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William N. Shaw (Editor)

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

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U.S. DEPARTMENT OF COMMERCE
Malcolm Baldridge, 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; administration staff meetings; exchanges of equipment, materials, and samples; several major technical conferences; and beneficial effects on international relations.

William N. Shaw-United States
Shigekatsu Sato-Japan

CONTENTS

NOTE: Some authors did not submit their papers for publication in the proceedings.

Joint Statement of the UJNR Aquaculture Panel October 18, 1979, Bellingham, Washington

The eighth Joint Meeting of the UJNR Aquaculture Panel was held October 17–18, 1979 at Western Washington University in Bellingham, Washington.

On the first day of the meeting five overview papers on the meeting theme, freshwater fish culture, were presented by Japanese and U.S. scientists. In addition six scientific papers were presented reflecting recent research advances in freshwater fish culture in the two countries. This exchange of papers was useful and informative to panel members and observers. The business meeting was held the second day of the meeting. Dr. Sato and Mr. Shaw who were elected cochairmen presided over the business meeting.

Successful UJNR activities during the last year were reviewed. These included an exchange of scientists involving extended study visits by 3 U.S. scientists and an industry representative to Japan and visits by 5 Japanese scientists to the U.S. under sponsorship of the UJNR.

It is anticipated that at least 2 U.S. scientists will visit Japan during the next year. A visit of intermediate length by Dr. Arai, a fish nutritionist, to the U.S. is also planned as well as additional shorter visits. Provision of information in advance of visits regarding opportunities for study and observation would help make exchanges of scientists more useful.

The exchange of selected scientific information in the field of aquaculture has continued. A set of 21 selected Japanese publications have been submitted to the U.S. and some of these are being translated. Selected U.S. publications are also being submitted to Japan by the U.S. panel and lists of these are widely distributed in Japan. Possibilities for translation of several new Japanese books are being explored.

A cooperative research project presently in progress is a joint study of summer mortality of oysters involving field testing of disease resistant U.S. strains in Japan. The joint study of oyster diseases which has been underway for 4 years is continuing and plans for joint publication of results are being made.

An official response regarding Japanese input for the World Index of Fish Disease was requested by the U.S. panel.

A plan was presented for formalizing future proposals for cooperative research projects and a draft proposal for research on evaluation of abalone seeding was presented by the U.S. members. This proposal will be reviewed by the Japanese panel and modified as necessary after discussion of practical aspects of the research.

The U.S. members have formed several committees to improve and expand their activities. One of these, the publication committee, is working on publication of the papers presented at the 1977 meeting, and has prepared a statement of editorial policy for the Aquaculture panel. It was agreed that papers presented at the UJNR meetings be published regularly in established journals and that the host country take responsibility for publishing papers presented at UJNR meetings in their country. A suggested format for authors will be made available prior to each meeting.

Preliminary plans for the next joint meeting were made. Plans are to hold the meeting in conjunction with the Indo-Pacific Fisheries Council (Symposium on Development and Management of Small Scale Fisheries) in Kyoto in May, 1980. Since the theme of the 1980 UJNR aquaculture joint meeting will be "Crustaceans" it is proposed that a field trip to shrimp hatchery and production sites be made following the meetings.

Respectfully submitted

William N. Shaw-United States
Shigekatsu Sato-Japan

Freshwater Finfish Culture in Japan

SHIGERU ARAI[1]

PRESENT STATUS OF FRESHWATER FINFISH CULTURE IN JAPAN

Fish have been raised for hundreds of years in Japan not only for food but also as a hobby. The culture of eel, carp, and rainbow trout was established before World War II and in 1943, 31,000 t of these fish were produced. Due to the severe damage caused by the war, the production of cultured freshwater finfish totaled only 4,300 t in 1950. However, the industry was restored in the early 1960's and has showed remarkable development; 82,000 t were produced in 1977 (Fig. 1), an increase of 19 times in 28 yr. On the other hand, the catch of wild freshwater finfish was 40,000 t in 1950 and 67,000 t in 1977, an increase of only 1.7 times.

The catches and values of various types of marine and freshwater fisheries are summarized in Table 1. As seen in the table, production of cultured freshwater finfish accounted for a very small proportion of the total—only 0.8% of production in 1977. However, harvest value of cultured freshwater finfish accounted for 3.7% of the total value, indicating that cultured freshwater finfish are highly valued in the market.

Principal species of freshwater fish being cultured in Japan are carp, *Cyprinus carpio*; eel, *Anguilla japonica*; rainbow trout, *Salmo gairdneri*; and ayu, *Plecoglossus altivelis*. The average wholesale prices of these fish during the past 10 yr are shown in Table 2. Among the cultured freshwater fish, eel and ayu are the most expensive. The price of eel has always been 3–5 times higher than that of rainbow trout and carp. The production and harvest values of the four major species cultured in freshwater in 1977 are shown in Figure 2 with the distribution ratios of each species. The production of carp ranked first, acounting for 36%; eel was second, accounting for 34%. However, the harvest value of eel accounted for 61% of the total and carp only for 14%. Thus, eel is very important in freshwater finfish culture in Japan.

