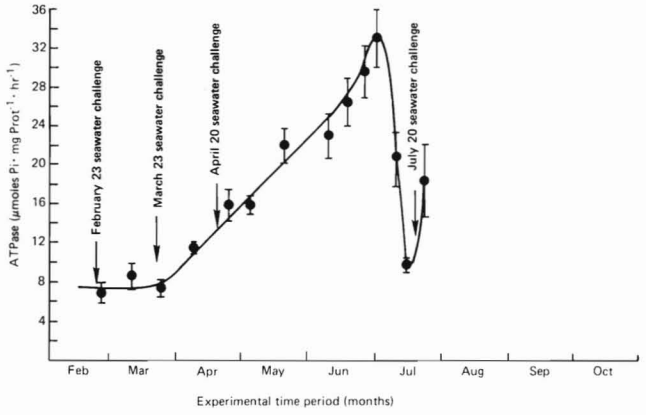

Figure 2.—Gill Na^+-K^+ ATPase levels of fall chinook salmon held in freshwater at Marrowstone Field Station from February 1982 to October 1982. Bars indicate 95% confidence intervals.

Pre-exposure Study

Cumulative mortality in both the February and March seawater challenges was high for unpreadapted fish and low for fish preadapted to 15 ppt salinity for 7 d (Fig. 3). Preadaptation resulted in reduced mortality after 6 h and a still further reduction after 24 h.

In April, one of the normal release times for Spring Creek fall chinook salmon, most of the fish were able to withstand direct

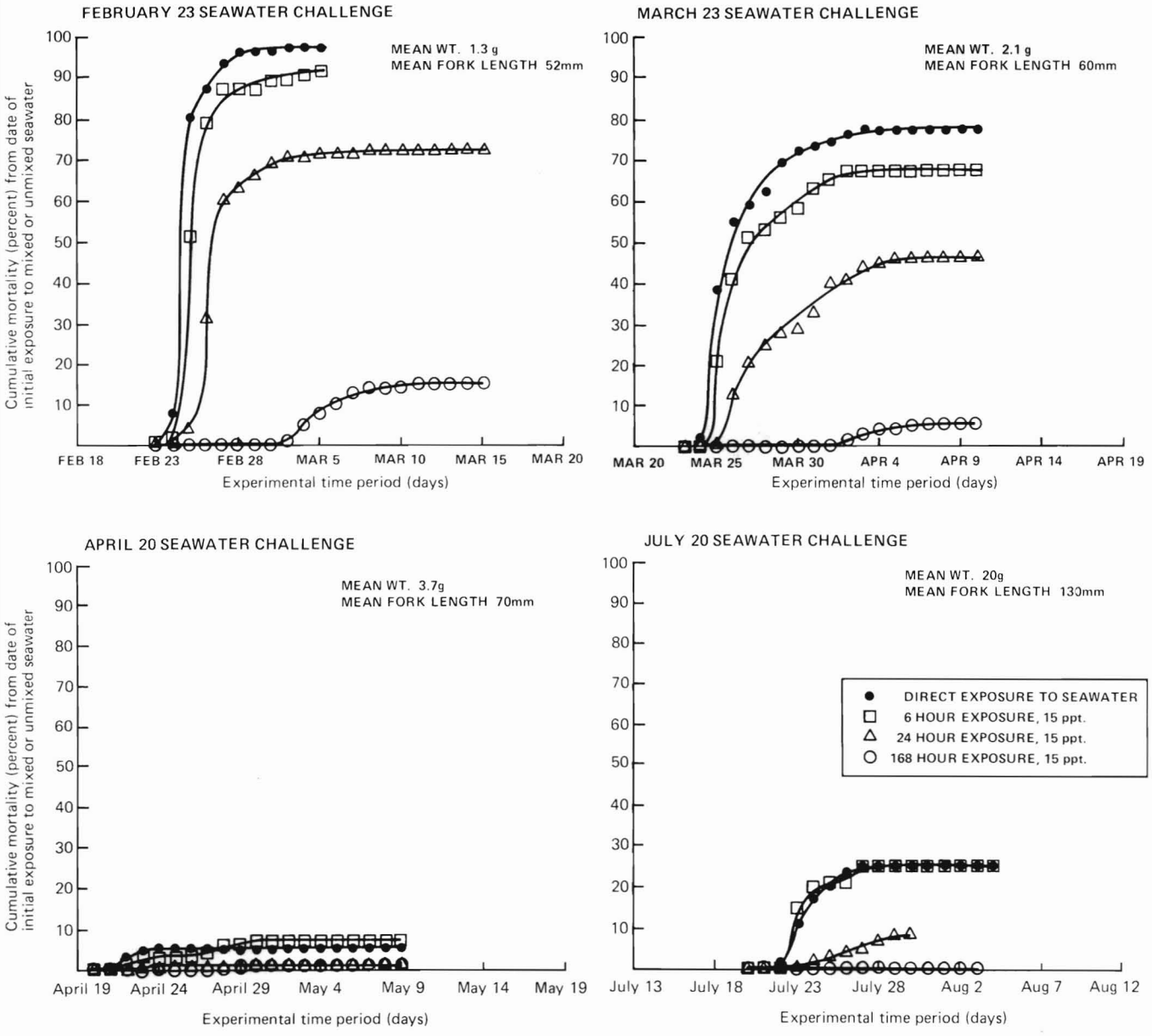

Figure 3.—Cumulative mortality of juvenile fall chinook salmon challenged at various times with mixed freshwater-seawater (≅15 ppt salinity) for 0, 6, 24, or 168 h before exposure to full-strength seawater (≅29 ppt). Each curve represents combined cumulative mortality from three equally treated lots. Each lot contained 50 fish—a total of 150 fish per treatment group.

seawater exposure (Fig. 3). Highest mortality in any group was 7%. The mortality pattern in July reflected the probable state of smoltification as indicated by ATPase levels: Much of the population had lost the ability to withstand direct seawater exposure. Acclimation to diluted seawater for 6 h did not seem to increase seawater tolerance, but 24-h acclimation improved survival. No fish were lost after 168-h acclimation. These results might be a reflection of the extremely rapid fluctuation in the ATPase levels observed in July. In addition, we detected high gas supersaturation (110-115%) and low dissolved oxygen (4 ppm) in our freshwater supply in July. During the 20 July seawater challenge, even though the mortality pattern between treatment groups was consistent with earlier challenges, stress on the fish could have affected mortality and gill Na^+-K^+ ATPase activity.

During all challenges, most kidney cultures resulted in no bacterial growth. Where growth occurred, the bacteria were classified as members of the genus *Pseudomonas*, which were probably secondary invaders after death of the fish.

Growth Experiment

Length and weight were determined for survivors of the 23 March and 23 April challenges. Little, if any, growth difference was observed (Figs. 4, 5). There was also little, if any, growth difference between survivors of various acclimation groups. Growth of fish used to monitor ATPase (maintained in freshwater) was greater than that of fish in saltwater. The lengths and weights for these fish follow: 66 mm, 3.0 g (12 April); 78 mm, 5.5 g (10 May); 93 mm, 9.8 g (10 June); 108 mm, 16.4 g (10 July); and 125 mm, 27 g (10 August). These values cannot be compared with those for saltwater growth because tanks receiving freshwater contained different numbers of fish, handling was different, and experimental environments were dissimilar.

DISCUSSION

Chinook salmon populations are experiencing increasing exploitation rates and deteriorating environmental conditions. To offset resultant declines, management agencies have called for large increases in hatchery production. Economic roadblocks, environmental degradation, and lack of suitable freshwater supplies in the Pacific Northwest significantly limit hatchery capacity for rearing fall chinook salmon. Early preadaptation of fall chinook salmon is a possible solution to these problems. Thinning releases are now common at many hatcheries. For example, Spring Creek National Fish Hatchery on the Columbia River, the source of our experimental animals, released 9.6 million fall chinook salmon before smoltification; and the Abernathy Salmon Culture Development Center, also on the Columbia River, released about 400,000 presmolts. Releases of presmolt chinook salmon have historically contributed far fewer adults to the fishery than were contributed by larger smolted fish released at the usual time in April or May. Loss of these presmolted fish is known to occur in river reservoirs and in the estuary, where small fall chinook salmon may remain and feed for several weeks before entering the

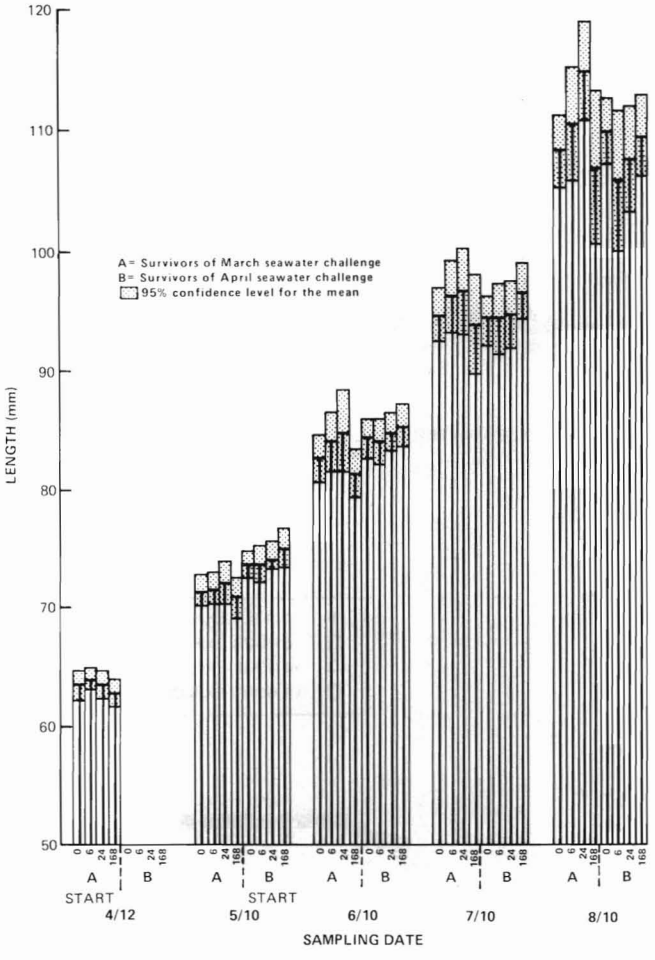

Figure 4.—Growth comparison (length) between two groups of fall chinook salmon, one (A) surviving a seawater challenge on 23 March, and one (B) surviving a seawater challenge on 23 April. Each group contained four treatment groups, each acclimated for 0, 6, 24, or 168 h in diluted seawater (≅15 ppt salinity) before exposure to undiluted seawater.

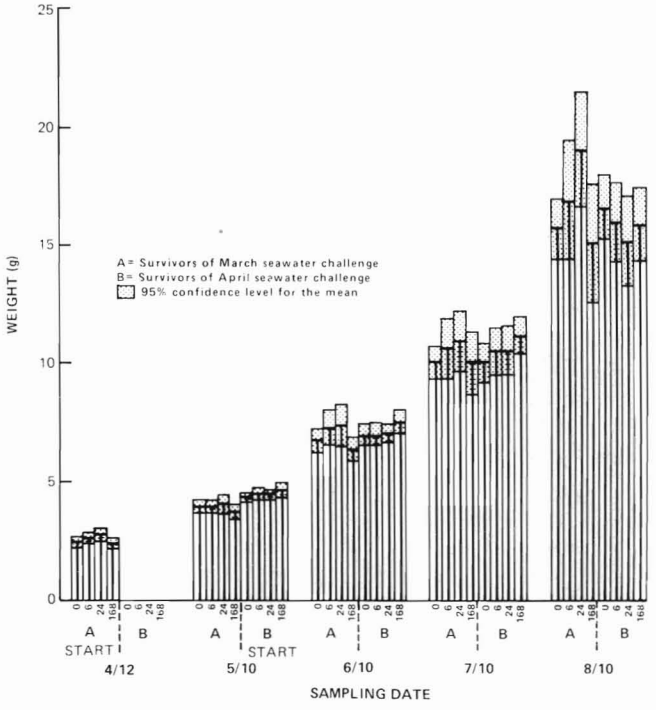

Figure 5.—Growth comparison (weight) between two groups of fall chinook salmon, one (A) surviving a seawater challenge on 23 March, and one (B) surviving a seawater challenge on 23 April. Each group contained four treatment groups, each acclimated for 0, 6, 24, or 168 h in diluted seawater (≅15 ppt salinity) before exposure to undiluted seawater.

ocean (Dawley et al. 1981). Mortality-causing factors such as predation or lack of food are believed to be important and might be avoided by transporting fish to a brackish water environment for short-term rearing and preadaptation, followed by release directly into seawater. If successful, this strategy for releasing at least a portion of fall chinook salmon hatchery production early in their life cycle could provide several advantages:

1) Greater flexibility in the use of hatchery facilities for multi-species artificial propagation, i.e., rearing of both fall chinook salmon and coho salmon, *Oncorhynchus kisutch*.
2) More economical rearing operations because more fish can be produced in existing hatcheries, or fish of better quality can be produced because rearing densities can be reduced. Studies now indicate that low-density rearing of coho salmon increases survival in the hatchery and contribution to the fishery (Fagerlund et al. 1979, 1981; Sandercock and Stone[5]).
3) Maximum effective use of available freshwater.
4) Minimum effect on wild juvenile salmonids rearing in waterways.
5) Higher survival of premigrants resulting from direct release to saltwater, thereby avoiding fish and bird predation in the freshwater reservoirs and estuary.
6) Possible avoidance of ocean density-dependent mortality on wild stocks if some fish are released earlier than others.

The final indicator of success for any management strategy is contribution to and long-term effects on the population. Our work indicates that during the test period, acclimated presmolt fall chinook salmon (survivors of the 23 March seawater challenge) grew as well as smolted fall chinook salmon (survivors of the 23 April seawater challenge) in seawater. This observation supports the thesis that preadapted fish may also grow and react normally as adults. Other authors (Kepshire and McNeil 1972; Bullivant 1961; Clarke et al. 1981) reported decreased growth for preadapted fish. They may have observed normal growth reduction caused by transition to seawater. Clarke et al. (1981), for example, began their experiments using 1.2 g fall chinook salmon held from early April to June. These fish would normally be approaching smoltification but would still display retarded growth when moved to full strength seawater (29 ppt) after 6 wk (early May).

There are few indications in the literature concerning the effects of early seawater entry on the contribution of adults. Available evidence indicates that the contribution may be equal to or better than that of "normally" released fish. The Japanese chum salmon, *Oncorhynchus keta*, industry has made favorable use of river-mouth releases and short-term, saltwater-rearing strategies for several years (Iioka 1978; Iioka et al. 1978), indicating that releases in saltwater are feasible and practical. Eriksson et al. (1981) demonstrated that smolts of Atlantic salmon, *Salmo salar*, made a greater contribution to the fishery when released into seawater sites than did smolts released from either an estuary site or directly into the river at the hatchery. Further experiments with direct seawater releases are required to document the contribution of preadapted juveniles, as well as to answer other related biological questions. An obvious ramification of preadaptation is impaired homing. Impaired homing behavior, however, may have exploitable economic and biological advantages. Fish may home to release sites, become confused, and remain in the area. Thus, release sites may serve as predetermined, open-sea terminal fishing areas. Since preadapted fish are excess to hatchery needs, heavy harvest is desirable. It is also possible that preadapted fish follow migration times and use rearing areas different from those of normally released hatchery smolts or wild smolts. If so, this behavior would allow fishery managers increased flexibility in setting harvest seasons and quotas protecting wild and important hatchery stocks. (These suggestions are of course highly speculative and require further research.)

Preadaptation of fall chinook salmon is by no means a primary strategy for rearing fall chinook salmon. The worth of the procedure lies in the economical use of previously "wasted" progeny of existing runs. If freshwater systems continue to be adversely affected by man's manipulations, new strategies such as preadaptation may be the only means of maintaining an economical and biologically sound harvest of anadromous salmonids.

[5]Sandercock, F. K., and E. T. Stone. [Undated.] The effect of rearing density on subsequent survival of Capilano coho. Mimeogr., 2 p. Fisheries and Oceans, Salmonid Enhancement Program, 1090 West Pender St., Vancouver, B.C. V6E 2P1 Canada.

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Chinook Salmon Fisheries and Enhancement in Alaska: A 1982 Overview

WILLIAM R. HEARD[1]

ABSTRACT

Chinook salmon, *Oncorhynchus tshawytscha*, fisheries and enhancement programs have distinct characteristics in different regions of Alaska. Major commercial fisheries are found in southeastern Alaska, Bristol Bay, and the Arctic-Yukon-Kuskokwim (A-Y-K) regions; important recreational fisheries are in southeastern Alaska and Cook Inlet, and subsistence fisheries are in Bristol Bay and the A-Y-K region. In many areas, chinook salmon are caught in more than one fishery. For example, fish returning to western Alaska (Bristol Bay and A-Y-K) are also caught in foreign high-seas gill net and trawl fisheries. In Cook Inlet, the principal fishery is recreational; however, commercial net fisheries that target on other species also catch some chinook salmon. In southeastern Alaska, both commercial and recreational marine troll fisheries catch fish from stocks that originate from Alaska, British Columbia, and the Pacific Northwest.

In 1982, 13 hatcheries were rearing chinook salmon in Alaska: 8 in southeastern Alaska, 3 in Cook Inlet, 1 on the Alaska peninsula, and 1 in interior Alaska. At satellite projects associated with several hatcheries, fry, fingerlings, or smolts are held in marine net-pens or are released in streams or lakes to produce anadromous adult returns.

Five organizations, including the Alaska Department of Fish and Game, two regional aquaculture associations, the National Marine Fisheries Service, and the Annette Island Indian Reservation, operate chinook salmon hatcheries. Transport of eggs to or from hatcheries and overall development of programs at each hatchery are regulated by the State of Alaska.

Many chinook salmon hatcheries and satellite programs in Alaska are too new to be evaluated; however, two in Cook Inlet (Crooked Creek and Halibut Cove Lagoon) and three in southeastern Alaska (Crystal Lake, Little Port Walter, and Deer Mountain) are contributing to regional fisheries. Different enhancement strategies are used to meet different regional needs. In Cook Inlet, the recreational fishery is primarily in freshwater and depends on mature adults returning to their natal area or release site. In southeastern Alaska, where chinook salmon are caught only in seawater, the fisheries depend on actively feeding fish. Because fisheries in Alaska require different life-history stages, managers developing enhancement strategies must consider ocean migration patterns, stock genetics, hatchery location, and specific fish-culture treatments that might influence maturation patterns and contribution potentials.

INTRODUCTION

Chinook salmon, *Oncorhynchus tshawytscha*, are found along much of the Alaskan coastline, from Dixon Entrance in the south to Kotzebue Sound in the north. Some of these stocks spawn in Alaska; others spawn in Washington, Oregon, California, Idaho, British Columbia, and Asia and migrate through nursery areas along the Alaskan coastline.

Often different fisheries in Alaska and elsewhere depend on the same stocks of chinook salmon; thus, allocation of this valuable fish can cause regional, interstate, and international controversy. In Cook Inlet, the catch is allocated between a major recreational fishery in freshwater streams and incidental catch in a commercial gill net and seine fishery in the inlet. In southeastern Alaska where the commercial troll and recreational marine fisheries target on a complex mixture of stocks, incidental catches in commercial gill net and seine fisheries become an important issue. In western Alaska, mature, returning chinook salmon are caught commercially in an inshore gill net fishery in Bristol Bay and in net fisheries in the Kuskokwim and Yukon Rivers. Throughout western Alaska, in addition to commercial fisheries, there is a heavy subsistence use of chinook salmon.

Regional allocation of salmon in western Alaska is international because fish from the Yukon River can originate in Canadian provinces as well as in Alaska. Furthermore, high-seas catches of immature, western Alaska chinook salmon by the Japanese mothership fleet in the Bering Sea can exceed the total inshore and river commercial harvest of mature fish in some years (Meacham and Arvey 1981; Major 1982).

These many controversies, in turn, directly affect research, management, and enhancement efforts to improve stocks and fisheries. In southeastern Alaska, much of the current chinook salmon research and enhancement effort is directed at resolving complex issues associated with the interstate and international allocation of depressed stocks.

The purpose of this report is to review major chinook salmon fisheries in Alaska and enhancement efforts that relate to some of these fisheries.

STOCKS AND FISHERIES

Major fisheries in Alaska can be categorized into four geographic areas: Southeastern, Cook Inlet, Bristol Bay, and the Arctic-Yukon-Kuskokwim region (A-Y-K) (Fig. 1). The commercial catch in Alaska in 1980 and 1981 is representative of catches in recent years (Table 1)—670,100 chinook salmon in 1980 and 820,000 in 1981. Most of these fish were caught in Southeastern, Bristol Bay, and A-Y-K regions; however, major management

[1]Northwest and Alaska Fisheries Center Auke Bay Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 155, Auke Bay, AK 99821.

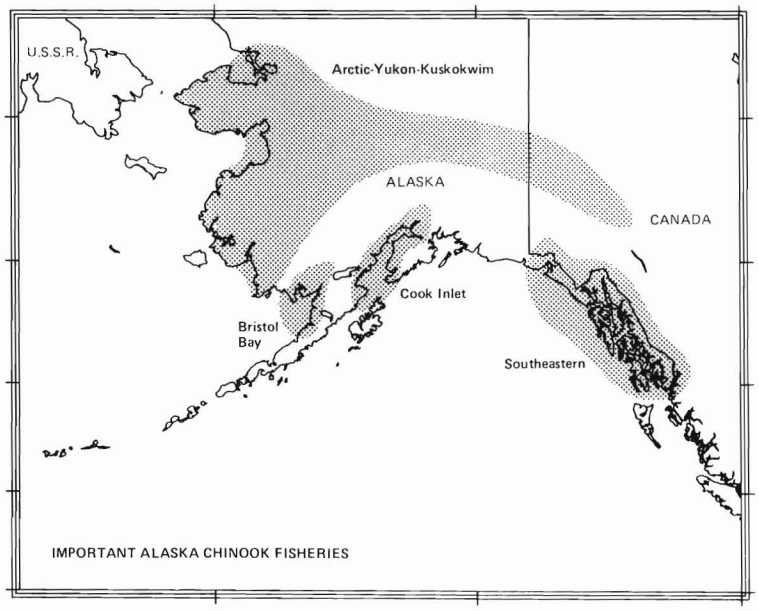

Figure 1.—Four geographic regions of Alaska with important chinook salmon fisheries.

Table 1.—Preliminary commercial catch of chinook salmon in Alaska by area, 1980 and 1981.[1]

Area	1980	1981
Southeastern	320,600	270,800
Copper River and vicinity	8,700	21,400
Cook Inlet	12,900	10,600
Alaska Peninsula and vicinity	24,700	31,900
Bristol Bay	95,700	239,000
Arctic-Yukon-Kuskokwim	207,500	246,300
Total	670,100	820,000

[1]Data compiled by the Alaska Department of Fish and Game, Division of Commercial Fisheries.

issues also occur in Cook Inlet because of conflicts between recreational and commercial fisheries.

Two other areas, Copper River and Alaska Peninsula, also have a significant commercial harvest of chinook salmon; however, neither area has special management concerns associated with the fisheries. In the Copper River, most chinook salmon are caught in a gill net fishery at the mouth of the river. On the Alaska Peninsula, most chinook salmon are caught along the northern peninsula and are associated with the outer districts and migration approaches to Bristol Bay. Some stocks originate from the southern Alaska Peninsula area, notably on Kodiak Island and at Chignik, but they usually make up a small part of the total Alaska Peninsula catch.

Cook Inlet Area

Chinook salmon from the Susitna, Kenai, Kasilof, Ninilchik, and Anchor Rivers, and Deep Creek all contribute to the Cook Inlet fisheries; however, most fish originate from the Susitna River. Commercial fisheries for chinook salmon in Cook Inlet include a purse-seine fishery in Lower Cook Inlet, and drift gill net and set gill net fisheries in Upper Cook Inlet. Between 1933 and 1953, the average annual commercial harvest in Cook Inlet was more than 90,000 fish (Cook Inlet Regional Planning Team 1981). However, the commercial catch has been declining since 1951, the year that 187,513 fish were caught and the highest annual commercial harvest of chinook salmon recorded. Since 1953, the annual catch has averaged about 13,500 fish.

The recreational catch of chinook salmon in the Cook Inlet area has been steadily increasing. The Cook Inlet area has the highest recreational fishing effort in Alaska because of population demographics in the state. In 1979, 125,000 recreational fishermen spent 766,556 d fishing in the Cook Inlet area and caught 25,800 chinook salmon (Cook Inlet Regional Planning Team 1981). On the Kenai River alone, recreational fishermen spend nearly 100,000 d annually fishing for chinook salmon that weigh an average of 14 kg (30 lb) and frequently exceed 27 kg (60 lb).

Most chinook salmon caught in Cook Inlet are mature adults approaching or in their natal streams. Only a few ocean-feeding salmon are caught in marine recreational fisheries in the outer part of Kachemak and Resurrection Bays, fisheries similar to other recreational fisheries in southeastern Alaska and southward along the North American coast. Rough marine waters and few launching and berthing facilities limit marine recreational fishing in Cook Inlet; however, there is a small, specialized marine recreational fishery for mature chinook salmon along beaches of the Kenai Peninsula south of Deep Creek. Wild stocks and hatchery stocks of chinook salmon from Oregon, Washington, British Columbia, and southeastern Alaska use Lower Cook Inlet as an ocean nursery area (Wallis 1980), and a small marine recreational fishery on immature, ocean-feeding chinook salmon in the outer part of Kachemak Bay provides valuable recovery information on coded-wire tagged chinook salmon.

Southeastern Alaska

Commercial and recreational fisheries in southeastern Alaska harvest chinook salmon from stocks that are endemic to the area and stocks that originate as far south as Oregon (Parker and Kirkness 1956). From analyses of recovered coded-wire tags, the North Pacific Fisheries Management Council tentatively assigned the origin of stocks contributing to the southeastern Alaska chinook salmon fishery as follows: 40% Canada; 40% Washington, Oregon, and Columbia River; and 20% Alaska. The major endemic stocks of chinook salmon from southeastern Alaska are from the Taku, Stikine, Alsek, Chilkat, Situk, Unuk, and Chicka-

min Rivers. Other stocks exist, but they are small or their current status is unknown.

Most chinook salmon are caught by the commercial power-troll and hand-troll fleets, which concentrate in certain inside and outside waters of southeastern Alaska (Gunstrom 1980). Sport fisheries for chinook salmon are in urban-area marine waters principally around Juneau, Sitka, Ketchikan, Petersburg, and Wrangell. The recreational harvest, estimated at 17,096 chinook salmon in 1977 (Mills 1979), represented about 5.6% of the total catch of chinook salmon in southeastern Alaska; whereas the harvest of chinook salmon in the commercial troll, gill net, and seine fisheries represented about 89.9, 2.7, and 1.7%, respectively, of the chinook salmon harvested in southeastern Alaska in that year.

The Magnuson Fisheries Conservation and Management Act of 1976 led to development of Fishery Management Plans which regulate ocean fisheries for chinook salmon in jurisdictional waters of the United States. In southeastern Alaska, the commercial troll fishery and recreational fishery are partly dependent on chinook salmon originating from outside the region. The North Pacific Fisheries Management Council and the Alaska Board of Fisheries implemented the first Fisheries Management Plan for southeastern Alaska during the 1979 fishing season. The first upper-limit Optimum Yield for southeastern Alaska was set at 320,000 fish/yr; however, the Optimum Yield has since been adjusted downward and was set at 255,500 chinook salmon for the 1982 season. Because many stocks of chinook salmon that contributed to the troll fishery in southeastern Alaska were declining, new regulations for this fishery included reduced fishing periods, minimum-size limits, and catch quotas. Gunstrom (1980) gave a detailed account of the southeastern troll fishery and included the history, management problems, objectives, and development of the Fishery Management Plan.

Bristol Bay

In Bristol Bay, all of the principal river systems, including the Naknek, Kvichak, Nushagak, Togiak, Egegik, and Ugashik Rivers, support one or more stocks of chinook salmon. Since the 1950's, 70% of the commercial harvest in Bristol Bay has come from Nushagak District, and in 1981, the commercial gill net catch of chinook salmon in the Nushagak District was 195,000 fish.

Recreational fisheries for chinook salmon in Bristol Bay are not significant; however, subsistence catches of mature fish in rivers draining into Bristol Bay are significant. In 1981, an estimated 15,000 chinook salmon were caught in this subsistence fishery, which is primarily a gill net fishery (Meacham and Arvey 1981). A recent escapement model for Nushagak chinook salmon (Alexandersdottir and Mathisen 1981) recommends building a stronger data base for commercial and subsistence fisheries, a data base that takes into account selectivity of different meshes of gill nets used in these fisheries and increasing the precision of escapement estimates.

Arctic-Yukon-Kuskokwim Region

The large A-Y-K region has many stocks of chinook salmon. Some originate from short, lowland coastal streams; others originate from the 3,700 km (2,300-mi) long Yukon River, which has its source in British Columbia, Canada. Most chinook salmon commercially caught in this region are from the Kuskokwim and Yukon Rivers.

Principal stocks in the Yukon River, largest river in Alaska and fourth largest in North America, have been characterized according to their spawning grounds: Lower (Andreafsky, Anvik, and Nulato Rivers), Middle (Koyukuk and Tanana River tributaries), and Upper (Big Salmon, Nisutlin, and Teslin Rivers) (McBride and Marshall 1983; Arvey[2]). An unknown portion of the chinook salmon in the Upper Yukon River spawn in Canada, and, in 1981, an estimated 5,500 chinook salmon were commercially harvested in the Canadian portion of the Yukon River (Meacham and Arvey 1981). Subsistence catches of chinook salmon are also significant in the A-Y-K region. In 1981, the subsistence catch of chinook salmon was estimated at 50,000 for the Yukon River and 65,000 for the Kuskokwim River (Meacham and Arvey 1981).

In 1980, the Japanese mothership fishery caught 703,798 chinook salmon in the high-seas fishery, primarily in the Bering Sea. Major (1982) has estimated that 380,417 or 54% of these fish originated from western Alaska, mainly from the Yukon and Kuskokwim Rivers and Bristol Bay. Most of these fish were immature (0.2 ocean age) when caught and would have matured 1-3 yr later. The loss of chinook salmon to U.S. fishermen was estimated to be 5.62 million kg (12.4 million lb) (Major 1982).

CHINOOK SALMON ENHANCEMENT

Although chinook salmon enhancement is presently concentrated in southeastern Alaska and Cook Inlet, there are two projects in other areas. By the end of the 1982 spawning season, 13 hatcheries were rearing chinook salmon (Fig. 2): 8 in southeastern Alaska, 3 in Cook Inlet, and 1 each in the Alaska Peninsula and interior Alaska. One new facility, Trail Lakes Hatchery on the Kenai Peninsula, was scheduled to receive 1982-brood chinook salmon eggs but had construction delays. Many of these programs are in early stages of brood-stock development, and only small numbers of eggs or fingerlings are being cultured.

The 13 chinook salmon hatcheries in Alaska are operated by five organizations: The Alaska Department of Fish and Game operates nine, and the two regional aquaculture associations, the National Marine Fisheries Service and the Annette Island Indian Reservation, each operate one. The State of Alaska controls the transport of chinook salmon eggs to or from hatcheries and the development of the overall program at each hatchery.

In satellite projects associated with several hatcheries, chinook salmon fry, fingerlings, or smolts are held in marine net-pens or are released in streams or lakes to produce returns of anadromous adults. In a few projects, mostly in the Anchorage urban area and on the Kenai Peninsula, chinook salmon fry are planted in landlocked lakes for a recreational fishery.

In programs producing anadromous chinook salmon, brood stocks for the hatcheries and satellite projects are carefully selected so that wild spawning populations are protected and maintained, and the particular enhancement needs in the area are met. Brood stocks usually come from the region where the hatchery is located, and most hatcheries are placed where chinook salmon are not endemic. Only one hatchery project has been developed on a stream with a large, wild population of spawning chinook salmon: At Crooked Creek, a tributary of the Kasilof River, on the Kenai Peninsula of Cook Inlet, the same stock that spawns in the stream is used in the hatchery and in several satellite projects in the region. In another stream, Ship Creek, near

[2]W. D. Arvey, Regional Research Supervisor, Commercial Fisheries Division, Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK 99502, pers. commun. December 1982.

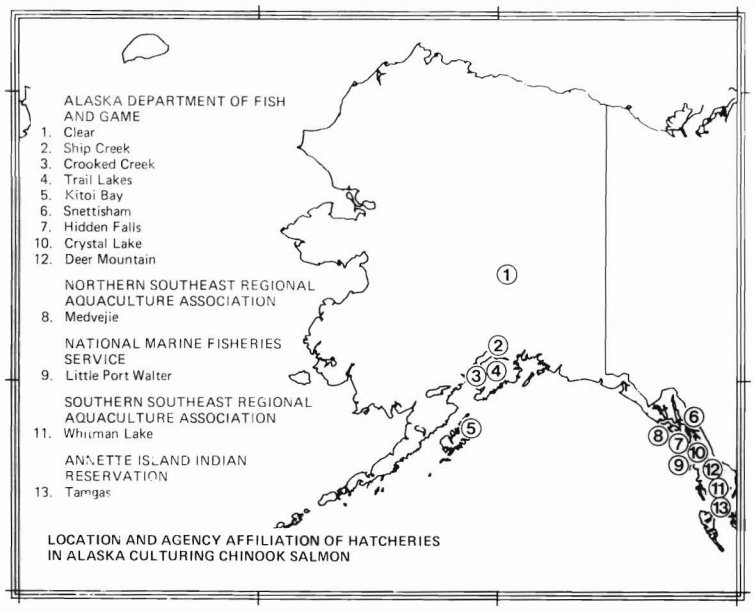

Figure 2.—Location and agency affiliation of hatcheries raising chinook salmon in Alaska.

Anchorage, wild chinook salmon spawn in the stream; however, most adult chinook salmon in that stream apparently originate from hatchery production. Fish from other areas have also been transplanted to Ship Creek.

Before considering some enhancement projects more closely, I will briefly review the freshwater biology of Alaska chinook salmon. Smolts migrate into seawater in April, May, and June (Meehan and Siniff 1962; Kissner 1977; Raymond 1981[3]), and most migrate in May and June. Juvenile chinook salmon can have two life history patterns, generally referred to as ocean type or stream type. The ocean type migrate to seawater during their first year; the stream type migrate after remaining 1 or 2 yr in freshwater (Gilbert 1912). (The terms "ocean-type" and "stream-type" are similar to the terms "fall" and "spring"; however, the terms "fall" and "spring" apply to the time of spawning migrations.) Most chinook salmon in Alaska have a stream-type biology (Yancey and Thorsteinson 1963; Rowland 1969; Waite 1979; Kissner 1981, 1982); however, recent research on chinook salmon in the Kenai River raises questions on the age that juveniles enter seawater in that system (Dave Wangaard[4]). In North America, ocean- and stream-type chinook salmon are probably different genotypes rather than environmentally regulated phenotypes and, because of different ocean-migration traits, have different potentials for contributing to specific fisheries (Healey 1983).

On the Taku River in southeastern Alaska and on Crooked Creek in Cook Inlet, 0-age chinook salmon fry move downstream during mid- to late-summer and early fall (Kissner 1977; Waite 1979) and apparently remain overwinter in downstream freshwater areas some distance from the spawning area. Presumably, other siblings remain overwinter in upstream waters closer to their natal areas. Other stocks of stream-type chinook salmon also have this behavior (French and Wahle 1959; Royal 1972).

Chinook salmon in Alaska spawn in July, August, and September. Most spawn in August, and in many large Alaskan rivers, chinook salmon are the first spawning salmon to appear each year.

Cook Inlet

The three hatcheries in Cook Inlet that culture chinook salmon —Ship Creek, Crooked Creek, and Trail Lakes—each have a slightly different enhancement strategy. Because of arctic winters in Cook Inlet, most overwinter culture of chinook salmon is at Ship Creek Hatchery, which uses warm water from the cooling ponds of a large power plant. Eggs are collected from racks on Crooked Creek and Ship Creek in the fall, transported to Ship Creek Hatchery, and raised 6-8 mo in warm water to 0-age smolts. Smolts are released either in the stream of origin or in satellite projects in the region. Some fish from almost all releases are coded-wire tagged to evaluate the projects. In 1981, some Crooked Creek chinook salmon eggs were retained at the Crooked Creek Hatchery, where, because of cooler water, most smolts are scheduled to be released as yearlings.

At the Trail Lakes Hatchery, located on the headwaters of the Kenai River System, eggs will be incubated and reared to only early stage fry. This modular hatchery was designed to simultaneously culture several stocks in isolation. The fry will be planted in areas with unused rearing potential in the Cook Inlet area. In 1982, it remained undecided as to which stocks would be used at this hatchery and where the fry would be planted.

Chinook enhancement at Crooked Creek has had some success: From 0.9 to 1.5% of the released smolts returned to Crooked Creek as adults, including jacks (Waite[5]). In 1982, 74% of the 3,503 fish returning to the Crooked Creek Hatchery were estimated to be hatchery fish, and an estimated 79% of the 2,800 fish caught in a recreational fishery at the stream mouth were from the hatchery.

Evaluating adult chinook salmon returns at Crooked Creek (and other areas) from either hatchery or wild stocks is complicated by

[3]Raymond, J. A. 1981. Outmigration of salmon smolts from Clear Creek, Alaska. Unpubl. rep., 19 p. Alaska Dep. Fish Game, Div. Fish. Rehabilitation, Enhancement, Dev., Juneau, AK 99801.

[4]D. B. Wangaard, Fishery Biologist, U.S. Fish and Wildlife Service, 1011 East Tudor, Anchorage, AK 99503, pers. commun. July 1981.

[5]D. C. Waite, Fishery Biologist II, FRED Division, Alaska Department of Fish and Game, P.O. Box 3150, Soldotna, AK 99669, pers. commun. October 1982.

four factors: 1) Inadequate sampling of precocious males returning after 1 or 2 yr in the ocean; 2) the long-lived nature of the species (some mature and return only after 6, 7, or even 8 yr); 3) a fishery that captures different numbers of multiple age groups that originate from the same brood; and 4) highly variable marine survival of smolts from different broods.

In 1975, the first release of smolts from Crooked Creek included only 3,679 smolts. Since then, from 50,000 to 380,000 smolts have been released annually. Average smolt sizes at release have ranged from 15 to 35 g.

The number of Crooked Creek chinook salmon caught in commercial and recreational fisheries is largely unknown because, presently, neither fishery is systematically sampled for marked fish. The recreational fishery, especially along Cook Inlet beaches approaching the Kasilof River, has increased significantly in recent years. The Crooked Creek chinook salmon enhancement program needs a careful, critical analysis to accurately measure its effectiveness and determine whether or not the hatchery program is adversely affecting wild stock production on that stream.

Three satellite projects in the Cook Inlet area, the Whittier, Seward, and Halibut Cove Lagoon projects, all use smolts reared in warm water at the Ship Creek Hatchery. Age-0 smolts are released into local waters, and in some cases, are kept in marine net-pens before release to improve imprinting to the release site.

The project at Whittier, in Prince William Sound, began in 1981 when smolts were released to provide adults for a recreational marine fishery and eggs for some Prince William Sound hatcheries.

In 1976-79, 442,000 smolts from the Seward project were released into Box Canyon Creek to establish a self-sustaining run for a local marine recreational fishery. The 14-31 g smolts from four broods of Ship Creek and Crooked Creek stocks were released in June each year from 1976 to 1979. Although no adults have been caught in the recreational fishery, 132 spawners, mostly age 0.3 from the 1978-brood releases in 1979, have returned to Box Canyon Creek and spawned (McHenry[6]).

The satellite project at Halibut Cove Lagoon, in Kachemak Bay across from Homer, has been one of the most successful projects in Alaska, as measured by the number of returning adults. The Halibut Cove Lagoon project is evaluated from the percentage of adults returning to the release site that have coded-wire tags. About 100,000 tagged smolts have been released at Halibut Cove Lagoon over an 8-yr period, and over 900 tags have been recovered near the release site. Return rates (including jacks) for smolts released from five broods ranged from 0.8 to 7.3% and averaged 2.7% (Dudiak[7]). Returning adults are snagged (legal in seawater) in a local fishery in the terminal marine area, and in 1982, more than 2,500 fish from this project were caught. However, Halibut Cove Lagoon tags have not been recovered in the marine recreational fishery that catches ocean-feeding chinook salmon only a few miles away in outer Kachemak Bay (Fig. 3).

Southeastern Alaska

Chinook salmon enhancement in southeastern Alaska differs considerably from that in Cook Inlet because fisheries in southeastern Alaska are restricted to marine waters, and most are caught by trolling, which requires feeding fish. A successful enhancement program must, therefore, produce chinook salmon that are actively feeding in specific marine waters in southeastern Alaska. Most chinook salmon in southeastern Alaska are cultured to age-1 rather than 0-age fish. All chinook salmon hatcheries in southeastern Alaska rear transplanted stocks, and several are situated in remote, roadless areas. All except one, the Snettisham Hatchery, are located on islands. One hatchery, Little Port Walter, is a research facility operated by the National Marine Fisheries Service and the Alaska Department of Fish and Game, and since 1976, a variety of chinook salmon enhancement techniques have been studied at this facility.

Four of eight hatcheries in southeastern Alaska—Whitman Lake, Hidden Falls, Medvejie, and Tamgas Hatcheries—started raising chinook salmon only within the past 3 yr, and their pro-

[6]E. T. McHenry, Fishery Biologist III, Sport Fish Division, Alaska Department of Fish and Game, P.O. Box 285, Seward, AK 99664, pers. commun. October 1982.

[7]N. C. Dudiak, Fishery Biologist III, FRED Division, Alaska Department of Fish and Game, P.O. Box 234, Homer, AK 99603, pers. commun. October 1982.

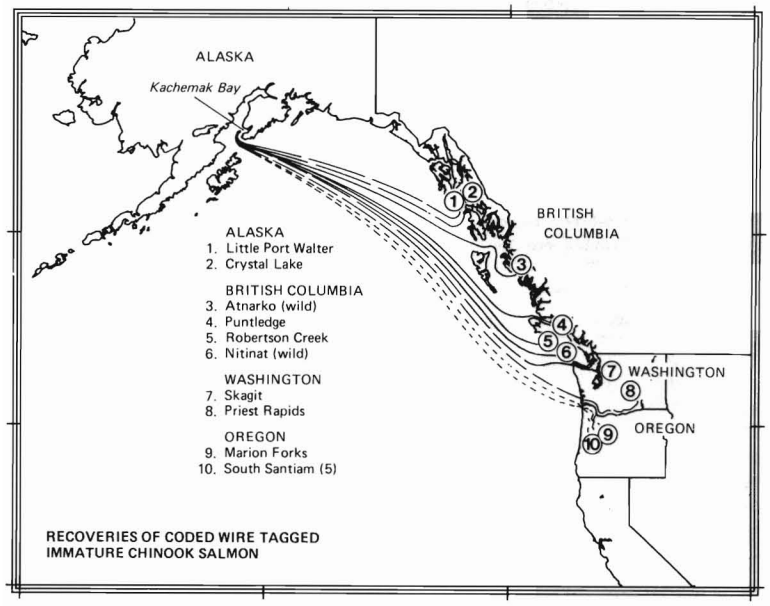

Figure 3.—Recoveries of immature chinook salmon with coded-wire tags from Oregon, Washington, British Columbia, and Alaska stocks in outer Kachemak Bay, Cook Inlet. Modified after Wallis (1980)

grams cannot be evaluated. Medvejie and Tamgas Hatcheries began culturing chinook salmon from 1982-brood eggs.

Three other southeastern hatcheries, Crystal Lake, Little Port Walter, and Deer Mountain Hatcheries, all show promise because chinook salmon from these hatcheries are contributing to the recreational and commercial troll fisheries in the region. Effective programs began at Crystal Lake and Little Port Walter in 1976 and at Deer Mountain in 1977.

Crystal Lake Hatchery was first operated in 1972 and was designed to use recirculating warm water heated by oil furnaces. After dramatic increases in world oil prices, however, the facility has used single-pass, ambient-temperature water similar to other southeastern hatcheries.

Five stocks of chinook salmon are being raised in hatcheries in southeastern Alaska. Two stocks, Andrew Creek stock from the Stikine River and Cripple Creek stock from the Unuk River, are most widely used, both in number of eggs and number of hatcheries. These two stocks and three other stocks (from the Chickamin, King Salmon, and Situk Rivers) all originate from southeastern Alaska. Heard (1982) has reviewed in detail the use of specific chinook stocks at southeastern Alaska hatcheries through 1981. Presently, Crystal Lake Hatchery is using only the Andrew Creek stock, and Deer Mountain Hatchery is using only the Cripple Creek stock. The Little Port Walter Hatchery is conducting some research with three stocks (Cripple Creek, Chickamin River, and Situk River stocks). At Little Port Walter, stocks are maintained separately and returning adults are spawned according to specific matings.

Hatcheries in southeastern Alaska have used different strategies for rearing and releasing smolts. Age-0 smolts (11.4 g) from the 1976-brood were released from Crystal Lake after they were reared in heated water. Smolts from two different 1976-brood stocks were released at Little Port Walter in nine separate groups including one age-0 (36.0 g) and eight age-1 smolt (63.0-82.8 g) groups. Yearling smolts (7.4-10.1 g) from the 1977-brood were released from the Deer Mountain Hatchery.

Preliminary adult returns and contribution to the fisheries are available for 1976-brood releases at Crystal Lake and Little Port Walter, and 1977-brood releases at Deer Mountain. Preliminary overall survival rates (return to hatchery and fishery contributions) of 1976-brood smolts through 5-yr-old fish (1981) was 6.8% for Crystal Lake releases and 7.1-7.3% for Little Port Walter releases (Table 2). Survival of the nine smolt groups at Little Port Walter ranged from 1.0 to 14.1% (Table 3). This includes both adult returns to the hatchery and estimates of contributions to commercial and recreational fisheries. From preliminary analyses of recoveries from 1977-brood at Deer Mountain Hatchery, marine survival (through age-5 adults in 1982) will be about 6.0%. The 1976-brood releases from Crystal Lake and Little Port Walter contributed a significant number of 4-yr-old immature chinook salmon to fisheries throughout the northern part of southeastern Alaska. At Crystal Lake, many mature 4-yr-old females returned with 4-yr-old males to the hatchery from age-0 smolts (Zorich[8]); however, at Little Port Walter, only males matured and returned as 4-yr-olds from yearling smolts. In 1982, about 50 5-yr-old females that returned to Deer Mountain Hatchery were spawned for the first filial (F-1) generation of eggs taken at that facility. Collectively, in 1982, about 1.4 million chinook salmon eggs were taken from adults returning to Crystal Lake, Little Port Walter, and Deer Mountain Hatcheries.

Two satellite projects for enhancing chinook salmon in southeastern Alaska began in 1982. Both projects are designed to determine whether natural rearing areas can be used to increase smolt production. In the first project, eggs from 1981-brood Chickamin stock were cultured to early fry stage at Whitman Lake Hatchery, a Southern Southeastern Regional Aquaculture Association Hatchery, and the fry were then planted in the Carroll River. In the second project, fry from 1981-brood Chickamin River stock were reared at the Little Port Walter Hatchery and planted into two small nearby lakes.