The production ratios of wild and cultured finfish in 1977 are shown in Figure 3. The percentages of cultured eel and trout were over 90%; carp was 81%. The percentage of cultured ayu was only 30%; the remainder of ayu production came from rivers. Due to their importance as game fish, ayu have been stocked in rivers every year by fishery cooperatives. Ayu are herbivorous and in nature they eat diatoms found on stones or rocks. Wild ayu are normally caught during the summer season in the southern part of Japan.

Culture methods for the four major species are shown in Table 3. The running water pond system is a common method for rainbow trout culture. There are 1,222 farms with surface area totaling 1,612 km² using the running water pond system, which have produced 15,018 t of rainbow trout. The production rate is 9.3 kg/m², indicating that rainbow trout culture is intensive, and needs high quality and large quantities of water.

Ayu are mostly cultured in a running water system like rainbow trout. There are 314 farms with surface area totaling 438 km², which

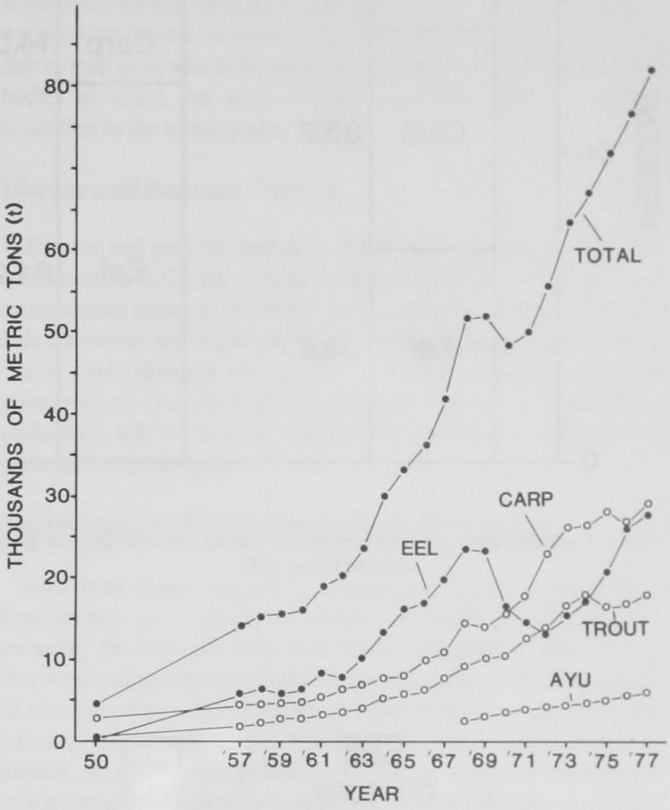

Figure 1.—Annual production of freshwater finfish culture.

Table 1.—Distribution and value of the various types of marine and freshwater fish harvest in 1977 (Anonymous 1979).

	Harvest		Harvest value	
Distribution of harvest	1,000 t	%	100 million Yen	%
Marine harvest	9,695	90.0	20,513	80.6
Sea culture	861	8.0	3,522	13.8
Inland freshwater harvest	126	1.2	486	1.9
Inland freshwater culture	82	0.8	930	3.7
Totals	10,764	100.0	25,451	100.0

Table 2.—Average price of freshwater fish (yen/kg) (Anonymous 1979).

Year	Trout	Ayu	Carp	Eel
1967	197		220	571
1968	199		197	655
1969	195		280	880
1970	236		309	1,320
1971	373		389	1,320
1972	373		319	1,954
1973	470	964	427	1,778
1974	517	1,184	438	1,965
1975	492	1,250	425	2,020
1976	535	1,176	405	1,960
1977	611	1,445	444	2,058

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[1] Fish Nutrition Division, National Research Institute of Aquaculture, Fisheries Agency, Hiruta, Tamaki-cho, Watarai-gun, Mie-ken, Japan.

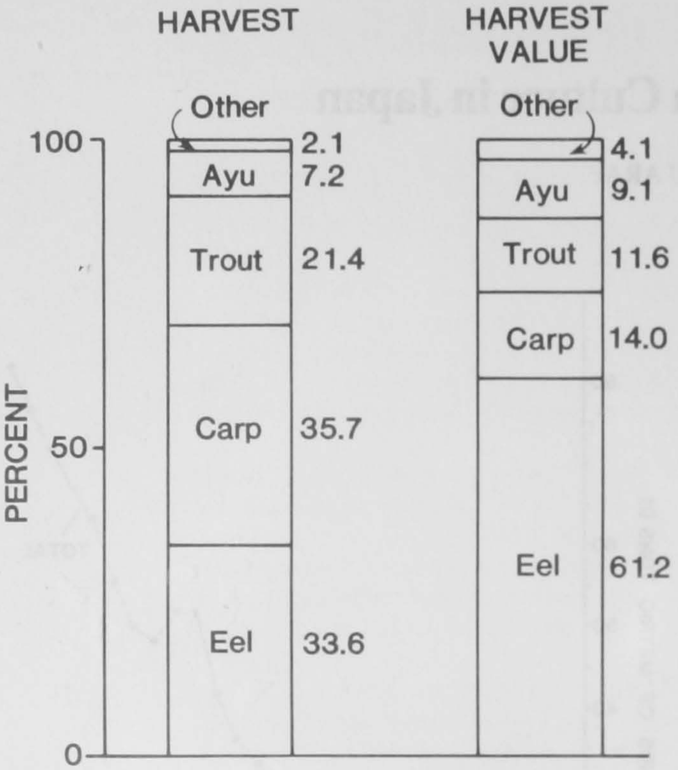

Figure 2.—Distribution ratios of harvest and harvest value of cultured freshwater finfish in 1977.

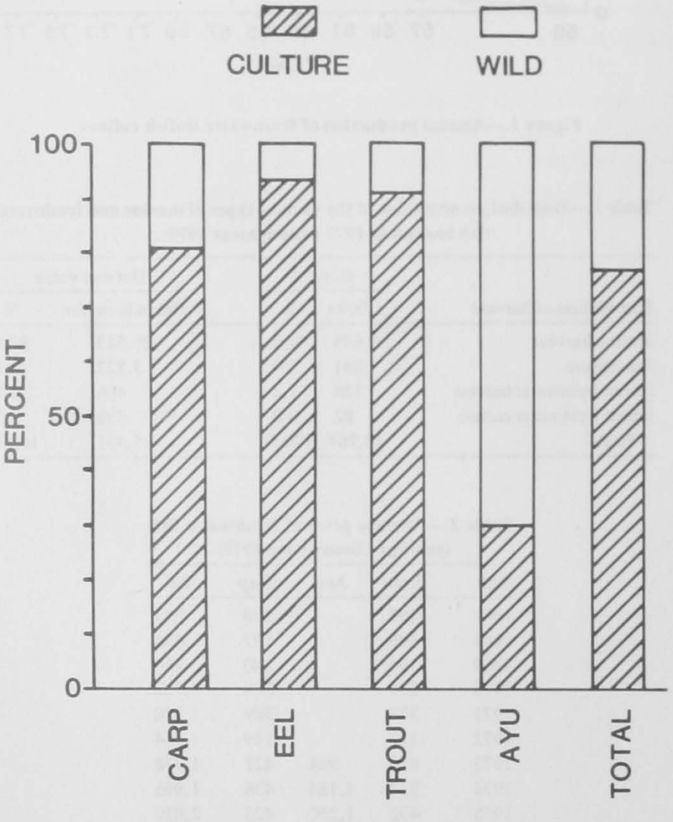

Figure 3.—Harvest ratios of wild and cultured freshwater finfish in 1977.

Table 3.—Number and types of farms, surface area, and production (four major freshwater fish species cultured) in 1977[1] (Anonymous 1979).

	Running water ponds	Still water ponds	Farm ponds	Nets or cages	Total
Trouts					
Managements	1,222	9	5	2	1,238
Surface area (km²)	1,612	15	10	10	1,647
Production (t)	15,018	30	11	18	15,077
Ayu					
Managements	314	4	—	—	318
Surface area	438	2	—	—	440
Production	4,906	84	—	—	4,990
Carp					
Managements	882	1,087	989	474	3,432
Surface area	1,279	4,082	24,160	342	29,863
Production	3,668	3,826	8,766	10,460	26,720
Eel					
Managements	168	2,507	1	1	2,677
Surface area	374	24,473	2	0	24,849
Production	915	20,826	0	0	21,741

[1] Figures do not include figures of minor production prefectures.

have produced 4,906 t. The production rate is 11.2 kg/m² and ayu is more intensively cultured than rainbow trout.

In carp culture, there are several types of culture methods. The most productive method is net or cage culture; this method can be used only in lakes or reservoirs. The production rate of net or cage culture is 30.6 kg/m². Further expansion of this production system seems to be limited, because the feces from fish and food residues are factors in the eutrophication of these closed bodies of water. The running water pond system is also a very intensive method. The highest production rate, 220 kg/m², has been recorded by K. Tanaka in Gunma Prefecture. However, the average production rate of the running water method was 2.9 kg/m². The most extensive method is the farm pond system; the production rate is only 0.4 kg/m². This system is used principally for seed production.