Table 2.—Preliminary marine survivals through age 5 of 1976-brood chinook salmon smolts released at Crystal Lake Hatchery[1] and at Little Port Walter in southeastern Alaska.

Stock	Smolts released (No.)	Adults recovered (No.)	Survival (%) All smolts	Survival (%) Age-1 smolts
Crystal Lake Hatchery:				
Andrew Creek	166,030	11,363	6.8	—
Little Port Walter:				
Cripple Creek	22,508	1,598	7.1	7.1
Chickamin River	18,431	1,344	7.3	9.7

[1]Data provided by Bob Zorich, Alaska Department of Fish and Game, Crystal Lake Hatchery.

Other Areas

The two other chinook salmon enhancement projects in Alaska are at Kitoi Bay and Clear. Clear Hatchery (Fig. 2) is located at

[8]R. G. Zorich, Fishery Biologist II, FRED Division, Alaska Department of Fish and Game, Swanson Building, P.O. Box 667, Petersburg, AK 99833, pers. commun. October 1981.

Table 3.—Marine survival through age 5 of nine 1976-brood chinook salmon smolt groups released at Little Port Walter in southeastern Alaska.

Treatment group[1]	N	Release date	Size (g)	No. recovered Age 2	Age 3	Age 4	Age 5	Total	Survival (%)
C-5	5,034	8-21-77	36.0	0	1	37	11	49	1.0
U-10	4,918	4-12-78	64.8	2	3	56	46	107	2.2
U-11	4,536	4-13-78	63.9	7	8	62	26	103	2.3
C-12	4,552	4-14-78	72.2	1	0	104	29	134	2.9
C-13	4,472	5-11-78	64.2	3	2	382	156	543	12.1
C-14	4,373	5-12-78	84.6	0	5	411	202	618	14.1
U-15	4,408	5-13-78	64.5	18	55	342	132	547	12.4
U-16	4,462	5-10-78	64.7	23	56	311	87	487	10.9
U-17	4,184	6-07-78	82.8	46	64	170	74	354	8.5

[1]Identifies stock and tag codes C = Chickamin River stock; U = Unuk River stock.

Clear Air Force Station, near Anderson, and like Ship Creek Hatchery, uses warm water from cooling ponds of a power plant. Juvenile salmon from Clear Hatchery are released into a nearby tributary of the Nenana River, which flows into the Tanana River, which in turn flows into the Yukon River.

In 1981, eggs were collected from fish in the Salcha River, a tributary of the Tanana River, and transported to Clear Hatchery. The chinook salmon were cultured to 0-age smolts (3.4 g), and 103,000 were released at the hatchery in May 1982 (Raymond[9]). Twenty-five thousand smolts were coded-wire tagged and represent the first marked juveniles and the first chinook salmon enhancement effort in the A-K-Y region. This experimental program is also exploring the feasibility of enhancing runs of chinook salmon in the interior arctic Alaska.

The Kitoi Bay Hatchery has a satellite project at Lake Rose Tead, Kodiak Island. Beginning with the 1975 brood, chinook salmon eggs were collected from the Chignik River stock on the Alaska Peninsula, transported to Kitoi Bay Hatchery, and cultured to the early fingerling stage. Fingerlings were then released into Lake Rose Tead to produce adult returns for a local recreational fishery (Murray[10]). Some adults returning to Lake Rose Tead (F-1 adult returns) were used as a brood stock. In 1981, about 25% of the 133,000 eggs collected were from F-1 adults returning to Pasagshak River, the outlet stream to Lake Rose Tead (McMullin and Kissel 1982). In 1982, about 37,000 of the eggs taken for the project were from returning F-1 adults (Murray footnote 10).

In an earlier Kodiak Island project similar to the one at Lake Rose Tead, chinook salmon fry were transplanted to Frazer Lake from Kitoi Bay Hatchery to establish a self-sustaining anadromous run (Blackett 1979). The Karluk River stock, also on Kodiak Island, was used to establish the run at Frazer Lake.

DISCUSSION

Of the five species of Pacific salmon, chinook salmon provide the fewest fish to Alaska's varied fisheries; however, they are the most valuable and highly prized species in all the fisheries. Although most fisheries in Alaska are still based on natural chinook salmon production, hatchery fish are contributing to fisheries in Cook Inlet and southeastern Alaska. In southeastern Alaska, however, much of the hatchery contribution comes from outside the region. Increased enhancement activity in Alaska has developed partly to provide more chinook salmon to these fisheries.

In Cook Inlet, new recreational fisheries have developed from hatchery or satellite projects, such as the Crooked Creek Hatchery and the Halibut Cove Lagoon project. Other satellite enhancement programs should increase production or develop new natural runs of chinook salmon. Although sampling is incomplete and varied, in 1982, between 8,000 and 10,000 adult chinook salmon from Alaska enhancement programs were caught in Alaska fisheries, divided about equally between Cook Inlet and southeastern Alaska. The full potential for enhancement of chinook salmon in Alaska may not be realized for several years because many programs are still developing and will be influenced by the complex biology of chinook salmon, specific enhancement objectives, and regional and international sociopolitical issues.

One of the more challenging and complex aspects of chinook enhancement in Alaska is to meet the needs of diverse fisheries throughout the state. The needs of the chinook salmon fishery in southeastern Alaska, for example, are different from those in Halibut Cove Lagoon. In southeastern Alaska, the troll fishery is dependent on ocean distribution and migration patterns of specific stocks of chinook salmon. Hatchery programs contributing to this fishery must produce chinook salmon that actively feed in marine waters where the fishery occurs. In Halibut Cove Lagoon, a highly successful program has developed based on returns of maturing chinook salmon that have completed their ocean-feeding phase. Healey (1983) pointed out that ocean trolling is more effective in harvesting immature than mature chinook salmon. An excellent example of this is seen in lower Cook Inlet where ocean feeding chinook salmon from many North American stocks are caught in the small sport-troll fishery in outer Kachemak Bay (Fig. 3); yet, no fish from the nearby Halibut Cove Lagoon project have been caught in this fishery. Ocean-type and stream-type stocks, because of different ocean-migration traits, may have different potentials for contributing to troll fisheries (Healey 1983); therefore, stock genetics, location of hatcheries or satellite projects, and enhancement techniques will influence how well different stocks contribute to specific fisheries that have diverse needs in different parts of Alaska.

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Systematic Genetic Selection and Breeding in Salmonid Culture and Enhancement Programs[1,2]

WILLIAM K. HERSHBERGER and ROBERT N. IWAMOTO[3]

INTRODUCTION

Genetic selection and directed breeding have been a part of animal husbandry for perhaps 10,000 yr. The benefits of these procedures are quite apparent in the production realized from domesticated agricultural animals. While a large part of these accomplishments were achieved without any real knowledge of genetic principles and concepts, the approach used was one of basic genetic management. The practices employed included choosing superior individuals for breeding, culling of inferior individuals, development of specific strains, and cross-breeding of strains to improve specific traits. These techniques are still employed as part of the genetic management of agricultural animals and continue to play a major role in improvement of their production.

Some of these same procedures have been practiced in the culture of salmonid fishes. However, because of the relatively short history of successful cultivation of these species in captivity, changes beneficial to the intensive cultivation of this group of fishes have been slow to be realized.

Because control can be exercised over the entire life cycle by rearing in a hatchery, most of the selection and breeding work conducted on salmonids has been with *Salmo* and *Salvelinus* species. Significant gains in performance characteristics have been realized with these species. Early work with brook trout, *Salvelinus fontinalis*, demonstrated the efficacy of the genetic approach to improve disease resistance (Embody and Hayford 1925). Lewis (1944) reported alteration of the life history traits of rainbow trout, *Salmo gairdneri*, by use of selection. Perhaps the most long-term selection program reported to date on salmonids is that of Donaldson (1968) on rainbow trout and chinook salmon, *Oncorhynchus tshawytscha*. Gains in a number of traits important to culture of these species were reported after 35+ yr of selective breeding.

All of these studies were based on the concept of selective breeding, generally, the process whereby the reproducing adults are chosen only on the basis of their phenotype. While this approach has been demonstrably successful, it has several undesirable characteristics. From a commercial point of view, the most important of these are 1) unpredictability of selection response, 2) the inability to monitor genetic change, 3) more likely probability of inbreeding problems, and 4) the slow response of some less heritable traits. By application of more systematic selection and breeding methods (Falconer 1960), these problems can be largely avoided. Thus, it would seem desirable to attempt to apply a more systematic approach to the genetic improvement of these fish for intensive culture.

Very little basic genetic selection and breeding work has been conducted with Pacific salmon (*Oncorhynchus*) species. As previously mentioned, chinook salmon have been selectively bred (Donaldson and Menasveta 1961), largely to change the age at return to spawn. Other short-term and largely nongenetically oriented reports have suggested the hereditary nature of a number of traits (see review by Ricker 1972) and their potential response to selection and breeding. However, few have involved a genetic assessment of the traits studied or satisfactorily measured a response to selection.

A large part of this lack of research can be attributed to the inability to control the entire life cycle of the salmon and to assure adequate returns for breeding. Without these capabilities, it is not possible to obtain accurate measurement of the genetic component involved in traits important to intensive culture. With the development of the technology necessary to raise Pacific salmon species in marine net-pen enclosures (Novotny 1975), these two problems were largely negated. In addition, commercial interest in raising and marketing Pacific salmon utilizing this approach provided an impetus to develop a more systematic and predictable approach to selection and breeding of these species.

MARINE NET-PEN CULTURE PROGRAM

In the United States, marine net-pen culture of Pacific salmon began in 1970 (Novotny 1975). The industry that developed was, and still is, based almost exclusively on the production of immature 350-400 g coho salmon, *O. kisutch*. Details on the culture of these fish and related technology can be obtained in the report by Novotny (1975). The choice of species was based largely on hardiness and general adaptability to production conditions. Also, because of a large emphasis on culturing this species in state and federal hatcheries, a ready supply of eggs and sperm was initially available. However, there was soon a realization that to improve the efficiency of production and minimize associated costs, it would be necessary to develop a "domesticated" stock adapted to conditions of complete captive culture.

In 1978 we initiated a program to develop a coho salmon broodstock for the marine net-pen industry. This cooperative program between the University of Washington, the Sea Grant Program, and Domsea Farms, Inc., had a long-range goal to develop a coho salmon stock with desired characteristics for marine pen culture. Specific traits chosen for genetic improvement, based on economic considerations of the industry, were 1) freshwater growth rate, 2) saltwater growth rate, and 3) smoltification. Thus, the breeding goals were defined and limited to the traits that would be of maximum economic benefit.

Since no information was available on the genetics of these traits in coho salmon, the first step was to estimate the genetic and phenotypic parameters associated with the expression of these

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traits. Determination of these values was necessary to 1) indicate the likelihood of a selection program to change the genetics of a trait, 2) devise the appropriate selection scheme, and 3) predict the amount of change that could be expected. We found that adequate genetic variability (expressed as heritability (h^2)) for all three traits existed in this stock, thus assuring a reasonable response through a selection program. Heritability estimates for freshwater and saltwater growth measurements are shown in Table 1. These values agree very favorably with data reported on

Table 1.—Heritability estimates (based on sire component) on freshwater and saltwater growth measurements for progeny from adults spawned in 1977 and 1978.

Measurement date	Trait	BY 1977	BY 1978
Freshwater			
Apr. (4)[1]	Weight	0.61±0.31[2]	0.36±0.21
May (5)	Weight	0.38±0.25	0.47±0.22
	Length	0.30±0.24	0.56±0.25
July (7)	Weight	0.25±0.22	0.26±0.20
	Length	0.22±0.21	0.37±0.21
	Stage[3]	0.29±0.19	0.31±0.09
Saltwater			
Nov. (11)	Weight	0.17±0.15	0.31±0.18
	Length	0.19±0.16	0.38±0.20
	Stage[3]	0.25±0.14	0.32±0.11
Mar. (15)	Weight	0.19±0.11	0.62±0.21
	Length	0.18±0.11	0.45±0.17

[1]Months postfertilization.
[2]Standard error.
[3]Based on morphological smolt index (0 = Parr, 1 = Smolt).

these traits in other salmonids (Aulstad et al. 1972; Chevassus 1976; Refstie and Steine 1978). In addition to h^2 estimates, several other genotypic and phenotypic parameters were estimated to provide information on the relationships of the traits and to give guidance on the types of selection that would yield the maximum gain (Hershberger et al. 1982; Iwamoto et al. 1982; Saxton et al. 1982).

Based on these data and the production needs of Domsea Farms, a selection scheme was devised that would provide the best selection results with the physical facilities available. The selection program developed is shown in Figure 1. This selection strategy includes independent culling during incubation followed by family selection during the saltwater phase. Family selection is based on a selection index incorporating both freshwater and saltwater performace traits. At maturity, spawners from the selected families are chosen on the basis of individual merit and mated according to a circular mating design (Fig. 2). The specific mating design was chosen to minimize the increase in inbreeding per generation (< 0.1% per generation).

This system has been used on two odd (BY 1979 and BY 1981) and two even (BY 1980 and BY 1982) year cycles of coho salmon in this program. Gains in the areas of improving freshwater and saltwater growth have exceeded our original expectations (Hershberger et al. 1982; Iwamoto et al. 1982; Saxton 1980). For example, as a result of one generation of selection, realized gains in freshwater growth were 97% and 52% in progeny from the 1979 and 1980 brood years, respectively. These values can be compared with a maximum predicted gain of 46% for the 1979 brood year progeny. While these gains cannot be totally attributed to genetic change because of the lack of an appropriate control population,

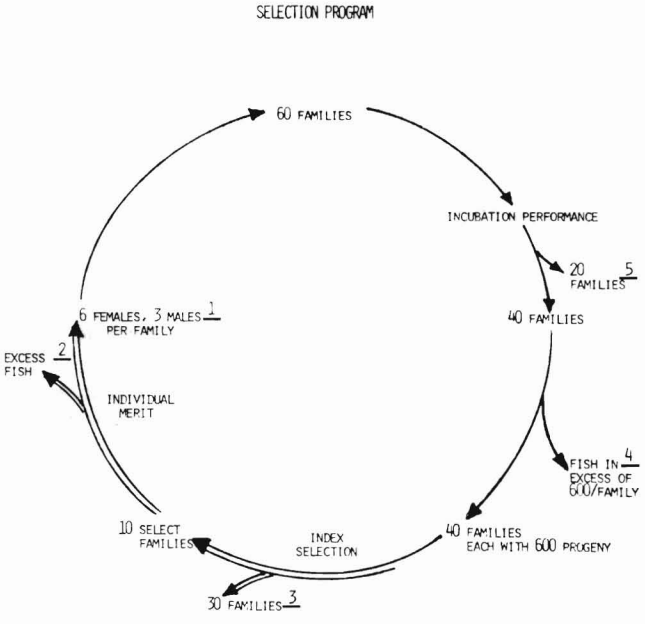

Figure 1.—Diagram of the selection program used to develop a coho salmon stock for marine pen culture. The single line indicates rearing in freshwater and the double line rearing in saltwater. The underlined numbers indicate a "relative selective value" of the groups "rejected."

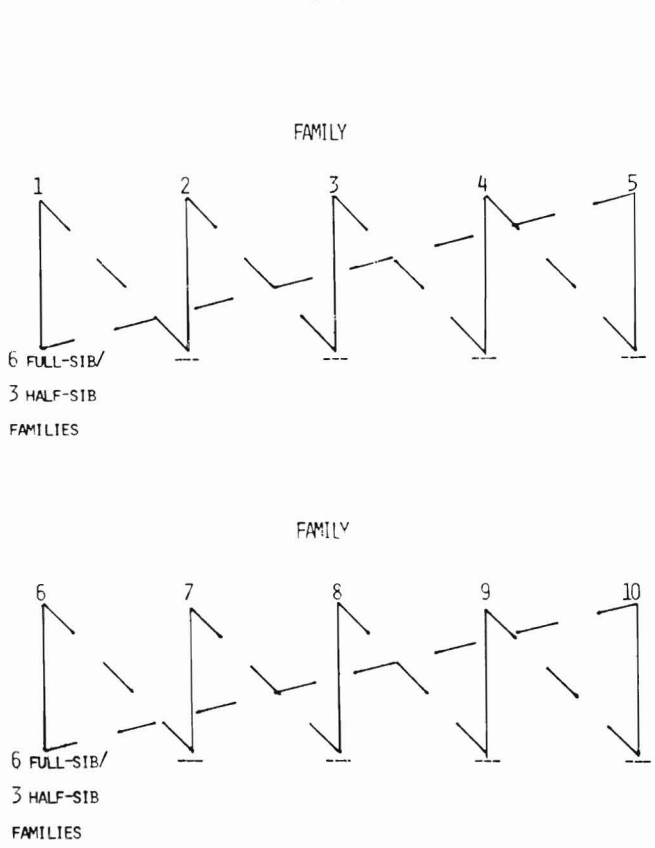

Figure 2.—Diagram of the mating system used in spawning selected individuals to develop a coho salmon stock for marine pen culture.

the improvement is substantial and meaningful for commercial production.

Another critical area of production in which substantial improvement has been realized is survival on transfer to saltwater. Under natural circumstances this movement is volitional and is probably controlled by the ability of the fish to physiologically function in a saltwater environment (Hoar 1976). However, in marine net-pen culture the fish are directly transferred to saltwater, with no previous opportunity for adaptation. In the past this technique has resulted in very low survival rates (<30%). In 1981 progeny from selected parents were compared with an unselected group of coho salmon from Washington Department of Fisheries hatcheries. After identical incubation and rearing conditions, 95% of the fish from the selection program were ready to transfer to marine net pens, versus 67% of the control group. This reflected a substantial improvement in this area of production after one generation of selection. Further, since readiness to transfer to saltwater seems to be a function of size (Mahnken 1973; Saxton 1980), this result also indicates a more rapid and consistent growth rate.

In addition to the directly selected traits, it has been necessary to develop procedures for improving other areas of fish culture to assure the continuation of the program. The most crucial of these has been the technique of maintaining maturing adult fish in captivity. Because of the "pioneering" nature of this work, little research had been conducted on such basic problems as brood stock nutrition, disease treatment, and specific husbandry requirements. These areas have been approched in a number of different ways. A Sea Grant funded program is currently underway to develop a broodstock diet to improve gamete quality and viability. Preliminary results indicate several dietary components have major effects on gamete quality. The major disease problems in maturing adults (vibriosis and bacterial kidney disease) have been controlled by use of a vaccination program using a bivalent vibrio vaccine (Schiewe and Hodgins 1977) and an erythromycin injection during the first spring and second summer of saltwater growth, respectively. Mimicking the natural life history of coho salmon by returning them to freshwater for final maturation and spawning has increased egg quality dramatically. For example, survival to the "swim-up" stage averaged 70.5% and 80.0% for those adults transferred to freshwater in 1980 and 1981, respectively. In comparison, fish spawned directly from saltwater exhibited an average of 30.2% in 1980. The overall success of these procedures can be seen in Table 2. Substantial progress has been realized in improving survival in all stages of rearing, including mature adults.

POTENTIAL ENHANCEMENT APPLICATIONS AND FUTURE DIRECTIONS

The major emphasis of this program has been to improve traits desirable to the commercial net-pen culture of coho salmon. Because of this focus, a majority of the information is not directly applicable to the free-ranging characteristics of salmon used for enhancement or ocean ranching. However, there are a number of areas where data gleaned from this program can be applied. The first is in the freshwater culture of young salmon. Our stock development program has shown that substantial genetic variability exists for freshwater growth characteristics, and these can be substantially improved by selection (Iwamoto et al. 1982). Size prior to migration to saltwater has been shown to be a major factor in the success of smoltification (Mahnken et al. 1982). Thus, by improvement of growth in freshwater the potential exists for greater survival in saltwater (Saxton et al. 1982).

Related to this, we found in one brood year (1978) a relatively high correlation of freshwater growth with subsequent saltwater growth (Hershberger et al. 1982). Although this result is preliminary and needs further verification, it suggests that increased growth in freshwater may be accompanied by a similar response in saltwater. Thus, selection in the hatchery may result in a greater growth in saltwater. This would be a definite benefit in harvest of adult fish.

Finally, successful culture of adult Pacific salmon in captivity can provide two major benefits. First, investigation of the processes involved with gamete maturation and reproductive physiology, which are necessary for a captive breeding program, will give us a better understanding of the requirements for optimum

Table 2.—Summary of percent survival values at different rearing stages of the various cohorts from selected families in the coho stock development program.

	Swim-up	Freshwater rearing[1]	Percent survival initial saltwater rearing[2]	Market size	Adult[3]	Adult[4]
Odd year line						
BY 1977	72.0	94.9	41.5	54.3	22.7	9.8
BY 1979	53.5	82.2	81.0	80.8	29.6	12.1
BY 1981	[5]78.9	86.9	88.5			
Even year line						
BY 1978	60.5	87.9	55.2	70.2	21.6	7.6
BY 1980	51.5	92.9	94.1	[6]62.5		

[1] $\frac{\text{No. at end of freshwater rearing}}{\text{No. ponded}}$

[2] $\frac{\text{No. surviving 3 mo postsaltwater transfer}}{\text{No. at end of freshwater rearing}}$

[3] $\frac{\text{No. surviving to spawn}}{\text{No. transferred to saltwater}}$

[4] $\frac{\text{No. surviving to spawn}}{\text{No. eggs incubated}}$

[5]Reflects improvement resulting from transfer of adults to freshwater.

[6]Reflects mortalities in the fall of 1981 from infection by gill parasites (*Sarcodina* and *Costia* spp.).

reproduction. Second, this technology will provide the opportunity to maintain endangered, or threatened stocks without fear of extinction, and may give us a tool for conducting more precise selection programs for ocean ranching concerns. One of the problems in conducting selection and breeding programs for ocean ranching is the uncertainty of retrieving an adequate sample of brookstock for reproduction purposes. Maintaining a cross-section of selected families in marine net-pens for spawning purposes may solve this problem.

Caution must be expressed in applying the data from the present program to ocean ranching too extensively, however. Conditions in the two situations are very different and, consequently, may largely negate any cross-use of genetic information.

Considerable success has been achieved through the combined use of systematic genetic selection and breeding and culture technique modifications during the short tenure of this project. However, several areas need further work and continued investigation, and the program must be flexible enough to meet production requirements. One of the most important aspects to be addressed this next year is the evaluation of the genetics of the traits emphasized during the course of this program. Continued selection will alter the genetic factors determining a trait (Pirchener 1969), which will concomitantly change the response to selection and type of selection needed to realize a constant response. Thus, monitoring of genetic changes is necessary to assure continued success in improving the stock.

A further aspect to be considered is genetic analysis of additional traits that are important to production. Several are currently being investigated for possible incorporation into the selection program. These include flesh color, yield at processing, and adult reproductive characteristics. The first two are important to the production and marketing of the coho salmon. It has been shown that flesh color is one of the main factors in consumer differentiation of salmon and trout (Ostrander et al. 1976), and thus will have a large influence on the price of the product. Improvement in yield at processing (dress-out weight) has the potential to increase the efficiency of growing a marketable product, and thus decrease production costs. Finally, rainbow trout has shown adequate genetic variability in some reproductive traits to expect some response to selection (Gall and Gross 1978). We are now evaluating several adult reproductive traits for possible incorporation into the selection program in order to improve the quality and quantity of gamete production.

SUMMARY

The use of a systematic selection and breeding program to develop a coho salmon broodstock for the marine net-pen industry has shown that such an approach can be applied beneficially to improve production traits. Freshwater growth, saltwater growth, and smoltification have all been increased by a greater extent than predicted. Further, by use of the appropriate design, genetic changes over time can be monitored, production needs can be met, and potential inbreeding effects can be minimized. Some of the results obtained with the marine net-pen system can be used as indicators for possible gains in ocean ranching endeavors, but a cautious approach must be used in generalizing the data. Additional studies are needed on other desirable production traits to enhance the marine net-pen culture of coho salmon. Through long-term, systematic selection and breeding programs on salmonid, and other species important to aquaculture, significant gains in desirable traits can be realized to enhance production of these species.

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Advances in Tagging and Tracking Hatchery Salmonids: Coded Wire Tags, Multiple-Coded and Miniature Radio Tags, and the Passive Integrated Transponder Tag

GERALD E. MONAN[1]

ABSTRACT

An overview of four advanced fish tags that can be used effectively by aquaculturists and biologists working with hatchery salmonids is given. The four tags are: The coded wire-rare earth tag, the multiple-coded radio tag, the miniature radio tag, and the passive integrated transponder tag. Descriptions of each tag and its related equipment as well as a discussion of each tag's capabilities are given.

INTRODUCTION

Aquaculturists and fishery biologists working with Pacific salmon, *Oncorhynchus* spp., and steelhead, *Salmo gairdneri*, have a vital interest in the fish they raise and study. They need to know: How much they grow, how they survive, where they migrate, and how they behave. To obtain this information, they must have a means of distinguishing one group of fish from another and/or one fish from another within the group.

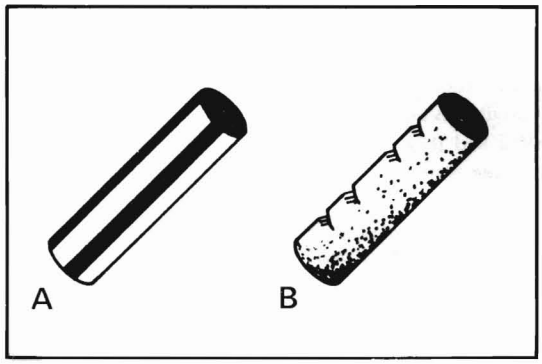
A variety of marking and tagging techniques have been developed to provide a means of identifying specific fish or groups of fish (Konstantinov 1977). These include but are not limited to: Complete or partial fin clipping (Rounsefell 1963); various passive tags like the Petersen tag, Atkins tag, body-cavity tag, strap tag, internal anchor tag, and spaghetti tag (Jensen 1962); tattooing (Chapman 1957); branding (Raymond 1974); subcutaneous injection (Thresher and Gronell 1978); coded wire tags (Bergman et al. 1968); and sonic and radio tags (Monan et al. 1975). The tags have developed from simple external visual identifiers to sophisticated electronic devices that can provide a variety of information about the tagged fish and its surroundings.

The objective of this paper is to provide an overview of four of the latest fish tags developed in North America that can be used effectively by aquaculturists and biologists working with hatchery salmonids. The tags to be discussed are the coded wire tag (CWT), the multiple-coded radio tag, the miniature radio tag, and the passive integrated transponder (PIT) tag.

CODED WIRE TAGS

The coded wire identification tag (CWT) was developed by Jefferts et al. (1963); Bergman et al. (1968) and Hager and Jewell (1968) evaluated the tag. The CWT's greatest attributes are that it can be applied to fish as juveniles and recovered when they are adults, it has an almost unlimited number of codes, and it has a minimum effect on the behavior of the fish.

The CWT, as it is used on Pacific salmon and steelhead in the Pacific Northwest, is a 1 × 0.25 mm magnetized stainless steel wire that is either color coded or binary coded (Fig. 1). The wire is



Magnified color-coded (A) and binary (B) wire tags
(actual size 1 x 0.25 mm)

Figure 1.—Coded wire tags.

injected into the snout of the juvenile fish where it can be carried for life. Overall tag loss during growth of fish from juvenile to adult size can be as low as 3% (Ebel 1974). A half-tag has also been developed that is suitable for fry such as pink salmon, *O. gorbuscha* (Kaill[2]).

Tagging is fast and easy; anesthetized fish are positioned nose first into a specially formed head mold that positions the fish in the proper relationship to the tag injector. The pressure of the fish against the mold triggers the injector in one system, whereas the operator presses a button in another, and the tag is injected into the cartilaginous wedge of chondrocranium located in the fish's snout anterior to the eyes. Head molds that fit the snouts of the size and species of fish being tagged are critical to effective tagging. An experienced tagger can tag up to 1,000 fish/h.

Appropriate detectors can determine if a fish is carrying a CWT. These detectors are equally effective with juvenile fish right after tagging or years later when the tagged fish has reached adulthood. The detection system can be a hand held device that is pass-

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[2]M. Kaill, Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK 99502, pers. commun. October 1982.

ed over the fish or it can be a more sophisticated device that can automatically detect tagged fish and separate them from untagged fish (Ebel 1974).

In the automatic separator widely used on the Columbia River (Ebel 1974), adult fish that were tagged as juveniles ascend a fish ladder and after passing over a false weir slide down a chute through the detector coil. If a tag is detected, a gate is activated deflecting the fish into a holding pen; untagged fish simply return to the fishway to resume their migration.

Once the tagged fish has been detected, the tag must be removed from the fish's snout for decoding. This is usually accomplished by removing a plug of flesh from the fish's snout. The plug with the tag inside is then placed in a concentrated solution of potassium hydroxide to free the tag which is then read with the aid of a microscope. Freeing the tag and reading the code is a relatively slow process—an experienced worker can extract and read 10-15 tags/h.

The cost of tags is approximately $16 to $25/thousand, a tagging machine costs about $20,000 to $23,000, and tag detectors cost from about $3,600 to $9,300.

To increase the usefulness of the CWT by eliminating the need to remove the tag from the fish is the objective of research being conducted by National Marine Fisheries Service (NMFS) scientists in Seattle, Wash. (Park[3]). The major goal of NMFS scientists is to produce a tag and detector that will allow a tagged fish to be detected and its code determined automatically without the fish leaving the water.

The system they have developed involves coating the tag with one or more rare earth metals (e.g., cerium, lutetium, etc.). Presently at least 45 codes are available at a cost of about $25/thousand tags. The tags are applied with a regular CWT tagging machine. At this stage of development, detection and decoding are in two steps. The tags are detected with a conventional magnetic detector. Once the tagged fish is in hand, the fish is placed in a moist tray and subjected to X-ray fluorescent spectroscopy. The X-ray process takes 5 to 15 s, and the fish is out of water for a total of about 30 s. Following the X-ray treatment, the system analyzes the data, determines the tag code, indicates the results on a video screen, and makes a permanent record on punched tape.

In 1980, the system correctly identified all 15 adult chinook salmon, *O. tshawytscha*, returning from a group of juveniles tagged with rare earth tags in 1979. In addition, the system has correctly identified numerous juvenile fish tagged with rare earth tags.

An automatic system of in-water identification, while deemed feasible, will probably not be developed by NMFS scientists in the near future because of funding restraints. Nevertheless the system as developed has significant merit in that: 1) The fish is not sacrificed; 2) faster tag identification (tag would not have to be extracted from the fish); 3) computerizing data in real time—reducing errors and decreasing processing time; and 4) genetic studies where selected groups of adults could be tagged, identified as to their genetic makeup prior to spawning and selected genotypes mated.

ELECTRONIC TAGS

The problem with conventional tags is that for all practical purposes, once the fish has been tagged and released, any information subsequently obtained relies on either seeing an external tag in situ or after recovery, sacrificing the fish to recover an internal tag. Since fish live in an environment that is not easily penetrated by man's normal senses, most data collection relies on recapture of the tagged fish. Basically, this provides information at two points—the point of release and the point of recapture. If a researcher wants to know about the fish's activities between these two points, a variety of electronic tags are available.

Electronic tags generally fall into two categories—those operating on radio frequencies (operative in freshwater only) and those operating on ultrasonic frequencies (operate in fresh or saltwater). Within these two categories, the tags can be further grouped as simple beacon or pinger tags (tags that can be remotely tracked) and telemetry tags. Telemetry tags not only allow the researcher to track the fish but also can provide a variety of biologically and environmentally important factors, e.g., compass heading (Mitson et al. 1982), salinity of the surrounding water (Priede 1982), temperature (Coutant and Carroll 1980), depth (Luke et al. 1973), heart rate (Priede and Young 1977), tail beat (Ross et al. 1981), swimming speed (Voegeli and Pincock 1980), etc.

Several excellent reviews of electronic tags have been published (Stasko and Pincock 1977; Ireland and Kanwisher 1978; Nelson 1978; Harden Jones and Arnold 1982). In addition, the *Underwater Telemetry Newsletter* published an extensive bibliography of underwater telemetry in biological applications in its initial issue —Volume 1, Number 1—in April 1971. This bibliography has been continuously updated in subsequent issues.[4]

In this paper, I will discuss two recently developed radio tags and their related tracking systems and a new electronic tag being developed.

Multiple-Coded Radio Tag For Adult Salmonids

Radio tags developed by NMFS personnel were first used in the field to study the behavior of adult spring chinook salmon in the Columbia River as they approached a major hydroelectric dam interrupting their upstream migration (Monan and Liscom 1971[5]).

The tag initially used was a battery powered, high-frequency radio transmitter that operated on a carrier frequency of approximately 30 MHz, had a 167 mW input and an effective tracking range of 0.8 km or more, and was operational for about 15 d. Tag life was variable and could be extended to up to 60 d if desired. The transmitter and batteries were sealed in a plastic capsule about 89 mm long and 19 mm in diameter (Fig. 2). Each tag weighed about 28 g in water and was carried in the stomach of the fish except for a small wire antenna that extended from the tag, through the fish's esophagus, and was attached to the roof of the fish's mouth. The tags were frequency coded. There were nine separately identifiable codes (30.17, 30.18,. . . , 30.25 MHz) and herein was a major area that needed improvement. Nine codes were not enough to permit sufficient numbers of fish to be tracked during the limited migration periods of the salmon being studied.

Development of a multiple-coded radio tag and decoding receiver was a significant advance in fish tracking capabilities.

[3]D. Park, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. East, Seattle, WA 98112, pers. commun. September 1982.

[4]Issues are available by writing: Dr. Charles Coutant, Editor UTN, Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box X, Building 1505, Oak Ridge, TN 37830.

[5]Monan, G. E., and K. L. Liscom. 1971. Radio tracking of adult spring chinook salmon below Bonneville Dam, 1971. Natl. Mar. Fish. Serv. North Pac. Fish. Res. Cent., Seattle, Wash., Final Rep. to U.S. Army Corps Eng., Delivery Order NPPSU-PR-71-2617.

Figure 2.—Multiple-coded radio tag suitable for adult salmonids.

With the new tag and equipment, it is possible to identify up to 80 tags/frequency or 720 total.

The multiple-coded tag uses a pair of pulses to establish its code. The first or main power pulse is 15 ms in duration; a 5 ms code pulse follows. The time between the two pulses varies from 0.5 to 40 ms (Fig. 3) and dictates the code of the tag. The size, weight, and external appearance of the multiple-coded tag are essentially the same as the initial radio tag.

Special decoding receivers were designed; pulses from a 2 kHz oscillator were gated into a register starting at the trailing edge of the 15 ms power pulse and stopped at the trailing edge of the 5 ms code pulse. The decoding receiver decodes the tag and prints the frequency and code of the tag, and a conventional receiver and antenna are used to determine the location of the tagged fish.

The cost of radio tags for adult salmon is about $100-140/tag, a basic receiver and antenna unit is approximately $2,000, and a decoding receiver is about $5,000.

Miniature Radio Tag

The tags described previously are suitable for adult salmon and steelhead to carry in their stomachs without noticeable modification of their behavior. However, to track smaller fish, particularly salmon and steelhead smolts, a much smaller tag was needed. To fill this need, NMFS researchers designed a miniature tag 26 mm long by 9 mm wide by 5 mm thick weighing 2.6 g in water (Fig. 4). The transmitter is assembled on a hybrid circuit substrate and is powered by two silver oxide batteries. Once assembled, the tag is coated with a mixture of paraffin and beeswax and sealed in dental acrylic. The tags operate on a carrier frequency of approximately 30 MHz and have a battery life of 72 h. The tags can be frequency coded (9 codes) or multiple-coded (720 codes) depending upon application. The effective tracking range is about 300 m when the tagged fish is near the surface; the range decreases rapidly when the fish is deeper than 9 m. The cost of each tag is about $100-140.

Prior to using the miniature tag in the field, testing was carried out with juvenile coho salmon, *O. kisutch*, using sham tags (same size, shape, and weight but inoperable). The tag was inserted into the fish's stomach through the esophagus, and the 125 mm long antenna wire was allowed to trail out of the fish's mouth. The tagged fish were placed in a holding tank with untagged coho salmon and observed for 30 d. After recovering from the anesthetic and handling, they appeared to feed and behave normally. When tested in a swimming chamber, there was no difference in the performance of tagged and untagged fish. The tagged fish ranged in fork length (FL) from 150 to 160 mm.

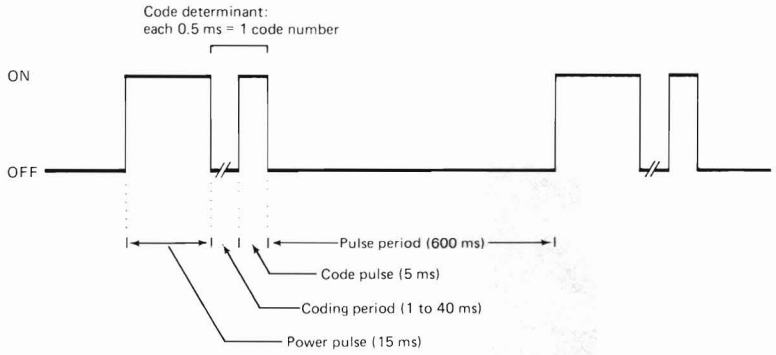

Figure 3.—Pulsing sequence used to establish code of multiple-coded radio tag.

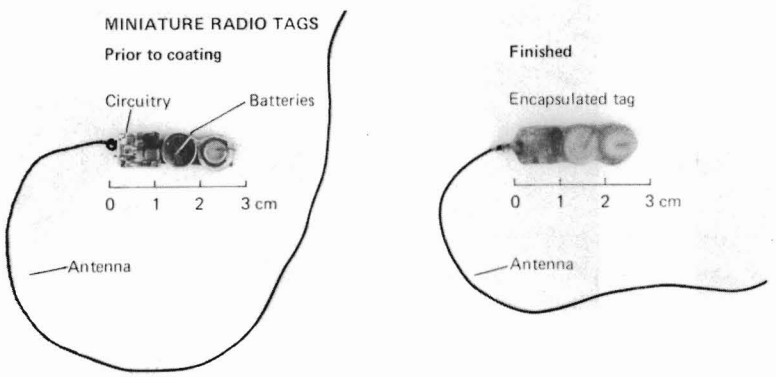

Figure 4.—Miniature radio tag for juvenile salmonids.

The miniature radio tag was used in three field studies to monitor the behavior of downstream migrating juvenile salmon and steelhead as they approached a major hydroelectric dam in the Columbia River (Sims et al. 1981;[6] Faurot et al. 1982[7]). A total of 99 smolts (63 chinook salmon—145 to 192 mm FL and 36 steelhead—161 to 220 mm FL) were tracked. Tracks normally lasted from 4 to 6 h.

Because of the short range of the tag, new tracking procedures were developed. Tracking involved two, two-man crews (a boat operator and a tracker) in two separate boats. Operators used conventional receivers with directional loop antennas to establish the location of the fish in relation to the boat. They then determined the positions of the boats using horizontal sextants to take bearings to markers accurately positioned strategically along the shore. The fish's location was indicated on an accurate scale chart of the study area. A series of these plots were then connected by a line, and a record of the fish's movement was established. The technique provides accuracy within about 25 m, which is somewhat less accurate than obtained with the more sophisticated fixed shore stations and central plotting and control station (Fig. 5) used when tracking adult salmon (Monan et al. 1975). Automatic recording of date, time, direction of travel, and tag code for tagged fish passing an appropriately located monitor is also possible.

Passive Integrated Transponder Tag

Coded wire tags provide a relatively inexpensive means to obtain basic release and recapture data from large numbers of fish. Radio tags provide a means to get behavioral and physiological information on a limited number of fish—but at a substantial cost. Aquaculturists and fisheries researchers need a relatively inexpensive tag that can provide better data than the CWT but at less cost than the radio tag.

The passive integrated transponder (PIT) tag being developed by Identification Devices Inc., of Denver, Colo.,[8] for identification of livestock is currently being evaluated for use on fish by scientists of the NMFS (Prentice[9]).

The PIT tag is basically a silicon computer chip and an antenna encapsulated in ceramic material (Fig. 6). The 32-bit chip will store code information for about 4.3 billion unique codes. During manufacture, groups of tags may be batch coded or each tag could have a unique code in a serial sequence. The theoretical life expectancy of the tag is about 100 yr. The manufacturer estimates the initial fish tag will be about 4.2 mm long by 1.6 mm in diameter. It is expected that the length subsequently will be reduced by 50%. Currently a sham tag is being evaluated for tagging location, retention, physiological acceptance, etc. at the Manchester Marine Experimental Station.

The tag can be placed by an injection device similar to that used for CWT's. However, unlike the CWT, it is unimportant how the tag is oriented in the fish. Therefore, a number of areas other than the snout are being evaluated, e.g., the abdominal cavity and the musculature under the dorsal fin.

Detection and decoding of the tag are done with a data scanner. The data scanner, when activated by the operator, sends out a signal which is received by the tag's antenna. The signal is converted to power which drives the tag's chip. The unique preprogrammed signal is sent back to the scanner where it is instantly visually displayed in a numeric format. Current tests indicate the tag can be detected when the fish is surrounded by up to 16 cm of water and the scanner is 30 cm away. The fish can pass at any reasonable speed and in any orientation.

More sophisticated versions of the scanner can have added functions such as:

[6]Sims, C. W., J. G. Williams, D. A. Faurot, R. C. Johnsen, and D. A. Brege. 1981. Migrational characteristics of juvenile salmon and steelhead in the Columbia River Basin and related passage research at John Day Dam Vol. I. Natl. Mar. Fish. Serv. Northwest and Alaska Fish. Cent., Seattle, Wash. Final Rep. to U.S. Army Corps Eng., contracts DACW57-80-F-0394 and DACW68-78-C-0051, 61 p.

[7]Faurot, D. A., L. C. Stuehrenberg, and C. W. Sims. 1982. Migrational characteristics of juvenile salmon and steelhead trout in the Columbia River System, 1981, Vol. II. Radio tracking juvenile salmonids in John Day Reservoir. Natl. Mar. Fish. Serv. Northwest and Alaska Fish. Cent., Seattle, Wash. Final Rep. to U.S. Army Corps Eng., contract DACW57-81-F-0342, 24 p.

[8]Reference to trade names or products does not imply endorsement by the National Marine Fisheries Service, NOAA.

[9]E. Prentice, National Marine Fisheries Service, Manchester Marine Experimental Station, P.O. Box 38, Manchester, WA 98353, pers. commun. June 1982.

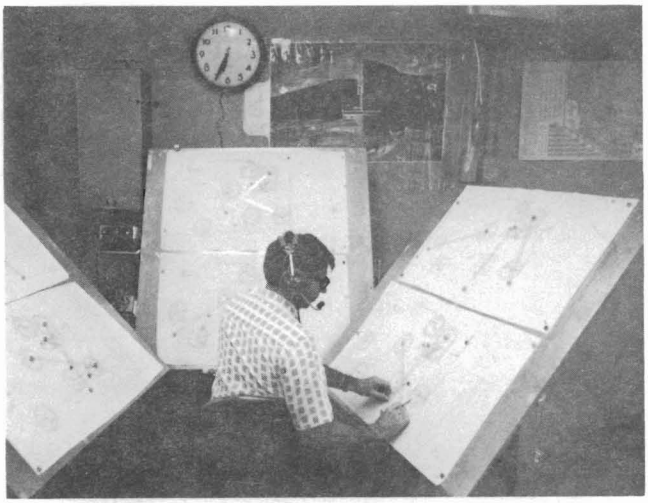

Figure 5.—Tracking coordinator in the control station plotting locations of adult salmon tagged with radio tags.

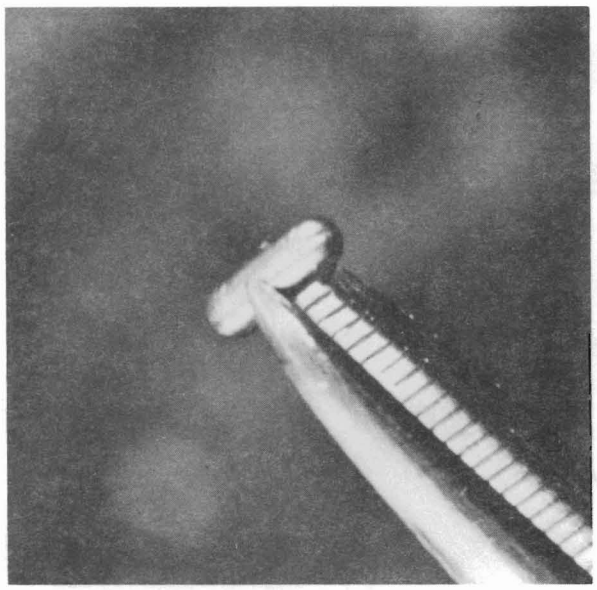

Figure 6.—Passive integrated transponder (PIT) tag (approximately 4.2 mm long × 1.6 mm in diameter).

1) a logic module, so signals from more than one tag can be decoded and counted "simultaneously" but displayed in the sequence of arrival;
2) a 32-128 K-bit internal memory that will allow the operator to obtain tag information in the field, store it in the scanner, and bring it back to the laboratory for processing; and
3) a RS 232 plug to make the scanner compatible with ADP.

When cost of tagging and decoding are considered, the cost of the system is reasonably comparable with the CWT system. Cost of the tag is currently estimated at about $5/tag, but quantity manufacturing can be expected to reduce this figure. The data scanner used with livestock costs $1,500 to $3,000 depending upon options.

The PIT tag has a great potential for use in salmon aquaculture and research because of the following:

1) virtually unlimited number of tag codes;
2) tag detection and decoding accuracy $\geq$ 95%;
3) detection and decoding can be done while the fish is in the water without handling or sacrificing the fish;
4) injection system can be simpler and less costly than the CWT injector; and
5) data can be directly fed into a computer—greatly reducing time lag, errors, and cost of data processing.

If the development of the PIT tag for fish is successful, a new era in tagging will have been reached.

SUMMARY

Tags available to aquaculturists and fishery biologists are increasing and becoming more sophisticated. Researchers are no longer restricted to visual identifiers but have a variety of advanced tags available—largely due to the rapidly expanding field of electronics.

In the preceding portion of the paper, four advanced tags were discussed that may be used effectively with salmonids: The coded wire-rare earth tag, multiple-coded radio tag, miniature radio tag, and PIT tag. Each tag represents advances and has distinct advantages, but none represent the ultimate in tag development. The rare earth coded wire tag makes decoding the tag possible without removing it from the fish, but the fish must be handled. The multiple-coded radio tag makes monitoring the behavior of large numbers of separately identifiable, free-swimming adult salmonids possible. Miniaturization of the radio tag allows studies of the behavior of free-swimming juvenile salmonids. The PIT tag, when fully developed, will provide a means of individually identifying fish (once they are tagged) from juveniles to adults without sacrificing or handling them—if fully developed, it will allow the acquisition of data heretofore impossible or impractical to obtain.

ACKNOWLEDGMENTS

I would like to acknowledge Donn Park for his work on the rare earth tag; Charles Bartlett, Gordon Esterberg, Kenneth Liscom, Lowell Stuehrenberg, Donald Thorne, and Charles Volz for their parts in development of the multiple-coded and miniature radio tags; and Earl Prentice for his vision and pursuit of a PIT tag for fish.

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Trends in Natural and Hatchery Production of Chinook Salmon

DONALD E. ROGERS and ERNEST O. SALO[1]

INTRODUCTION

Chinook salmon, *Oncorhynchus tshawytscha*, are the least abundant but the oldest and heaviest at maturity of the Pacific salmon. They are sought by commercial and recreational (sport) fishermen because they are large and they are more vulnerable to salmon fisheries because they have a long ocean life, typically 3-4 yr and sometimes 5-6 yr at sea (Major et al. 1978). They are also unique among the Pacific salmon because a very high proportion of them are caught in high seas and coastal troll fisheries while immature, and often at long distances from their home streams. This fact makes it difficult to determine the status of individual stocks along the North American and Asian coasts.

Fredin (1980) reviewed the historical trends in the catches of Pacific salmon through 1977. The pink, *O. gorbuscha*, chum, *O. keta*, and sockeye, *O. nerka*, catches in most fisheries were at a historical low in the 1970's, whereas catches of coho, *O. kisutch*, and chinook salmon remained relatively stable or increased in the 1970's. Since 1978 there have been some dramatic changes in the catches and abundances of Pacific salmon.

We will examine the recent trends in chinook salmon abundance largely on the basis of catch statistics because numbers of fish in escapements are either unknown or imprecisely known over much of the chinook salmon's range. The production of chinook salmon in Alaska and Asia is almost entirely from wild stocks whereas hatcheries produce a significant portion of the chinook salmon from California to Washington and these fish enter the fisheries in British Columbia and southeastern Alaska.

DATA SOURCES

Catch statistics through 1978 were obtained from Fredin (1980), International North Pacific Fisheries Commission (1979), and INPFC Statistical Yearbooks. Catches for 1979 and 1980 were from internal reports of INPFC and state and federal fisheries agencies of the United States and Canada. Catches for 1981 and 1982 were available only for Alaskan fisheries and were obtained from the Alaska Department of Fish and Game. Although these were preliminary estimates, the final catches for 1981 and 1982 are unlikely to be significantly different.

Estimates of chinook salmon escapements were obtained from the Pacific Fisheries Management Council's proposed management plan for 1981, internal reports of state fisheries agencies, and personal communication with these agencies. Escapement estimates for wild stocks are not as precise as catch statistics and in some cases are only order-of-magnitude estimates.

CATCH AND ESCAPEMENT

Commercial catches of chinook salmon have declined in recent years in Oregon, southeastern Alaska, and central Alaska (Fig. 1). Since the 1960's the Cook Inlet fishery in central Alaska has been severely restricted and the chinook salmon troll fishery in southeast Alaska has been restricted by quotas. About 75% of the commercial catch (1976-80) in the southern region (California to southeast Alaska) was made by troll fisheries operating on a mixture of stocks. The pronounced increase in British Columbia troll catches has come largely from chinook salmon produced in Oregon and Washington.

During 1976-80, Oregon and Washington had about 57% of the 1.1 million estimated average escapement in the southern region, whereas the catch (commercial and sport) was only 34% of the regional average catch of 4.0 million (Table 1). In contrast, the escapements to British Columbia constituted about 17% of the regional escapement, whereas the catches made up 41% of the regional catch.

In the northern region, catches have increased since the 1960's largely from increased exploitation by inshore fisheries in western Alaska and the high seas fisheries (mainly in the Bering Sea). During 1976-80, the high seas catch constituted about 40% of the commercial catch in the northern region.

Based on coastal catches of pink, chum, and sockeye salmon, these species are more abundant along the northern rim of the

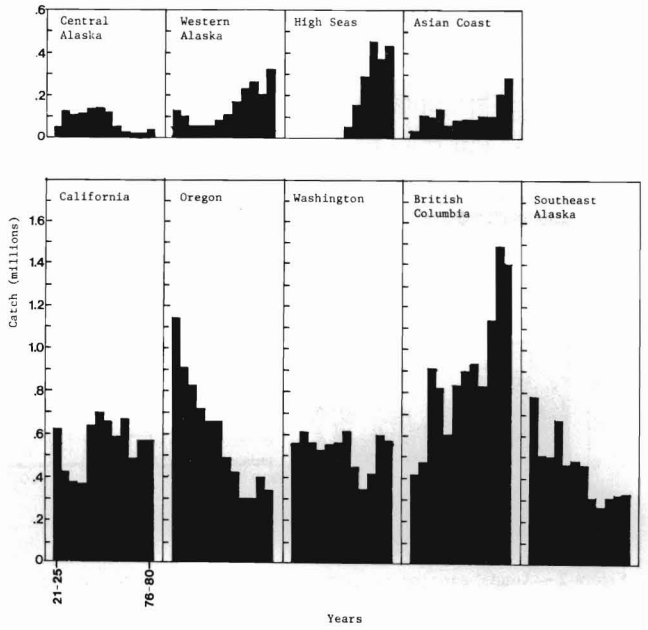

Figure 1.—Annual commercial catches of chinook salmon by 5-yr periods beginning 1921-25 and ending 1976-80.

[1]Fisheries Research Institute, School of Fisheries, University of Washington, Seattle, WA 98195.

Table 1.—Estimates of chinook salmon escapements (wild and hatchery), 1976-80. (Fish in thousands.)

Year	California	Oregon-Washington	British Columbia	Southeast Alaska	Total
1976	[1]258	593	164	18	1,033
1977	[1]258	660	224	30	1,172
1978	290	702	196	20	1,208
1979	269	581	177	25	1,052
1980	216	643	[1]190	39	1,088
Average 1976-80	258	636	190	26	1,110
Average catch (all gear)	671	1,361	1,679	339	4,050

[1]Estimate from average of other years.

North Pacific than they are along the western coast of North America (Fig. 2). There have been exceptionally large catches of all species of salmon in western and central Alaska since 1978 and the catches of pink, chum, and sockeye salmon in 1981 were historical records. Coho and chinook salmon have been much more abundant in the southern region (Fig. 3). However, rates of exploitation of these species have been much lower in the northern region because other species are so much more abundant

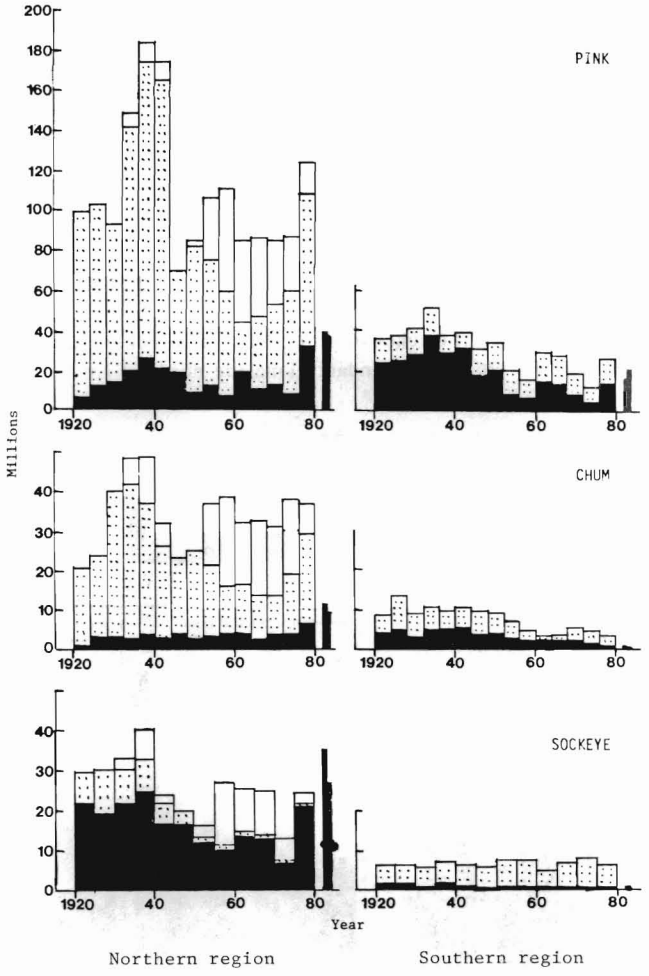

Figure 2.—Annual commercial catch of salmon, 1921-80 by 4-yr averages for pink and chum salmon and 5-yr averages for sockeye salmon. Northern region: Western and central Alaska (black), Asian coastal (stippled), and high seas (open). Southern region: Southeastern Alaska (black) and California to British Columbia (stippled). Alaskan catches in 1981 and 1982 indicated by narrow bars.

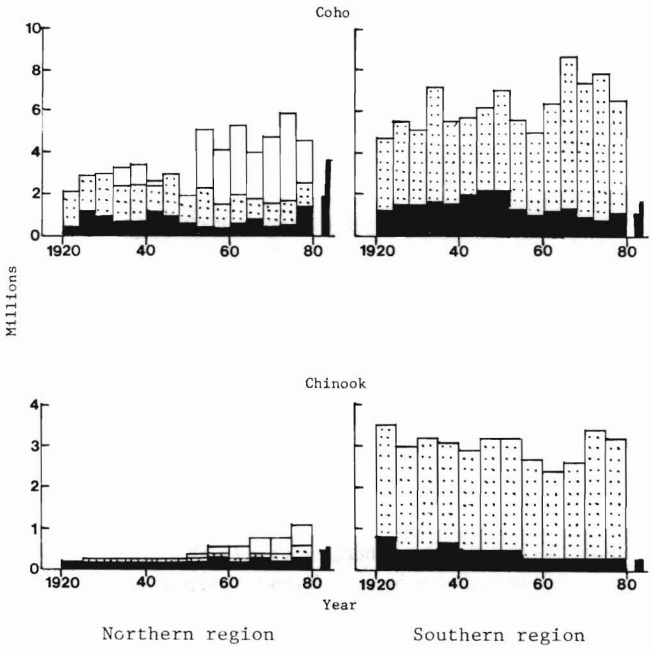

Figure 3.—Annual commercial catches of coho salmon (4-yr averages) and chinook salmon (5-yr averages), 1921-80. Northern region: Western and central Alaska (black), Asian coastal (stippled), and high seas (open). Southern region: Southeastern Alaska (black) and California to British Columbia (stippled). Alaskan catches in 1981 and 1982 indicated by narrow bars.

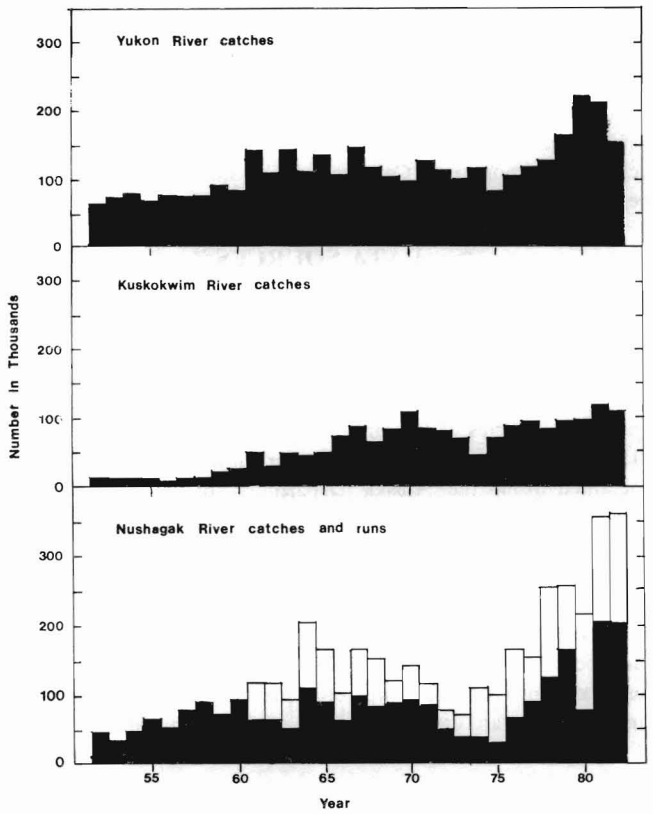

Figure 4.—Annual catches (commercial and subsistence) of chinook salmon from the Yukon and Kuskokwim Rivers and estimates of the runs (catch and escapement) to the Nushagak River, 1952-82.

there. In 1982 there were historical record high catches of coho and chinook salmon in western and central Alaska, whereas catches in the southern region remained relatively stable in recent years.

The Yukon, Kuskokwim, and Nushagak Rivers are the major producers of chinook salmon in Alaska and for the Nushagak River there have been annual estimates of the escapements since 1961 (Fig. 4). These rivers contribute a significant number of fish to the high seas catches, ranging since 1961 from 116,000 to 642,000, except in 1980 when about 1 million chinook salmon were caught. The inshore runs to the Nushagak River increased in 1978 and the run in 1982 was 362,000.

Statistics from the Nushagak District of Bristol Bay are well suited for examining the historical trends in the abundance of salmon because there has been extensive exploitation of chinook, sockeye, and chum salmon since 1900 (Fig. 5). The late-summer fisheries for pink and coho salmon have been sporatic depending on the abundance of the runs and the early summer catches of the other species. However the catches of all species declined in the early 1920's and the catches of the more abundant sockeye declined again in the early 1950's. The large runs beginning in 1978 were unpredictable from either the abundances of parent spawners or juveniles in freshwater. The cause of the large runs in recent years seems to be from an increase in marine survival that is related to a change in the climate over western and central Alaska.

Winter temperatures in the Gulf of Alaska and Bristol Bay declined in the late 1940's, were exceptionally cold in the early 1970's, and then beginning with the winter of 1976-77, temperatures have been comparable with those of the 1920's and 1930's (Fig. 6). The major changes in salmon abundance in western and central Alaska since 1920 have generally followed the changes in temperature. Although the biological mechanisms by which changes in climate affect the survival of salmon (particularly at sea) are unknown, the outlook for salmon production in Alaska is good as long as temperatures remain mild.

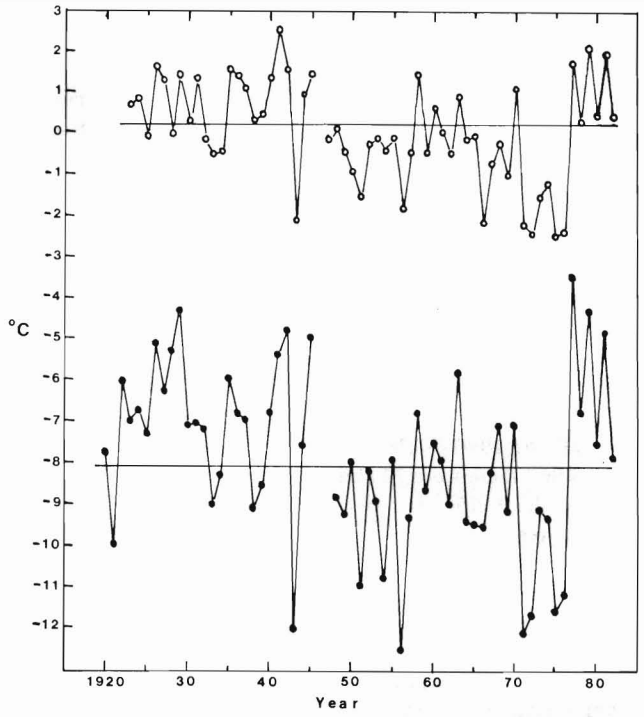

Figure 6.—Average winter (November-March) air temperatures at Kodiak (top) and Bristol Bay (bottom) weather stations through the winter of 1981-82.

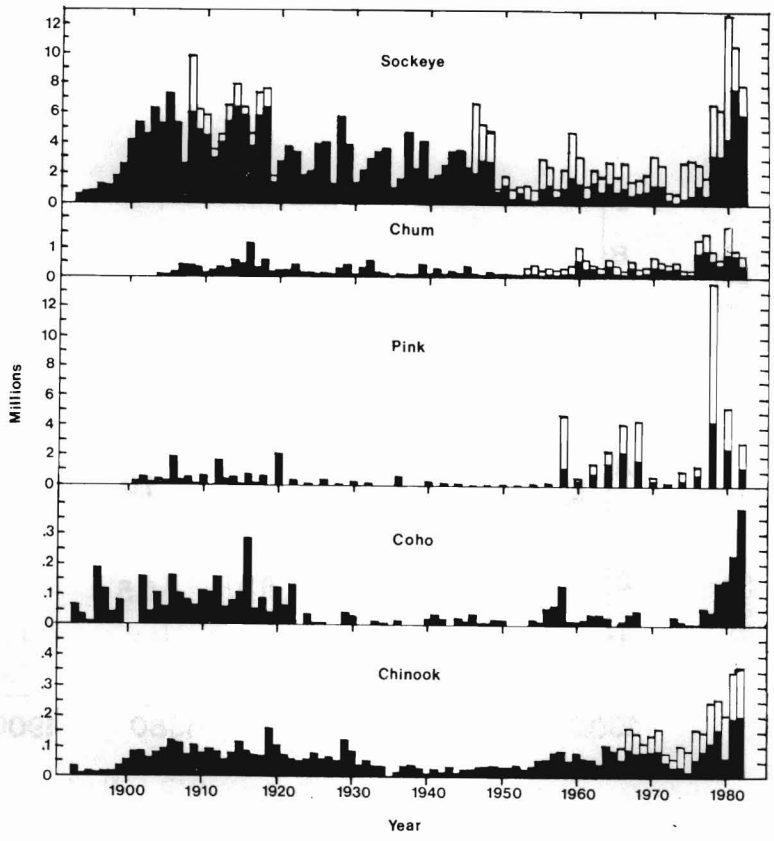

Figure 5.—Annual commercial catches of salmon and estimates of the runs (catch plus escapement) where available for the Nushagak District of Bristol Bay 1893-1982.

HATCHERY PRODUCTION

In the early 1900's there were large numbers of state and private hatcheries that propagated primarily coho, chum, and chinook salmon. This was followed by a de-emphasis on hatcheries in the 1930's and 1940's. In the 1950's and 1960's there was an increase in the use of hatcheries for mitigation of lost salmon and steelhead habitat and the production of coho and chinook salmon was emphasized. Currently in the states of Washington and Oregon, the hatchery releases in numbers of fish of chinook and chum salmon are the largest followed by coho, pink, and sockeye salmon, although the total production (biomass) of coho is the highest. In Alaska, the private aquaculture corporations release large numbers of pink salmon in the north and chum and coho salmon in the south. The Alaskan goal is a billion fish annually by 1990 (McNeil 1982).

In 1960 there were 72 hatcheries producing salmon and steelhead on the Pacific coast and by 1976 the number reached 154. In 1960 a total of 150 million fish were released from hatcheries on the coast of the eastern Pacific. By 1977, 377 million were released and for a 1-yr period in 1980-81 this had increased to 935 million (Tables 2, 3). Thirty percent of this total was pink salmon in Alaska and sockeye salmon from spawning channels in British Columbia. The releases of chinook salmon increased from approximately 200 million in 1977 to 250 million in 1980 whereas coho releases increased from 90 to 140 million. The release from nonpublic hatcheries increased from zero in 1977 to about 14% of the total in 1981. This is expected to grow, especially in Alaska, although it has tapered off in Oregon and, except for the Indian Tribes, releases from private hatcheries are not legal in the State of Washington. Using the State of Washington as an example, since the 1950's the releases of coho salmon have increased from about 15 million to over 40 million, while in the same period the numbers of chinook increased from 15 million to over 70 million (Simenstad et al. 1982). Correspondingly the catch of coho salmon has increased in Washington from 1,250,000 in the 1950's to 2,800,000 in the late 1970's. The catch of chinook salmon has increased from 600,000 in the early 1960's to over a million in the late 1970's. This includes the recreational (sport) fisheries (Fig. 7).

At the present time, approximately 44% of the coho salmon harvest in the southern region is from natural production and 56% is from hatcheries, while the chinook salmon harvest is 60% from natural production and 40% from hatcheries, although it is expected that the chinook salmon harvest will be about 50/50, natural and artificial, in the near future. In the last 70 yr, about 60% (54% from the Columbia River and 70% from the Sacramento-San Joaquin Rivers) of the chinook salmon spawning and rearing area has been lost in the Sacramento-San Joaquin and Columbia River systems, the principal producers of chinook salmon (Salo and Stober 1977; Kjelson et al. 1982). Interestingly,

Table 2.—Public hatchery juvenile salmon releases in 1977 in millions. (From: National Aquaculture Plan 1980.)

	Chum	Pink	Steelhead	Coho	Chinook	Total
Washington	65	0	6	73	120	264
Oregon	1	0	2	15	55	73
Idaho	0	0	0	0	9	9
Alaska	0	0	0	1	0	1
California	0	0	3	1	25	29
Total	66	0	11	90	209	376

Table 3.—Hatchery releases of juvenile salmon in millions for a 1-yr period in 1980-81. (From: McNeil 1982.)

	Chum	Pink	Sockeye	Coho	Chinook	Total
Alaska	61	141	25	4	1	232
British Columbia	93	6	143	5	19	266
Washington	67	5	0	95	153	320
Oregon	6	0	0	35	40	81
California	0	0	0	1	29	30
Idaho	0	0	0	0	6	6
Total	227	152	168	140	248	935

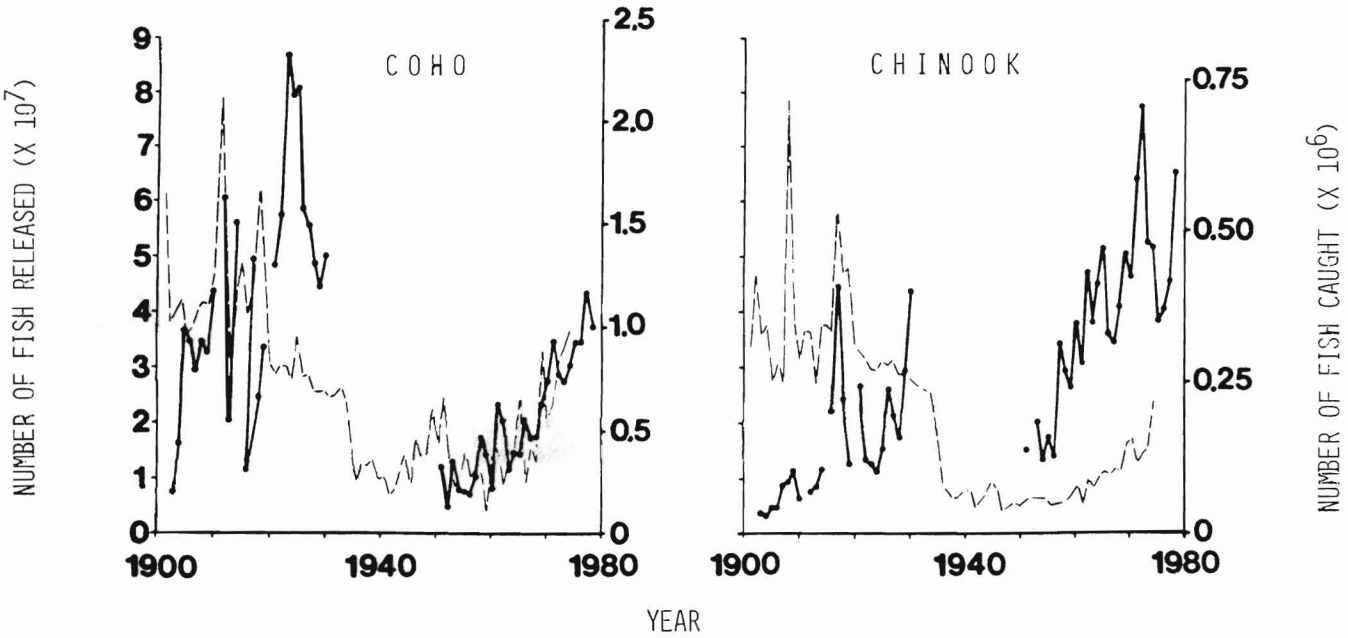

Figure 7.—Releases of artificially propagated salmon in Washington State (solid line) and Puget Sound salmon catches (dash line), 1901-79. From Simenstad et al. (1982).

the production of the Sacramento River has dropped about 70% (Kjelson et al. 1982). How much of this was due to fishing and how much has been compensated for by hatcheries in the Sacramento River is not clear. The Fraser River in British Columbia has a calculated optimum escapement of 200,000 chinook salmon while the current escapements are 60,000-70,000. Overfishing of the Fraser River stocks, in mixed stock fisheries where the contributions of Washington and Oregon hatcheries may be as much as 70-90% of the Canadian catch of chinooks, appears to be the principal cause of decline in Canada (Pearse 1982).

SUMMARY

The sustained catches of chinook salmon in the southern region of the North Pacific can be largely attributed to hatchery production that has replaced the declining production from natural stocks. The outlook for chinook salmon production is good but problems remain as to the allocation of the catch among the fisheries along the west coast of North America.

Catches of chinook salmon in the northern region, mainly from western Alaska to Kamchatka, have increased since the 1950's from increased exploitation of natural stocks; and, since 1977, from an increase in marine survival that was associated with a change in climate. The outlook for future production is good as long as temperatures remain mild.

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Hatchery Approaches in Artificial Chum Salmon Enhancement

OSAMU HIROI[1]

INTRODUCTION

Almost all the chum salmon, *Oncorhynchus keta*, resources in Japan have been supported by artificial propagation. To promote efficient artificial propagation of chum salmon, it is important for us to make a model of some aspects of behavior in the life cycle of the fish, especially those concerned with migration, spawning, breeding, downstream migration, and feeding migration.

CHUM SALMON RESOURCES AND REPRODUCTIVE EFFICIENCIES

Annual Changes in Catches in the Japanese Salmon Fishery

Annual changes in catches in the Japanese salmon fishery are shown in Table 1. Almost all the coastal catches are due to artificial propagation in Japan. The percent of coastal catch in tons has increased over 50% since 1978 to about 70% in 1981.

Annual Changes in Adult Returns and Return Percent in Chum Salmon Liberated From Japan

Annual changes in adult returns in chum salmon liberated from Hokkaido and Honshu Islands of Japan are shown in Table 2. Adult returns in rivers and coastal seas totalled over 10 million fish since 1974, and over 20 million fish since 1979. The largest return, about 30 million fish, was in 1981.

Annual changes in the percentage of adult returns in chum salmon liberated from Hokkaido and Honshu Islands of Japan are shown in Table 3. The percentage of adult returns of liberated chum salmon fry have stabilized since 1968 in Hokkaido and since 1976 in Honshu.

[1]Hokkaido Salmon Hatchery, Fisheries Agency, 2-2, Nakanoshima, Toyohiraku, Sapporo, Hokkaido, Japan 062.

Table 1.—Annual changes in catch in the Japanese salmon fishery.

Year	Far seas catch (thousand tons)	Coastal sea catch (thousand tons)	Total (thousand tons)	Percentage of coastal catch
1965	120	22	142	15.5
1966	101	22	123	17.9
1967	115	27	142	19.0
1968	92	17	109	15.6
1969	110	27	137	19.7
1970	91	24	115	20.9
1971	99	35	134	26.1
1972	90	26	116	22.4
1973	96	36	132	27.3
1974	87	42	129	32.6
1975	91	64	155	41.3
1976	82	40	122	32.8
1977	62	50	112	44.6
1978	41	58	99	58.6
1979	42	86	128	67.2
1980	42	77	119	64.7
1981	42	106	148	71.6

Table 2.—Annual changes in adult returns in chum salmon derived from Hokkaido and Honshu Island of Japan (thousands).

	Hokkaido			Honshu			Total		
Year	Coastal sea	Rivers	Total	Coastal sea	Rivers	Total	Coastal sea	Rivers	Total
1966	3,408	396	3,804	451	187	638	3,859	583	4,442
1967	3,908	592	4,500	370	142	512	4,278	734	5,012
1968	1,902	236	2,138	260	115	375	2,162	351	2,513
1969	3,595	578	4,173	313	134	447	3,908	712	4,620
1970	4,651	627	5,278	424	149	573	5,075	776	5,851
1971	6,806	845	7,651	652	245	897	7,458	1,090	8,548
1972	6,343	614	6,957	698	229	927	7,041	843	7,884
1973	7,724	597	8,321	616	238	854	8,340	835	9,175
1974	9,026	601	9,627	901	224	1,125	9,927	825	10,752
1975	14,217	1,557	15,774	1,550	362	1,912	15,767	1,919	17,686
1976	8,342	463	8,805	1,344	270	1,614	9,686	733	10,419
1977	9,466	742	10,208	1,977	374	2,351	11,443	1,116	12,559
1978	12,284	863	13,147	2,667	394	3,061	14,951	1,257	16,208
1979	17,751	1,151	18,902	4,518	608	5,126	22,269	1,759	24,028
1980	13,786	1,660	15,446	5,873	1,099	6,972	19,659	2,759	22,418
1981	20,296	1,630	21,926	7,251	727	7,978	27,547	2,357	29,904

Table 3.—Annual changes in the percentage of adult returns in chum salmon liberated from Hokkaido and Honshu Islands of Japan.

	Hokkaido			Honshu		
Year	Liberated fry (thousand)	Adult returns (year class) (thousand)	Return rates (%)	Liberated fry (thousand)	Adult returns (after 4 yr) (thousand)	Return rates (%)
1962	280,743	3,025	1.08	138,267	718	0.52
1963	272,106	4,983	1.83	116,476	572	0.49
1964	334,463	2,119	0.63	139,575	415	0.30
1965	549,278	2,572	0.47	109,836	497	0.45
1966	272,036	5,943	2.19	196,469	653	0.33
1967	434,729	8,110	1.87	161,240	987	0.61
1968	207,438	4,881	2.35	121,193	1,017	0.84
1969	361,571	8,737	2.42	139,536	1,004	0.72
1970	442,101	10,110	2.29	144,673	1,295	0.90
1971	575,986	12,913	2.24	211,464	2,112	0.99
1972	475,805	11,909	2.50	224,943	1,764	0.78
1973	445,510	9,036	2.03	271,223	2,651	0.98
1974	484,849	11,342	2.34	271,708	3,311	1.22
1975	801,991	21,322	2.66	343,988	5,606	1.63
1976	523,361	13,088	2 50	287,180	7,282	2.54
1977	693,222	(18,456)[1]	(2.66)[1]	412,625	8,408	2.04
1978	779,261			433,177		
1979	873,489			589,905		
1980	1,146,047			750,113		
1981	1,079,708			738,055		

[1]Numerals in parentheses indicate number or rate up to 4-yr-old fish returns.

The recent rapid increases in adult returns and percentage of returns are due not only to an increase in number of liberated fry (by expansion and improvement of hatchery facilities, effective use of spring waters, and full protection of river fish from control of coastal catches), but also to regulation of fry-releasing times by prolonged (1 to 4 mo) feeding during artificial propagation.

Reproductive Efficiencies of Chum Salmon Fry in Japan

Recently, the ratios of liberated fry to eggs taken in chum salmon are about 80% in Japan—a mortality of about 20% up to fry-liberation (Hiroi 1981). In the 1979 to 1983 salmon enhancement program, adult returns of 38.6 million chum salmon was expected from 2,150 million fry liberated in the last year. Reproductive efficiencies and percentage of returns planned for the enhancement program have been exceeded already by the actual values for the past 5 yr. In addition to maintaining a quantitative increase in resources, we also have been selecting adult chum salmon with a long freshwater life during anadromous migration. These are valuable commercially because of silvery fish in coastal seas near home streams.

TECHNICAL APPROACHES AND BASIC STUDIES FOR ARTIFICIAL PROPAGATION OF CHUM SALMON

Sexual Maturation and Artificially Induced Maturation

Maturation in chum salmon progresses synchronously in the testicular lobules of males (Hiroi and Yamamoto 1968) and in the ovarian oocytes of females. Moreover, male and female chum salmon, as well as males and females of other species belonging to the genus *Oncorhynchus*, are destined to die after spawning, in the final step of their anadromous migration to the home river from the far seas.

Maturation patterns of adult chum salmon in each of the rivers of Hokkaido.—The period of freshwater life of adult chum salmon up to full maturation after entering rivers differed drastically in different home rivers, being 0 to 40 d in rivers of Hokkaido. Differences in the period closely resembled that in degree of sexual maturation. There was no difference in the period from year to year, but there was a definite seasonal change in each of the rivers. From these differences in the period of freshwater life after entering rivers, adult chum salmon in each of the home rivers were divided into three maturational groups—early, intermediate, and late maturing homing types.

In the early maturing homing type, adults migrate as a silvery, maturing fish in the coastal sea near the home stream and ripen after a prolonged period—about 25 to 40 d—of freshwater life. In the intermediate maturing homing type, adults migrate as a silvery or slightly nuptial-colored, maturing fish in the coastal sea near the home stream and ripen after a relatively long time, about 10 to 25 d, of freshwater life. In the late maturing homing type, adults migrate as a nuptial-colored, maturing or mature fish in the coastal sea near the home stream and ripen after a short time, about 0 to 10 d, of freshwater life. Location of the rivers included in each of the types in Hokkaido is shown in Figure 1. When the seedlings taken from adults in each of the home rivers were transplanted to other rivers, the returned adults had a tendency to follow the same maturing homing type as that of the original river.

Changes in serum concentrations of steroid hormones, thyroxine, and vitellogenin during anadromous migration of chum salmon.—In order to clarify endocrine factors related to sexual maturation and osmoregulatory adjustments for entrance into freshwater, serum concentrations of various steroid homones (estradiol-17β, androgens, 17α, 20β-dihydroxy-4-pregnen-3-one)

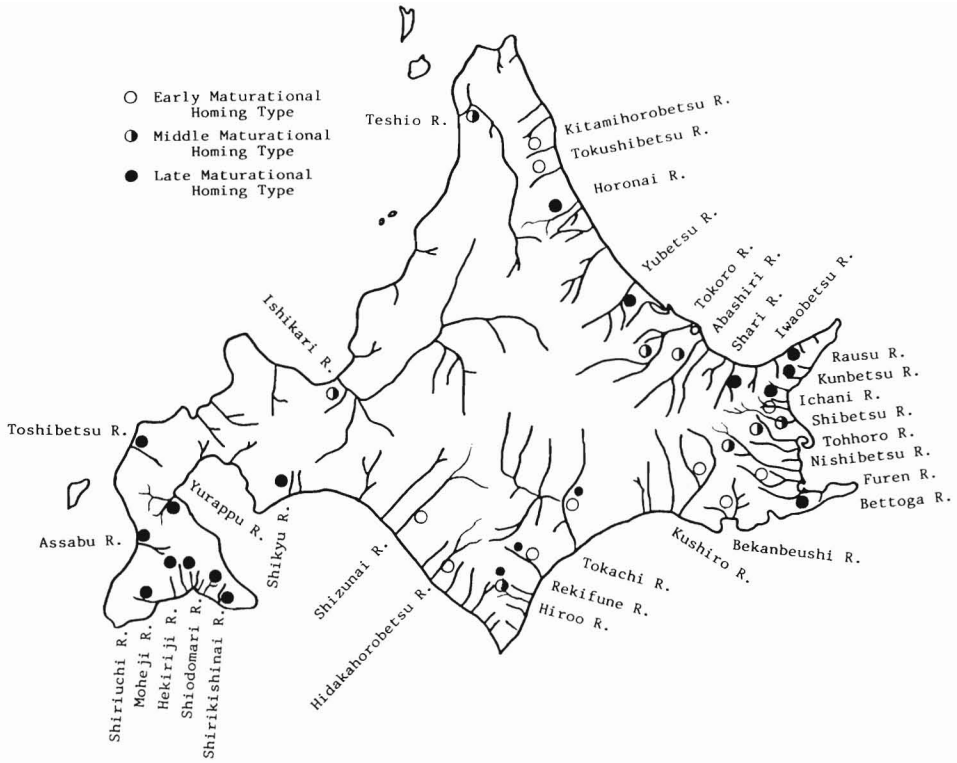

Figure 1.—Maturational pattern of adult chum salmon in each of the rivers of Hokkaido.

and thyroxine were measured with radioimmunoassay techniques, and vitellogenin was measured with radial immunodiffusion methods during the anadromous migration of male and female chum salmon (Hiroi et al. 1982; Ueda et al. in press).

In females, estradiol-17β levels were high in fish taken at sea and in midstream, but significantly decreased in fish at the time of final maturation, including oocyte maturation and ovulation (Fig. 2). Changes in estradiol-17β levels coincided with those of serum vitellogenin levels (Fig. 3). Thereby, these results provide strong evidence that estradiol-17β is responsible for the synthesis of vitellogenin in chum salmon.

Serum 17α,20β-dihydroxy-4-pregnen-3-one (17α,20β-diOHprog) levels were low in maturing chum salmon taken at sea and in midstream, but rose dramatically in mature and ovulating females. This provides strong evidence that 17α,20β-diOHprog is the natural maturation-inducing steroid and relates to final oocyte maturation in chum salmon females (Fig. 4).

Serum androgen levels in male and female chum salmon are shown in Figure 5. The antiserum employed in the present study binds both testosterone and 11-keto-testosterone. In females, serum androgen levels were high throughout the course of anadromous migration. The levels were much higher in females than in males throughout the sampling period. Although the precise roles of androgens in female fish are presently unknown, the close relationship observed between estradiol-17β and androgen levels during late vitellogenesis in chum salmon supports the suggestion that testosterone may act as a substrate for estradiol-17β biosynthesis.

In males, serum androgen levels were high in maturing fish taken at sea and in midstream during spermatogenesis, but declined sharply around the time of spermiation. This observation suggests that androgens are involved in the process of spermatogenesis rather than that of spermiation.

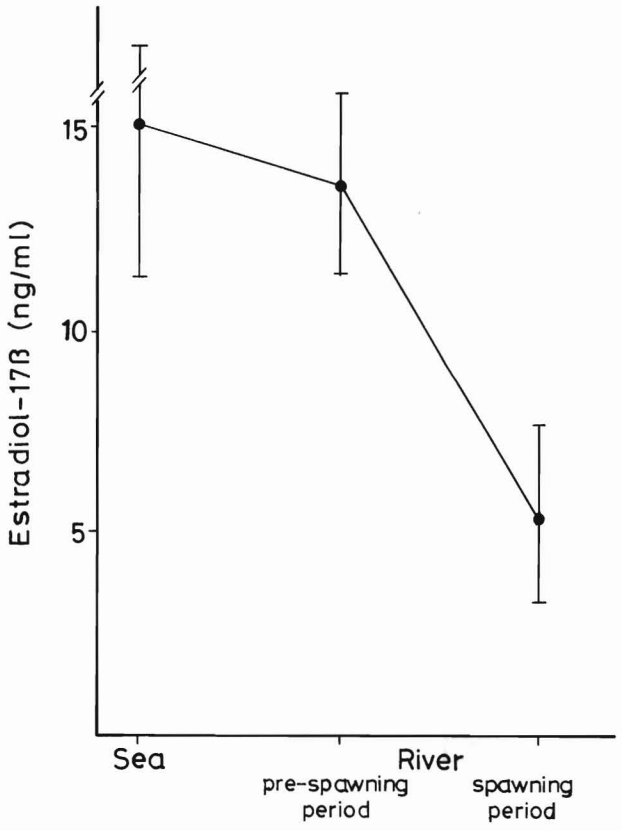

Figure 2.—Changes in serum estradiol-17β levels during sexual maturation in female chum salmon. The vertical bars represent the mean ± SEM.

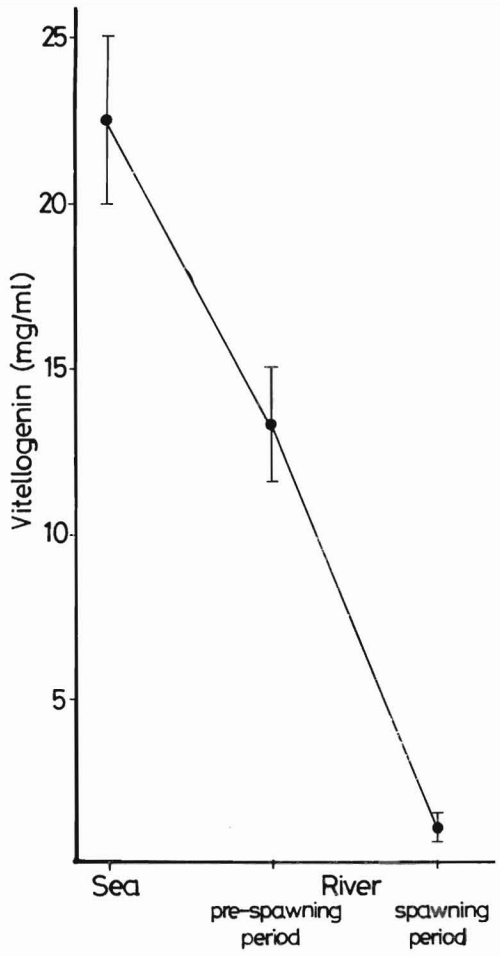

Figure 3.—Changes in serum vitellogenin levels during sexual maturation in female chum salmon. The vertical bars represent the mean ± SEM.

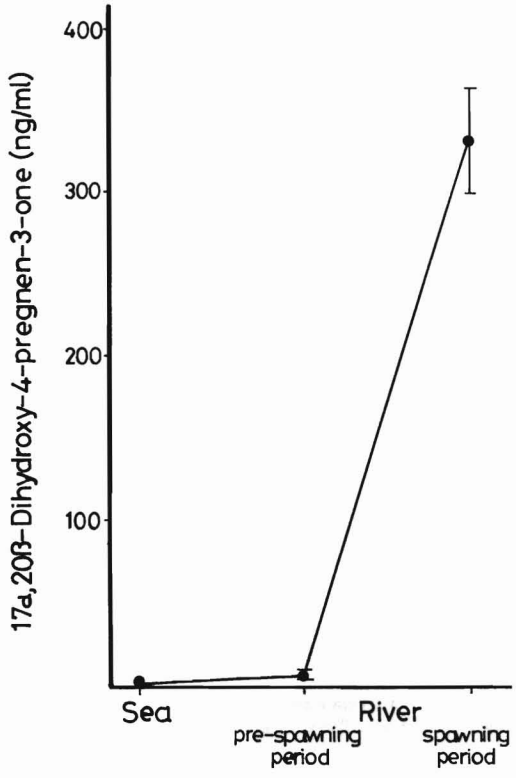

Figure 4.—Changes in serum 17α,20β-dihydroxy-4-pregnen-3-one levels during sexual maturation in female chum salmon. The vertical bars represent the mean ± SEM.

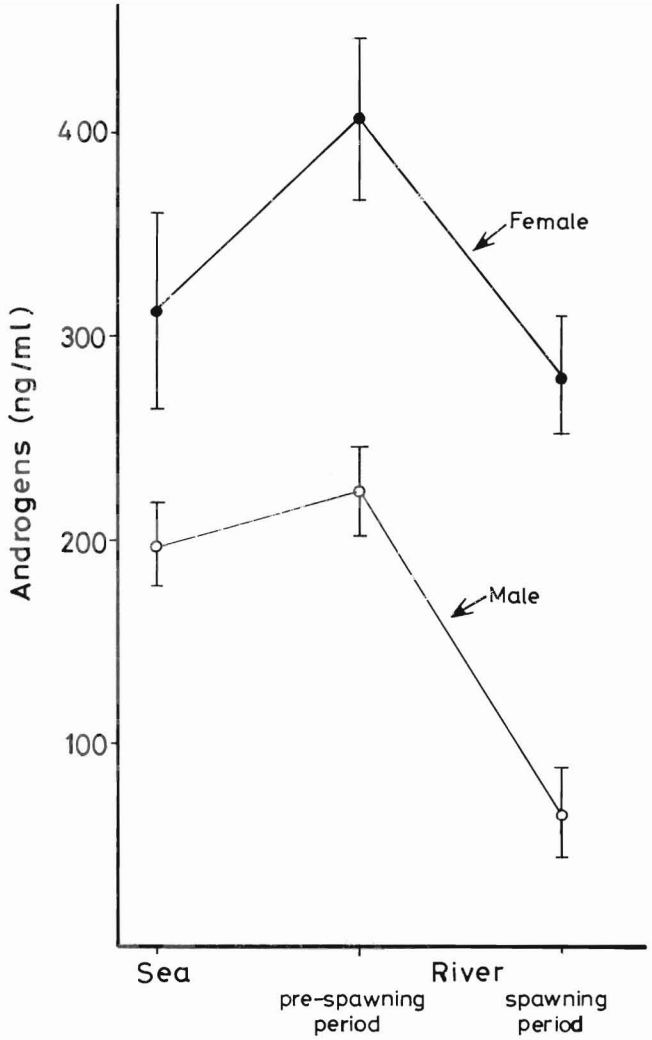

Figure 5.—Changes in serum androgen levels during sexual maturation in female and male chum salmon. The vertical bars represent the mean ± SEM.

Serum 17α,20β-diOHprog levels in males, similar to females, increased rapidly during spermiation, although the magnitude of elevation in males was smaller than in females. This observation provides strong evidence that 17α,20β-diOHprog is involved in the process of spermiation (Fig. 6).

Serum thyroxine levels were highest both in females and males collected in the coastal sea, and the levels decreased during anadromous migration (Fig. 7). The present findings in chum salmon, showing high serum levels of thyroxine during their life in the coastal sea, raise the possibility that thyroxine is involved in determining the readiness for the movement of the salmon from the sea to freshwater.

In vitro effects of chum salmon gonadotropins (SGA) on oocyte maturation in chum salmon.—To look for the possibilities of artificially induced maturation, in vitro effects of chum salmon gonadotropin (SGA) on estradiol-17β and 17α,20β-diOHprog production by ovarian follicles and on the induction of

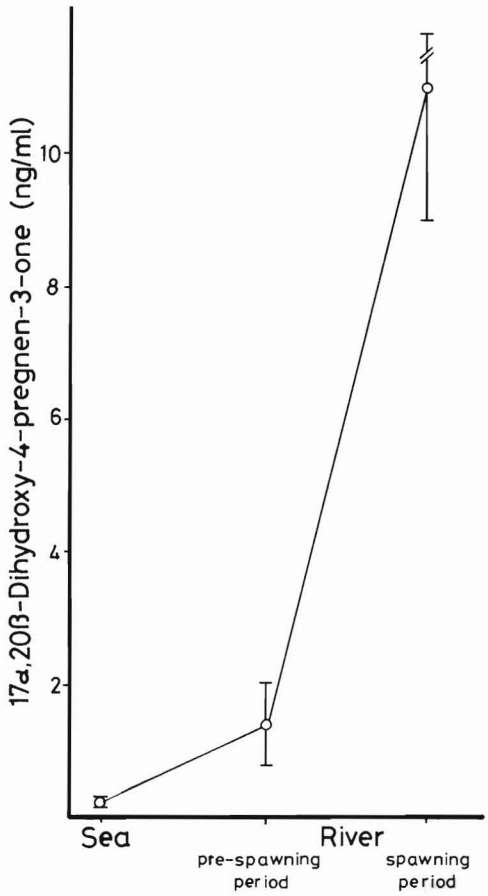

Figure 6.—Changes in serum 17α,20β-dihydroxy-4-pregnen-3-one levels during sexual maturation in male chum salmon. The vertical bars represent the mean ± SEM.