In eel culture, the still water pond system is most common; only a small amount of eels were produced by the running water pond. The production rate is 2.4 kg/m² in the running water pond and 0.9 kg in the still water pond. Productivity of the running water system is higher than that of other methods; however, this method was adopted by only 7% of the farms. As a result of the expansion of eel culture, demand for eel elvers exceeded the possible production along the coast of Japan. Also, due to the large fluctuation in elver catch, European elvers are being imported from France. Eel farmers have tried to raise them in the traditional still water pond. However, most of the farmers failed to culture the European eels, because they are sensitive to high water temperature and death often occcurs in the summer season. The eels are also highly susceptible to parasitic diseases. At present, several farmers have succeeded culturing European eel in running water ponds. Success has been attributable mostly to lower water temperature and constant water conditions in the running water system.

The types and amounts of feed used for freshwater finfish culture are listed in Table 4. At present, formulated dry feeds are used intensively for every species. Usually, more than half of the ingredients of the formulated feeds are composed of fish meal, especially whitefish meal. The amount of fish meal used for freshwater finfish culture was estimated to be about 70,000 t, equivalent to 420,000 t of raw fish. A certain amount of fresh and frozen trash fish is still used as food in eel culture, and the amount used in freshwater finfish culture will decrease year by year. No fish meal other than whitefish meal is used as fish feed in Japan. The whitefish meal industry suffered from

Table 4.—Type and amounts (t) of feed used for freshwater fish culture in 1977 (Anonymous 1979).

Type of feed	Rainbow trout	Ayu	Carp	Eel	Total
Fresh and frozen fish	149	30	120	6,590	6,889
Fresh silk worm pupae	0	0	13,437	2	13,439
Dry silk worm pupae	28	0	7,155	17	7,200
Combined feed	25,573	8,313	33,234	40,034	107,154
Fish meal	134	3	340	15	492
Others	475	133	2,013	788	3,409
Total	26,359	8,479	56,299	47,446	

the establishment of the U.S. 200-mi exclusive zone, and fish meal production has decreased steadily, resulting in the rise of the price of meal as well as the cost of feed formation. An example of the production cost of rainbow trout culture in 1975 is shown in Table 5 (Brown 1977). Feed cost accounted for 57% of the total; this high cost is a serious problem in finfish culture in Japan at present.

Table 5.—Production costs, selling price, and net returns for rainbow trout, Fujinomiya Trout Cooperative, Shizuoka prefecture (1975) (Brown 1977).

Item	Production costs (cents/kg)	%
Fry	14.7	12.2
Feed	69.0	57.1
Wages, including bonus	16.0	13.2
Pumping costs	9.7	8.0
Repairs and maintenance	3.0	2.5
Depreciation	2.0	1.7
Insurance and taxes	2.0	1.7
Office and transportation	2.0	1.7
Miscellaneous	2.3	1.9
Total costs	120.7	100.0
Selling price	150.0	—
Net returns	29.3	19.5

PROBLEMS OF FRESHWATER FINFISH CULTURE

Shortage of Fish Meal for Formulated Feed

As mentioned above, the farming of freshwater finfish in Japan depends largely on formulated feeds, and the feeds rely on a stable supply of fresh trash fish meal. With the increasing demand for formulated feeds as well as the serious effects of the U.S. 200-mi zone in the northern Pacific Ocean, the fish culture industry is now suffering from a shortage of whitefish meal. To cope with the shortage, brown fish meal from anchovy, mackerel, and saury has been considered as an alternative to whitefish meal and research on the availability of the meal for fish feed has begun. Oil content of these fish is very high, thus elimination of the toxicity of oxidized oil is considered essential, when large amounts of the meal are included in the feed.

On the other hand, it is necessary to intensively study the utilization of vegetable protein or single cell protein as fish feed. Amino acid supplementation is needed in order to improve protein quality. A method is proposed by the author in another paper (Arai 1981).

Pollution from Fish Culture

As mentioned above, most of the freshwater finfish culture in Japan is very intensive. With the expansion of production, pollution problems occur in rivers close to culture ponds and in lakes. In Lake Suwa and Lake Kasumigaura, cage culture of carp is claimed to be responsible for eutrophication (Suzuki 1976). In Lake Kasumigaura, the plankton blooms sometimes resulted in severe damage to cultured fish as well as to wild fish during the summer season. In those closed bodies of water, the scale of fish production must be regulated according to the water quality data.

Disease and Parasite Control

Disease and parasite control is one of the important problems for consideration in finfish culture. In intensive culture of fish, diseases cause serious damage; therefore, early diagnosis of diseases and suitable treatments are important. For bacterial diseases or parasitic diseases chemotherapy is effective. In the near future, more governmental control on the use of these chemicals, especially of antibiotics, will be initiated. An epizootic prevention system must be undertaken in fish culture.

Stable Supply of Seed, Especially in Eel Culture

Eel culture is very important, as mentioned above, but its production depends on the supply of elvers. The supply of elvers is determined by the catch of elvers under natural conditions. Before 1968, elvers were imported from Taiwan, but since that year Taiwan began its own eel culture and the industry has expanded rapidly. Now Taiwan exports annually about 20,000 t of food size eels to Japan. At present, no elvers are supplied from Taiwan. Artificial spawning of eels is carried out with silver eels. They are collected from rivers near the sea and fertilization is carried out under artificially controlled conditions. Hormone injection techniques are also used to assist the acceleration of maturation and spawning. At present, a good survival rate is reported until hatching, after which it decreases rapidly. Artificial larval production is a problem, but worth the challenge for the stable development of eel culture.