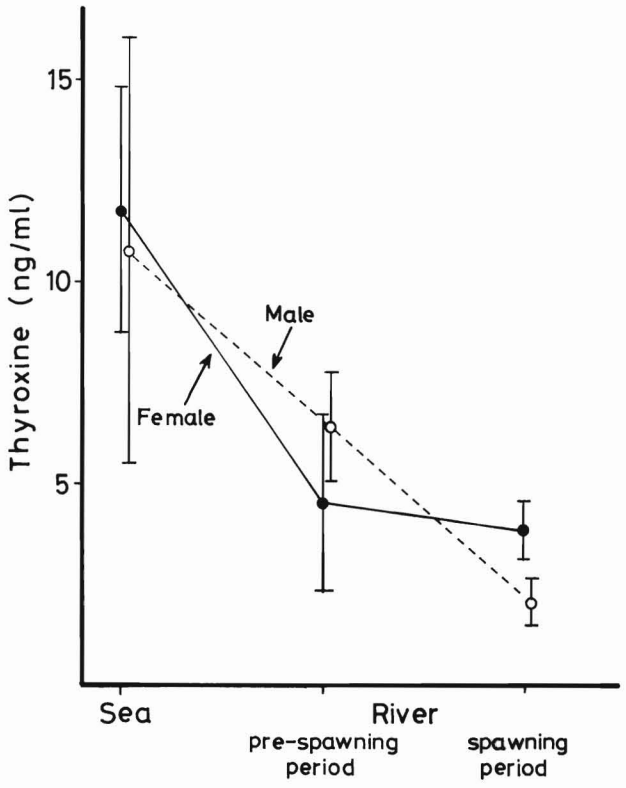

Figure 7.—Changes in serum thyroxine levels during anadromous migration in female and male chum salmon. The vertical bars represent the mean ± SEM.

germinal vesicle breakdown (GVBD) of oocytes were investigated in maturing females captured in midstream, which were in the late vitellogenesis phase, about 10-15 d before ovulation (Hiroi et al. 1982).

Ovarian follicles of 10 oocytes, which had only thecal and granulose cell layers, were incubated in vitro 18 h at 15°C in each concentration of SGA Ringer solution. Estradiol-17β was obviously produced by the incubations (Fig. 8), but no significant differences in production levels between the SGA treated groups and the Ringer control solution were observed, thereby showing that the levels were contained originally in follicles. On the other hand, 17α,20β-diOHprog production levels, as compared with that of the Ringer control, significantly increased with the increase in SGA doses. This provides strong evidence that 17α,20β-diOHprog, under SGA stimulation, is produced in ovarian follicles of the late vitellogenesis phase.

Fifteen oocytes were incubated in vitro 72 h at 15°C in various doses of SGA Ringer solutions. Although the oocytes were not changed by incubation in Ringer control (Table 4), oocyte matura-

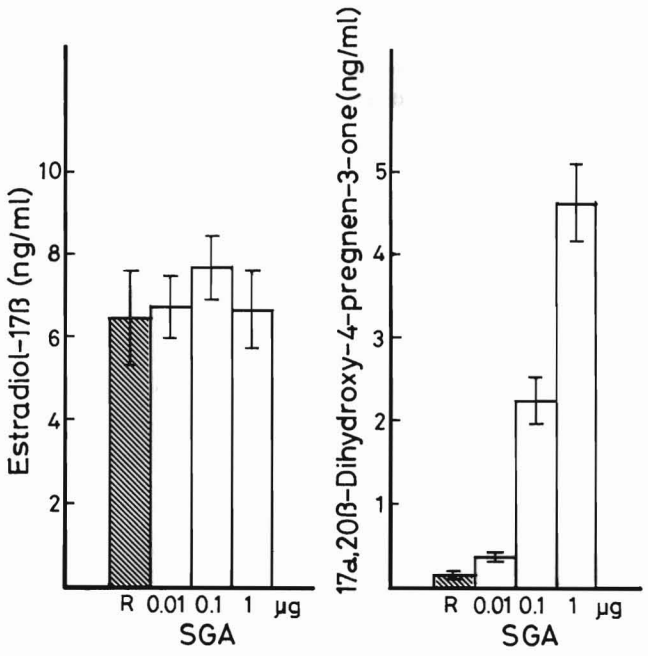

Figure 8.—Effects of chum salmon gonadotropin (SGA) on estradiol-17β and 17α,20β-dihydroxy-4-pregnen-3-one production by chum salmon follicles. The columns with oblique lines show the mean levels of ringer control. The vertical bars represent the mean ± SEM.

Table 4.—Effects of chum salmon gonadotropin (SGA) on the induction of GVBD of chum salmon oocytes in vitro.

Treatment	Oocyte condition (%±SEM)		
SGA dose (μg/ml)	GVBD	Migrated nucleus	Immature
3.3	100	0	0
1.0	80±12	20±12	0
0.33	100	0	0
0.1	47±29	53±29	0
0.033	0	100	0
0.01		7±7	93±7
Ringer control	0	0	100

tion from migrated nucleus to GVBD were induced by the incubation of various doses of SGA solutions, showing 100% GVBD over 0.33 μg/ml dose of SGA. These results show that it is possible to induce GVBD artificially (but not ovulation) by in vitro incubation of SGA in maturing oocytes of the late vitellogenesis phase in chum salmon.

Retention of Gametes in Chum Salmon

In order to promote effective utilization of gametes, including the production of excellent stocks or the future development of selective breeding, short-term retention of gametes and long-term cryopreservation of sperm were investigated in chum salmon.

Changes in fry-liberation rates of short-term stored chum salmon gametes.—Gametes were enclosed in vinyl sacks containing O_2-gas and stored in corrugated cardboard boxes at a room temperature of 2° to 9°C or in a refrigerator (only sperm) at a temperature of 2° to 5°C.

Fresh eggs fertilized with stored sperm stabilized over 90% in the fry-liberation rate up to 4 d after storage (Fig. 9), but after 5 d preservation, fluctuated between 60 and 90% with a weakening in sperm motility and gradual increase in microbial contamination showing 75% after a 7-d retention. Preserved eggs inseminated with fresh semen showed fry-liberation rates over 90% up to 2 d after storage, but after 3 d preservation, dropped gradually in fry-liberation rate to 12% after 7 d storage. Almost all the mortality of stored eggs was due to unfertilized eggs (Table 5) which were derived from the increase of cloudy water at the inner surface of the vinyl sacks apparently caused by diurnal temperature fluctuations of 2° to 9°C. Stored eggs inseminated with preserved semen under the same conditions (Hiroi 1978) showed fry-liberation rates over 97% after 2, 8, and 15 h of storage, which were higher than that of control eggs (96%). From 1 to 3 d, the fry-liberation rates declined slowly to 75%, and dropped suddenly to 39% after 4

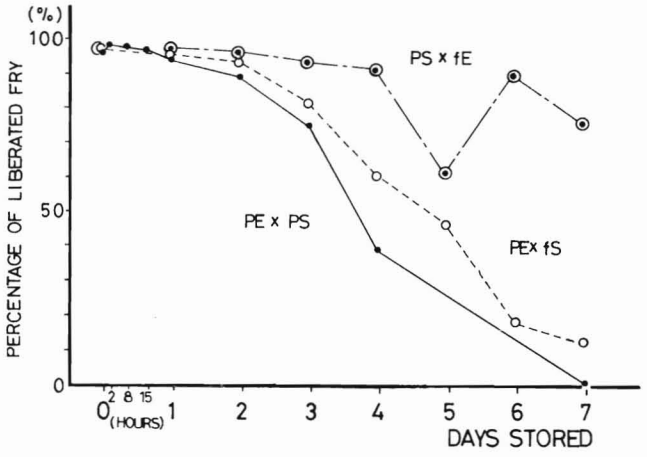

Figure 9.—Changes of fry-liberation rate in chum salmon as inseminated fresh eggs (fE) with preserved sperm (PS), preserved eggs (PE) with fresh sperm (fS), and preserved eggs with preserved sperm.

Table 5.—Sources and types of dead eggs in chum salmon.

Types	Nonsperm eggs		Fertilized eggs	
Elements	Stillborn eggs	Unfertilized eggs	Early dead-fertilized eggs	Late dead-fertilized eggs
Entrance of sperms into micropyle	None	None	Present	Present
Activation with water supply	None	Present	Present	Present
Blastodisc formation	None	Present	Present	Present
Isotonic regulation of chorion	None	Present	Present	Present
Cleavages	None	None	Present	Present
Isotonic regulation of embryonic body	None	None	None	Present
Multiplying frequency of fungi	Extremely	Little or none	Little or none	Extremely
Sources	Physiological degenerations and over-shocking during holding period	Water supply before insemination, mixing of broken eggs and stillborn sperms at collected eggs	Probable accidents of incubator or water supply and over-shocking	Probable accidents in incubation process and multiplication of fungi
Remarks	Almost all the eggs coagulate opaque within 24 h. Multiplication of fungi	Living aspects up to shocking selection time with faint pinkish color	Living aspects after shocking selection with faint yellowish color	Multiplication of fungi and opaque coagulation soon after dying with definite embryonic body

d and to 0.13% after 7 d of storage. Among the stored eggs, in addition to a gradual increase in unfertilized eggs, dead eggs before insemination increased accompanying prolongation of storage, which was considered to be due to direct or indirect influences of microorganisms.

Counts of microorganisms in stored semen and coelomic fluid increased rapidly accompanying prolonged storage (Table 6; Nomura and Hiroi unpublished). The count in coelomic fluid (3.1×10^5 body/ml) was larger than that in semen (2.7×10^3 body/ml) in the initial control. The increase in microorganisms after 7 d of retention was as much as 4,000 times in semen and 4,500 times in coelomic fluid compared with that of the control.

Table 6.—Viable counts of microorganisms in the semen and coelomic fluid of chum salmon.

Days stored	Viable counts of microorganisms per 1 ml	
	Semen	Coelomic fluid
0	2.7×10^3	3.1×10^5
3	6.3×10^4 (×23)[1]	1.6×10^7 (×52[1])
7	1.1×10^7 (×4,074)[1]	1.4×10^9 (×4,516)[1]

[1]Numerals in parentheses show the times to control.

Cryopreservation of chum salmon sperm.—These data were cited from Kurokura et al. (1982).

Chum salmon semen was immediately diluted with extender and DMSO, and cryopreserved in liquid nitrogen after freezing by methanol-dry ice bath (Kurokura and Hirano 1980). Fertility tests with sperm cryopreserved for 17 d gave about 19% eyed eggs, ranging from 5.3 to 29.9% (Table 7). This result demonstrated the possibility of long-term preservation of chum salmon sperm.

Table 7.—Fertility of cryopreserved chum salmon sperm. (n=8, mean 18.6%, SE 8.9%.)

Sperm	Total eggs	Eyed eggs	% eyed
Preserved	417	24	5.8
	419	41	9.8
	472	53	11.2
	347	60	17.3
	570	122	21.4
	445	105	23.6
	465	134	28.8
	384	115	29.9
Fresh	468	411	87.8
	612	579	94.6

Technical Conditions and Mortality Factors Up to Fry-Liberation During Artificial Propagation of Chum Salmon

Basic conditions required for holding maturing chum salmon in rivers.—Four basic conditions for holding maturing fish in rivers are described. First, maturing adults must be held in home stream waters because of their instinctive homing nature. Second, we have to understand the seasonal changes in degree of sexual maturation in the adults soon after entering each of the rivers. Knowledge of the degree of maturation is necessary to determine the holding time for optimum selection of mature fish and collecting eggs. Third, maturing adults must be kept in optimum water temperatures of 6° to 12°C by mixing spring water into the river water. Fourth, water currents in holding ponds must be kept slow, under 10 cm/s, with periodic exchanges of new water. In the present approaches, holding or rearing ponds with the water supply welled up from the bottom are most suitable.

Various infectious viruses and *Aeromonas salmonicida* in adult salmon in rivers in Hokkaido.—These data were cited from Nomura and Kimura (1981) and Kimura et al. (1982).

Infectious viruses and *A. salmonicida* were determined by usual methods, mainly from the semen of males and coelomic fluids of females, and from fresh kidney. Although the detection rates were extremely low, four kinds of infectious viruses, IHN, OMV, CSV, and VEN virus, were found in adult salmon in some rivers in Hokkaido from 1976 to 1981. IHN virus was found in only one sample of chum salmon adults in 1976 and 1977. CSV virus was detected in only one sample from chum salmon adults in 1978. OMV virus was determined in only one sample from Masu salmon adults in 1980. VEN virus was observed in only 1 sample from chum salmon adults in 1980 and in 8 samples from chum salmon adults in four rivers and in 14 samples from pink salmon adults of three rivers in 1981.

The detection rates of *A. salmonicida*, which causes furunculosis, were unexpectedly high in chum salmon adults. The rates increased with prolongation of the holding period, reaching over 50% in some rivers, but showed no significant difference between sexes.

Sources and kinds of dead eggs in chum salmon.—Dead eggs were divided originally into four types (Table 5; Hiroi 1981). A large number of dead eggs were either stillborn or unfertilized.

Stillborn eggs were deprived of normal fertility before fertilization and were found in broods held a long time under poor conditions. They were sources of fungi during artificial incubation of the eggs, because of the absence of isotonic regulation by the chorion. The unfertilized eggs were activated only with a water supply, without the entrance of the sperm into the micropyle, and accomplished blastodisc formation and isotonic regulation of the egg chorion, but did not proceed through cleavage. The occurrence of dead eggs was due to unskillful techniques in the artificial process of collecting eggs for insemination.

Among the fertilized eggs, dead eggs were divided into two types, early and late mortalities, depending on the developmental stage. The fertilized eggs which died in the early developmental stage did so as a consequence of over-shocking, unsuitable water currents, and defects in egg-incubation facilities. The eggs which died in the late developmental stage after maintaining isotonic regulation did so as a consequence of over about 200°C in daily cumulative water temperature. They were sources of fungi because of the solubility of the embryonic contents as a consequence of the loss of isotonic regulation of the chorion.

Technical approaches to insemination.—Since chum salmon are destined to die soon after their first spawning, eggs must be obtained by the "incision method" rather than the stripping method. Chum salmon eggs are activated instantaneously by contact with water. On the other hand, the sperm are activated immediately with ovarian coelomic fluids and effect entrance into the micropyle by their motility. However, the sperm can become abnormally mobile with water or Ringer solution. Because of this, eggs must be inseminated without water, namely the "dry method" of insemination.

Technical approaches during transfer of fertilized eggs to incubators.—Optimum washing times of eggs soon after fertilization were determined by mortality from a 2-h suspension of

the water supply (Hiroi 1980). The mortality of fertilized eggs decreased in proportion to the prolongation of washing times and became stable at over 25 min (Fig. 10). Therefore, eggs which have been recently artificially inseminated need to be washed for over 30 min in running water with an adequate current.

Fertilized eggs in the early developmental stage were weakened by strong shocking, and almost all the eggs died. Resistance of eggs to weak shocking is shown in Figure 11. Mortality of fertilized eggs was smaller up to 8 h after fertilization, but increased suddenly after 9 h, when the developing eggs initiated the first cleavage at a water temperature of 8°C (Hiroi et al. 1973). Therefore, the fertilized eggs have to be transported gently and settled into incubators within 8 h at 8°C after fertilization.

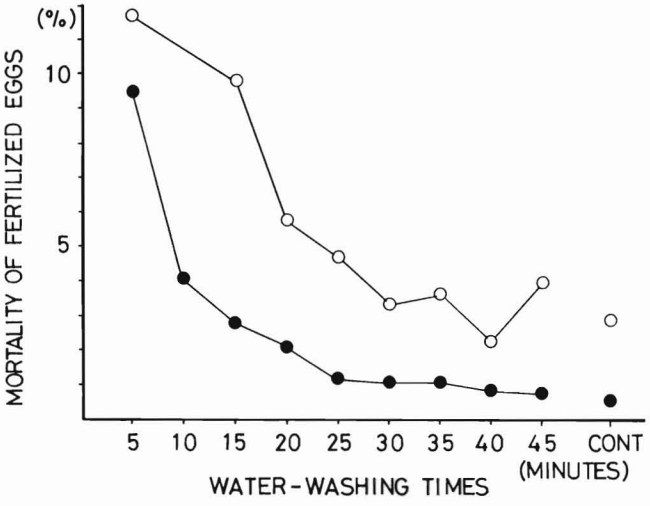

Figure 10.—Changes in mortality of fertilized chum salmon eggs by 2-h suspension of water supply soon after the artificial fertilization in the Chitose (solid circles) and Nijibetsu (open circles) Hatcheries.

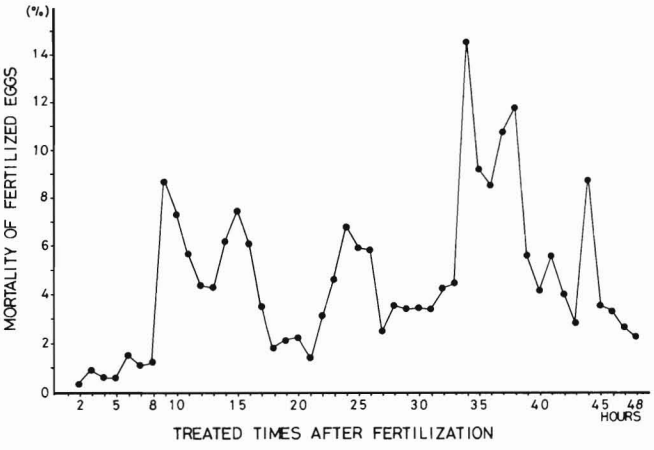

Figure 11.—Change in mortality of developing chum salmon eggs by weak shock.

Technical approaches used with developing eggs in incubators.—Developing eggs must be incubated without lights by upwelled currents of spring water with an appropriate constant water temperature. Egg resistance to hard shocking similar to the hard-shocking selection of dead eggs in the eyed stage is shown in Figure 12. Mortality of fertilized eggs was larger both up to 32 d

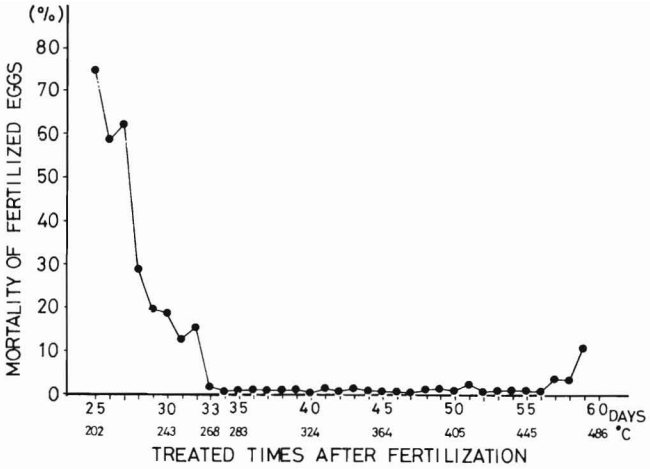

Figure 12.—Change in mortality of developing chum salmon eggs by hard shock.

and over 56 d at 8°C after fertilization, but became stable below 1% from 33 to 55 d. Therefore, eyed eggs can be detected from 35 to 55 d at 8°C (about 280° to 440°C in daily cumulative water temperature) after fertilization.

Technical approaches used with sac-fry in fry ponds.—Emerged fry must be hatched in artificial incubation beds modeled on natural conditions, especially with regard to sunlight, gravel, and water supply including upwelled currents. Developing fry do not seem to need sun, up to about 900°C in daily cumulative water temperature, after fertilization at 8°C. Because of their lack of mobility after emergence, they remain on the bottom in the sac-fry pond. It is necessary to maintain the water currents in the sac-fry pond below 3 cm/s with upwelled currents. Gravel on the bottom of the pond is important in maintaining the upwelled currents.

Technical approaches used with feeding fry in rearing ponds.—Feeding fry require sunlight and water currents, with an adequate food supply, to accomplish their downstream migration followed by their feeding migration to the sea. Feeding must be initiated during the period of 900° to 960°C in daily cumulative water temperature when the fry have functional digestive systems. Water in the rearing pond must have currents, with both riffles and pools like river streams, as well as an adequate exchange of new water with suitable, dissolved oxygen (over 70% in the outflow of ponds). Water currents as riffles in rearing ponds are especially important for the fry to have full swimming ability.

Bacterial gill disease and blue sac disease.—Bacterial gill disease and blue sac disease are serious problems for chum salmon fry. Almost all the fry-liberations from the lots exposed to both diseases resulted in little or no adult returns. Bacterial gill disease is infectious in a large number of fry, over about 850°C in daily cumulative water temperature. They are caused by flat, long rods on the surface of gill filaments. As shown in Figure 13, from scanning electron microscope observations (Hiroi, Nomura, and Urawa, unpublished), long rods were always detectable on the surface of the gill filaments of the infected fry. This disease is treatable by bathing with 0.5 to 1 ppm of nifurpirinol for 1 h.

Blue sac disease is essentially a form of dropsy in which the yolk sac is a visible blue color. This is caused by exposure of

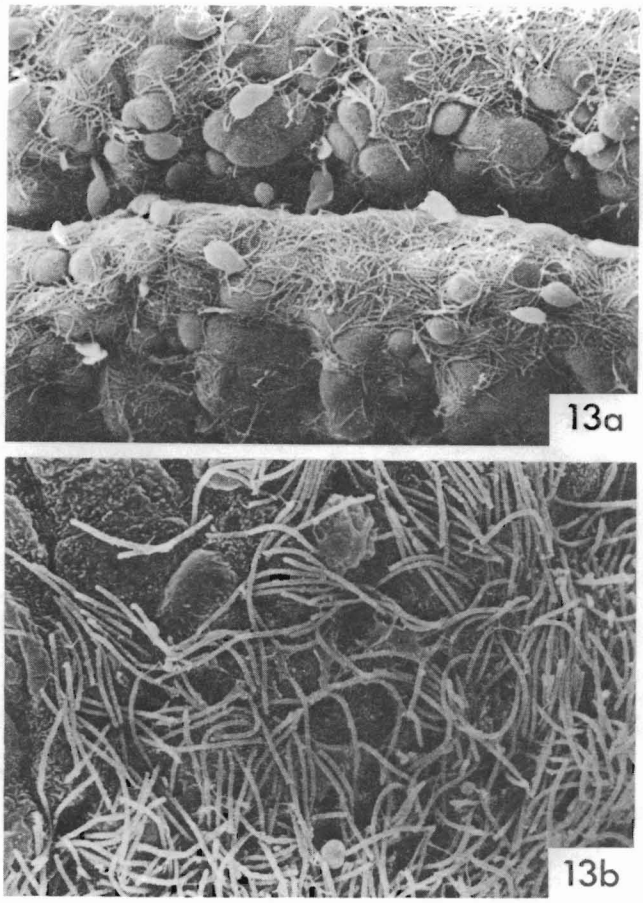

Figure 13.—Scanning electron micrographs of gill filament of infected chum salmon fry to bacterial gill disease. On the surface of the gill filaments, flat, long rods are detectable. Figure 13a, x 950; Figure 13b, x2,800.

developing eggs or fry to waters containing over 130% in nitrogen gas. Almost all the waters with this gas content were due to pump malfunction rather than the original gas content in natural flowing waters. At present, this disease is not treatable.

Timing of fry-liberation.—To prevent early mortality of chum salmon in artificial propagation, it is important to release healthy fry at the most suitable time to accomplish adequate feeding migration to the northern Pacific Ocean from the home rivers.

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The Migration and Ecology of Young Salmon in Early Marine Life

TAKAHIKO IRIE[1]

ABSTRACT

The ecology of juvenile chum and pink salmon is described for Abashiri Bay of the Okhotsk Sea and the Pacific Ocean off Hokkaido. Ecological and morphological changes are discussed together with developmental stages. Juvenile chum salmon development is divided into four stages. The patterns and routes of offshore migration are discussed in relation to water masses. It is suggested that the migration routes of juvenile salmon coincide with the distribution of the coastal water mass, and are connected with an isothermal area with surface water temperatures ranging from 8° to 13°C. Furthermore, the timing of juvenile salmon release is discussed, considering environmental conditions and the developmental stage of the juveniles. The most suitable time for release is when the coastal water mass is spreading along the coast. Optimal size of chum salmon at release was considered to be over 5 cm in fork length.

INTRODUCTION

Juvenile chum, *Oncorhynchus keta*, and pink salmon, *O. gorbuscha*, migrate from rivers into marine habitats and live in coastal waters for a few months, before they migrate toward offshore waters. In Japan, little has been known about the ecology and morphology of young salmon during this period, and there are few studies on the mechanism of migration toward offshore waters (Sano and Kobayashi 1952, 1953; Mihara 1958; Okada and Nishiyama 1970; Okada and Taniguchi 1971; Kobayashi 1977; Kobayashi and Abe 1977).

In general, fish develop in successive ontogenetic periods which are morphologically, physiologically, and ecologically distinguishable. Furthermore, each period is divided into stages or phases (Nikolsky 1963; Balon 1975). In the general distinction of development, chum and pink salmon in early marine life correspond to the juvenile period.

This paper deals with the migration and ecology of young salmon in early marine life. The paper also discusses the developmental stages of juvenile chum salmon using comparisons of ecological and morphological changes. Furthermore, patterns and routes of migration toward offshore waters, and the timing of release in relation to the developmental stages are discussed. This may not only help in describing an unknown period in the life history of salmon, but may also be useful in determining the optimum time of release to reduce the mortality rates of juvenile salmon.

MATERIALS AND METHODS

In recent years, we have obtained new information about the ecology of young salmon in a special project, "Technical development of large-scale farming of anadromous salmons," sponsored by the Agriculture, Forestry, and Fisheries Research Council. This report is based on our recent studies and my own data (Kobayashi et al. 1980; Irie et al. 1980, 1981a, b, 1982; Irie 1982a, b).

Investigations were mainly carried out in Abashiri Bay and adjacent waters of the Okhotsk Sea, and in the Pacific Ocean off Hokkaido in 1977-81 (Fig. 1). Oceanographic conditions in Abashiri Bay are affected by the Soya Warm Current and those along the Pacific coast of Hokkaido are affected by both the Tsugaru Warm Current and the Oyashio Current (Fig. 2).

To collect juvenile salmon, a small purse seine (117 m long, 2.6-9 m deep) was used during the day and a spoon net (5 m long, 40 cm diameter) with fish-gathering lamp (100 V, 2.5 kW) was used at night.

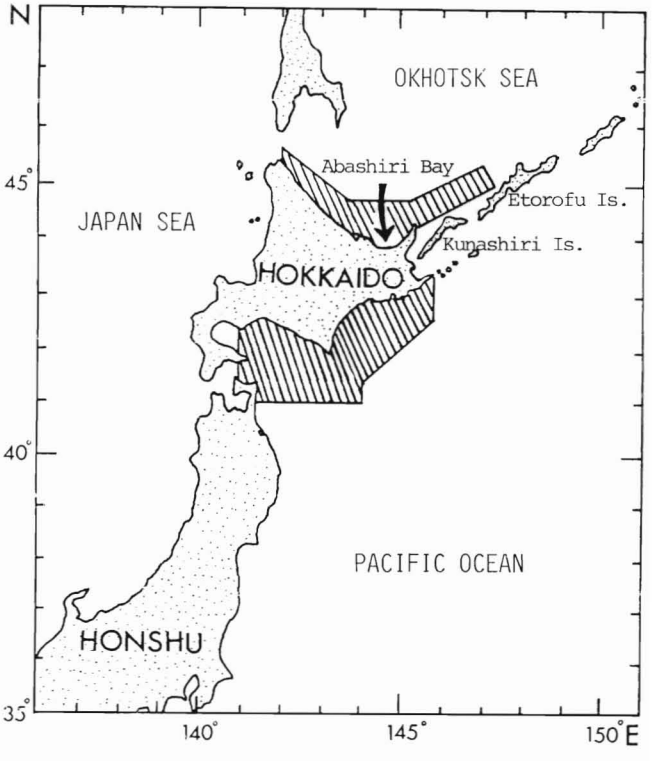

Figure 1.—Map showing the location of Abashiri Bay and adjacent waters and the Pacific Ocean off Hokkaido where investigations were carried out.

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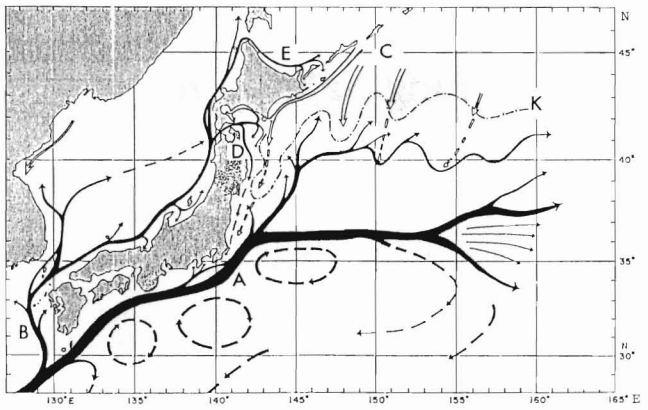

Figure 2.—A schema of the upper structure of currents and waters around Japan (after Uda 1935). A: Kuroshio water, B: Tsushima warm current, C: Oyashio water, D: Tsugaru warm current, E: Soya warm current, K: boundary zone of the cold water and the warm water.

Table 1 shows the data from the investigations and collections of juvenile salmon. Oceanographic observations and plankton sampling were made in each investigation. Table 2 shows the fork length distribution of the juvenile salmon.

DISTRIBUTION PATTERN AND BEHAVIOR OF YOUNG SALMON

In mid and late May in Abashiri Bay, juvenile chum salmon of 3-6 cm fork length (FL) and pink salmon of 3-5 cm FL generally occurred within 1-2 km of the shore (Figs. 3, 4, Table 2). They were often found in schools or assembled in inlets and ports. Under fish-gathering lamp, they were observed swimming in the extreme surface of the water (Irie et al. 1980, 1981a).

From late June through early July, juvenile chum salmon of 4-12 cm FL and pink salmon of 4-10 cm FL were observed within 16 km of the shore (Figs. 3, 4, Table 2).

The number of juvenile salmon decreased with distance from the shore. The larger juveniles were distributed further offshore (Irie et al. 1980, 1981a). Mishima, Yamamoto, and Shimazaki (1982) and Mishima, Shimazaki, Yamamoto, Ishii, Sasaki, and Meguro (1982) indicated a similar phenomenon. Reviewing past reports published in Japan, Ito (1980) pointed out that the larger chum salmon appeared further offshore even in coastal areas. The same phenomenon was reported for pink salmon off the British Columbia coast (Gilhousen 1962; Healey 1980).

Under fish-gathering lamp, the juveniles were observed swimming quickly in circles in schools just below the surface water (Irie et al. 1980, 1981a). There were changes in the schooling and swimming behavior over time and with the stage of development. Hoar (1976) stressed that schooling behavior was very important in the evolution of the strongly migrant seagoing stocks of oncorhynchids.

Most juvenile salmon had disappeared from Abashiri Bay by early or mid-July (Figs. 3, 4). The results suggest that juvenile salmon live first in the area adjacent to the shore and gradually extend to the area along the coast and further offshore.

Juvenile pink salmon were collected together with chum salmon in Abashiri Bay (Figs. 3, 4). Similar phenomena were reported off the coast of the South Kuriles (Ibankov and Shershnev 1968) and off the British Columbia coast (Manzer 1956;

Table 1.—Data from investigations and collections of juvenile chum and pink salmon by various methods in 1977-81.

Cruise no.	Year	Period	Area	Sampling gear	no. tows	No. collected	
						O. keta	*O. gorbuscha*
1	1977	19 July - 17 August	Japan Sea - Okhotsk Sea	Isaac-Kidd mid-water trawl	12	1	—
				Larva net	18	—	—
				Gill net	5	—	—
				Spoon net with fish lamp	8	6	—
2	1978	18-22 May	Abashiri Bay	Larva net	13	2	—
				Spoon net with fish lamp	4	41	4
3	1978	29 June - 2 July	Abashiri Bay	Larva net	16	—	—
				Gill net	2	—	—
				Spoon net with fish lamp	2	166	36
4	1978	15-20 July	Abashiri Bay	Larva net	7	—	—
				Gill net	2	—	—
				Spoon net with fish lamp	6	2	—
5	1979	21-27 May	Abashiri Bay	Larva net	5	—	—
				Spoon net with fish lamp	9	149	75
6	1979	26 June - 2 July	Abashiri Bay	Spoon net with fish lamp	17	225	52
				Purse seine	3	—	—
7	1979	5-10 July	Abashiri Bay	Spoon net with fish lamp	21	143	32
				Purse seine	2	5	2
8	1980	18-27 May	Abashiri Bay	Spoon net with fish lamp	20	111	160
				Purse seine	2	1	—
9	1980	30 June - 6 July	Abashiri Bay	Spoon net with fish lamp	7	79	69
				Purse seine	13	202	8
10	1980	8-12 July	Abashiri Bay - Off Etorofu Is.	Spoon net with fish lamp	8	—	1
11	1980	14-18 July	Abashiri Bay	Spoon net with fish lamp	15	5	3
				Purse seine	4	—	—
12	1981	2-15 June	Pacific Ocean	Larva net	14	—	—
				Spoon net with fish lamp	24	19	—
13	1981	6-19 July	Pacific Ocean	Larva net	43	3	—
				Spoon net with fish lamp	43	77	—

Table 2.—Fork length distribution of juvenile chum and pink salmon collected in 1977-81.

Fork length (cm)	Year	1977	1978	1978	1978	1979	1979	1979	1980	1980	1980	1980	1981	1981	
	Period	21-26 July	18-22 May	29 June -2 July	15-20 July	21-27 May	26 June -2 July	5-10 July	18-27 May	30 June -6 July	8-12 July	14-18 July	2-15 June	6-19 July	Total
Oncorhynchus keta															
2-3									1						1
3-4			3			71			53				6		133
4-5		2	21	1		71	18	2	54	2			3	3	177
5-6		3	18	31		6	68	27	3	2			4	4	166
6-7			1	124		1	63	41	1	8				4	243
7-8		2		8	2		59	56		26		1		5	159
8-9				2			11	18		46		2	1	12	92
9-10							4	4		124		2	2	27	163
10-11							1			64			1	17	83
11-12							1			9			1	6	17
12-13														2	2
13-14													1		1
Total		7	43	166	2	149	225	148	112	281		5	19	80	1,237
Oncorhynchus gorbuscha															
3-4						75			146						221
4-5			4				7	3	14	3					31
5-6				10			17	7		5					39
6-7				24			26	9		17					76
7-8				2			2	13		35		1			53
8-9								2		10	1	1			14
9-10										7		1			8
Total			4	36		75	52	34	160	77	1	3			442

Neave 1966a, b). This suggests that the habitats of the two species resemble each other closely at this stage of development.

DISTRIBUTION OF YOUNG SALMON AND ENVIRONMENTAL FACTORS

Oceanographic Conditions

Figures 3 and 4 show the distribution of juvenile salmon and the surface water masses in Abashiri Bay. In mid and late May, the coastal water mass is distributed along the coast, and the Okhotsk Surface Water is spread further offshore. Juvenile salmon were in the coastal water mass, near the shore.

In late June and early July, the coastal water mass is ordinarily replaced by the Soya Warm Water, with the Okhotsk Surface Water remaining offshore (Figs. 3, 4).

Figure 5 shows juvenile salmon densities and water masses. Juvenile salmon are found mainly in coastal water masses with surface water temperatures from 10° to 13°C and salinity from 33.00 to 33.70‰. They are also found in low salinity areas, below 33.8‰, even in the Soya Warm Water; some were in the area of the Okhotsk Surface Water.

The Soya Warm Water is widely dispersed by late July and, as a result, the number of juvenile salmon decreases sharply (Irie et al. 1980, 1981a, b). During this period, juvenile salmon were observed in the Okhotsk Surface Water off Etorofu Island (Irie et al. 1982).

Figures 6 and 7 show the distribution of juvenile chum salmon and water masses in the Pacific Ocean. From early June to mid-July, the coastal water mass was distributed near the Pacific coast; the Oyashio Water was offshore. Juvenile chum salmon were mainly found in the coastal water mass with some in the lower salinity area of the Oyashio Water (Irie 1982a).

This suggests that in Abashiri Bay, juvenile salmon live in contact with the coastal water mass throughout their coastal residence. They leave the coastal waters by the time the Soya Warm Water becomes dominant in the area.

Compared with the Okhotsk Sea, the oceanographic conditions in the parts of the Pacific Ocean where juvenile salmon are distributed are similar in temperature but lower in salinity. Comparing water masses in the Pacific Ocean and the Okhotsk Sea shows a parallel phenomenon.

Distribution of Zooplankton

Figure 8 shows the distribution of zooplankton and water masses in Abashiri Bay and adjacent waters. In mid and late May, the density of zooplankton in the nearshore coastal water mass was higher than in the offshore areas. In late June, it was higher in the offshore areas, with the Okhotsk Cold Water, than in the nearshore areas. In early July, it was higher off Etorofu Island in the Okhotsk Cold Water than in Abashiri Bay where the Soya Warm Water occurred (Irie et al. 1982).

These results suggest that, through the intermediation of water masses, there is a definite relationship between the distribution of zooplankton and juvenile salmon.

FOOD FOR YOUNG SALMON

Juvenile chum salmon 3-5 cm FL collected near coasts fed on small zooplankton, insects, and fish larvae. The main prey animals were different at the different stations where samples were collected. Consequently, it has been suggested that young salmon do not feed on specific animals but feed on the easiest prey available in a region (Kobayashi et al. 1980).

Chum salmon of 5-11 cm and pink salmon of 5-8 cm FL collected in Abashiri Bay were mainly feeding on larger zooplankton such as calanoida, amphipoda, fish larvae, and Euphausiacea larvae. They were feeding on especially *Calanus*

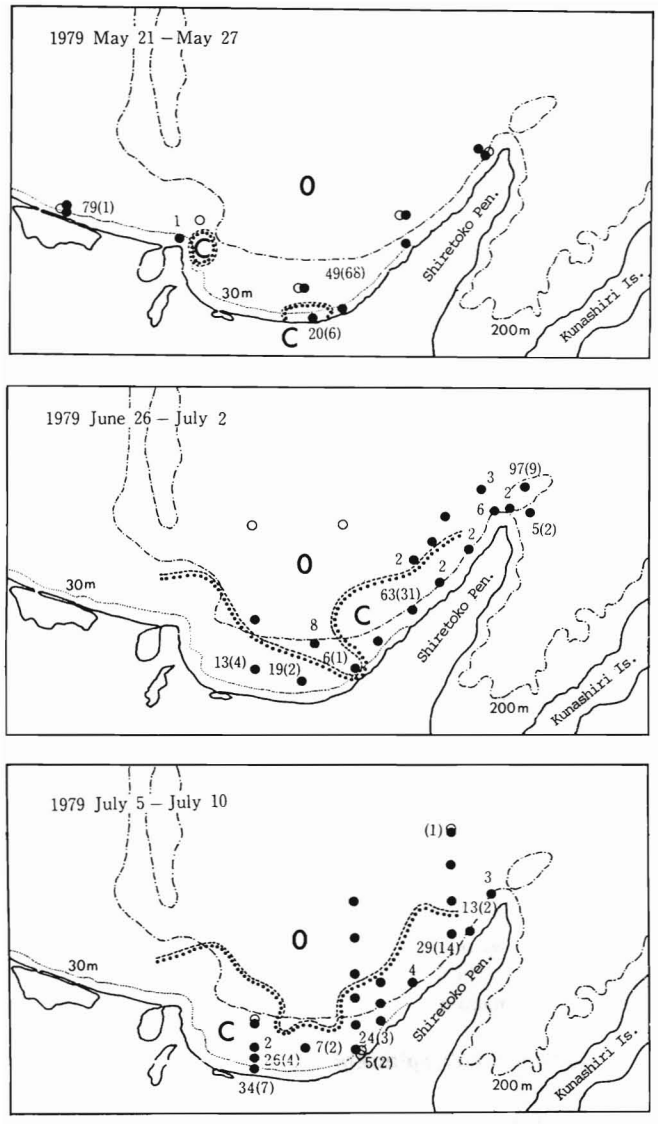

Figure 3.—Distribution of juvenile salmon and surface water masses in Abashiri Bay from 21 May to 10 July 1979. Numerals indicate number of chum salmon collected. Numerals in parentheses indicate number of pink salmon collected. No number indicates zero. Dotted lines indicate the boundary of two water masses. Solid circles indicate spoon net with fish lamp, open circles indicate larva net or purse seine. O: Okhotsk surface water, C: coastal water mass.

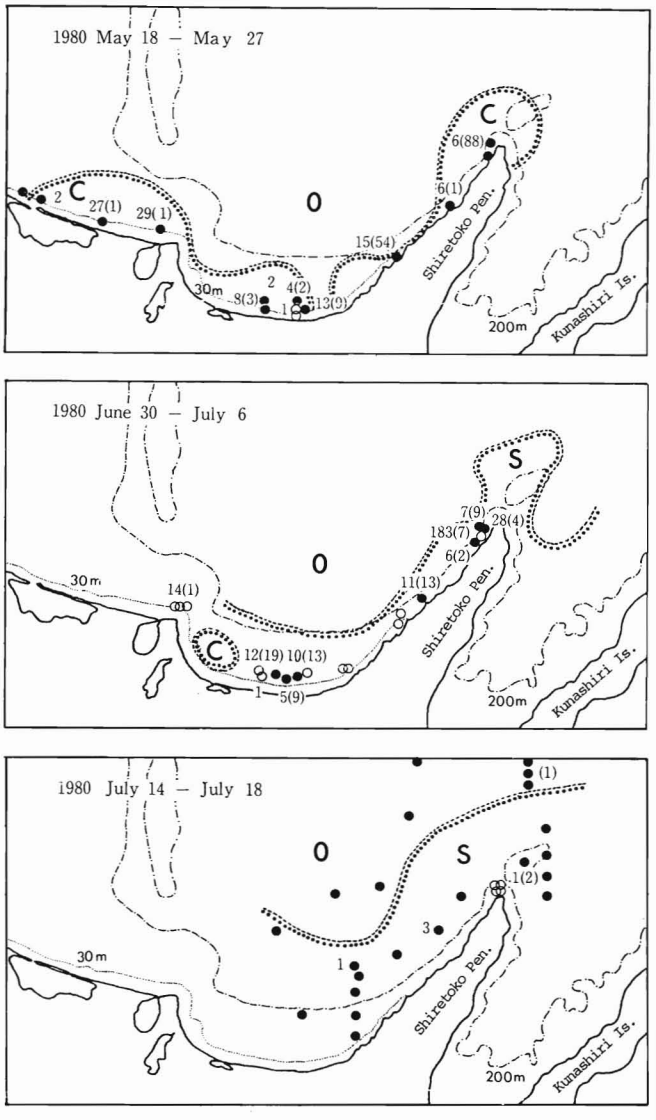

Figure 4.—Distribution of juvenile salmon and surface water masses in Abashiri Bay from 18 May to 18 July 1980. O: Okhotsk surface water, C: coastal water mass, S: Soya warm water. (For further explanations, see Figure 3.)

plumchrus and *Parathemisto japonica* which are the most common and abundant there (Irie et al. 1982).

Shershnev (1970) pointed out that prey size for juvenile salmon was larger in May and June than in April. Okada and Taniguchi (1971) reported that the size of prey animals apparently changed before and after 55 mm FL. Simenstad et al. (1980) clarified that outmigrating juvenile chum salmon exhibited a high degree of selectivity in prey size, and they also discussed the mechanism of prey selection in detail.

MORPHOLOGICAL CHANGES WITH DEVELOPMENT

In juvenile chum salmon, parr marks persist on the body for a time after entering the sea from rivers. Scales first appear on specimens of about 4 cm FL and are present in all specimens over 5 cm. Simultaneously with the appearance of scales, the body becomes more silvery, parr marks become obscure, and the tips of the dorsal and caudal fins begin to turn black (Irie 1982b).

Figure 9 shows gill raker number versus fork length in juvenile chum salmon. Gill rakers reached the full number at about 5 cm FL at the earliest and they were almost complete at a fork length over 11 cm (Irie et al. 1980).

Figure 10 shows the development of body parts versus fork length in juvenile chum salmon. Inflections in growth were observed in 11 body measurements: Head length, eye diameter, upper jaw length, mouth width, pectoral fin length, caudal fin length, dorsal fin height, anal fin height, body height, body width, and anal length. In eye diameter, mouth width, and pectoral fin length, growth inflections were observed at a fork length of about 5 cm and about 8 cm (Irie et al. 1981b; Irie 1982b). These changes in

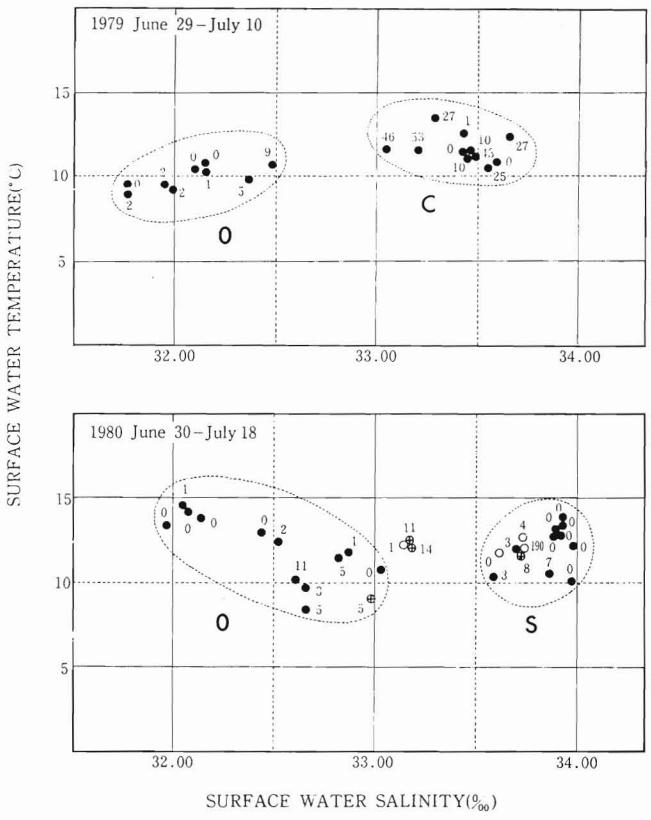

Figure 5.—Relation between surface water masses and number of juvenile chum and pink salmon observed. Surface water temperature and salinity were measured at the same time as the juvenile sampling. O: Okhotsk surface water, C: coastal water mass, S: Soya warm water. Solid circles numerals indicate number of juvenile salmon observed during a half hour period of lighting (29 June-10 July 1979 and 8-18 July 1980). Open circles numerals indicate number of juvenile salmon collected by purse seine (30 June-6 July 1980). Circles with crosses numerals indicate number of juvenile salmon collected by spoon net during a half hour period of lighting (30 June-6 July 1980).

the slope of the relative-growth line indicate sudden changes in organization (Martin 1949).

DISTINCTION OF DEVELOPMENTAL STAGES

Morphological changes can be distinguished to correspond to the above ecological changes in food habits, behavior, and extension of the living area away from the shore. In Table 3 the data are arranged in sequence, and four substages are distinguished in the early marine development of the chum salmon: Stage A with a fork length of 3 to 5 cm, just migrated seaward but not yet completely adapted to seawater; Stage B with a fork length of 5 to 8 cm, further adaptation to seawater and preparing for offshore migration; Stage C with a fork length of 8 to 11 cm, completely adapted to seawater and beginning ocean migration; Stage D with a fork length of 11 to 17 cm, ordinarily migrating offshore.

The end of stage D, 17 cm FL, is estimated from the size of juvenile chum salmon collected in coastal and offshore areas for our present investigation. The maximum fork length was reported to be 18.6 cm with almost all below 17 cm (Mihara 1958; Hayashi and Odate 1980; Hashiba and Yasui 1980; Ito 1980; Mishima and Shimazaki 1980; Irie et al. 1981a; Irie 1982b). Similarly, specimens with 11-17 cm FL were caught in the offshore areas of the Okhotsk Sea (Birman 1969).

Considering the sampling results and morphological changes (Irie et al. 1981a, b; Irie 1982b, unpubl. data), it may be concluded that juvenile pink salmon migrate offshore at smaller sizes than juvenile chum salmon.

Physiologically, chum and pink salmon show a higher salinity tolerance than other salmonid species in the early stages of development (Weisbart 1968; Hoar 1976). According to McInerney (1964), the preference for salinity increases gradually and is temporally associated with seaward migration. Kashiwagi and Sato (1969) and Kashiwagi and Iioka (1978) reported that in chum salmon, salinity tolerance increases gradually as the fish becomes older, and juveniles more than 90 d after hatching (6 cm, 2 g) all survived in 100% seawater.

The results show that it takes time for juvenile chum salmon to fully adapt physiologically to seawater, and changes in morphology, ecology, and physiology, the so-called "smoltification," occur from 5 to 8 cm FL. LeBrasseur and Parker (1964) suggested that such changes occurred at about 6-8 cm FL in pink salmon.

MIGRATION PATTERNS AND ROUTES OF YOUNG SALMON

Based on the results, the migration pattern for juvenile salmon in relation to water masses is shown schematically in Figure 11. Area B corresponds to estuaries, ports, and inlets. Area D corresponds to the boundary of two water masses or areas where they are mixing.

In early marine life, juvenile salmon live first in the coastal water mass which is influenced by freshwater. Thereafter, the living area gradually expands along the coast. When development is complete, they begin to migrate in schools to the offshore cold water mass. As shown in Figures 5 and 7, there were no abrupt changes in temperature and salinity between the coastal water and the offshore cold water. The migration occurs with an increase in swimming ability and changes in the animals preyed upon, as well as with the movement of the water mass itself. The remaining juvenile salmon migrate offshore responding to changes in environmental conditions such as the decline of the coastal water mass, the rise in water temperature and salinity, and changes in food conditions.

In conclusion, the migration route of juvenile salmon in early marine life coincides with the coastal water mass. Due to the oceanographic conditions in Abashiri Bay, the route was within about 16 km of the shore along the coast. In the Pacific Ocean, the route is more complex than in Abashiri Bay (Fig. 12). The route should be considered in relation to isothermal areas with surface water temperatures ranging from 8° to 13°C, as shown in Figure 13.

TIMING OF YOUNG SALMON RELEASE

The most suitable time for release of juvenile salmon is when the coastal water mass with lower salinity is spreading along the coast. A temperature of 13°C and a salinity of 33.8‰ in the surface water may be used as an upper limit for the release of juvenile salmon.

As shown in Figure 13, the release should be earlier in southern areas and later in northern areas of Japan. There are annual differences, however. The rise in temperature in 1981 was more than 10 d later than in 1978. In the coastal areas off the northeastern part of Honshu, isothermal areas with a surface water temperature

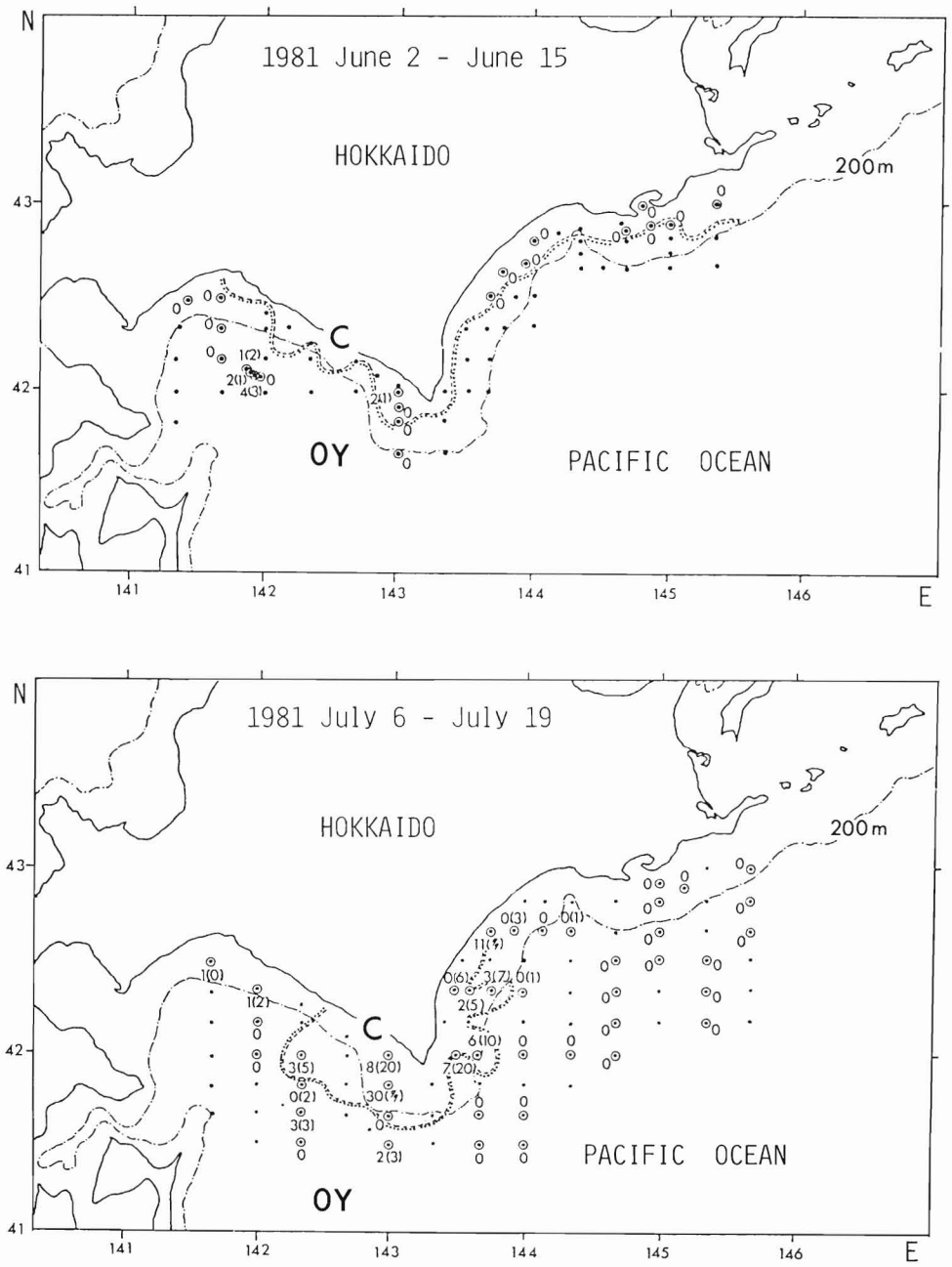

Figure 6.—Distribution of juvenile chum salmon and surface water masses in the Pacific Ocean off Hokkaido from 2 June to 19 July 1981. Numerals indicate number of chum salmon collected by spoon net for a half hour period of lighting. Numerals in parentheses indicate number of juvenile salmon escaped. C: coastal water mass, OY: Oyashio water. Solid circles indicate station of oceanographic observation and plankton sampling; circled solid circles indicate sampling station by spoon net with fish lamp.

ranging from 8° to 13°C are not generally found after late June (Fig. 13). Juvenile chum salmon have not been observed offshore of Tohoku, the northeastern part of Honshu, after late June (Hayashi and Odate 1980; Hashiba and Yasui 1980). With further data, it may become possible to determine the optimum time of release for juvenile salmon in a particular sea area.

Providing that release in the later developmental stages reduces natural mortality, it will be advantageous to rear juvenile chum salmon artificially until they reach more than 5 cm FL. This is the critical size for juveniles living in inlets or along shorelines.

As a next step, it may prove more effective to release juvenile chum salmon at over 8 cm FL, when they have developed fully.

From results by Iioka, Urano, Takechi, Sato, Okawa, Hebiishi, Terashima, and Minato (1980) and Iioka (1982), in experimental releases of juvenile chum salmon in Yamada Bay, Iwate Prefecture, chum salmon showed various rates of return as adults depending on the size of juveniles released. Particularly high rates of return were attributed to the juveniles having body weights of 1.3 and 8 g at the time of release. Changing body weight to fork length, 1.3 g in body weight corresponds to about 5 cm FL, and 8 g

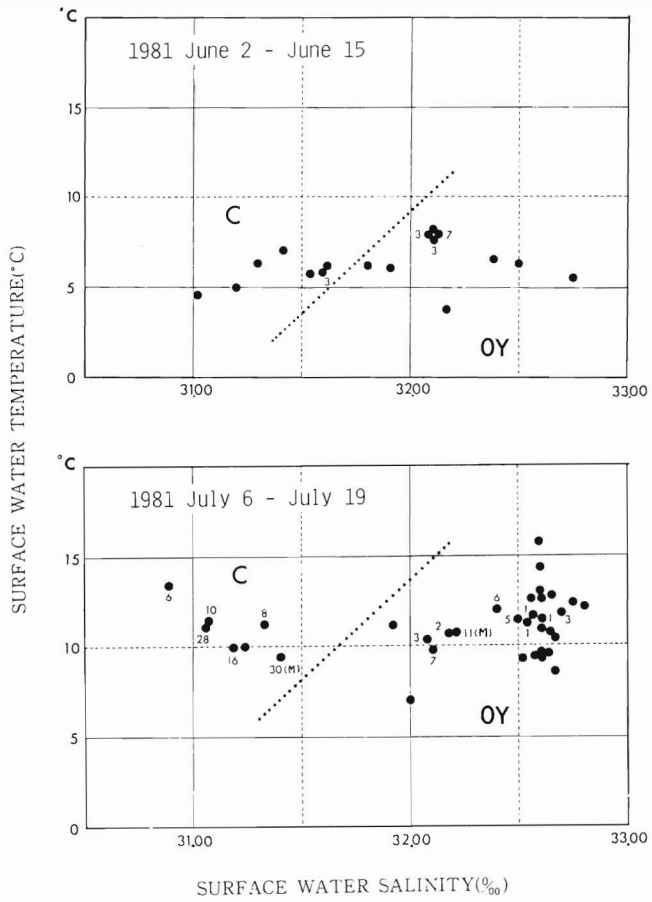

Figure 7.—Relation between surface water masses and number of juvenile chum salmon observed during a half hour period of lighting in the Pacific Ocean off Hokkaido from 2 June to 19 July 1981. No number indicates zero. M: many, C: coastal water mass, OY: Oyashio water.

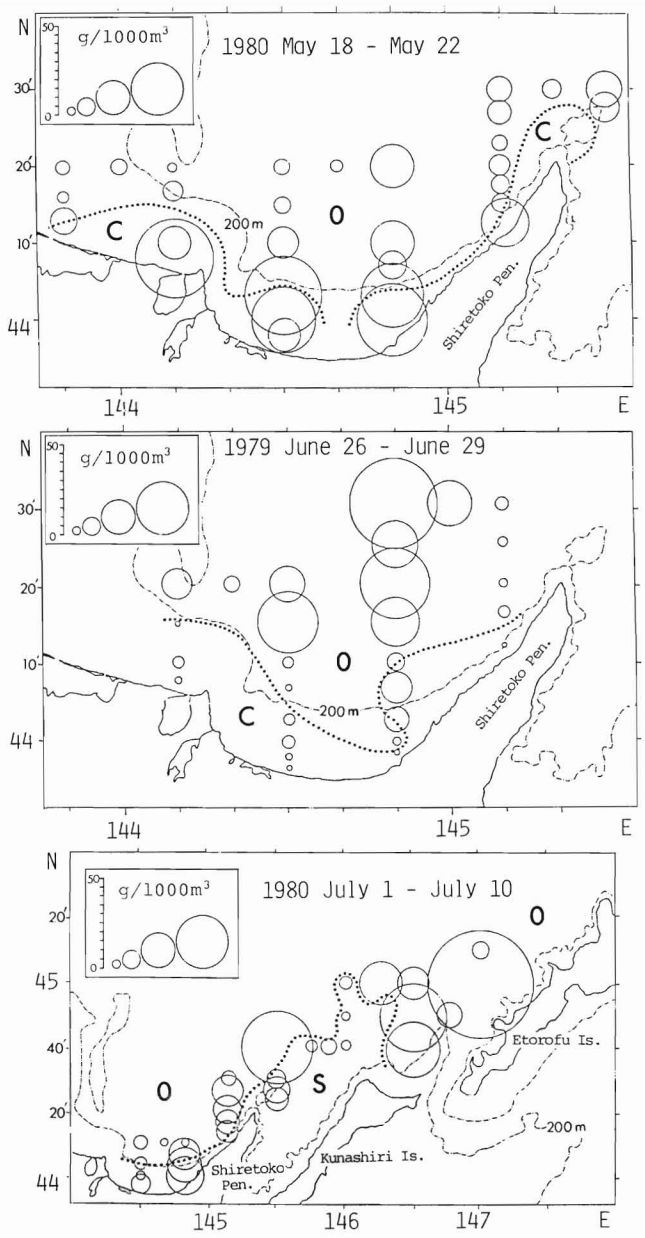

Figure 8.—Distribution of zooplankton and water masses in Abashiri Bay. Density of zooplankton was estimated by a vertical haul of NORPAC net. Dotted lines indicate the boundary of two water masses. O: Okhotsk surface water, C: coastal water mass, S: Soya warm water.

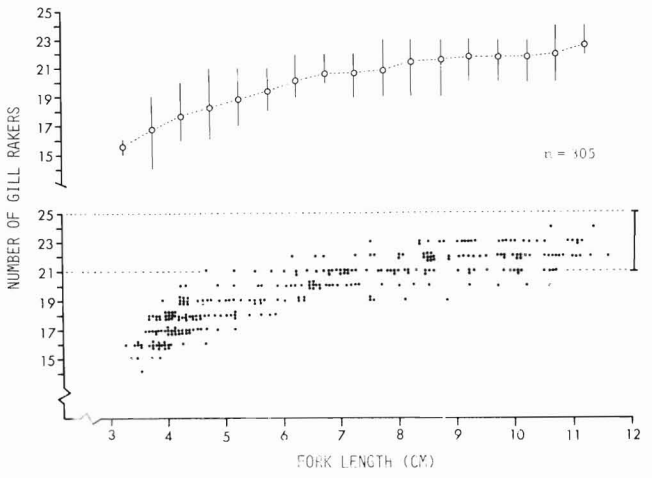

Figure 9.—Number of gill rakers with development in juvenile chum salmon. Circles with vertical rules indicate average number and range in each 5 mm of fork length. Vertical bar in lower figure indicates range of gill raker number in adults.

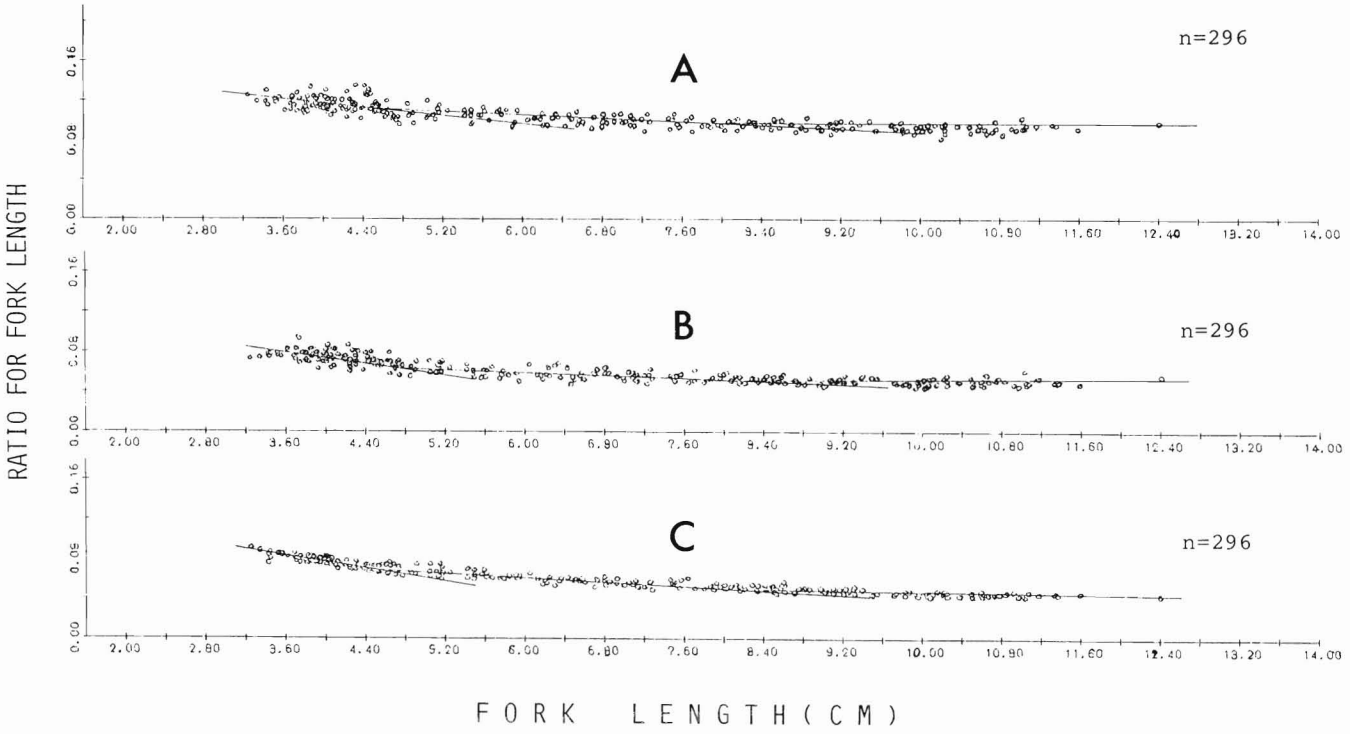

Figure 10.—Development of each body part against fork length in juvenile chum salmon. A: pectoral fin length, B: mouth width, C: eye diameter.

Table 3.—Substages in the development of juvenile chum salmon.

Stage	Range of fork length (cm)	Distribution area	Characters in morphology	Habitat	Prey animals	Behavior
A	3-5	Coastal within 1.6 km Ports, inlets	Parr marks present. Scales incomplete. Eye diameter, mouth width and pectoral fin length is large against fork length. Gill rakers incomplete.	Coastal water	Insects Small zooplankton; calanoida, fish eggs and larvae, Polychaeta	Schooling behavior. Swim near surface water. Phototaxis observed.
B	5-8	Coastal within several kilometers	Parr marks become obscure. Scales formed. Silvering advanced. Tips of dorsal and caudal fins become blackish.	Coastal water	Large zooplankton; calanoida, amphipoda, fish larvae, Euphausiacea	Schooling and migration behavior strong. Phototaxis observed.
C	8-11	Coastal within 16 km ~ offshore	Rate of each body part fixed.	Coastal water, lower salinity part of cold and warm current water	Large zooplankton; calanoida, amphipoda, fish larvae, Euphausiacea	Schooling and migration behavior strong. Phototaxis observed. Swim just below surface water.
D	11-17	Offshore	Gill rakers completed.	Offshore cold water	Large zooplankton; calanoida, amphipoda, fish larvae, Euphausiacea	Schooling and migration behavior strong. Phototaxis observed. Swim just below surface water.

in body weight corresponds to about 9-10 cm FL. The results agree well with our results from the developmental stages of juvenile chum salmon. In applications to release of juvenile salmon, it is necessary to consider both the size of the juveniles and the environmental conditions in the sea.

ACKNOWLEDGMENTS

I am particularly indebted to Masanao Osako and Tokimasa Kobayashi for their many helpful discussions during the develop-

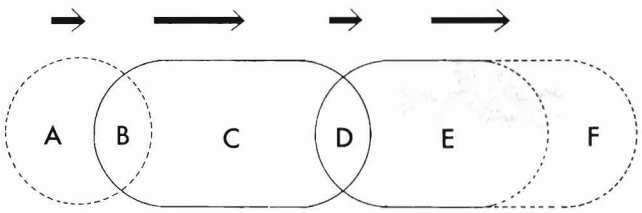

Figure 11.—A schema of the seaward migration pattern against water masses in young salmon. A: freshwater, B: brackish water, C: coastal water, D: lower salinity part of the cold water or that of the warm water, E: offshore cold water, F: subarctic water. Arrows indicate migration course.

ment of this study. I wish to thank Soichiro Shirahata for critically reading the manuscript.

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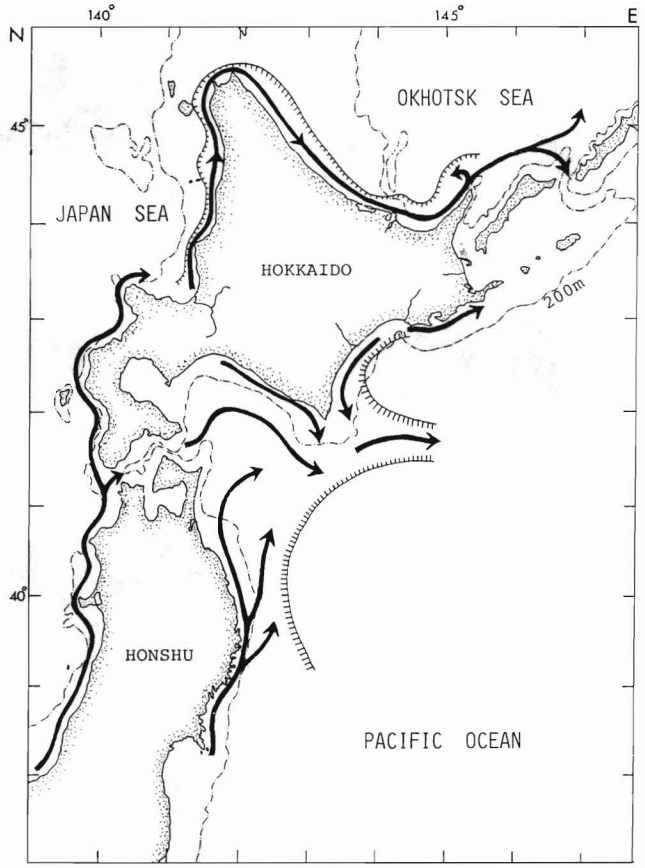

Figure 12.—Estimated migration route and distribution area of young salmon in their early marine life. Arrows indicate migration route; hatch lines indicate distribution area. (Data, partly modified: Iioka, Takechi, Sato, and Minato 1980; Irie et al. 1981a,b; Hoshiai et al. 1981; Irie 1982a, unpubl. data; Hashiba et al. 1982; Ito 1982; Kato 1982; Mishima, Shimazaki, Yamamoto, Ishii, Sasaki, and Meguro 1982.)

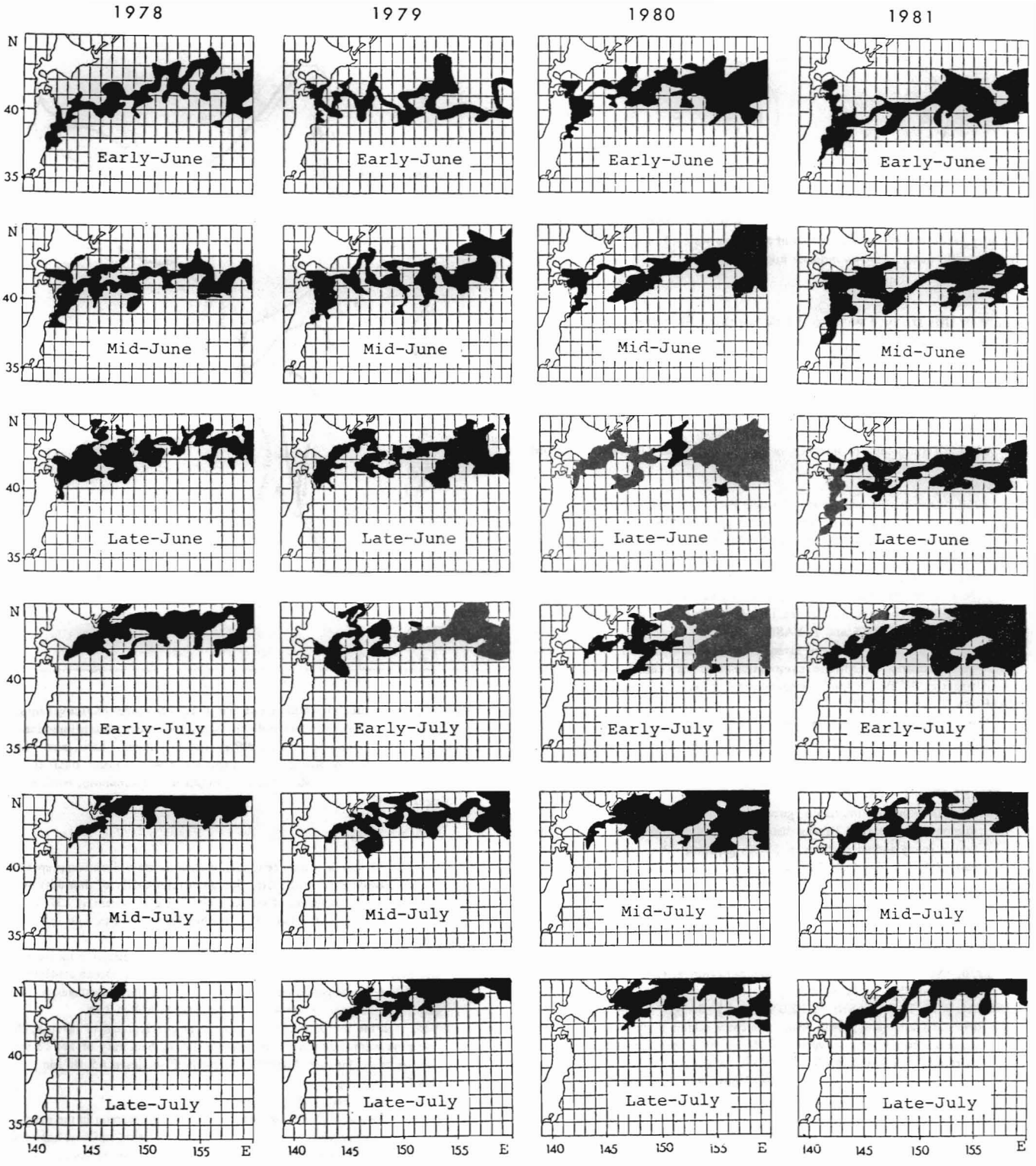

Figure 13.—Periodical and annual differences of the water zone with surface water temperature from 8° to 13°C in the northwestern part of the Pacific Ocean. (Data: A brief report of fisheries and oceanographic conditions, Fisheries Information Service Center, 1978-81.)

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Recent Information on Europium Marking Techniques for Chum Salmon

MAMORU KATO[1]

ABSTRACT

A marking experiment using an activable tracer method was conducted with 4 million chum salmon fry which originated in the Ishikari River System in 1979. Europium was detected in young chum salmon which were collected in the river and coastal waters along Hokkaido. Scales and livers were used as the detection organs for europium. Europium could be detected most effectively from scales. Forty-three europium marked fry, 13.4% of the total, were caught in the Chitose River. Seventy-two europium marked juveniles, 7.7% of the total, were recovered in coastal waters, consisting of 59 fish, 14.7% from the Japan Sea coast and 13 fish, 2.4% from the Okhotsk Sea coast. Chum salmon juveniles from the Ishikari River System were distributed close to the shore along the Japan Sea coast and further from the shore along the Okhotsk Sea coast. They still depended on coastal waters even though they spent more than 2 months in seawater. Considering the relationship between fish size and area of distribution, differences in fish size among areas in the same period exceeded that among periods in the same area. Europium was clearly detected from 2-year-old adult chum salmon that returned to the Ishikari River System. This indicates that europium was still present in the fish body for 580 days after being released.

INTRODUCTION

Activable tracer is a marking method based on neutron activation analysis. The method has the following advantages when applied to fish: 1) Marking can be used for very small fish, including fry and juveniles. 2) Marking can be used for a large number of fish (unit of million). 3) The fish body is not injured in the marking process. 4) There are no radioactive contaminations to the fish and the environment.

In the activable tracer method, a nonradioactive element is administered to fish fry with their feed. After they have been released, they gradually emit the element. Some of the element, however, accumulates in the fish organs and tissues over an extended period of time. The element, of course, must be harmless to both fish and humans.

Europium, one of the rare earth elements, exists in the earth in very small quantities, has a large cross section to thermal neutrons, has a long half-life after being activated, and remains for a long time within fish organs. For these reasons, europium is one of the most effective activable tracer elements.

Marking is an important means for studying fish resources and evaluating the artificial enhancement of fish. Applying the activable tracer method to young chum salmon, the author tried to obtain more information and knowledge on their migration and growth.

The Hokkaido Salmon Hatchery released 27 million chum salmon fry from the Chitose Hatchery in April 1979. Among them, 4 million fish were marked by europium. Four organizations collected chum salmon fry and juveniles in the river and coastal waters from April to June in 1979 and adult fish which returned to the Chitose River from October to November in 1980. Europium marked fish were recovered among them by activation analysis.

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MATERIALS AND METHODS

Twenty-seven million chum salmon fry were released from the Chitose Hatchery, a branch of the Hokkaido Salmon Hatchery, to the Chitose River, a tributary of the Ishikari River System, from March to May 1979. Among them, 4 million chum salmon fry, 14.8% of the total, were fed europium-containing food for 40 d from 13 February to 23 March and then released there between 26 March and 5 April. Europium chloride ($EuCl_3 \cdot 6H_2O$) was mixed into pellet-type food at a mean europium content of 817 ppm (SD 85 ppm). A total of 920 kg europium-containing food was fed (23 kg/d). Daily food supply increased from 4 kg on the first day to 30 kg on the last day. Of fry marked by europium, 1,200,000 fish were also marked by fin-clipping the adipose fin. All the europium-marked fry were released during the peak period of releasing.

Sampling of fry was conducted in rivers and on the coasts using various gears by four organizations—Hokkaido Salmon Hatchery, Far Seas Fisheries Research Laboratory, University of Hokkaido, and Wakkanai Experimental Station. Hokkaido Salmon Hatchery also caught adult chum salmon in the Chitose River.

River

The Hokkaido Salmon Hatchery collected chum salmon fry before being released to the Chitose River in April at the Chitose Hatchery and also caught them with trap-nets set at the middle section of the river near Ebetsu during the period of 6 April to 18 May 1979 (Fig. 1).

The hatchery also caught adult chum salmon (age .1 fish) in the Chitose River on 31 October and 6 November 1980.

Coastal Areas and Offshore Waters

The Hokkaido Salmon Hatchery captured chum salmon juveniles with a purse seine in the coastal zone of the Ishikari Bay and also caught them with stationary nets in Mashike and Shosan-

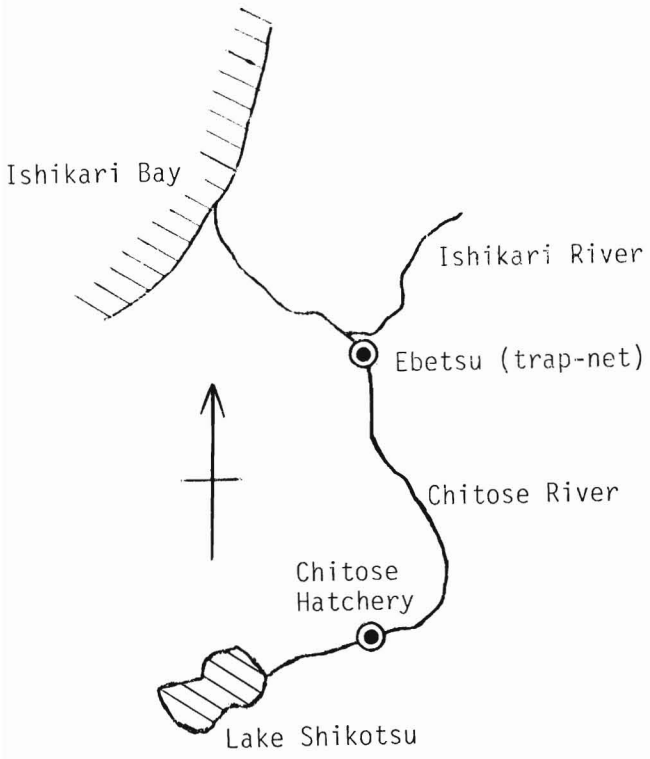

Figure 1.—The sampling stations of chum salmon fry in the Ishikari River System.

betsu, along the northern Japan Sea coast from March to June, and in Soya Toyoiwa, along the Okhotsk Sea coast, in June 1979.

Using the *Hokusei-maru*, a research vessel of the University of Hokkaido, and a purse seine, small mesh gill nets, and larval nets with wings, the University of Hokkaido and the Far Seas Fisheries Research Laboratory collected chum salmon juveniles in offshore waters of the Japan Sea coast from Ishikari Bay to Shosanbetsu and on the Okhotsk Sea coast from Abashiri Bay to the Shiretoko Peninsula on 3-27 June 1979.

The Wakkanai Fisheries Experimental Station caught chum salmon juveniles with stationary nets set along the coast from Shosanbetsu to Soya from May to June 1979.

Scales, livers, muscles, and vertebrae from fry and juveniles were used as samples for activation analysis. Scale samples were 4 to 37 mg, liver samples (whole organ) were 6 to 115 mg, muscle samples 17 to 48 mg, and vertebra samples were 1 to 5 mg in dry weight.

Scale samples taken from adult fish weighed from 68 to 240 mg.

Activation analysis for europium detection was conducted using the JRR-2 atomic reactor of Japan Atomic Energy Research Institute. Samples were bombarded with thermal neutrons (thermal neutron flux: 8×10^{13} n/cm^{2}s) for 20 min in the reactor. The radioactivity of ^{152}Eu (half life: 12.7 yr) in the samples were measured with a Ge(Li) gamma-ray spectrometer and multichannel analyzer (4,096 channels) after about 6 mo of cooling following the activation.

Cooling Time

When an activable tracer element is included in the fish organs in a very small amount, other elements forming the organs often work to disrupt finding the tracer element in activation analysis. Scales consist of a large amount of calcium carbonate ($CaCO_3$) and calcium phosphate ($Ca_3(PO_4)_2$). In addition, scales taken from fish in seawater are covered with sodium chloride (NaCl) on the surface. These elements Ca, P, and Na are converted to radioisotopes of ^{45}Ca (half life: 165 d), ^{32}P (14 d), and ^{24}Na (14 h) by neutron radiation.

The photo-peaks of ^{152}Eu come out in the vicinity of 122, 345, 779, 965, 1,087, 1,113, and 1,408 KeV of gamma-ray energy. The author used three photo-peaks—122, 345, and 1,408 KeV—for detection of ^{152}Eu. These photo-peaks, however, especially coming out in lower energy channels as 122 and 345 KeV, are often disturbed by the Compton effect caused by a large number of gamma-rays radiated from other elements, when the analysis is conducted a short time after neutron radiation. ^{152}Eu, however, has a very long half life, 12.7 yr, when the analysis is carried out after a long cooling time; photo-peaks, even in lower energy channels, can be clearly found.

In the experiment, the author used a cooling time of about 6 mo, which is longer than the half life of ^{45}Ca, obtaining clear photo-peaks of ^{152}Eu.

RESULTS AND DISCUSSION

Detection of Europium From Fry in Freshwater

Activation analysis was conducted for 47 fry (mean fork length: 38 mm, mean body weight: 0.5 g) collected in the Chitose Hatchery on 2 April, just before being released to the Chitose River and 30 fry (mean fork length: 37 mm, mean body weight: 0.4 g) caught in the Chitose River as background samples on 19 March. Muscles, vertebrae, and livers of these fry were taken for activation analysis. Two photo-peaks of ^{152}Eu in the vicinity of 122 and 345 KeV were clearly recognized in the gamma-ray spectrograms of europium-marked fry. On the other hand, there was no clear photo-peak in the unmarked fry (Fig. 2). The highest europium absorption was observed in the liver among the three organs and tissues. Detection rate was 100% in livers, whereas it was 16.7% in muscles and vertebrae (Table 1). Europium contents of livers ranged between 0.18 and 3.50 ppm, averaging 1.15 ppm, that of vertebrae ranged from 0.01 to 2.94 ppm, averaging 0.32 ppm, and that of muscles ranged between 0.02 and 0.27 ppm, averaging 0.14 ppm. The europium content in liver varied significantly among individuals and in some cases the content in one individual was 20 times as much as that of the other individual. The variation is considered to be mainly caused by the different amount of feed for the fry during rearing.

The Hokkaido Salmon Hatchery caught 365 chum fry with a trap-net set near Ebetsu from 6 April to 18 May. Europium was detected from their liver samples. Europium was detected from 49 fish, which was 13.4% of the total (Table 2). The rate of europium detection on each day was 8.6% on 6 April, 38.9% on 9 April, 29.5% on 12 April, 22.5% on 14 April, 7.7% on 17 April, 2.2% on 20 April, 0% on 3 and 7 May, 8.3% on 11 May, and 7.7% on 18 May. A peak number of europium-marked fry passed through Ebetsu from 9 to 12 April, and none was found from late April to early May. Then they again appeared there in mid-May. This indicates that most europium-marked fry migrated seaward 10 to 15 d after being released, however, a portion of the migrating fry remained for about 2 mo in the upper stream of the river. Sano and Kobayashi (1953) and Mayama et al. (1982) reported two types of fin-clipped chum salmon fry in seaward migration in the Chitose River—one migrated in a short period of about 10 d;

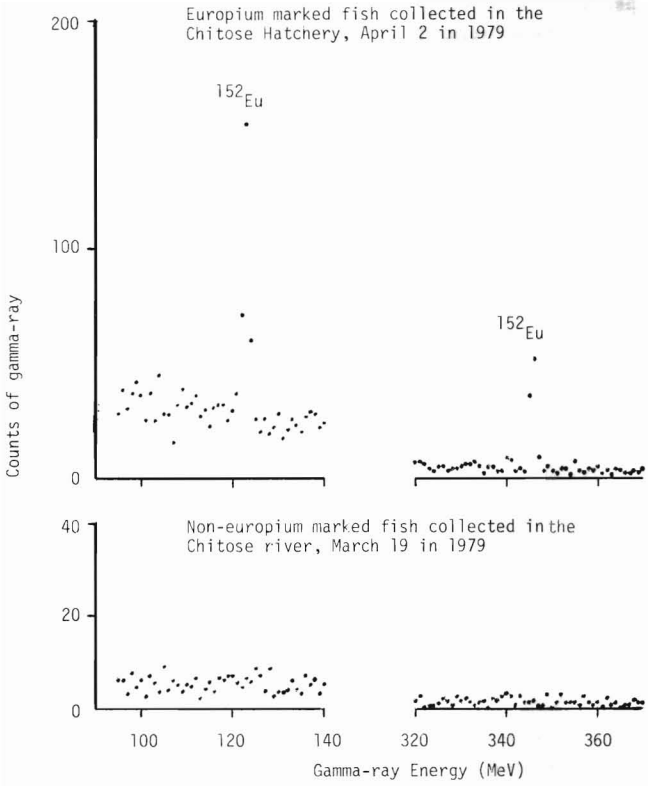

Figure 2.—Europium detection in liver samples of chum salmon fry.

Table 1.—Europium contents in organs of chum salmon fry caught in the Chitose Hatchery.

Organ	Number of fish analyzed (*A*)	Number of fish with europium (*B*)	*B*/*A* (%)	Europium contents Mean	Europium contents Range (ppm)
Muscle	30	5	16.7	0.14	0.02-0.27
Vertebra	30	5	16.7	0.32	0.61-2.94
Liver	47	47	100.0	1.15	0.18-3.50

Table 2.—Europium-marked chum salmon fry caught in the Chitose River by trap-net near Ebetsu detected by liver samples.

Date	Number of fish analyzed	Fish with europium: Number of fish	Fish with europium: Rate of detection (%)	Europium contents (10^{-3} mg): Mean	Europium contents (10^{-3} mg): Range
April					
6	35	3	8.6	8.40	6.70-10.21
9	36	14	38.9	5.64	2.41- 6.77
12	44	13	29.5	6.44	2.62-13.25
14	40	9	22.5	7.44	3.69-12.91
17	39	3	7 7	3.82	2.35- 4.99
20	31	1	3.2	14.33	
May					
3	34	0	0	—	
7	31	0	0	—	
!1	36	3	8.3	8.94	6.16-14.13
18	39	3	7.7	10.10	8.14-11.67
Total	365	49	13.4		

while the other stayed for more than 1 mo in the upper section of the river. The results obtained by europium marking on seaward migration of fry agree with those of their reports.

Detection of Europium Marked Juveniles In Coastal Waters

From May to June, 1,990 juveniles were caught in the coastal waters around northern Hokkaido. In order to detect europium, scales and livers were taken. Fork length and body weight of the juveniles ranged from 40 to 170 mm and 0.5 to 42 g, respectively. Scale samples weighed 8.1 mg on the average, ranging from 1 to 37 mg, and that of dried liver samples weighed 30 mg on the average, ranging from 5 to 14 mg.

Detection of europium from scales.—According to Shibuya (1979), europium in scales is eliminated from the fish body by the metabolism of organs and tissues. However, a certain level remains in the body throughout the life of the chum salmon. Thus, scales were the most suitable organs for the detection of europium.

Activation analysis was conducted for scales of 208 fish and europium was detected from 33 fish, 15.8% of the total. The rate of europium detection and the europium content in coastal waters along northern Hokkaido are shown in Table 3.

Mean values and ranges of europium contents by area were 0.50 and 0.13 to 1.32 ppm in Ishikari Bay, 0.33 and 0.15 to 0.59 ppm in Ofuyu, 0.38 and 0.19 to 0.74 ppm in Mashike, 0.29 and 0.15 to 0.43 ppm in Shosanbetsu, and 0.09 and 0.07 to 0.10 ppm from Abashiri Bay to the Shiretiko Peninsula, respectively. The farther an area was from Ishikari Bay, the lower the europium content. Europium-marked fish were recovered within a comparatively short time period (24 d). These facts show that a decrease in europium content depends not on a decrease in the total amount of europium by fish metabolism but on scale growth. Europium content in scales was calculated as follows:

$$\text{Eu content in scales} = \frac{\text{Eu weight in scales}}{\text{Weight of scales}} \times 1{,}000.$$

Mean body weight of europium-marked juveniles was 2.9 g in Ishikari Bay, 3.1 g in Ofuyu, 3.0 g in Mashike, 4.7 g in Shosanbetsu, and 32.1 g from Abashiri Bay to the Shiretoko Peninsula, respectively. Thus, the body weight in Abashiri Bay-Shiretoko Peninsula was 10 times as much as that in Ishikari Bay. Considering that scales grow in proportion to body growth, even if the weight of europium in the scales is constant during this period, the europium content decreased rapidly with scale growth.

Table 3.—Europium-marked chum salmon juveniles detected by their scales.

Area	Number of fish analyzed	Fish with europium: Number of fish	Fish with europium: Rate of detection (%)	Europium contents: Mean	Europium contents: Range (ppm)
Japan Sea					
Ishikari Bay	52	8	15.4	0.50	0.13-1.32
Ofuyu	46	11	23.9	0.33	0.24-0.59
Mashike	28	3	10.7	0.38	0.15-0.56
Shosanbetsu	57	8	14.0	0.29	0.15-0.74
Abashiri Bay - Shiretoko Pen.					
Coast	5	0	0	0	—
Offshore	21	3	14.3	0.09	0.08-0.10
Total	209	33	15.8	0.34	0.08-1.32

Activable tracer elements can be detected most effectively from scales for the following reasons: 1) Samples can be taken easily from the fish body. 2) It is easy to treat samples (not necessary for Formalin[2] fixation and desiccation). 3) Higher element contents and longer retention.

Detection of europium from livers.—When europium is absorbed by the body of chum salmon fry, no scales are yet formed. Therefore, europium retained in the scales is thought to shift from other organs and tissues. As mentioned earlier, europium contents in the liver were higher than those in other organs. Judging from this, the liver is also an organ from which europium can be detected effectively.

Europium was detected from livers of chum salmon juveniles as follows:

1) Liver samples were taken from 155 juveniles caught by the *Hokusei-maru* from 3 to 27 June. In activation analysis of these samples, europium was detected from 15 fish, 9.7% of the total. The rates of europium detection and mean europium weight by area were 11.4% and 2.57×10^{-3} mg in Ishikari Bay, 19.5% and 1.71×10^{-3} mg in Ofuyu, and 10.3% and 1.36×10^{-3} mg in the Shiretoko Peninsula, respectively. No europium-marked fish were found in the area between Mashike and Shosanbetsu. The rate of detection was lower in livers than in scales, indicating that the liver is less fit for the detection of europium in fish living in seawater. Some of the 15 fish from which europium was detected in their livers overlapped with some of the 33 fish from which europium was detected in scales. As a result of europium detection from both organs, europium was detected from 41 or 4.4% of 284 juveniles.

2) Wakkanai Fisheries Experimental Station collected liver samples from 413 chum salmon juveniles from 18 May to 18 June. In activation analysis of these samples, europium was detected from only one fish among eight juveniles caught in Hahoro along the Japan Sea coast on 23 May. The weight of europium of the sample was 4.62×10^{-3} mg. This was the first fish with europium marking in coastal waters.

3) Hokkaido Salmon Hatchery took liver samples from 243 chum salmon juveniles caught from 1 to 16 June. In activation analysis, europium was detected from 30 fish, 12.4% of which were caught off the coast of Morai, Gokibiru, Mashike, Shosanbetsu, and Soya Toyoiwa. The rate of europium detection and the mean europium weight by area were 20.0% and 7.25×10^{-3} mg in Morai, 17.9% and 8.11×10^{-3} mg in Gokibiru, 8.9% and 5.56×10^{-3} mg in Mashike, 16.7% and 2.67×10^{-3} mg in Shosanbetsu, and 12.0% and 5.56×10^{-3} mg in Soya Toyoiwa, respectively.

As described above, europium was detected from livers of 46 fish, which was 5.7% of 812 chum salmon juveniles caught from Ishikari Bay to the Shiretoko Peninsula. The mean europium weight of the samples was 4.89×10^{-3} mg and the mean europium content was 0.13 ppm (Table 4).

Table 5 shows europium weights and contents of liver samples collected in the whole area, including the rivers. The europium

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 4.—Europium-marked chum salmon juveniles detected by their livers.

Area	Number of fish analyzed	Fish with europium: Number of fish	Fish with europium: Rate of detection (%)	Europium contents: Mean	Europium contents: Range (ppm)
Japan Sea					
Ishikari Bay (offshore)	35	4	11.4	0.13	0.02-0.27
Ishikari Bay (coast)	61	11	18.0	0.21	0.07-0.54
Ofuyu	41	8	19.5	0.08	0.01-0.14
Mashike	124	9	7.3	0.16	0.04-0.26
Shosanbetsu	17	2	11.8	0.14	0.06-0.23
Okhotsk Sea					
Soya Koetoi	222	0	0	0	—
Soya Mineoka	123	0	0	0	—
Soya Toyoiwa	75	9	12.0	0.09	0.02-0.15
Esashi Menashidomari	60	0	0	0	—
Abashiri Bay - Shiretoko Pen. (offshore)	29	3	10.3	0.04	0.01-0.05
Shiretoko Pen. (coast)	25	0	0	0	—
Total	812	46	5.7	0.13	0.01-0.54

Table 5.—Change of europium weight and contents of liver in chum salmon juveniles from April to June.