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Freshwater Development and Smoltification in Coho Salmon from the Columbia River

LEROY C. FOLMAR,[1] WALTON W. DICKHOFF,[2] WALDO S. ZAUGG,[1]
and CONRAD V. W. MAHNKEN[1]

ABSTRACT

Changes in gill Na+-K+ ATPase activities and plasma concentrations of thyroxine (T_4), triiodothyronine (T_3), Na+, K+, and C1- were monitored during the period of smoltification in 10 groups of yearling and 1 group of zero-age hatchery-reared coho slamon, *Oncorhynchus kisutch*.

During this period, dramatic increases in ATPase activity and plasma T_4 concentrations were observed in the yearling groups but not in the zero-age group. Plasma T_3 concentrations increased in some, but not all, of the groups. Plasma T_4 concentrations were significantly correlated with both gill Na+-K+ ATPase and plasma T_3 concentrations. Plasma concentrations of Na+ and C1- were found to be significantly related, but unrelated to the other measured parameters.

Serial entry experiments with the zero-age fish have suggested that developmental stage was more important than size or age in successful adaptation to seawater. In the yearling fish, there was no relationship between survival and the number of smolted fish, suggesting that smoltification and seawater adaptation are not interdependent events.

A component of the T_4 curve in freshwater fish was found to be significantly related to seawater survival. The usefulness of this comparison in predicting hatchery releases is discussed.

INTRODUCTION

Due to the declining number of natural salmon runs on the Columbia River, it has become increasingly necessary to supplement these populations with hatchery-reared fish. Releases from Columbia River hatcheries now average 110 million fish (2.5 million lb) annually (Wahle et al. 1975). The success of these supplemental releases, in terms of returns and contribution to the fishery, can vary from one hatchery location to another and at the same location from year to year. If oceanic conditions are considered to be relatively uniform, the differential return rates among hatcheries are most likely due to differences in the quality (ability of the fish to migrate successfully and to survive and grow in seawater) of the smolts produced at the hatchery. Variation in the quality of the fish is probably due to different environmental conditions at the various hatcheries or annual environmental changes at a particular hatchery. However, before we can evaluate environmental factors such as temperature, photoperiod, xenobiotic chemicals, feed, or effects of pathogenic organisms, it is essential that we have a thorough understanding of the normal physiological changes which occur during freshwater development, migration, and entry into seawater.

The purpose of this study was to establish patterns of some basic quantifiable physiological changes (i.e., gill sodium, potassium-activated adenosine triphosphatase (Na^+-K^+ ATPase) activities, plasma thyroxine (T_4), triiodothyronine (T_3), sodium (Na^+), potassium (K^+), and chloride (Cl^-) ion concentrations) which occur in coho salmon, *Oncorhynchus kisutch*, during the period of smoltification in freshwater. All of the physiological measurements accumulated during the course of this investigation were compared with the number of surviving and smolted fish through 6 mo of seawater residence to: 1) determine whether any statistically significant relationship existed and 2) if such relationships could be used as an index to predict optimal hatchery release dates. Additionally, comparative physiological profiles were established for fish on an accelerated growth regimen to enter seawater as zero-age animals and cohorts reared under normal hatchery conditions to enter seawater as yearling animals.

MATERIALS AND METHODS

The yearling coho salmon used in the first part of this study were obtained from hatcheries on tributaries to the Columbia River: Klickitat, Kalama Falls, Rocky Reach, Toutle (Washington Department of Fisheries); Big Creek, Sandy (Oregon Department of Fish and Wildlife); and Willard (U.S. Fish and Wildlife Service).

Experimental fish used to determine developmental differences between zero-age and yearling coho salmon were obtained as eggs from the Toutle Hatchery. The eggs were transported to the National Marine Fisheries Service (NMFS) Northwest and Alaska Fisheries Center (NWAFC) in Seattle, Wash., and then divided into two test groups. One group was placed on an accelerated growth regimen to enter seawater as zero-age animals, and the other group was reared under normal hatchery conditions to enter seawater as yearlings. Acceleration of growth was accomplished by raising the water temperature in 1°C/d increments, from 8° to 12°C at the swim-up stage, and then maintaining the temperature at 12°-13°C until transfer to seawater.

Samples of gill filaments and plasma were collected from random samples of fish in the freshwater raceways at the indivdual Columbia River hatcheries, every 2 wk, from February through June 1978. In the developmental study at NWAFC, random samples of gill tissue and plasma were collected biweekly from April through August 1978.