Area	Date	Number of fish	Europium weight: Mean	Europium weight: Range (10^{-3} mg)	Europium contents: Mean	Europium contents: Range (ppm)
(A) Chitose Hatchery	2 April	47	15.88	4.12-58.82	1.15	0.18-3.50
(B) Chitose River	6-20 April	43	6.53	2.41-14.23	0.69	0.21-1.56
(C) Coastal waters	1-25 June	45	4.95	0.78-21.47	0.13	0.02-0.54
(B/A)			(41.1%)		(60.0%)	
(C/A)			(31.1%)		(11.4%)	

weight decreased to 41% within about 20 d and 31% within about 3 mo after the fry were released from the Chitose Hatchery.

Using samarium, one of the rare earth elements, as an activable tracer for medaka and gold fish, Machibata and Hori (1981) and Machibata (1981) also reported that samarium deposited in the scales and gills did not result from absorption through the gastrointestinal tract but from direct absorption from water, where the element was dissolved in feed or fish excrement; while Shibuya (1979) reported that europium was deposited mainly in scales after it was absorbed through the digestive organs. As mentioned above, no scales were formed when europium-containing feed was given to fry in the hatchery. However, europium was deposited in the scales of juveniles caught in coastal waters. On the other hand, the amount of europium in livers gradually decreased as time passed. These facts indicate that europium is absorbed by the digestive organs, goes outside the fish body, and at last some is deposited in the scales. Europium is thought to be absorbed from the digestive organs and then brought to the liver.

Seventy-two europium marked fish, 7.7% of the total, were recovered in coastal waters. Fifty-nine fish (14.7%) were recovered on the Japan Sea coast and the remaining (2.4%) on the Okhotsk Sea coast. The rate of europium detection on the Japan Sea coast was 14.7%, which was very similar to 14.8% in the Chitose Hatchery. This indicates that most of the chum salmon juveniles on the Japan Sea coast originated in the Ishikari River System. On the other hand, the rate on the Okhotsk Sea coast is much lower than that in the hatchery. This indicates that chum salmon juveniles on the Okhotsk Sea coast originated in the various rivers, including the Ishikari River System.

Migration Route of Chum Salmon Juveniles Originating in the Ishikari River System Estimated by Europium-Marked Fish

Migration route of chum salmon juveniles originating in the Ishikari River System could be estimated by tracing europium-marked fish.

Figure 3 shows the points where europium-marked fish were caught in coastal waters along northern Hokkaido and the estimated migration route of the juveniles.

After leaving the mouth of the Ishikari River, most juveniles migrated northward along the Japan Sea coast. Some of them, however, migrated southeastward. The migration in the opposite direction of the ordinary route is thought to be related to the direction of the current from the Ishikari River from May to June. The current flows most strongly during this period due to water from melted snow.

Europium-marked fish were continuously found in areas along the Japan Sea coast from Ishikari Bay to Shosanbetsu. The marked fish were not found between Shosanbetsu and Cape Soya. They appeared again in Toyoiwa, the eastern coast of Cape Soya facing the Okhotsk Sea. They were caught in an area shallower than 10

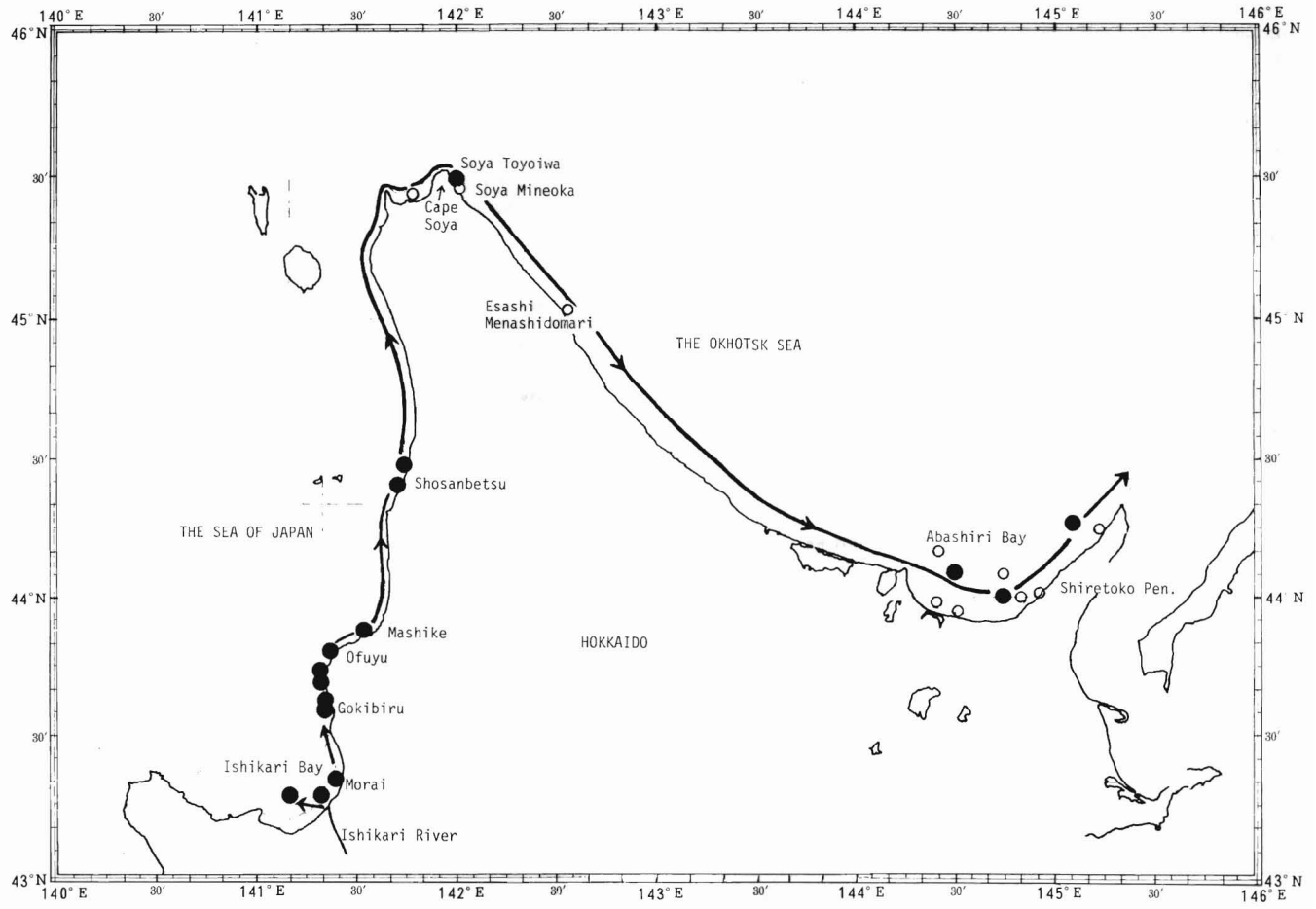

Figure 3.—The sampling stations of chum salmon juveniles (shown by open and closed circles), 1979. Closed circles mean europium-marked fish were obtained. Arrows indicate estimated migration route of chum salmon juveniles originating from the Ishikari River System.

m deep, indicating that they were distributed very close to the coast. No marked fish were found in the areas between Soya Toyoiwa and Abashiri Bay. Marked fish were again collected in offshore waters 8 to 16 km from the coast, from Abashiri Bay to the Shiretoko Peninsula.

The migration route of the marked juveniles is very similar to the route of the Tsushima and Soya current running along the northern part of Hokkaido. Chum salmon juveniles originating in the Ishikari River System seem to migrate through waters between the warm current and colder coastal waters. This indicates that they still depend on the coastal waters although they spend more than 2 mo in seawater.

Growth of Chum Salmon Juveniles of the Ishikari River System Indicated by Europium-Marked Fish

Growth of chum salmon juveniles originating in the Ishikari River System was traced using europium-marked fish in river and coastal waters. Mean fork length and mean body weight by area and by 10-d periods are shown in Table 6.

In the river, mean fork length and weight were 37 mm and 0.4 g in early April, 41 mm and 0.6 g in mid-April, and 47 mm and 1.0 g in mid-May, respectively. These values indicated a very low growth rate of fish during the freshwater phase.

In the coastal areas of Ishikari Bay, mean fork length and body weight were 43 mm and 0.6 g in early April which is a little larger than those in the river. They grew to 64 mm and 2.1 g in early May. Even in June, however, mean length and weight were 66 mm and 2.9 g, indicating almost the same values as those in early May.

Along the Japan Sea coast in early June, mean length and weight were 69 mm and 3.1 g in Ofuyu, 73 mm and 3.4 g in Mashike, and 73 mm and 4.0 g in Shosanbetsu, respectively, showing that fish were bigger in the north.

On the western coast of Cape Soya, mean length and weight of fin-clipped juveniles originating in the Ishikari River System were 70-75 mm and 3.6-4.4 g in mid and late May (Suzuki et al. 1980). Europium-marked fish were 87 mm in mean length and 5.7 g in mean weight in Soya Toyoiwa in mid-June. Juveniles around Cape Soya were much larger than those in the Japan Sea coastal areas during the same period.

Mean fork length and body weight were greatest, 126 mm and 26.4 g, in the areas between Abashiri Bay and the Shiretoko Peninsula in late June.

Considering the relation between fork length and area of distribution, juveniles whose average length was 8 cm were mainly distributed along the Japan Sea coast and when they grew to more than 10 cm they appeared in the Okhotsk Sea. In conclusion, difference in fish size among areas in the same period exceeded that among periods in the same area. This indicates that juveniles change their area of distribution according to their body sizes.

Europium Detection From Two-Year-Old Adult Chum Salmon

Chum salmon fry were released to the Ishikari River System in spring 1979 and then they migrated to the Pacific Ocean through coastal waters along northern Hokkaido.

Some of them returned to the Chitose River as two year (age 1) adult fish in fall 1980. Seven male fish (mean fork length: 46 cm, mean body weight: 1.1 kg) were collected on 31 October and 6 November. Activation analysis was conducted on their scale samples.

Europium was clearly detected (Fig. 4), though their scales were severely eroded except for the central parts. Europium contents were 0.04 and 0.05 mg, respectively. This indicates that europium persisted in the scales for 580 d since being released. Scales taken from 3-yr-old (age 2) adult fish returning in 1981 are now under analysis. The author expects that europium in chum salmon can be traced for a longer period of time than 2 yr.

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Table 6.—Mean fork length and body weight of europium-marked juveniles originating from the Ishikari River System by 10-d periods.

	Mean fork length (mm)									Mean body weight (g)								
	April			May			June			April			May			June		
Area	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L
River																		
Ebetsu	37	41	—	—	47	—	—	—	—	0.4	0.6	—	—	1.0	—	—	—	—
Coastal waters																		
Ishikari Bay	[1]43	—	—	[1]64	—	—	66	—	—	[1]0.6	—	—	[1]2.1	—	—	2.9	—	—
Ofuyu	—	—	—	—	—	—	69	—	—	—	—	—	—	—	—	3.1	—	—
Mashike	—	—	—	—	—	—	73	75	—	—	—	—	—	—	—	3.4	3.5	—
Shosanbetsu	—	—	—	—	—	71	73	—	—	—	—	—	—	—	4.0	4.3	—	—
Soya Toyoiwa	—	—	—	—	[2]75	—	—	87	—	—	—	—	—	[2]3.6	—	—	5.7	—
Abashiri Bay-Shiretoko Pen.	—	—	—	—	—	—	—	—	128	—	—	—	—	—	—	—	—	26.4

[1]Fin-clipped fish (Mayama et al. 1982).
[2]Fin-clipped fish (Suzuki et al. 1980).

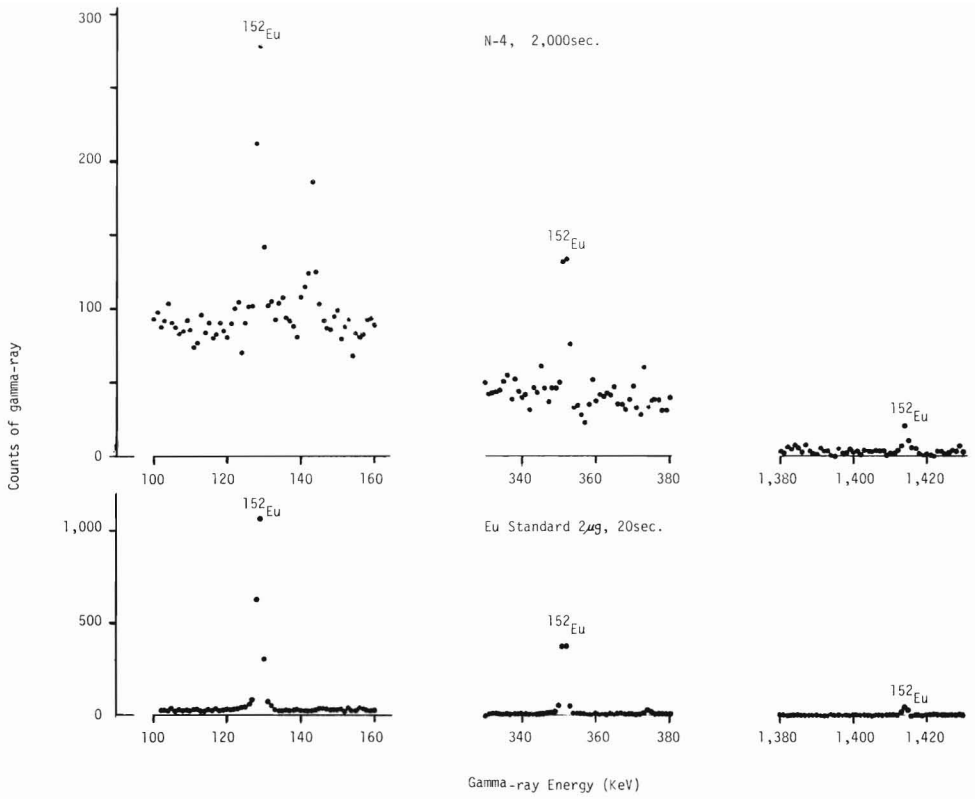

Figure 4.—Europium detection from scales of age 1 adult chum salmon which returned to the Chitose River on 11 November 1980. N-4: Male fish of 48 cm FL and 1.2 kg in body weight.

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Development of Seawater Net-Cage Culture and Release of Chum Salmon

AKIMITSU KOGANEZAWA and MINORU SASAKI[1]

INTRODUCTION

Until the latter half of the 1960's, production of chum salmon on the Pacific coast of the Tohoku District of Japan declined to slightly less than 1,000 tons (return rate: below 1.0%) The salmon propagation area was centered around 50 hatchery stations in the Tohoku District (Fig. 1). Starting in 1967, the technology of salmon hatchery development increased in Hokkaido. Therefore, knowledge of feeding of reared fry and timing of release produced favorable results. In 1971, feeding and releasing techniques were introduced to the northeastern district of Japan. Starting in 1975, the development and study of underwater rearing in cages was begun and releasing technology was introduced. This resulted in the development of a new technology in the local industry.

The development and study of underwater rearing in cages and releasing technology of salmon originated in an effort to produce salmon on a commercial basis for mass rearing and large fish cultivation in the sea utilizing artificial feed for chum salmon fry. This study started at the Miyagi Fisheries Experimental Station in the mid-1960's.

Koganezawa (1970) tested the seawater adaptability of salmon and trout (Genus *Oncorhynchus*, Genus *Salmo*, Genus *Salvelinus*) which were cultured in a freshwater area accessible to seawater. Consequently, the upper limit of the rearing temperature was overcome by the relationship between the size of chum salmon and salinity, although the critical period for the cultured salmon occurred during summer, when the seawater temperature increased considerably.

Afterward, a large-scale releasing experiment was conducted at the Iwate Prefectural Fisheries Experimental Station from 1973 to 1976. This was followed by studies of loss control and elimination of fry in underwater rearing and releasing. These studies were carried out mainly at the Tohoku Regional Fisheries Laboratory from 1977 to 1981 (Tohoku Regional Fisheries Laboratory 1977-81). In these studies, the setting of three different releasing points was made in geographical and topographical conditions to examine the returning conditions of chum salmon.

In this way, underwater rearing and releasing technology for chum salmon fry was conducted directly in seawater, without releasing the fry from hatcheries to rivers in the conventional method. The method is described as follows: The fry (above 0.6 g) are held in a net-cage set on the sea surface and fed until they have adapted to a seawater temperature of 13°C. The releasing method is designed to prevent the salmon fry from mortality caused by predation which is very common in rivers, estuaries, and seaside areas.

This study was carried out in cooperation with the research institutes of the Aomori Prefectural Aquaculture Center, Miyako branch of the Iwate Prefecture Farming Center, Iwate Prefectural Fisheries Experiment Station, Miyagi Prefectural Fisheries Experimental Station, Miyagi Prefectural Fish Farming Center, Tohoku Regional Fisheries Laboratory, Faculty of Science of Tokyo University, Nikko branch of the National Research Institute of Aquaculture, and National Research Institute of Fisheries.

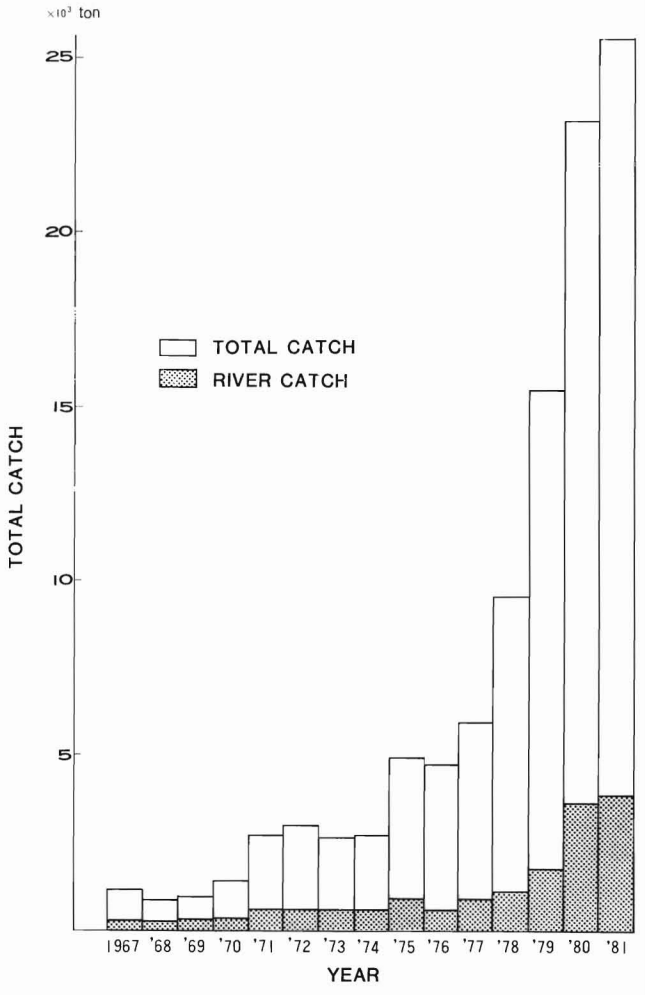

Figure 1.—Fluctuation of catches of chum salmon on the Pacific coast of the Tohoku district of Japan (Aomori Prefecture to Ibaragi Prefecture).

[1]Tohoku Regional Fisheries Research Laboratory, The Ministry of Agriculture and Forestry, Fisheries Agency, Shiogama, Miyagi 985, Japan.

METHODS AND RESULTS

Underwater Rearing and Releasing Research From 1973 to 1976

Figure 2 shows the positions of fry-holding cages and releasing sites and Table 1 gives the test results of releasing in Iwate Prefecture from 1972 to 1976. Figure 3 shows the construction of underwater cages set in Yamada Bay. Yamada Bay in Iwate Prefecture lies near the middle of Sanriku area coast with an inlet of average depth of 30 m. This bay has a 6° to 14°C water temperature during April to June. Experimental fry were reared as marked and unmarked fish in large underwater cages, and were released after a definite time period of feeding. As shown in Table 1, the return results vary each year. Delay in release time of small fry is responsible for the low return rate (1.84%) of the 1972 brood year, as compared with other released fry. The return rates from 1973 to 1975 were 7.58, 3.96, and 4.93%, respectively. In 1976 the return rate was 11.46%, which was the highest return during the period of study. Taking into account the fact that the return rate of salmon on the Pacific coast of the Tohoku District of Japan is slightly below 1.0% according to the conventional method of release in the river, this method provides an extremely high return rate. A close relationship between the size of fry when released and the return rate was confirmed by this releasing experiment as shown in Figure 4.

The 1973 and 1976 brood years showed extremely high return rates. Both brood years, however, were in excess of the 8.0 g releasing size. This resulted in a 6% or more return rate for 1973 and 1976. At this size, the fry move towards the outside of the bay within 7 d after release, and begin offshore migration. It is therefore presumed that the fry have a strong resistance to environmental conditions upon reaching 8.0 g in body weight. Great mortality has occurred during early release from the river to the

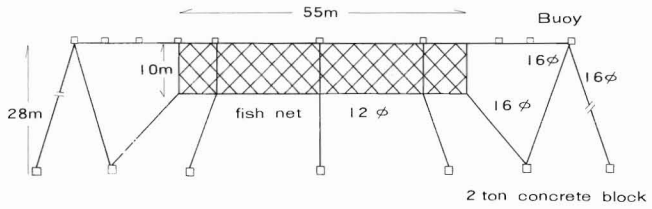

Figure 3.—Sectional drawing of underwater preserves in Yamada Bay of Iwate Prefecture.

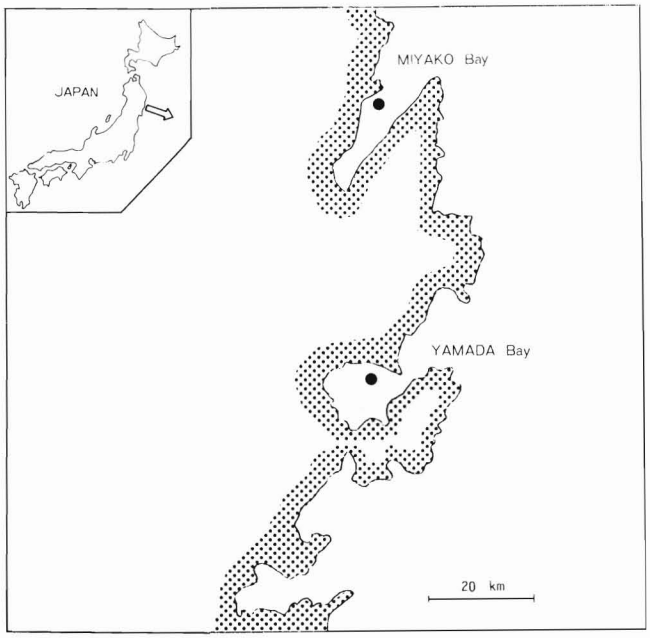

Figure 2.—Underwater rearing experimental stations in Iwate Prefecture.

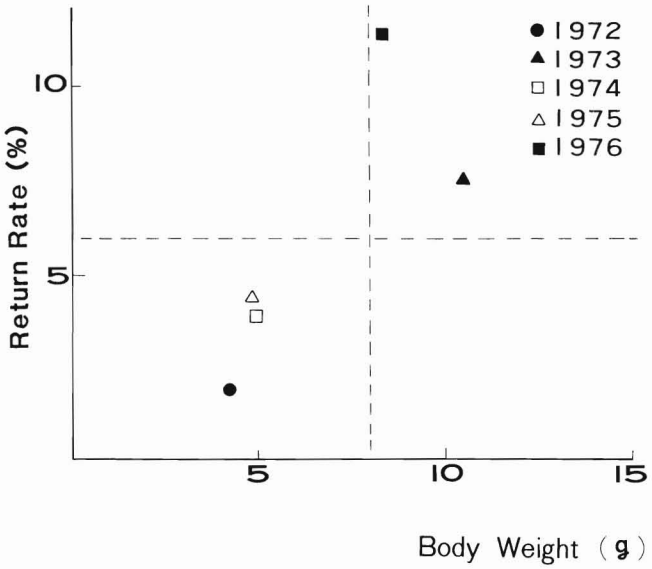

Figure 4.—Relationship between releasing size and return rate.

Table 1.—Return results of marked fish released in Iwate Prefecture.

Brood year	Release station	Number of fry released	Number of adult returns in each year class					Total number of adult returns	Rate of return (%)
			2	3	4	5	6		
1972	Yamada Bay	103,535	6	474	1,233	189	5	1,907	1.84
1973	Yamada Bay	114,611	360	4,218	3,848	262		8,688	7.58
1974	Yamada Bay	118,365	256	1,646	2,563	227		4,692	3.96
1975	Yamada Bay	135,510	35	1,473	4,435	729	3	6,675	4.93
1976	Yamada Bay	83,047	576	4,799	3,731	412		9,518	11.46

estuary and until coastal waters are reached. Loss in the early days which was caused by direct release in the river can be improved by rearing the fry to 8.0 g or more in underwater cages. This method minimized predation during outward migration by direct release into the sea. The results of this study showed that if the river, estuary, and coastal movement of the fry can be substituted as in the conventional method, the return rate (1.0%) can be improved to 10% or more, as during the brood year 1976.

Underwater Rearing From 1977 to 1981

On the basis of the data obtained from research from 1973 to 1976, experiments were conducted on the Pacific coast of the Tohoku District of Japan at Moura in Aomori Prefecture, Yamada Bay in Iwate Prefecture, and Samenoura in Miyagi Prefecture (Fig. 5). Underwater rearing and release were carried out to examine the condition of salmon upon return during that period.

With the chum salmon fry used in experimental release, seedlings of the Tokachi River brood at the Hokkaido Salmon Hatcheries were used in three areas. About 20% of the fry released from three stations were marked on the adipose fin and by ventral fin cutting. Table 2 gives the number of fry released from the experimental stations over a period of 5 yr from 1977 to 1981. The purpose of this study was: 1) To check the effects of the geographical conditions of three different experimental stations on releasing techniques of fry in the sea, and 2) to apply the fry releasing techniques which were developed during the period of study at different representative geographical locations. This will finally provide a more precise technology of fry releasing techniques based on geographical conditions within the Tohoku area. From physiological and ecological points of view, the following information provided data in the establishment of the underwater rearing techniques: 1) The size of fry during transfer from freshwater to seawater; 2) releasing time in the coastal area. The assumption was made, based on experiments, that fry more than 0.6 g were more adapted to seawater. Seawater temperatures could be monitored where cages were set in bays in the Sanriku area. These phenomena were the basis for the development of a releasing technique which would eliminate loss. Therefore, the natural movement of the fry upon release would be affected by coastal water temperatures of 12° to 13°C (toward the middle or end of May) which coincides with the time the salmon leave the coast to migrate offshore.

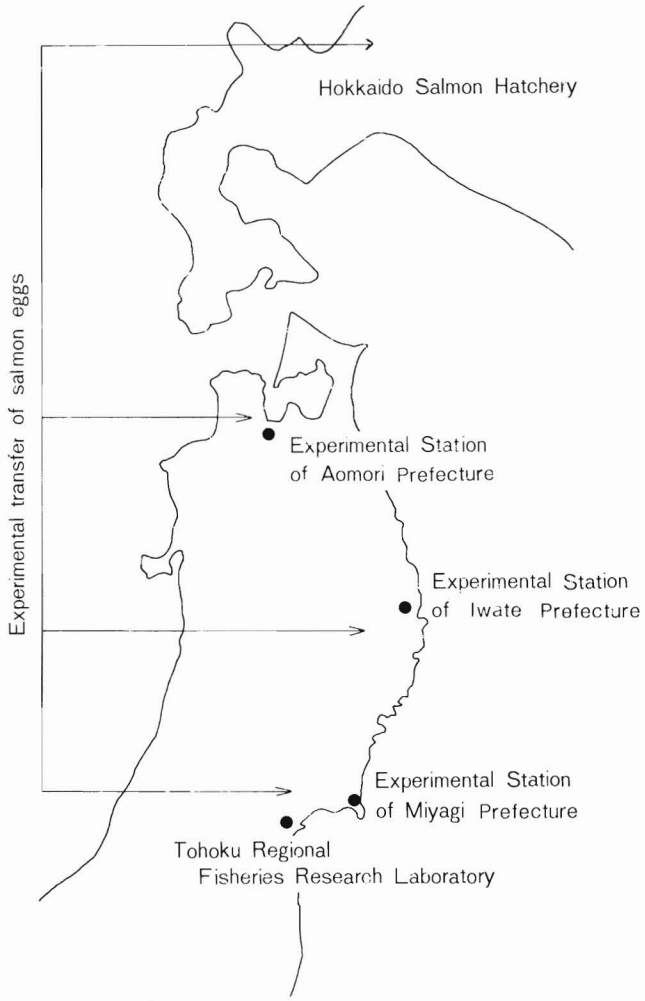

Figure 5.—Underwater rearing and releasing experimental stations in Tohoku district in Japan.

Table 2.—Number of fish released and number of fish marked for each experimental station in 1977 to 1981.

Year released	Station	Number of released fish ($\times 10^3$)	Number of marked fish ($\times 10^3$)
1977	Aomori	0	0
	Iwate	2,712	159
	Miyagi	1,930	152
1978	Aomori	2,086	204
	Iwate	2,899	300
	Miyagi	3,000	312
1979	Aomori	1,742	207
	Iwate	1,983	127
	Miyagi	2,510	208
1980	Aomori	1,903	207
	Iwate	1,390	107
	Miyagi	2,170	366
1981	Aomori	1,420	165
	Iwate	3,000	236
	Miyagi	2,500	300

The construction of underwater rearing cages used at three stations was divided into inland bay type and the float-type suitable for the open bay (Fig. 6). The methods and results of the releasing experiments for each area are given below.

Experimental sites in Iwate Prefecture.—The releasing sites in Iwate Prefecture are in Yamada Bay and Miyako Bay. Table 3 gives the number of fry reared and released and the number of marked fry released. Table 4 gives the return rates of the marked fish experiment, which was carried out at different stations centered around eight fish markets and river fisheries in Iwate Prefecture. For the brood year 1977, the return rate of 4-yr-old fish was 1.42%. The brood year 1978 produced a return rate of 3-yr-old fish of only 0.92%. However, the return rate increased in comparison with 3-yr-old fish of the brood year 1977. This result will be confirmed by the return of 4-yr-old fish in the autumn of 1982. The estimated coastal return rate of fry reared underwater and released brood fish, including unmarked brood fish, is shown in Table 5 as the return rate of marked fish. In this experiment, the early return brood in Hokkaido was used. It was expected that the returning brood from this experiment would have a silver color. Normally, fish caught on this coast take on nuptial colorations; therefore, the distinction could be made clearly. In the analysis of

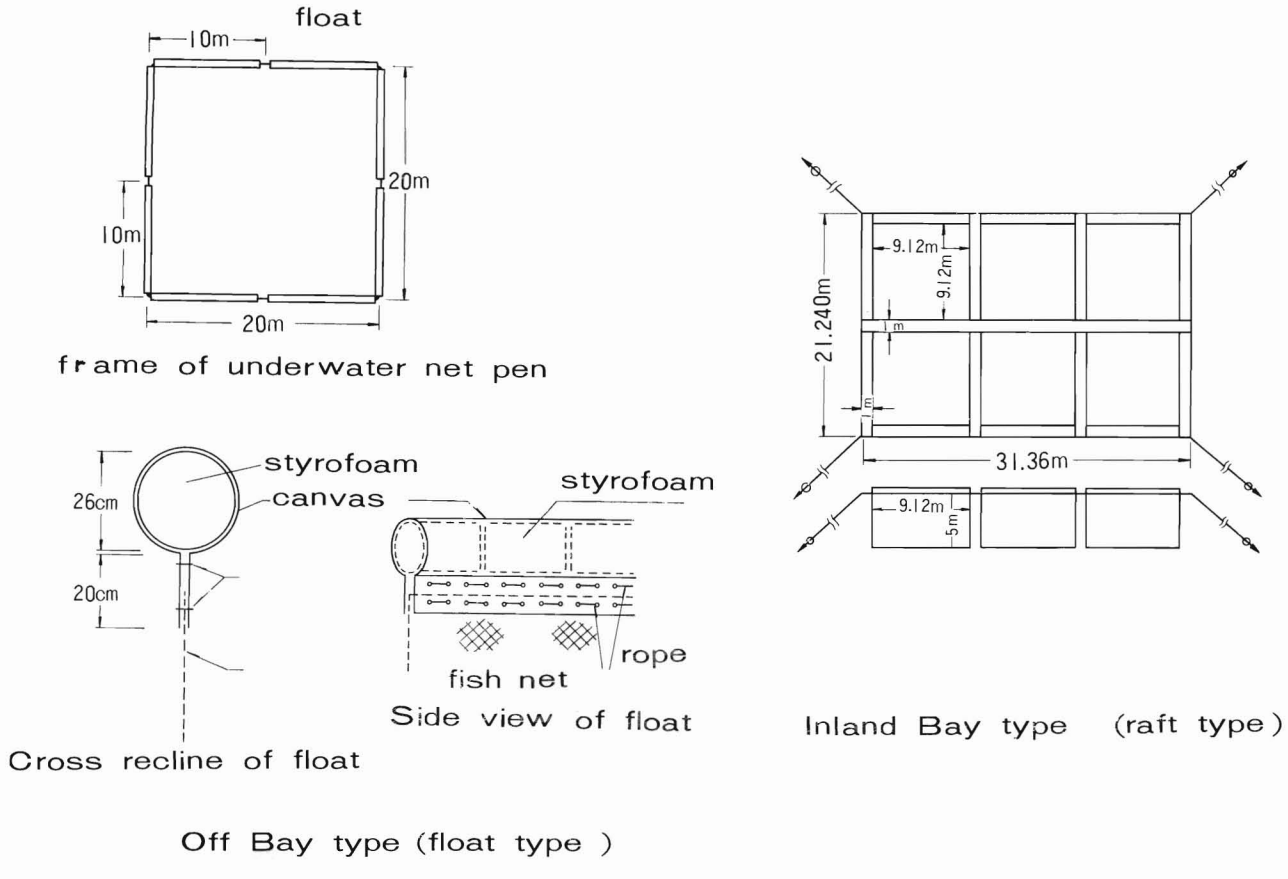

Figure 6.—Structural drawing of underwater preserves.

Table 3.—Number of fish released and number of fish marked at each experimental station in Iwate Prefecture.

Brood year	Date released	Station	Number of released fish ($\times 10^3$)	Number of marked fish
1977	1978.5.17	Yamada Bay	2,712	121,685
1978	1979.5.14	Yamada Bay	2,899	248,273
1979	1980.3.27	Yamada Bay	930	93,641
	1980.4.17	Miyako Bay	1,053	98,539
1980	1981.5. 6	Miyako Bay	322	84,418
	1981.5. 7	Yamada Bay	1,068	90,867

Table 4.—Return results of marked fish in Iwate Prefecture.

Brood year	Number of marked fish	Number of returns at each age			Total
		2	3	4	
1977	121,685	20	408	1,072	1,500
1978	248,273	26	2,296		2,322
1979	98,539	1			1

recapture conditions (classified by year and day) of marked fish caught in three fish market catches in Iwate Prefecture, it can be assumed that the increase in the fish market catch at Yamada Bay early in September and October of 1977 to 1978 can be attributed to the experimental brood of underwater rearing and releasing techniques and the resulting catch in the fishery (Fig. 7).

Table 5.—Estimated migrations of salmon to the coast in Iwate Prefecture experimental area.

Brood year	Number of released fish at underwater preserve experiment	Return rate of marked fish (%)	Estimated migrations to experimental area
1977	2,712,000	1.072	29,000
1978	2,899,000	0.924	27,000

Experimental sites in Miyagi and Aomori Prefectures.—The experimental releasing sites in Miyagi and Aomori Prefectures situated at Yagawa of Samenoura Bay, Moura and Noheji of Mutsu Bay, are shown in Figures 8 and 9, respectively. At these experimental sites, there is no river where the salmon can escape from the areas near the underwater rearing facilities. For example, Ushirogawa River is a small river at Samenoura about 2 m wide and 4 km long, and has a small quantity of water; it has little influence on the water from the coastal area. Therefore, it is possible that in these places the fish will return to the sea area which would be an underwater rearing site, as compared with the Iwate Prefectural experimental sites where the released fish return to the river.

Tables 6 and 7 show the number of underwater reared and released fry and that of marked fry released at these experimental sites. The return results of two experimental sites are as follows: The fishery for salmon where the releasing was performed at Samenoura Bay at the Miyagi Prefectural experimental site produced only about 40 to 50 fish annually prior to 1976. Thereafter, underwater rearing and releasing experiments started in 1977,

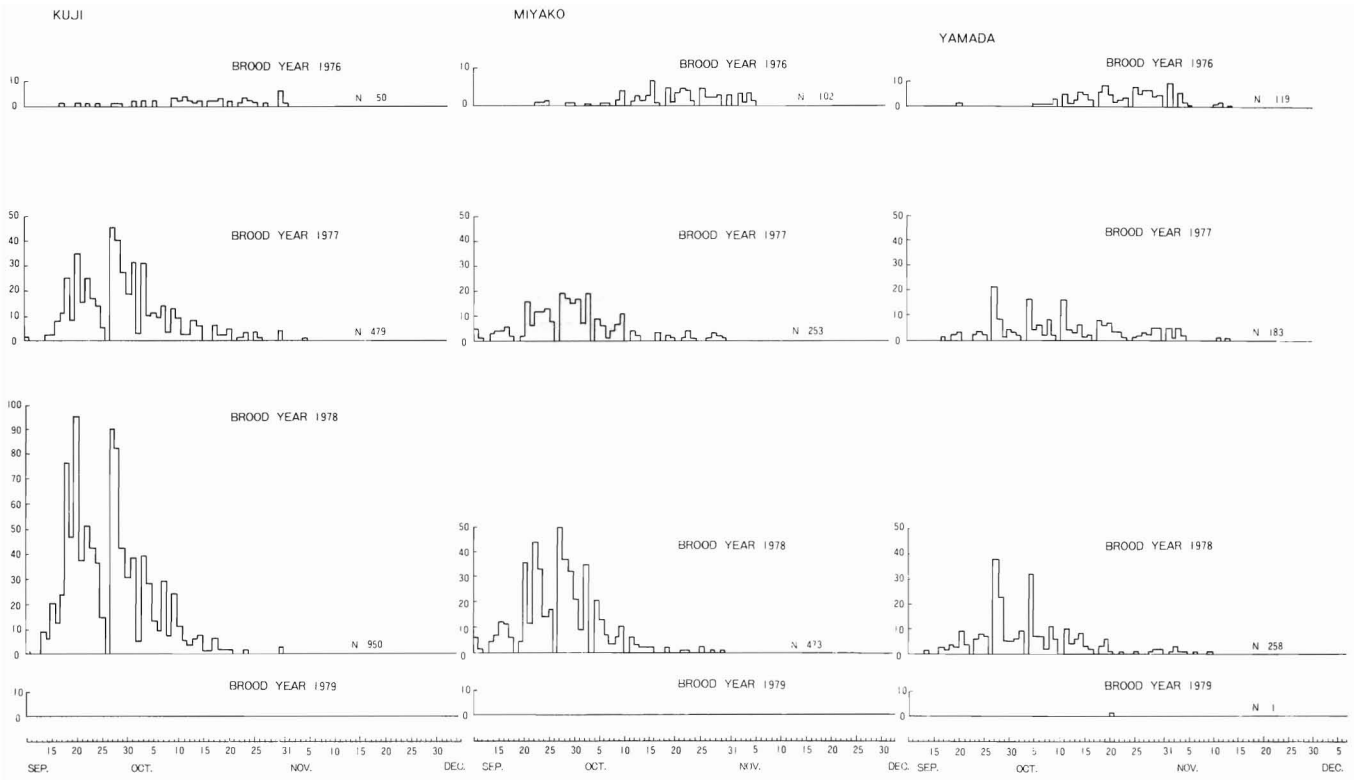

Figure 7.—Fluctuation of seasonal catches of chum salmon near the main fish market in Iwate Prefecture.

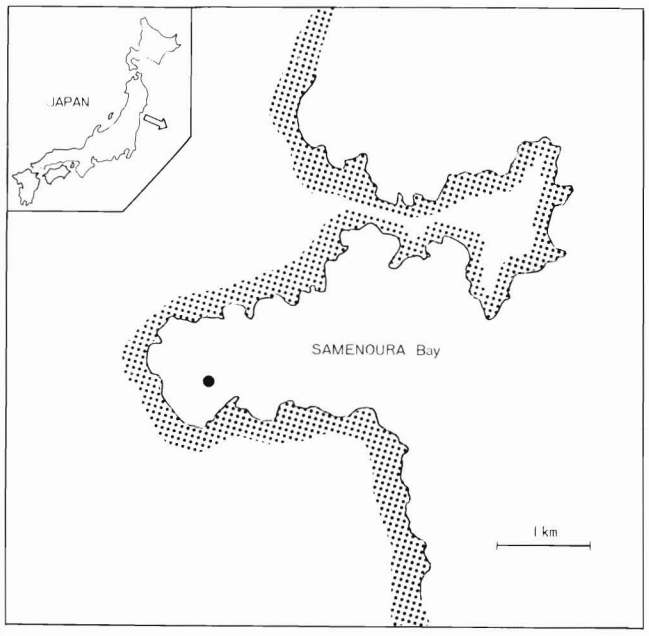

Figure 8.—Underwater rearing experimental station in Miyagi Prefecture.

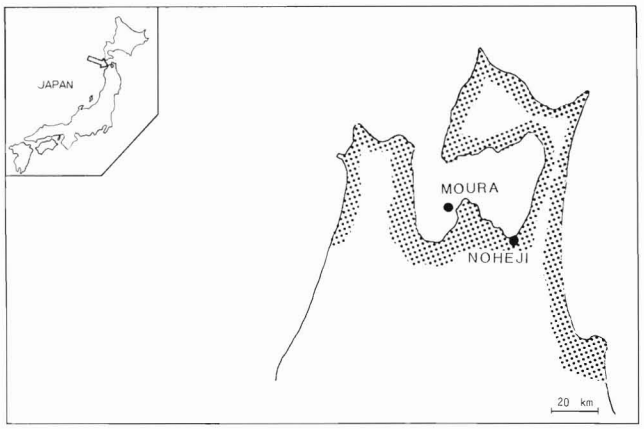

Figure 9.—Underwater rearing experimental station in Aomori Prefecture.

resulted in a gradually increasing fishery production from year to year. Set nets were constructed at nine points in this bay and a fish trap was set in a small river at Ushirogawa that flows into the bay. The number of chum salmon captured by the set nets and the number of fish that escaped in the river of Ushirogawa are given in Figures 10 and 11. The catch by set nets at nine locations was

Table 6.—Number of fish released and number of fish marked in Miyagi Prefecture.

Brood year	Date released	Station	Number of released fish ($\times 10^3$)	Number of marked fish
1977	1978.5.29	Yagawa	1,930	152,630
1978	1979.5. 7	Yagawa	3,000	312,000
1979	1980.4.18	Yagawa	1,160	58,000
	1980.5.21	Yagawa	1,350	150,000
1980	1981.6. 2	Yagawa	2,170	52,947
	1981.6. 2			314,596
1981	1982.5. 7	Yagawa	1,800	300,000

Table 7.—Number of fish released and number of fish marked in Aomori Prefecture.

Brood year	Date released	Station	Number of released fish ($\times 10^3$)	Number of marked fish
1979	1980.5. 9	Moura	1,905	—
	1980.5.19	Nohegi	180	—
1980	1981.5.16	Moura	—	152,000
	1981.5.21	Nohegi	853	53,000
1981	1982.5.16	Moura	987	101,000
	1982.5.29	Nohegi	962	106,000

2,000 fish or more in 1980. These salmon were the 1977 brood fish and therefore returned as 3-yr-old fish. The increase in escapement in the river of Ushirogawa is correlated with the increase in fish caught by set nets. However, in 1981, when the fish released in 1977 returned as 4-yr-old fish the return rates in both the set nets and river escapement was very low. It was also difficult to find the marked fish and only four of the 3-yr-old fish were recovered. Sixty of the marked 3-yr-old fish released from Samenoura Bay were recovered along the coast of Iwate Prefecture in 1981. Recapture of marked fish released from Moura and Noheji of Mutsu Bay in Aomori Prefectural experimental sites has not yet been confirmed. As a result of the research in 1981 centered at the Moura experimental releasing area, 1,236 chum salmon were captured between the middle of November and the end of December and the peak at the beginning of December. In comparison with the ages of the returned fish, the ratio of 3-yr-old fish is extremely high as compared with that of 4-yr-old fish (the ratio for 3-yr-old fish is 95.7% and 4-yr-old fish is only 3.8%). So far, the annual fishery catch of chum salmon in this district is only 10 fish. It can be assumed that the brood released in 1979 returned as 3-yr-old fish as shown in Table 8. It shows the number of chum salmon recovered at Moura. The Moura District in Mutsu Bay has no river where the salmon can escape, and the brood released by underwater rearing and releasing techniques was captured on the coast near the releasing site. It may be concluded, therefore, that when the underwater rearing and releasing area has no large accessible river, such as at Samenoura Bay in Miyagi

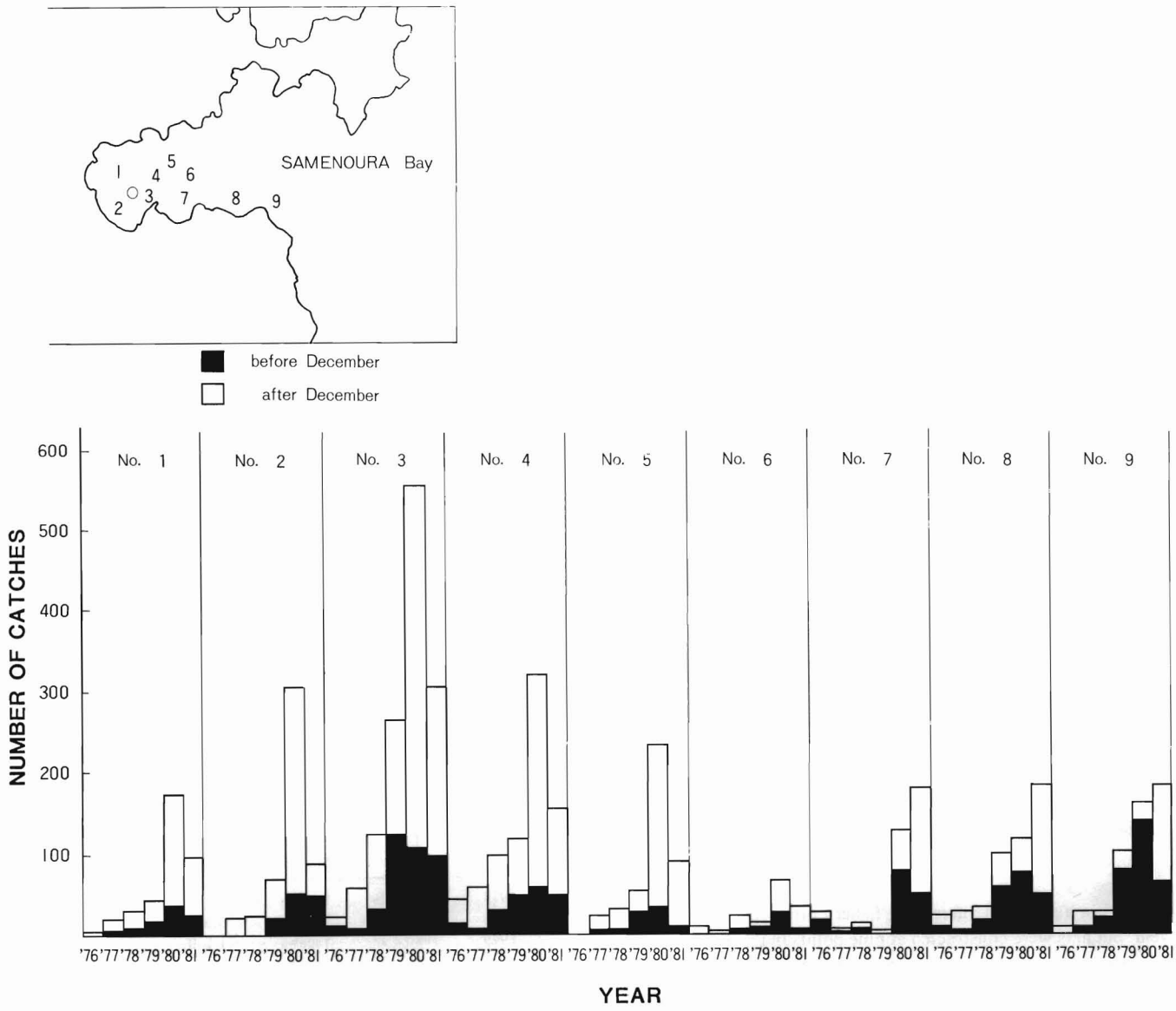

Figure 10.—Annual fluctuation of catches of chum salmon put in the set net of Samenoura Bay in Miyagi Prefecture.