Gill filaments were analyzed for Na^+-K^+ ATPase activity by the method of Zaugg (1979). Plasma T_4 and T_3 concentrations were determined by radioimmunoassay using the methods of Dickhoff et al. (1978). Plasma ions were measured with a flame photometer

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[1] Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[2] Department of Zoology, University of Washington, Seattle, WA 98195.

(Na$^+$, K$^+$) and chloridometer (Cl$^-$). Samples for plasma ion determinations were prepared in accordance with the manufacturer's suggested methods for each instrument. Normal clinical control serum of known composition was prepared and analyzed in parallel with every 20 samples.

Data resulting from these experiments were subjected to computerized statistical analysis. The statistical methods used to calculate linear regressions, correlation coefficients, and analysis of variance (ANOVA) were those of Sokal and Rohlf (1969).

RESULTS

Although there were some variations in the magnitude and duration of the responses, Figures 1 and 2 represent typical changes in gill Na$^+$-K$^+$ ATPase activities and plasma T_4 and T_3 concentrations which were observed for each of the Columbia River test groups. Values for both gill Na$^+$-K$^+$ ATPase and plasma T_4 measurements began to increase in March, peaked in April, and returned to starting levels by the end of May.

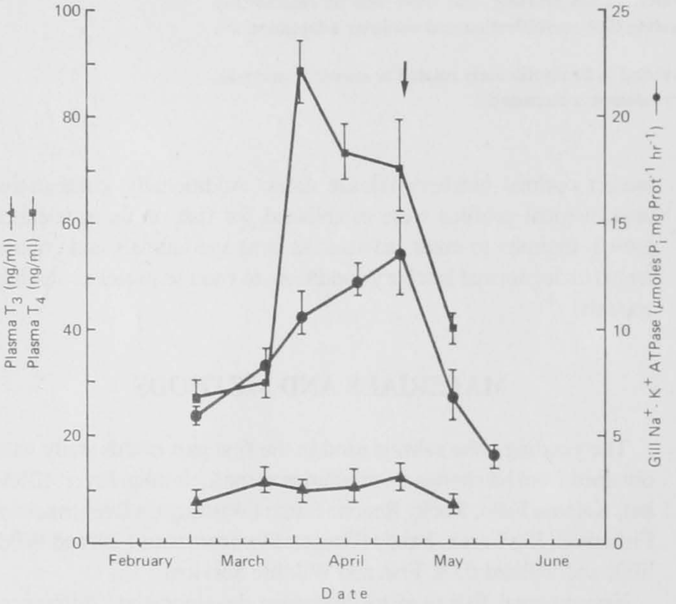

Figure 1.—Changes in gill Na$^+$ – K$^+$ ATPase specific activities and plasma T_3 and T_4 concentrations for coho salmon in freshwater reared at the Sandy Hatchery (hatchery release date shown by arrow).

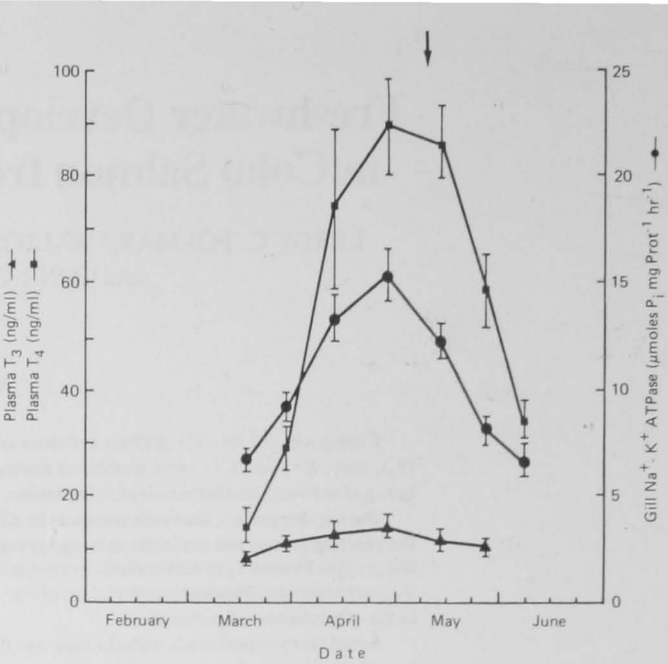

Figure 2.—Changes in gill Na$^+$ – K$^+$ ATPase specific activities and plasma T_4 and T_3 concentrations for coho salmon in freshwater reared at the Big Creek Hatchery ($N = 10$). (Hatchery release date shown by arrow.)

Typical patterns of plasma electrolyte (Na$^+$, K$^+$, Cl$^-$) fluctuations during the same period are shown in Figure 3. Sodium and chloride ions appear to be regulated by the same mechanism since their levels fluctuated together (Fig. 4, $P \leq 0.001$, $r = 0.76$, $N = 286$). However, potassium ions appeared to be independent of Na$^+$ and Cl$^-$ regulation. Although there was a slight trend for plasma Na$^+$ and Cl$^-$ to decrease with the increase in gill Na$^+$-K$^+$ ATPase activity during the same time period (Figs. 1, 2), the decrease was not significant and there was no statistical correlation between gill Na$^+$-K$^+$ ATPase activity and plasma Na$^+$ concentrations (Fig. 5, $r = 0.09$, $N = 428$).

This study was terminated on 1 November 1978. At that time, each vaccinated test group was evaluated to determine survival (Fig. 6) and the percentage of smolted animals among the survivors (Fig. 7). Smolted animals were determined by visual characteristics which included body and fin coloration as well as the presence or absence of parr marks. Survival ranged from 27% (Kalama Falls) to 80% (Sandy I), whereas the percentage of smolts ranged from 48% (Willard II) to 90% (Sandy II). The results of these final seawater evaluations were compared with the physiological measurements taken

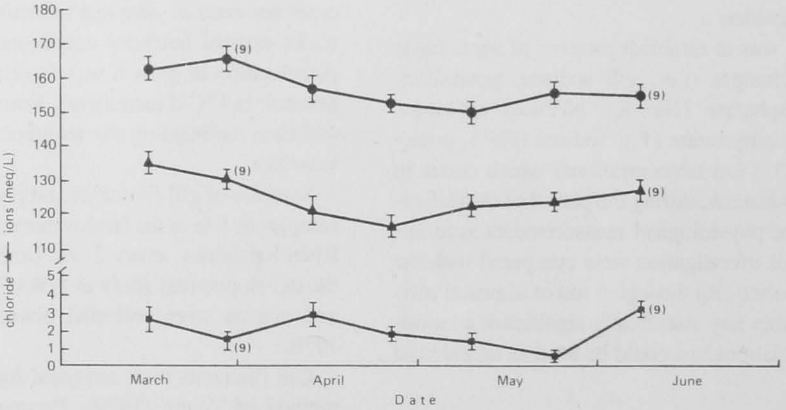

Figure 3.—Plasma electrolyte (Na$^+$, K$^+$, Cl$^-$) levels from coho salmon in freshwater at the Big Creek Hatchery. ($N = 10$ except where parenthetically noted.)

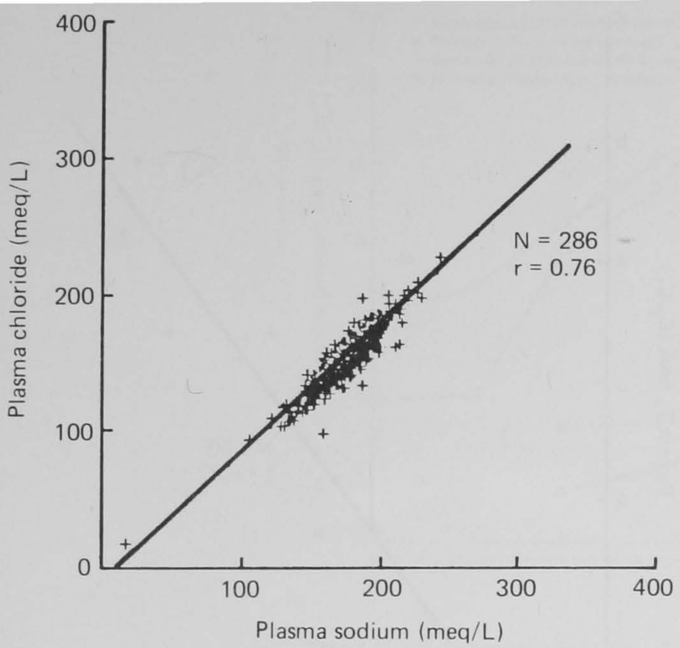

Figure 4.—A linear regression analysis of the relationship between plasma sodium and plasma chloride in seawater for all of the Columbia River stocks tested.

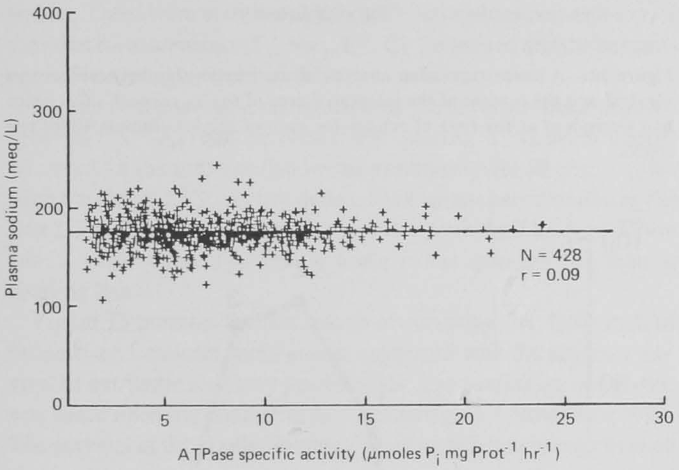

Figure 5.—A linear regression analysis of the relationship between gill Na^+-K^+ ATPase and plasma sodium concentrations in seawater for all of the Columbia River stocks tested.

during the period of freshwater residence.