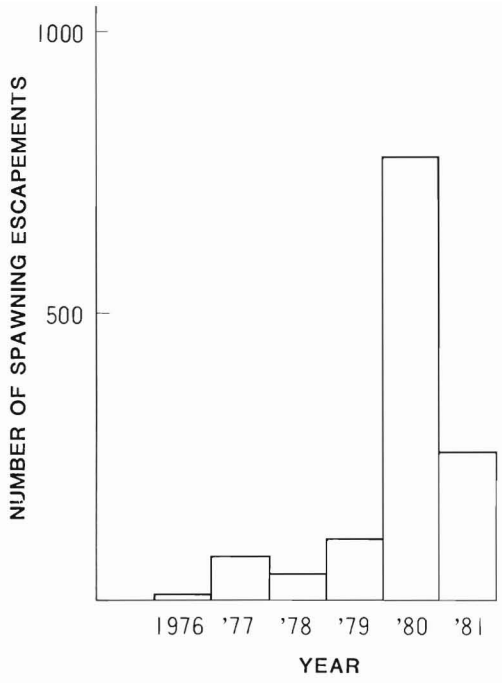

Figure 11.—Annual fluctuation of anadromous chum salmon at the Ushirogawa River of Samenoura Bay in Miyagi Prefecture.

Table 8.—Recaptures at Moura in Aomori Prefecture.

Recaptures	Period of recaptures	Number of recaptures ♀	♂	Unknown	Total
Fish farming center	1981.11.10-12.22	36	132	0	168
Fishermen	1981.11. 3-12.29	304	756	8	1,068

Prefecture and at Moura in Aomori Prefecture where underwater rearing was conducted, the fish return to their releasing points.

CONCLUSIONS

The Pacific coastal area in the Tohoku District of Japan has only small and medium-sized rivers where the propagation of salmon is limited due to low productivity of the rivers. These rivers are not fully supplied with the natural food necessary for nourishment of the released fry. Furthermore, it is not economical to rear and release a large quantity of fry (1.0 g or more) by feeding the fry during rearing at the hatcheries. The low productivity of the rivers and the economical limit at the hatcheries are overcome by using underwater rearing and releasing techniques.

In addition, these new techniques increase the amount of fry released and eliminate the initial loss in the river and on the coast by rearing the fry in cages before releasing them. In the process of this technological development, points clarified and points yet to be solved are as follows:

1) It is possible for the fry (0.6 g or more) to acclimate to seawater. Concerning a suitable release time, loss in the river or along the coast can be eliminated by release at the proper time when coastal water temperatures are 12° to 13°C.

2) The size of fry has been examined for effective experimental release. This has resulted in a remarkable improvement in return rate with a releasing size of 8.0 g or more. For example, the underwater rearing and releasing experiment which was carried out in Iwate Prefecture resulted in a return rate of marked fish of up to 11.5%.

3) At a releasing area where there is a very small river, such as at the experimental location in Miyagi Prefecture, the high fish catch was accomplished by a set net near the underwater rearing site. In an area having no salmon returning to the river, as in the experimental site in Aomori Prefecture, the fishery for salmon occurred near the underwater rearing cages. This phenomenon poses the question whether the salmon remember the sea as well as the river. An important phenomenon for underwater rearing and releasing techniques is the delay in river return caused temporarily by loss of the homing instinct by the salmon. When released in the rivers, imprinting of the homing instinct is made continuously under natural conditions. Fry which are taken to underwater rearing cages are artificially moved a distance of a few hundred meters or a few kilometers from the hatcheries to sea surface cages. Therefore, conditions for natural imprinting are temporarily removed. It can, therefore, be presumed that the fry reared in cages imprint on the sea conditions of their release. Hereafter, applicable research is required to determine the returning capacity of the river of release by underwater rearing and release and the relationship between the releasing site and temporary loss of imprinting of homing instinct.

4) In an area centered around the rivers in the northeastern district of Japan, propagation and research on these salmon was carried out. The theme of this research, the introduction of underwater rearing techniques for salmon, has enabled a remarkable increase in releasing quantity. Instead of releasing small fry in the rivers, it enabled the release of a large number of fry. Therefore, the loss caused by predatory fish in the rivers, in the estuary, and on the coast and the loss caused by capture among various fisheries has been reduced. The introduction of this underwater rearing technique and the timing of release increased production from 1,000 tons in 1960 to 25,500 tons in 1981. In the future, we expect that these techniques will be closely linked to effective utilization of inland bay areas in the northeastern district of Japan and further provide guidelines for fishery administration by overall utilization of inland areas and seawater for salmon production.

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Technical Innovations in Chum Salmon Enhancement With Special Reference to Fry Condition and Timing of Release

HIROSHI MAYAMA[1]

INTRODUCTION

A recent upward trend in the survival rate of chum salmon, namely the increase in the rate of adult returns, has followed an increase in the number of fry released after short-term feeding. The higher survival rate is thought to have been achieved by the release of larger fish at the proper time. Chum salmon fry are first released when coastal water temperatures in Hokkaido rise above 5°C. At the latest, the release of fry must be completed prior to 50 d before the average surface temperature of coastal waters reaches 15°C. During this period, it is important to adjust the number of fry released so they can be effectively produced in the river and along the coast.

This report deals with the proper releasing time and the condition of fry at the time of release based on experimental data from the chum salmon enhancement project in Hokkaido.

RELEASE OF FRY IN PREVIOUS YEARS

The artificial propagation of chum salmon began in Japan in the late 1880's. Until the early 1960's, fry migrated from hatchery ponds to streams and other natural waters, as soon as the yolk sac was absorbed. Therefore, timing of release was determined by the cumulative water temperature required for fry development and incubation.

Eggs and fry are reared in ground water (spring water), which is usually kept about 8°C in Hokkaido. The time period between fertilization and emergence is 110-120 d. For example, fry hatched out from eggs taken in mid-October are released in early to mid-February of the following year. Fry which have just hatched out are very small, around 0.3 g, and have limited swimming capability. They are reared in incubation ponds with a gentle current at a temperature of 8°C, but are released directly into streams with a rapid current and a temperature of 0°C. At this time, the surface of the streams in Hokkaido is usually covered with ice because of low ambient temperatures and a decrease in water level; the surface ice begins to melt in late March.

Fry which are released in cold streams have limited swimming capability and normal behavior is affected by this rapid change in environmental conditions. Most of the fry are brought to the sea drifting with the river current. However, in Hokkaido the coastal water temperature in February and March, when the fry migrate to sea, is the lowest of any coastal area (Fig. 1). For instance, water temperature is 3°-5°C at the Japan Sea coast, 0°C at the Pacific coast, and at the coast of the Okhotsk Sea drifting ice comes close to shore. Moreover, this is a difficult season with continual strong northwest winds. It is easy to understand that the survival rate of fry which migrated to sea at this time was remarkably low.

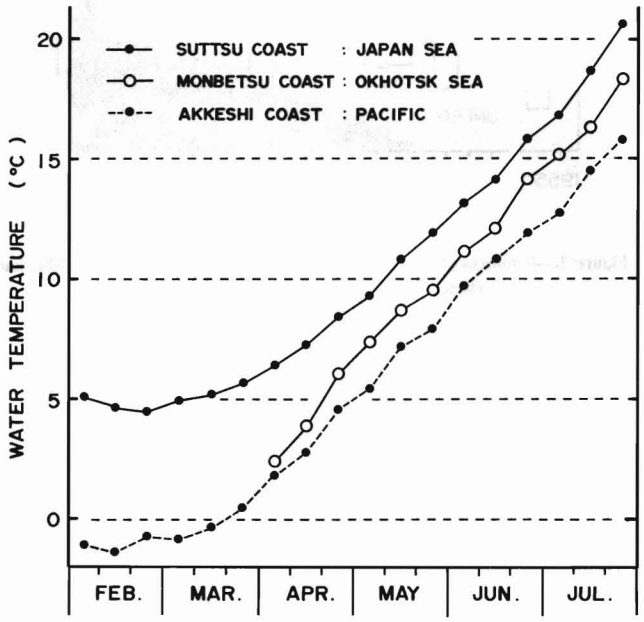

Figure 1.—Seasonal changes in average decade water temperature of three types of coast in Hokkaido. Each value is the mean of 10 yr, 1972-81.

Delayed Release After Feeding

To reduce the effects of these harsh environmental conditions, it is necessary to delay the release of fry. It is best to keep the fry in hatchery ponds until the proper release time.

In 1962, a project was undertaken to yield twice as many as the 300 million fry which were being released at that time. In this project, fry were grown on a proper diet and were released as large, healthy fry at the optimum time.

Figure 2 shows the number of unfed and fed chum salmon fry released from 1955 to 1976, and the rate of return of adults of the brood year stocks. The release of fed fry began in 1962. In the previous 4 yr, improvements in methods included improved diets, amounts of food used, and duration of rearing in the hatchery. Based on these experiments, feeding fry with dry diet was begun in the 1966 brood year to try to produce fry twice as heavy in about a month. In this year, over 50% of the total number of fry liberated were fed the dry diet. Since then 80 to 90% of the total releases (400-500 million fry) were fed. The remaining 10-20% delayed swimming up because of the low temperature of the hatchery water. The eggs were collected late in the spawning

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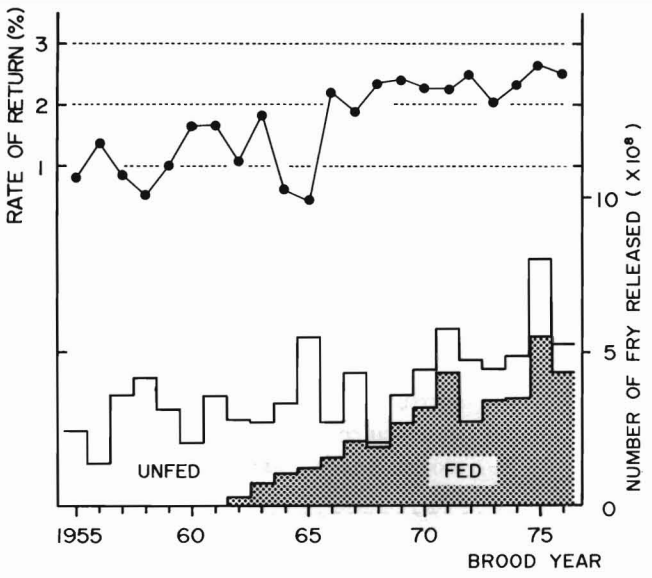

Figure 2.—Numbers of chum salmon fry released in Hokkaido, 1955-76, and rates of return of these brood year stocks.

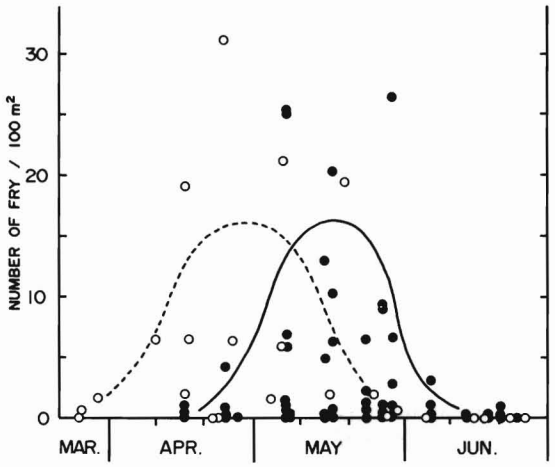

Figure 3.—Seasonal variations in the densities of chum salmon fry captured at the beach (open circles, mean value for each day) and offshore (solid circles, each value at every station) in Ishikari coast, 1977-81.

season, in December and January, and it was not necessary to feed them an artificial diet.

In the 1950-60 brood years, the average rate of return of those released from unfed rearing was 1.19%. In the 1966-76 brood years, the average rate of return was twice as high (2.31%) as in previous years and the variability between years was small. Therefore, stable reproduction of chum salmon was obtained.

The increased rates of return resulting from the liberation of fed fry were the result of decreased mortality of the fry released. That is, releasing larger fry (0.6 to 1.0 g) by feeding and delaying the time of release by a month was effective in increasing survival of the fry.

Limit of Time of Release

The problems of an early release time, as described above, were alleviated by means of delaying the release time. The problems of a late release time have not yet been considered. In some hatcheries, release of fry was delayed every year by the low water temperature for incubation and the small size of fry; therefore, the rate of return was low. Even in these hatcheries, a change to the higher temperatures of spring water increased the rate of return. From these results, the latest limit of the time of release could be estimated. In the case of reared releases, it is necessary to clarify the time limit to determine the duration of feeding. Based on research with trap nets on the coast, it is known that chum salmon fry disappear from coastal areas at a certain time every year.

Since the beginning of fry feeding, ecological research on chum salmon fry in coastal areas was undertaken to determine the proper time of release. Ecological research on the distribution and migration of chum salmon fry produced in the Chitose River, a tributary of the Ishikari River, was carried out on the Ishikari coast of the Japan Sea for 5 yr, from 1977 to 1981.

Figure 3 shows the density and distribution of chum salmon fry along the Ishikari coast, adjacent to the mother river, as a function of time. Fry appeared in the near shore, at approximately 1 m depth, beginning in late March when the water temperature rose to 3°-4°C. Beginning in mid-April, the distribution was widespread; however, most fry disappeared by late May. Most of the fry in this area were < 4 cm in fork length (FL) and even in May, small fry of this size stayed there. On the other hand, from results obtained using a purse seine at depths of 5-25 m, and from up to 5 km offshore, the numbers of fry were low in April, increased rapidly from late May to early June and disappeared by mid-June. The rapid decrease of large fry was found at the same time every year. This may indicate that the environment became inadequate causing the fry to migrate offshore. The fry were 6-8 cm FL and 2.5-4.0 g in body weight just before they disappeared from coastal waters adjacent to the mother river. Marked chum salmon fry produced in the Ishikari River were recaptured along the coast about 80 km north in early and mid-June. They averaged 7.4 cm FL (range 6.6-8.0 cm) and 3.5 g in body weight (range 2.7-4.5 g). Based on these results, a body size of about 7 cm FL and 3 g body weight was considered to be necessary for offshore migration. The growth of fry migrating a greater distance was better than that of marked fry recaptured at the same time. Therefore, it was suggested that offshore migration from the native coastal area near the mouth of the mother river occurred when fry grew to a certain size (Mayama et al. 1982).

The mechanism by which fry disappear from coastal areas adjacent to the natal river is not understood. However, offshore migration may be induced as changes in the marine environment occurring at this time produce inadequate conditions for growth.

Salinity and temperature of Ishikari coastal waters during the sampling of the fry are shown in Figure 4. The temperature at a depth of 5 m shows a linear increase and reached 11°-12°C in late May to early June, when the numbers of fry had decreased. Salinity decreased in April and May as a result of the influence of an increasing amount of water from the river, and then increased rapidly in late May. At this time, the effect of the Tsushima Warm Current increased, raising the water temperature and salinity, and seemed to produce some physiological effects that induced offshore migration. This is considered to be one of the factors responsible for migration. Also at this time, the amount of marine food for fry decreased due to a change in species composition of crustacean zooplankton from oceanic cold-water zooplankton species to coastal warm-water species. As the water temperature increased, the growth rate of fry increased rapidly and the amount of food they required increased. The decrease in amount of food at

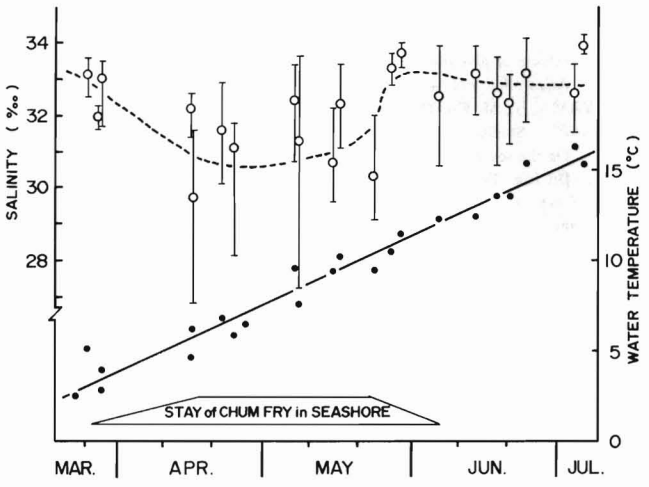

Figure 4.—Seasonal changes in average salinity (open circles) and water temperature (solid circles) of 5 m depth at Ishikari coast, 1977-81. Vertical bars show the ranges.

this time made the environment relatively worse. For these reasons, the fry may have been obliged to migrate from this area.

It is clear that fry growing to about 7 cm FL and 3 g in body weight, are able to migrate northward and their survival rate is high, until the surface temperature of the coastal water reaches 12°-13°C.

Since spring water is used in incubation and rearing in many chum salmon hatcheries, the release of fry can be completed after about a month. However, when stream water is used in the hatchery, development is delayed by low temperature. Even at the latest time of release, only a few fry with adequate growth can survive. For this reason, the rate of return is very low. The occasional absence of any returns indicates high mortality as a result of late release.

Problems During Feeding

Increasing the survival rate after liberation by adjusting the release time with fry feeding and producing larger fry by feeding was evaluated on the basis of the increase in the rate of return and numbers returned. In order to rear a large number of fry, a rearing pond and water are needed.

Reconstruction of the facilities began in the late 1960's. A new problem—diseases—arose as a result of the increase in the number of fry reared. This was not a problem in unfed reared fry. Even in a short time—1 to 2 mo—rearing large numbers of fry in a limited amount of water caused the water quality in the rearing pond to decline as the fry grew, and diseases occurred. Bacterial gill disease occurred frequently and became a serious problem. Because this disease is acute, it caused a high death rate. Bath treatment is effective, but under high rearing densities, it was difficult to apply. When this disease occurs, rearing densities must be decreased. Therefore, fry must be released that have not fully recovered, and are released at an improper time. Thus, inactive behavior and cessation of feeding by fry suffering from this disease make it difficult for them to adapt to the natural environment after release. Therefore, this causes a significant reduction in their numbers. Since chum salmon are liberated at the fry stage, recovery from the disease must be rapid if they are to be released at the proper time. Fry suffering from bacterial gill disease have decreased swimming capability and cannot stay in rivers with a fast current. Thus, they move quickly to coastal waters where serious problems can develop; fry suffering from the disease fail to adapt to seawater. Because it is difficult to culture the bacterium that causes gill disease, experiments involving adaptation of fry suffering from this disease have not yet been done. According to preliminary experiments, fry are thought to have little resistance to the stress of moving to seawater. It is known that rearing fry at a high density leads to decreased swimming capability. Another important goal is to develop a technique to produce healthy fry with a high survival rate after release. From experimental results (Kobayashi 1982[2]), it is clear that training in a current and adjusting loading densities of the rearing pond are required in order to produce strong fry.

Future Technical Problems

Artificial techniques can change the behavior of chum salmon, benefitting fish production. In the United States, active research on the effects of delayed release time on migration patterns in the sea have been carried out with coho and chinook salmon (Novotny 1980). However, in Japan, chum salmon fry are released within a restricted period because of the rapid increase in coastal water temperatures in spring. The migration route of fry depends on sea conditions, so it may not be possible to carry out the release operation needed to give the desired migration pattern.

The effects of a given age and body size of fry on returns has been discussed in combination with release timing in North America (Bilton 1978, 1980). In different species of salmon released after long-term rearing, body size is adjusted based on differences among rearing methods. However, in chum salmon fry liberated after short-term feeding, clear differences in body size of the adult upon return have not been recognized. Body size at the time of release was increased by fry-feeding; however, age composition, determined by 5-yr averages since 1951 (Table 1), showed no differences as a result of feeding.

Table 1.—Average age composition of chum salmon in Hokkaido.

Brood year	Percentage of return by age				Percentage of fry fed before release
	2	3	4	5	
1951-55	1.5	37.3	54.3	6.8	0
1956-60	1.3	32.4	54.7	11.5	0
1961-65	1.8	34.5	56.3	7.5	18.1
1966-70	1.6	33.2	57.8	7.5	67.4
1971-75	0.5	28.2	60.8	10.5	74.1

CONCLUSIONS

In order to delay the time of release and produce larger fry, the liberation of chum salmon fry after feeding was begun in the 1960's. This resulted in an increase and stability in the number of returns. Japan is located at the southern limit of the distribution of chum salmon. Along the coast, the effects of the warm current are pronounced during spring and summer. Therefore, chum salmon fry must migrate offshore until seasonal conditions are appropriate. Recently, about 1 billion chum fry were liberated from the island of Hokkaido, which has a 2,734 km coastline. It is important to adjust the number of fry released to increase future coastal

[2]Kobayashi, T. 1982. Technical development to produce healthy and strong chum salmon fry for liberation. [In Jpn.] Unpubl. manuscr. Hokkaido Salmon Hatchery.

productivity. Moreover, it has been explained that fry in poor condition cannot adapt to natural environments. Therefore, production of healthy fry and the development of techniques for the production of strong fry are urgent problems for future chum salmon research. These technical innovations should lead to an increase in the survival rate.

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Nutritional Studies for the Development of Formulated Diet for Salmon Fry

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INTRODUCTION

Chum salmon, *Oncorhynchus keta*, is one of the most important fishes in salmon enhancement operations in Japan. The rate of return to coastal areas or rivers of northern Japan has shown steady improvement as a result of technical progress in artificial propagation and feeding before their release. In most cases, fingerlings are released at < 0.8 g in March through June. According to the report by Okada and Taniguchi (1971), natural food organisms are abundant in coastal waters from May to June, but are too large to be consumed by fingerlings < 1 to 2 g. Akiyama and Nose (1980) reported that the larger fish could sustain their life longer under adverse conditions, because the larger the size of the fish, the higher the level of deposited energy sources and the lower the basal metabolic rate. Thus, release of fingerlings > 1 g seems to be more advantageous for their survival.

In order to achieve this goal, a high quality feed for chum salmon fry, especially for swim-up fry, is essential. However, there has been almost no information on the nutrient requirements of chum salmon and various commercial feeds for rainbow trout have been used. Under the special project entitled "Technical development of the large scale farming of anadromous salmons" sponsored by the Agriculture, Forestry and Fisheries Research Council, we have conducted several nutritional studies over the past 5 yr to develop a good formulated diet for chum salmon fry. The results of these studies will be presented, focusing mainly on growth and feed efficiency data.

OPTIMUM LEVELS OF DIETARY PROTEIN AND FAT

Two feeding experiments were conducted in a freshwater environment for 6 wk to determine optimum levels of dietary protein and fat at 9.4° and 16.3°C, because DeLong et al. (1958) reported that protein requirements of chinook salmon are remarkably higher at 14.4°C than at 8.8°C. Graded levels of dietary protein and fat were prepared using fish meal and pollock viscera oil as the sole protein and fat sources, respectively. Initial mean weight of the fish was 0.90 g for both 9.4° and 16.3°C studies. Since the moisture and fat contents in the carcasses changed as the fish grew, body protein gain instead of weight gain was used as a criterion, as suggested by Ogino and Saito (1970).

As shown in Figure 1, when the dietary fat level was 5%, body protein gain increased linearly as the dietary protein level increased up to 43% at both 9.4° and 16.3°C. Again at both water temperatures, body protein gain increased linearly to the protein level of 38% with the supplemental fat level of 10%. From these results, protein requirements of chum salmon fry were estimated to be 43% with 5% fat and 38% with 10% fat at water temperatures of both 9.4° and 16.3°C.

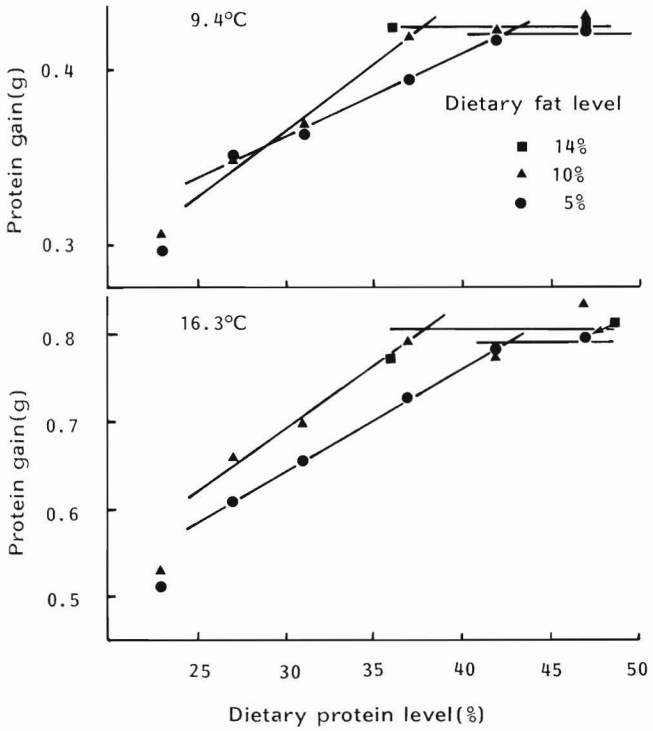

Figure 1.—Effect of dietary protein and fat levels on protein gain in fingerling chum salmon (7-wk feeding). Initial mean weight was 0.9 g (100 fish/tank) and 0.65 g (70 fish/tank) for 9.4° and 16.3°C studies, respectively. (Akiyama et al. 1981.)

DIETARY CARBOHYDRATE SOURCE

Carbohydrate is the least expensive energy source and more incorporation of carbohydrate in fish feed is necessary for the formulation of an inexpensive feed. However, utilization of carbohydrate in fishes is still a subject of controversy. Buhler and Halver (1961) reported that chinook salmon can utilize carbohydrates with smaller molecular weight more efficiently, but the opposite results have been shown in channel catfish (Simco and Cross 1966) and carp (Furuichi and Yone 1982). This experiment was conducted to determine the best carbohydrate source for chum salmon. Fish with a mean body weight of 2.5 g were fed diets containing 20% of either glucose, fructose, galactose, sucrose, maltose, lactose, dextrin, gelantinized potato starch, or cellulose (as a control) as a carbohydrate source. This feeding study was conducted for 4 wk.

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As shown in Table 1, the substitution of cellulose with any type of carbohydrate resulted in reduced feed consumption. Supplements of fructose, galactose, or lactose in lieu of cellulose depressed the growth slightly, but supplements of glucose, sucrose, maltose, dextrin, or starch slightly improved growth over that of the control group. Data on feed efficiency reflected weight gains. Among all dietary groups, fish fed the diet supplemented with starch showed the best growth rate and feed efficiency. These results indicate that chum salmon cannot utilize carbohydrate very efficiently at a 20% supplemental level, but gelatinized potato starch might be the best choice as a dietary carbohydrate.

Table 1.—Effect of dietary carbohydrate sources on feed consumption, growth, and feed efficiency of fingerling chum salmon (4-wk feeding). Initial mean weight was 2.5 g (40 fish/tank). (Akiyama et al. 1982.)

Carbohydrate source	Feed consumption (%/day)	Avg. wt. gain (%)	Feed efficiency (%)
Glucose	3.50	213	106
Fructose	3.59	184	96
Galactose	3.47	165	92
Sucrose	3.59	215	104
Maltose	3.41	213	108
Lactose	3.68	184	93
Dextrin	3.66	219	102
Starch	3.44	219	110
Cellulose	3.94	203	95

OPTIMUM LEVEL OF SUPPLEMENTAL MINERAL MIX

Optimum supplemental level of salt mixture (U.S.P. XII salt mixture No. 2 with trace elements, Halver 1957) for chum salmon fingerlings was determined as a preliminary step because essentially no information on mineral requirements for chum salmon is available at present. Two feeding studies were carried out for 6 wk at 16.5° and 8.5°C using purified diets. When water temperature was 16.5°C, both average weight gain and feed efficiency reached plateaus at 2% of the supplemental level (Fig. 2). At 8.5°C, similar results were obtained (Fig. 3). From these results, we concluded that the optimum level of supplemental mineral mix for the diet of fingerling chum salmon was about 2%.

ESSENTIAL FATTY ACIDS

Essential fatty acids for chum salmon fingerlings were examined by feeding diets containing different levels of methyl ester: 18:2ω6, 18:3ω3, 20:5ω3, and a mixture of 20:5ω3 and 22:6ω3 (ω3 HUFA), and their optimum levels were determined. A feeding study using purified diets was conducted for 7 wk. The substitution of lauric acid with either 1% 18:2ω6, 0.5% or 1% 18:3ω3, 0.5% 20:5ω3, or 0.5% ω3 HUFA improved growth. However, growth and feed efficiency were improved further by substituting lauric acid with either a mixture of 1% 18:2ω6 and 1% 18:3ω3 or 1% ω3 HUFA. These results indicate that ω3 HUFA or 20:5ω3 may be more effective than 18:2ω6 or 18:3ω3 as the essential fatty acids for chum salmon. The optimum level was concluded to be a combination of 1% 18:2ω6 and 1% 18:3ω3 or 1% ω3 HUFA (Table 2).

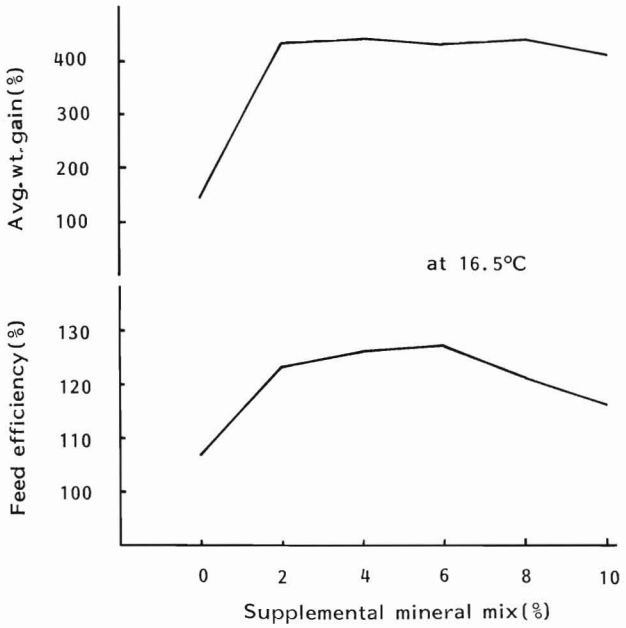

Figure 2.—Effect of dietary mineral on growth and feed efficiency in fingerling chum salmon (6-wk feeding). Initial mean weight was 2.1 g (40 fish/tank). (Akiyama et al. 1979.)

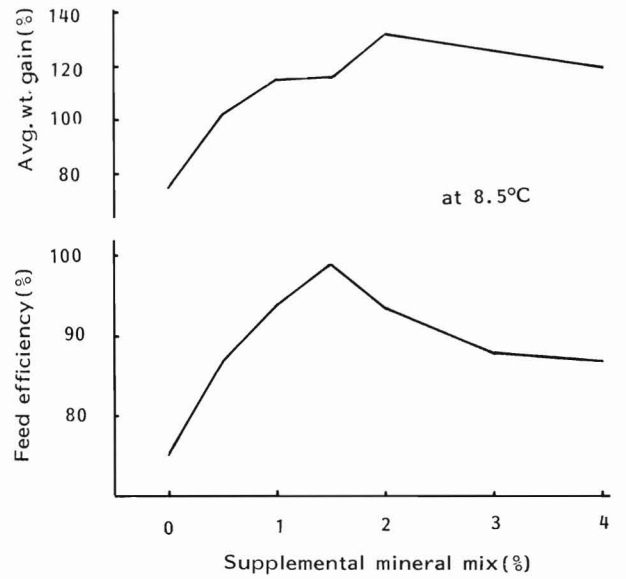

Figure 3.—Effect of dietary mineral on growth and feed efficiency in fingerling chum salmon (6-wk feeding). Initial mean weight was 1.2 g (50 fish/tank). (Akiyama et al. 1979.)

FEED ATTRACTANT

In order to stimulate feed consumption of swim-up fry, various meals which we considered to be potential feed attractants such as silkworm, beef liver, krill, and earthworm meal were supplemented to practical type diets at a level of 5% in lieu of fish meal. The protein source other than these meals was fish meal and the major fat source was pollock viscera oil. Swim-up fry with mean body weight of 0.21 g were fed the diets for 6 wk.

Table 2.—Effect of dietary lipids on growth and feed efficiency of fingerling chum salmon (7-wk feeding). Initial mean weight was 1.3 g. (Takeuchi et al. 1979.)

Lipid source	Avg. wt. gain (%)	Feed efficiency (%)
5.0% 12:0	52	69
4.0% 12:0 + 1.0% 18:2ω6	276	90
4.5% 12:0 + 0.5% 18:3ω3	206	66
4.0% 12:0 + 1.0% 18:3ω3	320	86
3.0% 12:0 + 1.0% 18:2ω6 + 1.0% 18:3ω3	402	101
4.5% 12:0 + 0.5% 20:5ω3	340	92
4.5% 12:0 + 0.5% ω3HUFA	325	91
4.0% 12:0 + 1.0% ω3HUFA	377	106

As shown in Table 3, none of the supplemented meals stimulated feed consumption of fry. However, fish fed the diets with any kind of meals showed at least 10% higher feed efficiency than that of the control group. Among the meals tested, supplement of only krill or earthworm meal substantially improved weight gain. The dietary group with earthworm meal showed almost 40% higher weight gain over that of the control group. These data clearly indicate that these meals were not a feed attractant for chum salmon, but supplement of either krill or earthworm meal could facilitate growth of chum salmon fry.

Table 3.—Effect of supplemental attractants on feed consumption, growth, and feed efficiency of fingerling chum salmon (6-wk feeding). Initial mean weight was 0.21 g (200 fish/tank). (Akiyama et al. 1980.)

Attractant supplemented	Feed consumption (%/day)	Feed efficiency (%)	Avg. wt. gain (%)
Silkworm	4.12	89.2	439
Beef liver	3.95	88.2	427
Krill	4.08	89.9	500
Earthworm	4.07	107.6	587
Control	4.60	77.1	429

OPTIMUM LEVEL OF SUPPLEMENTAL VITAMIN PREMIX

As with mineral requirements, no information on individual vitamin requirements of chum salmon was available. It is still true, therefore, that Halver's premix for the purified diet (Halver 1957) has been used even for a practical type diet. Since hypervitaminosis of some water soluble vitamins such as pyridoxine (Andrews and Murai 1979) has been shown, the supplementation of a high level of vitamin mix to a diet without knowledge may not only be economically wasteful but also dangerous. As a preliminary step, the optimum supplemental level for chum salmon fry was studied using Halver's premix. Fish with mean body weight of 0.58 g were fed practical type diets supplemented with five levels (0, 2, 4, 6, and 8%) of the vitamin premix for 4 wk. The protein sources were 61% fish meal, 5% brewer's yeast, and 5% earthworm meal; and 9% pollock viscera oil was used as the fat source. At a supplemental level of 8%, Halver's recommended level for the purified diet was attained.

As shown in Figure 4, both average weight gain and feed efficiency reached maximum levels at 2% of the supplemental level and declined thereafter. From these data, we concluded that the optimum level of supplemental vitamin premix to the practical diet for chum salmon fry was about 2%.

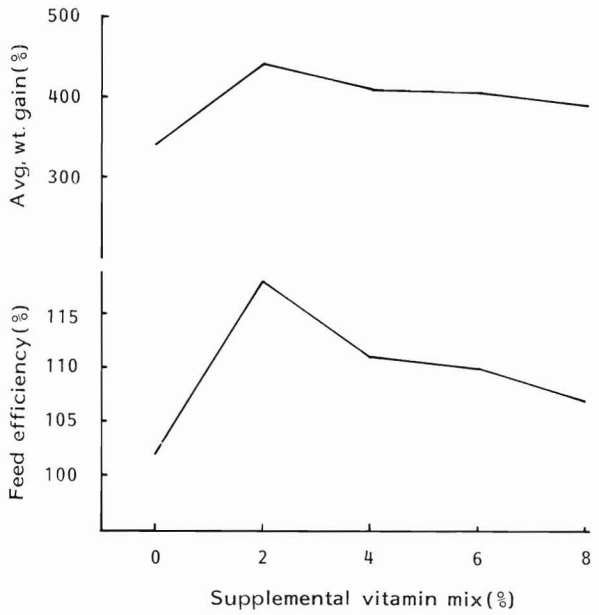

Figure 4.—Effect of supplemental vitamin premix on growth and feed efficiency in fingerling chum salmon (4-wk feeding). Initial mean weight was 0.58 g (50 fish/tank). (Murai et al. 1981.)

FORMULATION OF A PRODUCTION DIET

Based on the information obtained from the studies we have done, five types of production diets were formulated as shown in Table 4. In all diets, fish meal was used as a major protein source and 5% brewer's yeast was supplemented. In diets 3 and 4, fish meal was isonitrogenously substituted with 5% earthworm meal. In diet 5, krill meal was used instead of earthworm meal. About 5% pollock viscera oil can provide adequate quantities of ω3 fatty acids required by chum salmon (Takeuchi et al. 1979) and Yu and Sinnhuber (1981) reported that better growth performance is obtained by using a combination of tallow and salmon oil than use of salmon oil alone. Therefore, pollock viscera oil in diets 2, 4, and 5 was substituted with 5% beef tallow on an isocaloric basis. Gelatinized potato starch, which was found to be the best carbohydrate source (Akiyama et al. 1982), was used to adjust the total amount. Both vitamin and mineral mixtures were supplemented at a level of 2%. As a comparison, a salmon feed made by a commercial company exclusively for Hokkaido Salmon Hatchery (diet 6) and a commercial feed for salmon made by a commercial company in Europe (diet 7) were also tested.

Table 4.—Composition of the experimental diets.

Ingredient	Diet no. 1	2	3	4	5	6	7
White fish meal	66.62	66.62	62.37	62.37	61.34		
Brewer's yeast	5.00	5.00	5.00	5.00	5.00	Feed made by a commercial company	
Earthworm meal			5.00	5.00			
Krill meal					5.00		
Pollock viscera oil	9.96	4.96	9.82	4.82	5.10	A	B
Beef tallow		5.00		5.00	5.00		
Gelatinized starch	9.42	9.42	8.81	8.81	9.56		
Vitamin mix	2.00	2.00	2.00	2.00	2.00		
Mineral mix	2.00	2.00	2.00	2.00	2.00		
CMC	5.00	5.00	5.00	5.00	5.00		

As shown in Table 5, the experimental diets (1-5) prepared by us had similar nutrient contents, but crude fat content of diet 6 was about 7% and crude protein content of diet 7 was about 50%. A feeding study was conducted for 4 wk using swim-up fry with a mean body weight of 0.26 g.

Table 5.—Proximate analysis of the experimental diets.

Nutrient	Diet no. 1	2	3	4	5	6	7
Crude protein	45.3	45.9	46.3	46.5	44.9	46.8	49.9
Crude fat	13.4	13.6	13.0	12.5	13.1	7.3	13.5
Ash	13.3	13.5	13.0	13.0	13.0	10.2	10.6
Moisture	8.1	7.3	6.6	8.0	9.2	8.5	7.2

Results from the feeding study are summarized in Table 6. Feed consumption of fish fed the feed made by the European company

Table 6.—Feed consumption, feed efficiency, and growth of chum salmon fry fed the experimental diets for 4 wk. Initial mean weight was 0.26 g (150 fish/tank).

Diet	Feed consumption (%/day)	Feed efficiency (%)	Avg. wt. gain (%)	Final mean wt. (g)
Control	3.45	137	396	1.3
+ tallow	3.48	135	383	1.3
Earthworm	3.40	145	443	1.5
+ E and T	3.52	138	432	1.4
+ Krill and T	3.60	137	453	1.5
A	3.47	138	412	1.3
B	3.15	141	342	1.2

was substantially lower than the remaining groups, possibly due to the high protein and high calorie content of this diet. However, there was no clear difference in feed efficiency among all dietary groups. The substitution of beef tallow for pollock viscera oil failed to facilitate growth of chum salmon (diet 1 vs. 2 and diet 3 vs. 4), but showed at least a comparable weight gain in each dietary treatment. The substitution of either earthworm or krill meal for fish meal with or without tallow resulted in a substantially higher average weight gain than that of the corresponding dietary treatment. Average weight gain of these three groups was more than 430%, which was higher than that of fish fed the feed made by the Japanese commercial company. Average weight gain of 430% in 4 wk was almost twice as much as those of fish fed diets with fish meal as the sole protein source or the casein diets used in the previous studies described earlier. Thus, if water temperature is about 15°C, by feeding only one of these three diets, swim-up fry can be raised up to 1.5 g in body weight within 4 wk, which is the desirable size for release.

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Strategies in Salmon Farming in Japan

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INTRODUCTION

The present status of salmon propagation in Japan and the 5-yr program of salmon enhancement being conducted under the auspices of the Fisheries Agency will be discussed in this report. Strategies and related problems will be reviewed from a research point of view.

SALMON PROPAGATION: PRESENT STATUS AND TARGET

Figure 1 shows the variation in total catch of Pacific salmon in Japan for the past 25 yr. Recent catches fluctuate at a level of

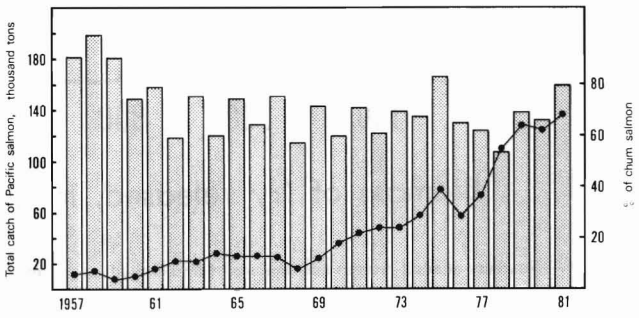

Figure 1.—Total catch of Pacific salmon and chum salmon as percent of total catch.

110,000-150,000 tons; from FAO statistics, this means 25% of all landings of salmon on the North Pacific coasts. In addition, in 1981 Japan imported salmon and their products amounting to 83,000 tons or 457 million U.S. dollars, equivalent to 12% of Japan's total import of marine products. In this figure, note the increase in chum salmon returns. Annual returns began to increase from around 1970, with great strides since 1975. In 1981, chum salmon returns reached 30 million fish, accounting for 70% of the total catch of Pacific salmon in Japan. This drastic increase in returns of chum salmon may have resulted from recent advances in artificial hatching and release operations.

In Figure 2, chum salmon returns are explained in more detail. From 1954 through 1970, annual returns crept up to near 5 million fish. Returns broke the 10 million record in 1974, 20 million in 1979, and 30 million in 1981. A breakthrough at the 10 million level in 1974 is especially noteworthy as this was the highest level under entirely natural spawning since the 1880's, 100 yr ago (Kobayashi 1979). Furthermore, in this figure note the increase in returns of chum salmon in mainland Honshu, especial-

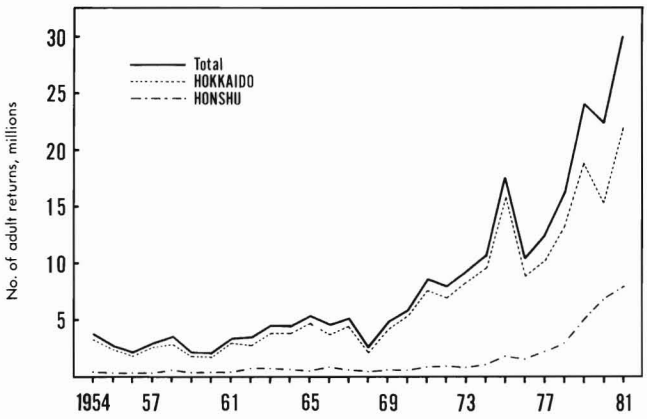

Figure 2.—Annual numbers of chum salmon adult returns (coastal catch plus escapements) from 1954 to 1981.

ly after 1975. Honshu, at present, takes 30% of the returns of chum salmon in Japan.

The Salmon Enhancement Program, now in operation under the Fisheries Agency, is a 5-yr program which began in the brood year 1979. Table 1 shows the progress and the final target for chum salmon. According to the Fisheries Agency, the return of 38.6 million fish, or 140,900 tons out of the release of 2,150 million fry in the brood year 1983, is set as a target figure to be achieved by the program. Judging from the numbers of fry released and adult returns in 1981, both being equal to about 80% of the target, the program appears to be successful.

To establish this program with success, it is necessary to 1) set up and/or improve hatchery facilities; 2) secure a desirable number of brood stocks; 3) enhance the rate of return; 4) transplant fry to barren rivers, especially in the Honshu area; and 5) rehabilitate salmon stocks in large river systems. As for the research operation on salmon enhancement, a large project (1977-81) was carried out by 27 institutions with a working budget of 830 million yen or 3.3 million U.S. dollars, in total. Results obtained for the 5 yr are currently being drafted.

Table 1.—Chum salmon enhancement program (1979-83).

Brood year	1979 No. of fry released (millions)	1981 No. of fry released (millions)[1]	1983 No. of fry released (millions)	Expected return of adults from 1983 fry	
				millions	1,000 tons
Hokkaido	871	1,080	1,150	27.6	100.7
Honshu	576	738	1,000	11.0	40.2
Total	1,447	1,818	2,150	38.6	140.9

[1]Number of adult returns in 1981: 21.89 (Hokkaido) and 7.59 (Honshu) in millions.

[1]Hokkaido Regional Fisheries Research Laboratory, Fisheries Agency of Japan, 116 Katsura-koi, Kushiro, Japan 085.

STRATEGIES: MANIPULATION OF THE RATE OF RETURN OF SALMON AND THEIR MIGRATION

The brood year 1966 is a memorable one in the history of salmon propagation in Japan. It was not until 1966 that dry formula feed was used with over 50% of the fry released in Hokkaido. The staff of the Hokkaido Salmon Hatchery initiated feeding trials from the brood year 1961 with the hope of obtaining more robust fry. They fed them with cod roe and bound diet having a high moisture content for a couple of years, followed by commercially formulated dry pellets. Of the roughly 100 yr of experience with the artificial release of salmon in Japan, the idea of raising fry for a longer period and thus releasing larger, more robust fry is relatively new—within the past 20 yr.

Figure 3 shows that the higher the feeding rate, the higher the rate of return. This relationship was originally introduced by Kobayashi in a paper presented at the FAO meeting in Kyoto in 1976. New plots were added to his figure with open circles representing the rate of return for nonfed fry before the brood year 1966, and solid circles for fed fry thereafter up to the brood year 1977. These salmon returned mainly in 1980 and 1981.

As a result of artificial feeding, the size of fish increased from 0.3 g for swim-up fry to 0.5 g at the time of release. It is important to note the size of fry, as well as the number of fry released, that is, the biomass. Figure 4 shows the remarkable increase in adult returns when the biomass of chum salmon fry at release surpassed 200 tons. Twenty years ago, in the 1960's, the release of 300 million fry or 100 tons of biomass was thought to be the limit based on reproduction curves for chum salmon in Hokkaido. As seen in this figure, it will be a long time before the number of returns decreases.

The problem of the appropriate size of fry at release will now be discussed. Figure 5 shows the relationship between the rate of return and size of fry. Data on cherry, coho, chinook, and sockeye salmon smolts were added to this figure for reference. Body weights of chum salmon used here range from 0.3 to 10.5 g. The

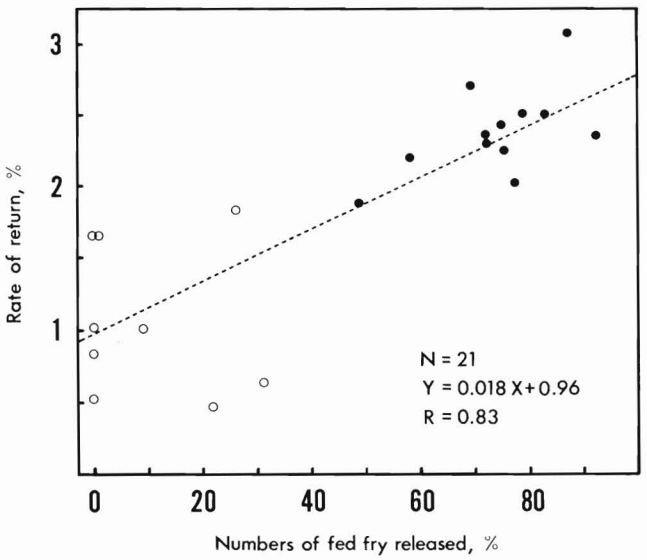

Figure 3.—Rate of adult return and percentage of fed fry released in chum salmon in Hokkaido. Open circles = 1957-65, solid circles = 1966-77 (supplemented to Kobayashi 1979).

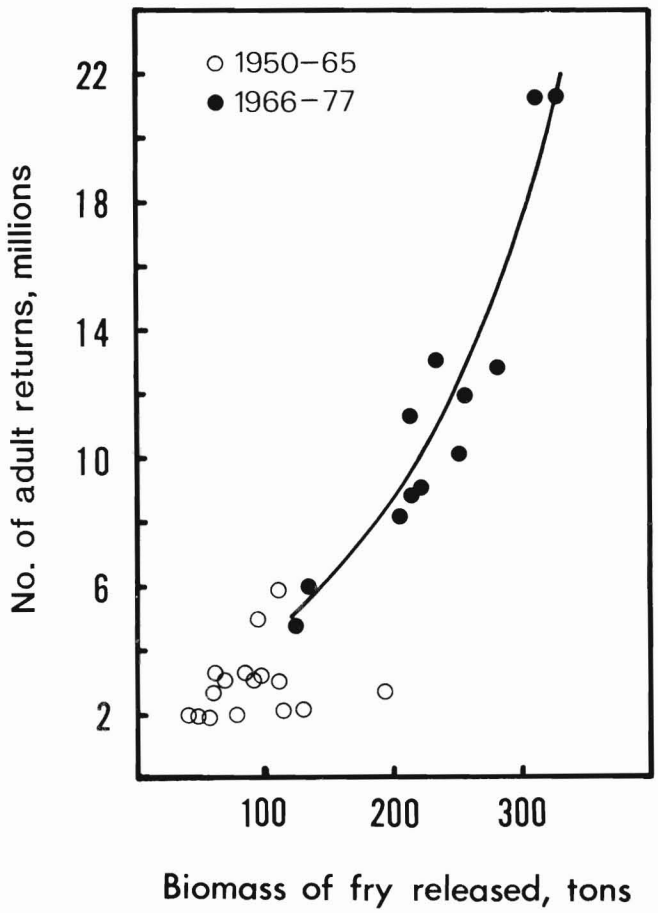

Figure 4.—Numbers of adult returns and biomass of fry released (no. × bw) in chum salmon of Hokkaido in the brood years 1950-77.

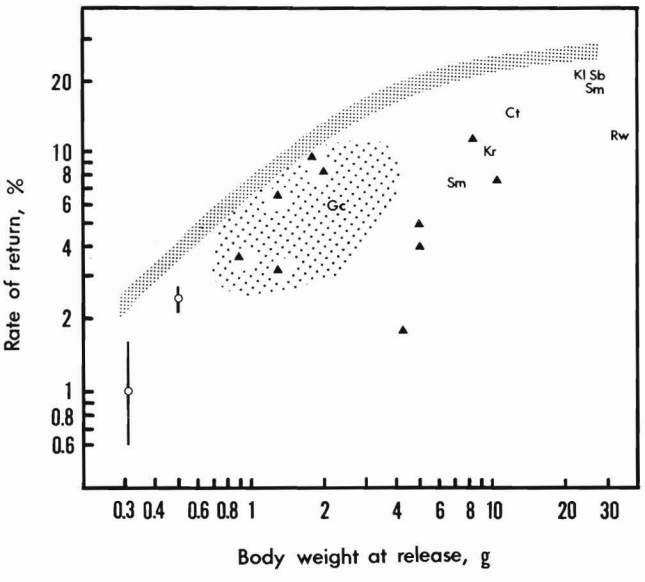

Figure 5.—Increase in rate of return as a function of size at release. Ct: Cultus sockeye from Foerster (1954), Gc: Great Central sockeye from LeBrasseur et al. (1978) and Manzer (1976), Kl: Karluk sockeye from Rounsefell (1958), Kr: Kurile sockeye from Krogius (1961), Rw: Rosewall coho from Bilton (1978), Sb: Shiribetsu cherry from Hokkaido Salmon Hatchery, Sm: Sacramento chinook from Reisenbichler et al. (1982).

longer bar on the lower side of the figure represents the rate of return when nonfed fry were released at 0.3 g, giving 1%; whereas the second bar represents the increased rate of return of 2.4% when fed fry were released at 0.5 g; both are averages for Hokkaido in total. The highest rate of return for chum salmon was 11.5% and was attributable to fin-clipped fry released at 8.3 g from a sea pen in Iwate Prefecture (Iioka 1982). The shaded curved line is a possible maximal rate of return in Pacific salmon. In this figure, note the dotted portion where comparatively higher values of return ranging from 3.4 to 9.7% are plotted against body weights of 0.9-2 g. Fry of 0.9-2 g appear as smolts, showing active swimming.

The larger the fry become, the sooner they migrate offshore. They were often found in big shoals mingling with other fish, such as young Atka mackerel. This migratory manner would enhance the possibilities for survival (Ito 1980). Further research must be directed to the behavior and physiology of young chum salmon in the transient phases of migration, and also to the changing pattern in their migration.

Having no experience in Japan with chum salmon fry of more than 10 g in body weight, except once in Iwate, we released larger fry of 18, 300, and 1,000 g in a transplant project in Chile, South America,[2] and are presently awaiting the results. In the next trial, we will devote our attention to what level the size at release can be decreased.

The rate of return in itself might be a result of many difficulties such as loss in river, estuarine, coastal, and ocean migration. We assumed that the greater part of natural mortality occurs in fry during coastal migration. Survival from fertilization to time of release, at present, is 80%. In Hokkaido, survival during downstream migration is 25-40% in nonfed fry, while much higher, 50-70%, in fed fry (Kobayashi 1976). In a radiotracer experiment with chum salmon fry in a small stream in Honshu, Hiyama et al. (1972) reported survival rates of more than 90% for larger fry (1.3 g) and 60% for smaller fry (0.4 g).

On the other hand, ocean mortality is considered to be relatively constant (Parker 1962). Hence, the first measure to be undertaken should be enhancement of survival during coastal fry migration after release. Figure 6 shows the relationship of the rate of return to coastal fry survival under various levels of ocean survival. In this figure, dotted lines shown the case in British Columbia for naturally wild chum salmon by Parker (1962). He provides estimates of survival for various phases from egg to adult. The final rate of return in B.C. chum salmon was estimated to be 0.08% of the number of eggs spawned. This rate of return corresponds to about 1% of the number of emerged fry.

As shown in Figure 3, the rate of return in Hokkaido was around 1% when fry were released without supplemental feeding. Assuming that ocean survival is in the range of 30-50%, coastal survival is estimated to be only 2-3%. In recent years in Hokkaido, coastal survival of fry released after feeding can be expected to be at a much higher level, as high as 6-10%, because their rate of return was nearly 3%. Furthermore, the highest rate of return was in Iwate Prefecture, northeast Honshu, where fry of 1.8 g in body weight at the time of release from the hatchery returned as adults at a rate of 9.7% (Iioka 1982). Again, assuming that ocean survival will be 30-50%, coastal survival can be estimated to be 20-35%.

[2]Yamada, pers. commun. 1982.

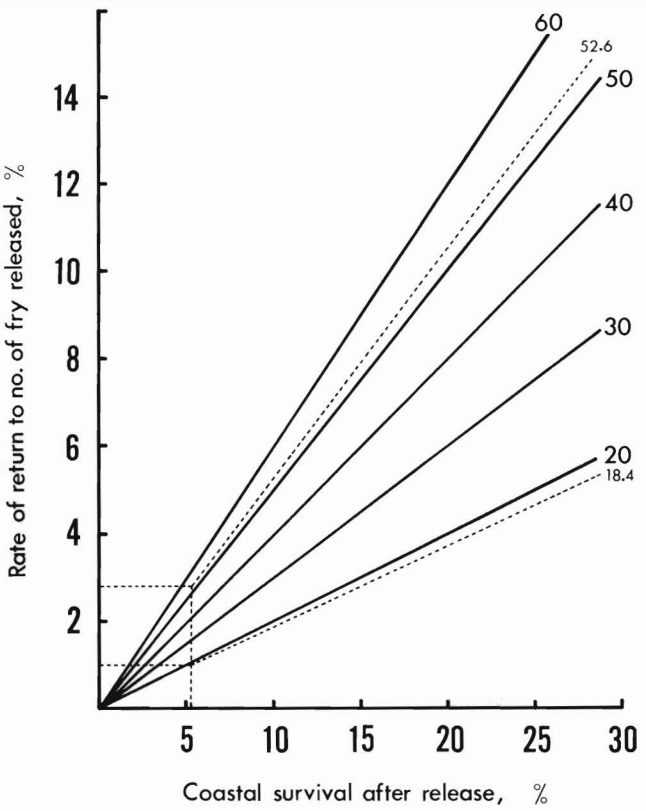

Figure 6.—Rate of adult returns and coastal survival rate of fry. Numbers in figure are survival rates during pelagic-coastal migration. Modified from Kobayashi, unpubl.

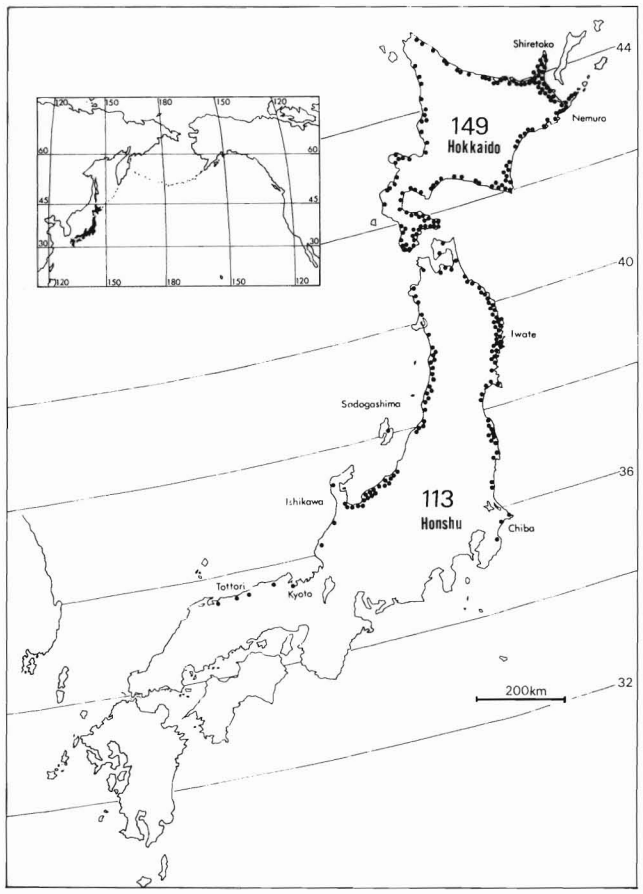

Figure 7.—Distribution of rivers of chum salmon return in 1981.

Past and present levels of survival of fry during early life in coastal waters has been estimated. The next question is where, how, and to what extent are they damaged. This is a very difficult, complicated problem. In Japan, we try to release robust fry at the appropriate time depending on local conditions of the river and coastal waters. Fry are usually released in Hokkaido timed to the rise in the rivers due to snow melt. Large quantities of turbid waters from rivers could provide increased chances of survival through reduction of predation, as well as through the supply of nutrients to coastal waters.

Seemingly, coastal survival is liable to be influenced by the localities where fry are released. Figure 7 shows the distribution of rivers to which statistically significant numbers of adults returned last year. In total there were 262 rivers; 149 in Hokkaido and 113 in Honshu, 1.6 times more than 10 yr ago. Eastern Hokkaido and Iwate Prefecture have many rivers with high rates of returns. Other remote localities such as Chiba, Sadogashima, Ishikawa, Fukui, Kyoto, Hyogo, and Tottori have very small returns but are steadily increasing. In this figure, it can be seen that chum salmon fry released from the Honshu area are forced to spend a longer period of time along the coast to get to eastern Hokkaido before starting offshore migration. This implies that they are more liable to be damaged.

High rates of return of more than 4% have been reported in some rivers feeding into the seas surrounding Shiretoko Peninsula, Hokkaido (Kobayashi 1979). Fry from these rivers need only travel < 100 km to reach the tip of the peninsula, while fry from the Yura River, Kyoto, must travel > 2,000 km. In Honshu, to overcome this topographic handicap it would be necessary to release much larger, more robust fry. There is one more problem different from that in Hokkaido—the temperature conditions of the seawater. Figure 8 shows the distribution of surface water temperatures around the Island of Japan during the season of fry release. Due to the northward movement of warm water currents in springtime, fry release must be completed by the end of April, especially in the western part of Honshu.

As outlined previously, the main manipulations at present for enhancement of salmon can be summarized as follows: Releasing a fairly large biomass of robust fry composed of the appropriate size, coupled with the suitable timing of release to environmental conditions.

Hatchery water supply places limitations on fry rearing. Presently, more than 260 hatcheries, in total, use water for incubation and fry rearing at a rate of 700 tons/min. This amount of water is sufficient to accommodate 4,400 million swim-up fry or 1,200 million 0.6 g fry at 8°C. This is a problem because our target for the number of fry to be released in the brood year 1983 is over 2,000 million. Since we cannot expect additional new water resources in the future, we should consider actively the effective use of fry produced resulting in a high rate of return, the rotation of fry production, re-use of water, and the use of seawater.

The recent increase in salmon resources in Japan could only be realized through the enormous input of energy, directly and in-

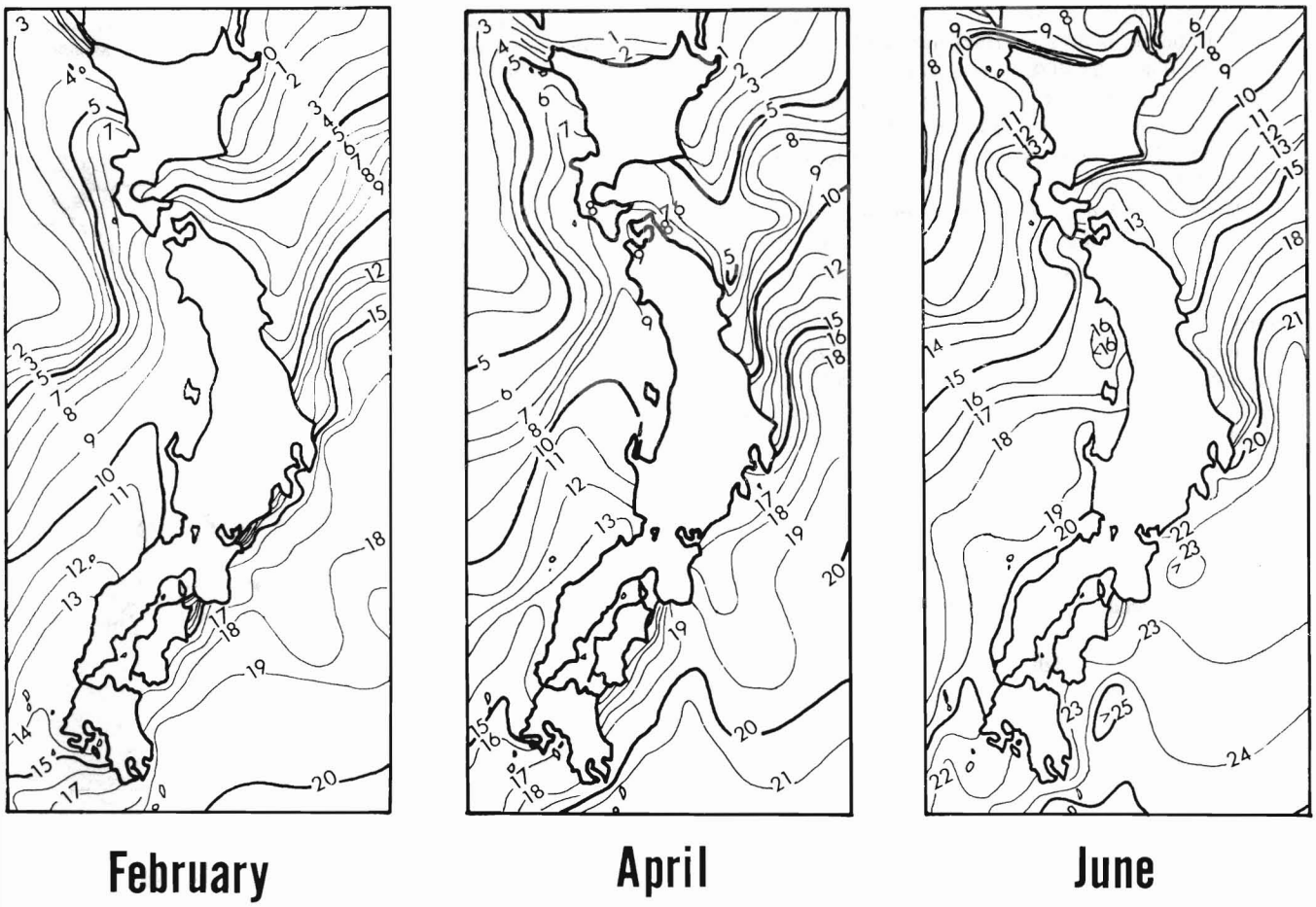

Figure 8.—Distribution of surface-water isotherms in the seas of Japan during fry migration. Redrawn from data supplied by the Japan Oceanographic Data Center.

directly, into the system of artificial fry release. As we enter the era of energy conservation, we must consider costs associated with water usage, human labor, and so forth, in relation to the production of healthy fry. Cost effective returns of quality salmon must become an important consideration.

ACKNOWLEDGMENTS

I am particularly indebted to my colleagues, Tetsuo Kobayashi, Hokkaido Salmon Hatchery; Jun Ito, Far Seas Fisheries Research Laboratory; and Takahiko Irie, Hokkaido Regional Fisheries Research Laboratory, who suggested valuable information and comments. I would like to extend my personal thanks to Byron Sigel, Hiroshima University, for reading the manuscript.

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An Electrophysiological Approach to the Olfactory Recognition of Homestream Waters in Chum Salmon

KAZUO UEDA[1]

INTRODUCTION

Behavioral studies have shown that salmon in the final freshwater stage of spawning migration can discriminate among stream waters by utilizing an olfactory sense (see reviews by Hara 1971; Hasler et al. 1978; Cooper and Hirsch 1982). Several attempts have been made to find neurophysiological correlates in salmon olfactory responses that are more or less characteristic of the quality of the odorants in the various stream waters (Hara et al. 1965; Ueda et al. 1967; Oshima et al. 1969; Cooper and Hasler 1974; Dizon et al. 1973; Bodznick 1975). In these earlier studies the amplitude of the response usually has been the exclusive parameter studied. However, the amplitude of the response may be of limited importance for studying the mechanism for discrimination of the quality of the stimulus since it varies greatly with the changing intensities of the same stimulus. The analytical procedures using the magnitude of the olfactory responses as an index have been criticized by Ueda et al. (1971) and Ueda (1982).

Recently, frequency analysis, a familiar technique in EEG data processing, has been applied to characterization of the olfactory bulbar responses in fish as a function of frequency by using a series of active band-pass filters (Ueda et al. 1971; Kudo et al. 1972), by a Heterodyne-Wave-Analyzer (Satou and Ueda 1975), and by a Fourier transform on a digital computer (Kudo et al. 1972; Hara et al. 1973; Ueda 1973; Kaji et al. 1975). These reports have suggested that specific odor quality may be associated with a characteristic response frequency spectrum.

In this paper I report a frequency analysis of the olfactory responses of adult spawning salmon. In this study the band-pass filters were used in an attempt to decide whether it is possible to recognize a neural coding mechanism for olfactory discrimination of stream waters in terms of the frequency components of the response.

MATERIALS AND METHODS

Adult male chum salmon, *Oncorhynchus keta*, were taken from the Tsugaruishi River and the Otsuchi River (Tohoku district, Japan) in the early phase of their upstream migration. Seawater chum salmon captured by set nets in Otsuchi Bay were also used. They were transported in a 220 l oxygenated tank to the Otsuchi Salmon and Trout Hatchery, where the experiments were performed (Fig. 1). No more than six fish were carried at one time. They were kept in a large tank with a constant flow (450 ml/s) of well water for 12-48 h before use. The techniques for the operation and recording of electrical activity were essentially the same as those described previously (Ueda et al. 1971).

Water samples tested were collected on the day of use from five rivers, just upstream of the fish barriers, i.e., the Tsugaruishi River, Origasa River, Otsuchi River, Kotsuchi River, and Unosumai River, and were kept at about 5°C until used. Water samples and rinsing water (redistilled water), both of which were kept at room temperature (17.5°-19.0°C), were infused alternately into the nasal cavity for 20 s at regular 30 s intervals at a flow rate of 0.6 ml/s. L-serine, reported to be an active component of the repellent in mammalian skin extract for adult migrating Pacific salmon (Brett and MacKinnon 1954; Idler et al. 1956), was also used as a test solution.

Electrical activities were recorded through Ag-AgCl bipolar electrodes (0.2 mm in diameter, 0.8 mm apart) from the olfactory bulb or telencephalon, ipsilateral to the stimulated naris; electrical responses were recorded on an FM tape recorder through a preamplifier for subsequent frequency analysis by a series of active band-pass filters (1/3 octave steps with attenuation rates of 65 dB/octave, see Kudo et al. 1972).

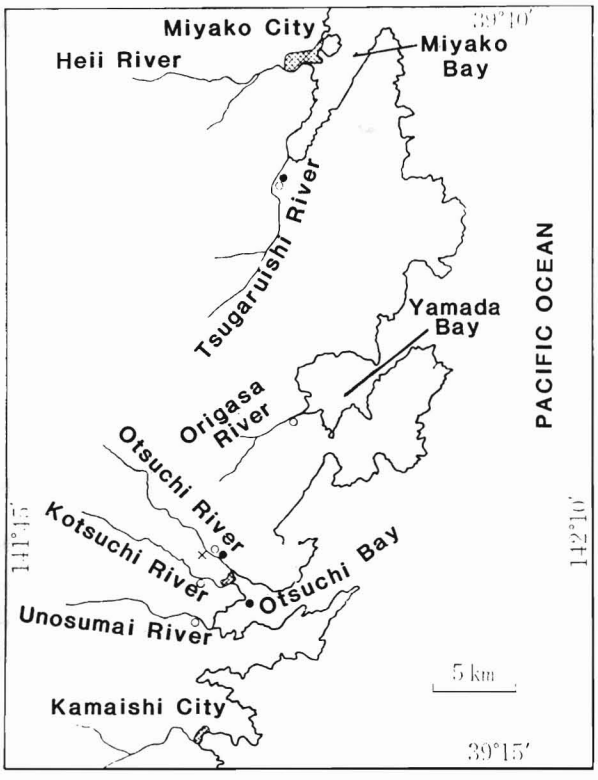

Figure 1.—Map of Otsuchi and vicinity, showing Otsuchi Salmon and Trout Hatchery (X) where the experiments were performed, and the sites where the fishes (solid circles) and test water samples (open circles) were collected.

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RESULTS

Spectral Analysis of Olfactory Responses

Discrimination among stream waters.—Time-frequency features "spectral patterns" of the responses to different waters are shown in Figures 2-4.

Figure 2 shows the typical responses of the "Tsugaruishi salmon," respectively to water samples from Tsugaruishi River (homestream water) (A), Origasa River (B), Otsuchi River (C), Kotsuchi River (D), Unosumai River (E), and to L-serine (F). The frequency analysis indicated that there are recognizable different spectral patterns for different stream waters and L-serine.

Figure 3 shows the typical responses of "Otsuchi salmon." Magnitudes of unprocessed responses to stream waters except Otsuchi River (home water) were small. However, different spectral patterns were also observed, after the spectral analysis, in the responses to different streams.

Since there are recognizable qualitative differences in the electrical responses of the brain to natural waters, this suggests that the characteristic chemical features can be discriminated by salmon among the different stream waters tested.

Recognition of homestream water.—In Figures 2 and 3 (see also Figs. 5, 6), it is clear that lower frequency components (3.15-5.0 Hz, mainly 4-5 Hz) appeared only when stimulated with home water. This finding suggests that activity of the frequency component in this range shows a part of information reflecting the home water memory (called, tentatively, memory wave) by which a given stream water is recognized as the homestream water.

Figure 4 shows the typical responses of "seawater salmon" captured in the Otsuchi Bay, into which three rivers (Otsuchi, Kotsuchi, and Unosumai Rivers) are flowing (Fig. 1). At this moment, no one knows the home river, or natal stream to which he should return. The spectral patterns of Figure 4, indicating the memory wave in response to Otsuchi River, are fundamentally similar to those of Figure 3 ("Otsuchi salmon"). Therefore, one may conclude that his homestream is Otsuchi River. The present method, based on memory wave, can be used to guess the home river prior to upstream migration.

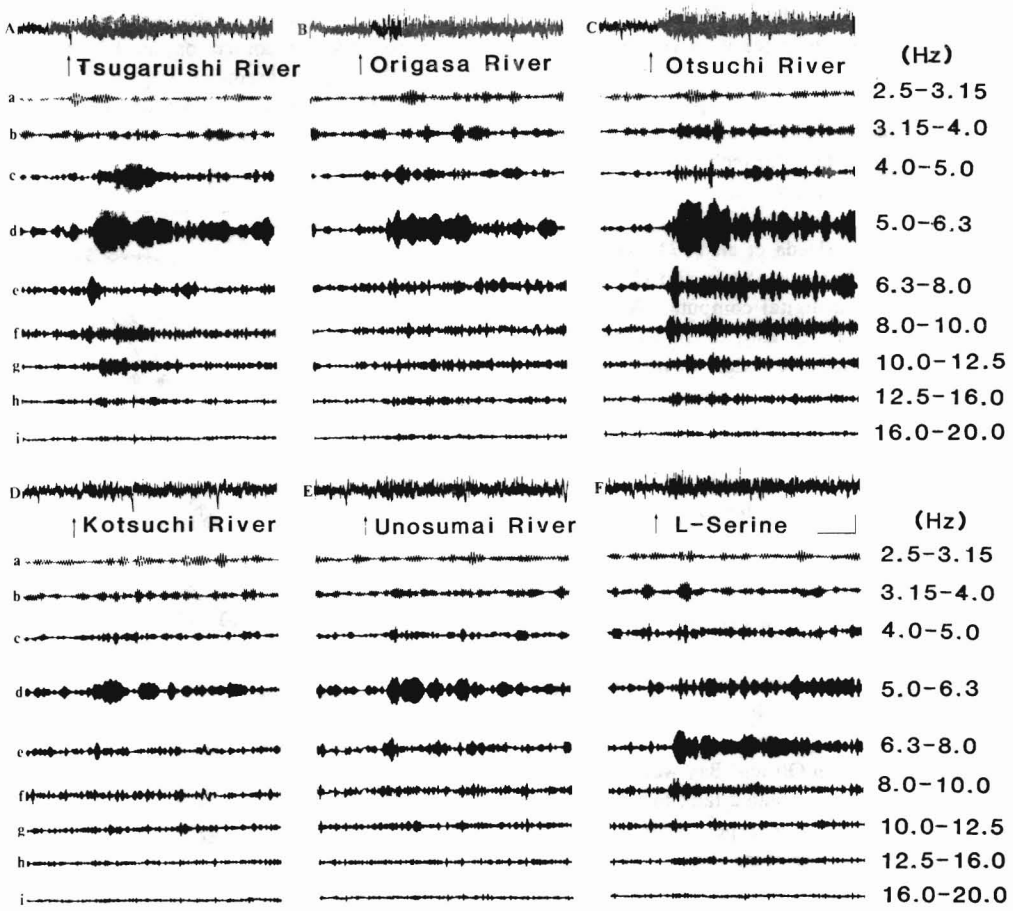

Figure 2.—Spectral patterns of the olfactory responses. This specimen had homed to the Tsugaruishi River. The uppermost trace of each column shows the original olfactory response to be frequency-analyzed. A, B, C, D, E, and F are the responses to Tsugaruishi River (homestream water), Origasa River, Otsuchi River, Kotsuchi River, Unosumai River, and 0.02% solution of L-serine. Traces from a to i show the frequency components within each response. The arrows indicate the onset of stimulation. Electrode position, surface to the anterior telencephalon; calibration, 5 s and 10μV. The amplitudes of traces a through i are enlarged twice.

The data presented here may prove that there is a memory-based brain mechanism for the recognition of homestream water.

Stimulants in Homestream Water

Hasler and Wisby (1951) suggested that young salmon are "imprinted" by a distinctive odor in the homestream water; through discrimination and memory, this serves later as a guide to the adult fish in orienting toward and reaching the homestream. So the experiments were designed to develop a laboratory bioassay, based on the spectral pattern, to facilitate the isolation and identification of the homestream odor(s).

Test water (homestream waters or their fractions) and rinse water (distilled water) were infused alternately into the nasal cavity for 20 s at regular 30 s intervals. The electrical activity was frequency-analyzed by means of a series of active band-pass filters. The experimental results obtained were the very same for all of the fish used (four Tsugaruishi and eight Otsuchi salmon). A preliminary study was reported elsewhere (Ueda et al. 1979).

Figure 5 shows the spectral patterns of responses to homestream water before (A) or after (B) a treatment with activated carbon. Memory wave disappeared in (B). This indicates the homestream odor is absorbed on activated carbon. When the homestream water was passed through a mixed bed of ion-exchange resin (IR 120B and IRA 402, by a ratio of 2 to 1), the fish no longer responded to it.

When the homestream water was fractionated by vacuum distillation at a low temperature (28°-32°C), the salmon consistently responded to the concentrate (nonvolatile fraction, adjusted to the original volume with redistilled water), but not to the distillate (volatile fraction). Even if the distillation was carried out with heating up about 80°C, the fish responded in the same way to the concentrate (Fig. 6). Figure 6 shows that the spectral patterns of the bulbar responses to the homestream water (A) and to its nonvolatile fraction (B) are very similar. The results indicate that the homestream stimulant is a nonvolatile and heat-stable substance. Successive experiments disclosed further that the homestream stimulant(s) is insoluble in petroleum-ether and is dialyzable.

Using behavioral assays with adult sockeye salmon, Idler et al. (1961) reported that the homestream stimulant(s) was volatile, heat-labile, neutral, and dialyzable (see also Hasler 1971). However, in further experiments with juvenile (Bodznick 1978) and adult sockeye salmon (Fagerlund et al. 1963), it became clear

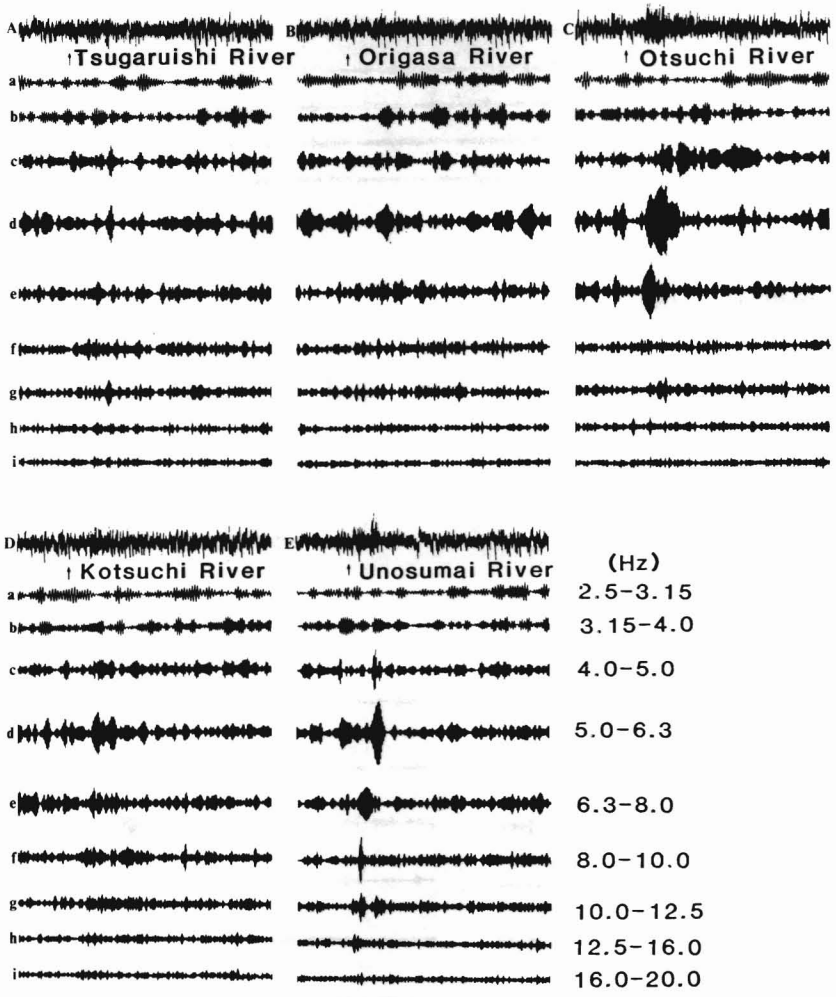

Figure 3.—Spectral patterns of the olfactory responses. This specimen had homed to the Otsuchi River. C is the response to homestream water (Otsuchi River). Electrode position, between the olfactory bulb and the telencephalon; calibration, 5 s and 50 μV. See Figure 2 for the other legends.

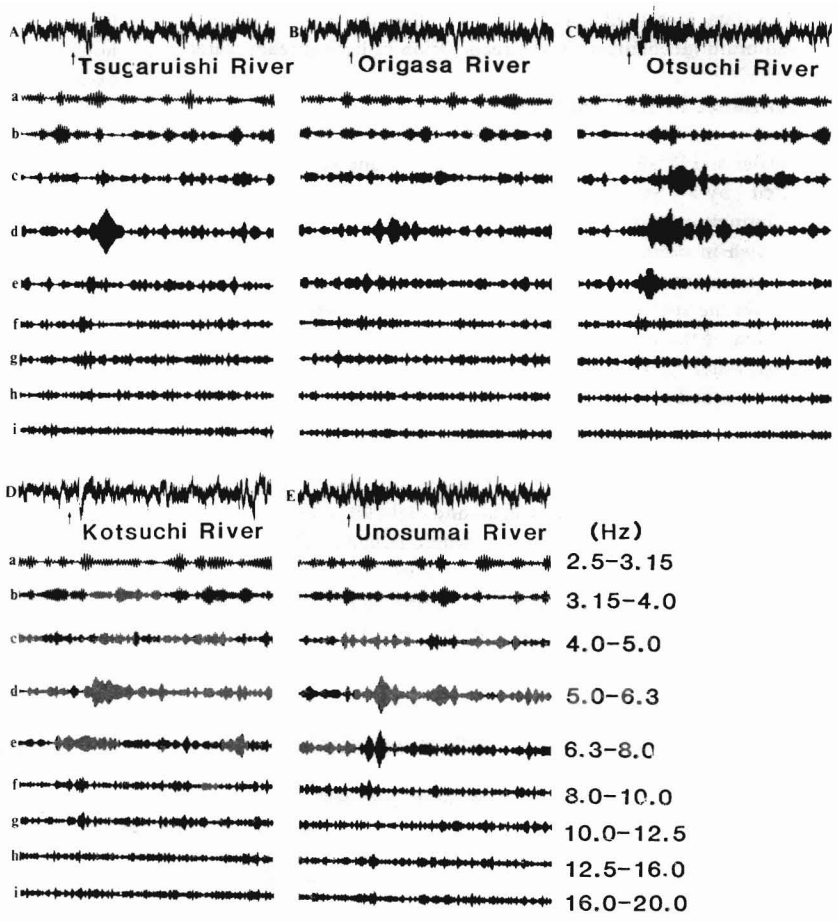

Figure 4.—Spectral patterns of the olfactory responses. This specimen was captured in the Otsuchi Bay; transferred directly to freshwater (well water), and adapted in it for 24 h before testing. Electrode position, surface of the posterior telencephalon; calibration, 5 s and 20μV. See Figure 2 for the other legends.

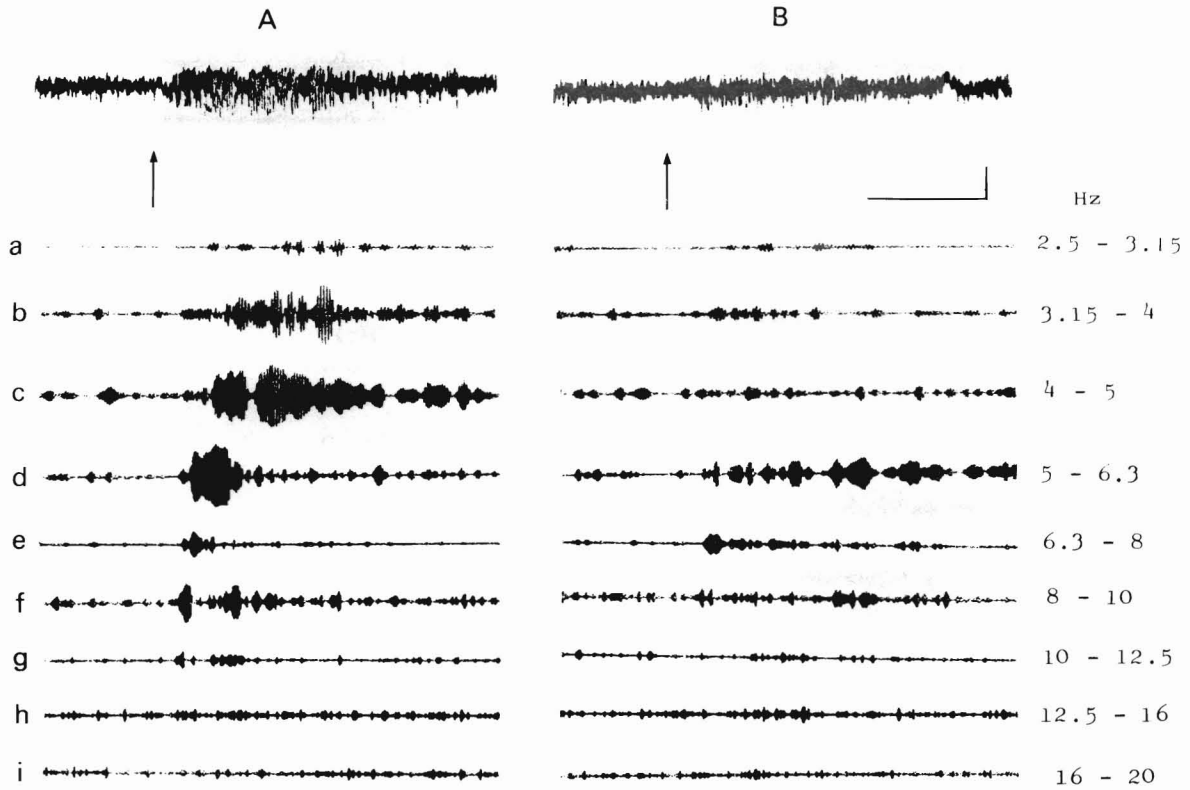

Figure 5.—Typical spectral patterns of the olfactory responses to homestream water (Otsuchi River) before (A) and after (B) a treatment with activated carbon. This specimen had homed to Otsuchi River. Electrode position, between the olfactory bulb and the telencephalon; calibration, 10 s and 50μV. See Figure 2 for the other legends.

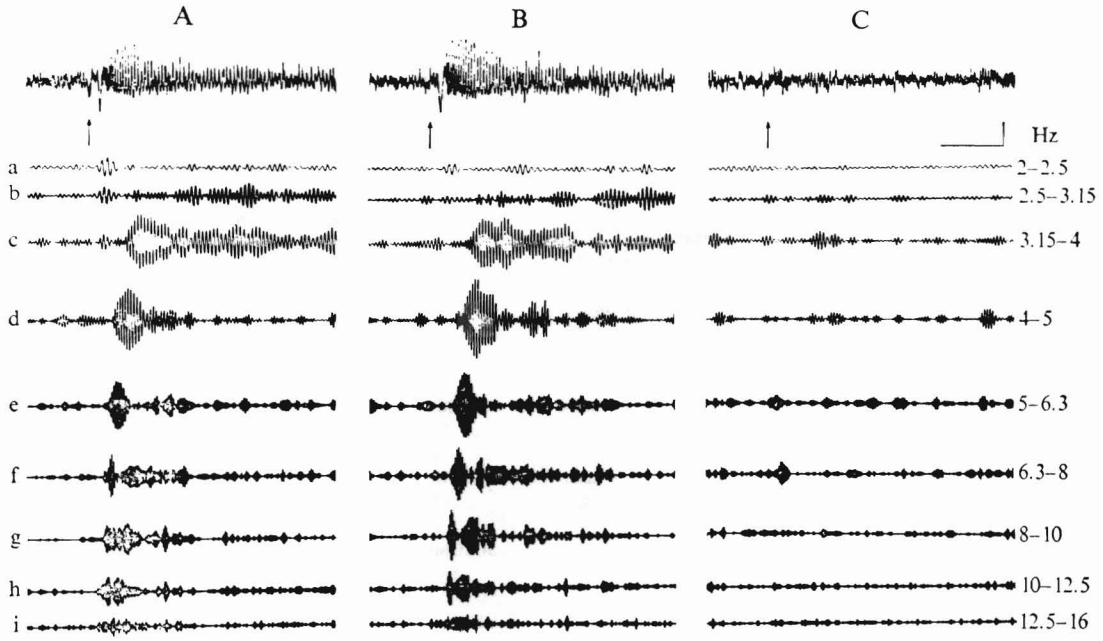

Figure 6.—Typical spectral patterns of the olfactory responses to homestream water and its fractions. This specimen had homed to Tsugaruishi River. A, B, and C are the responses to homestream water (Tsugaruishi River), its nonvolatile fraction, and volatile fraction, respectively. Homestream water was fractionated at 75°C. Electrode position, 0.86 mm below the surface of the posterior olfactory bulb; calibration, 10 s and 100μV. See Figure 2 for the other legends.

that the nonvolatile fraction was also important. Moreover, Cooper et al. (1974) have indicated, based on the amplitude of olfactory bulbar EEG of spawning coho salmon, that the stimulatory portion of the homestream water is nonvolatile.

Some inconsistency of the results between our electrophysiological assay and behavioral ones may be either because the active stimulant(s) is characteristic for each species or because of the differences in the bioassay method. The method used by Fagerlund et al. (1963) and Idler et al. (1961) seems to have serious defects; for instance, it was found that the behavioral response to homestream water, adopted as an indicator, was indistinguishable from that elicited by temperature changes of the test water.

Nordeng (1971), Solomon (1973), and Døving et al. (1974) have suggested that pheromones are used for homing. In the present experiment, however, the water samples tested were all collected upstream of the fish barrier where there were no adult spawning salmon. No young fish of the same species are known to remain in the river at this time of the year, since fingerlings released in the spring migrate immediately toward the sea. Therefore, it seems likely that the stream water samples used in the present experiments contained olfactory stimulants other than the putative conspecific pheromones suggested by Døving et al. (1974). However, it is not yet possible to rule out heterospecific fish pheromones as possible olfactory cues.

Hasler and his colleague have reported that coho salmon may imprint to morpholine in the same way as they do to naturally occurring homestream odors (see reviews by Hasler et al. 1978; Cooper and Hirsch 1982). By contrast, Hara (1974) and Hara and Macdonald (1975) have concluded, based on characteristic differences between olfactory bulbar responses induced by morpholine and natural olfactory stimulants, that the morpholine effect is probably caused by a mechanism not directly associated with normal olfactory function. In fact, morpholine is an irritant and corrosive to mucous membranes such as olfactory epithelium.

Further studies are needed to characterize the homestream stimulant(s).

SUMMARY

1) The electrical responses of the olfactory center of spawning chum salmon, *Onchorhynchus keta*, induced by the nasal infusion of various stream waters were frequency-analyzed by a series of active band-pass filters to investigate whether there is any neurophysiological coding in the discrimination of stream waters.

2) Temporal changes in each frequency component "spectral patterns" seemed to characterize a quality of the stream waters.

3) Lower frequency components (3.15-5.0 Hz) appeared only when stimulated with homestream water. They may indicate a part of the brain information by which the salmon can recognize, or identify one of the stream waters as their homestream water through "memory" imprinted at the young freshwater stage and retained until the spawning migration.

4) The analyses suggest that olfactory function in migrating chum salmon is useful in discriminating among various stream waters and in recognizing the homestream water.

5) A bioassay based on the spectral pattern was performed to determine the homestream stimulant(s). The stimulant(s) is absorbed on activated carbon and ion-exchange resin, insoluble in petroleum-ether, dialyzable, nonvolatile, and heat-stable.

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