While the fish were in freshwater, gill Na^+-K^+ ATPase activities and plasma T_4 concentrations appeared cyclical and related in time. To evaluate this possible interrelationship statistically and compare each of the individual curves with other events occurring in both freshwater and seawater, it was necessary to separate the measurable components in each curve (Figs. 8, 9). Figure 8 shows a hypothetical representation of plasma T_4 concentrations in the coho salmon groups in freshwater, indicating the peak height (A_1), duration of the curve (B_1), and the integrated area beneath the curve (C_1). In Figure 9, A_2 represents the proportion of the duration of the peak value at release, B_2 represents the proportion of the duration of the peak at seawater transfer, and C_2 (shaded area) represents the proportion of the area beneath the curve which had transpired at the time of release. As shown in Figure 10, there was a significant relationship ($P \leq 0.001$, $r = 0.92$, $N = 10$) between the proportion of the area of the T_4 curve which had transpired at the time of release (C_2/C_1) (Figs. 8, 9) and the percentage of the fish which survived until November in seawater (Fig. 6).

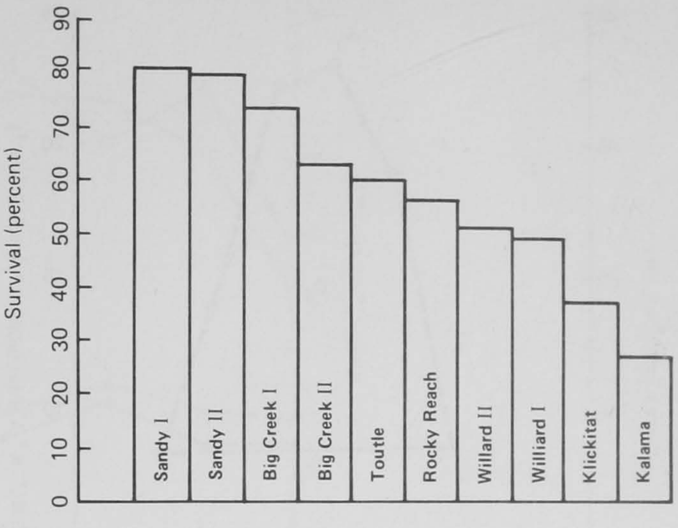

Figure 6.—Survival levels for each of the Columbia River test stocks after 6 mo in seawater.

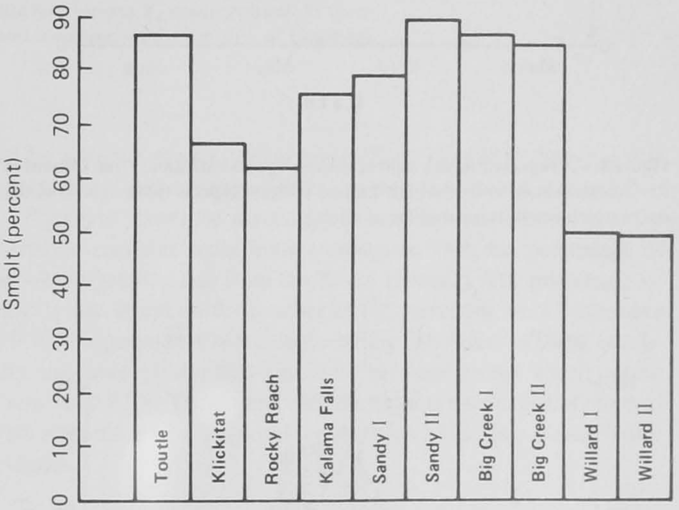

Figure 7.—Success of smoltification for each of the Columbia River test stocks after 6 mo in seawater.

The significance of this correlation has been illustrated in the scheme presented in Figure 11. The numbers 1 to 5 indicate hypothetical successive seawater entry dates along a T_4 curve. As the linear regression in Figure 10 shows, the further along the curve (i.e., points 1 through 5, Fig. 11) that the fish were transferred from the hatchery to seawater, the better was their survival. This suggests that the complete cycle of change in T_4 must occur in freshwater in order to have maximal survival. There was no relationship between the components of the T_4 curve and the number of successful smolts. The number of smolted fish was found to be statistically unrelated to the number of surviving fish. The presence of nonsmolted, but surviving fish has been previously reported for coho salmon reared in net-pen culture systems (Bern 1978; Clarke and Nagahama 1977; Folmar and Dickhoff 1981; Mahnken et al. in press). Since seawater parrs are not observed under natural conditons, this relationship may only be valid for net-pen cultured coho salmon. The gill Na^+-K^+ ATPase curve was evaluated in a similar manner; however, under our test conditions there were no significant relationships between the components of that curve with either survival or number of successful

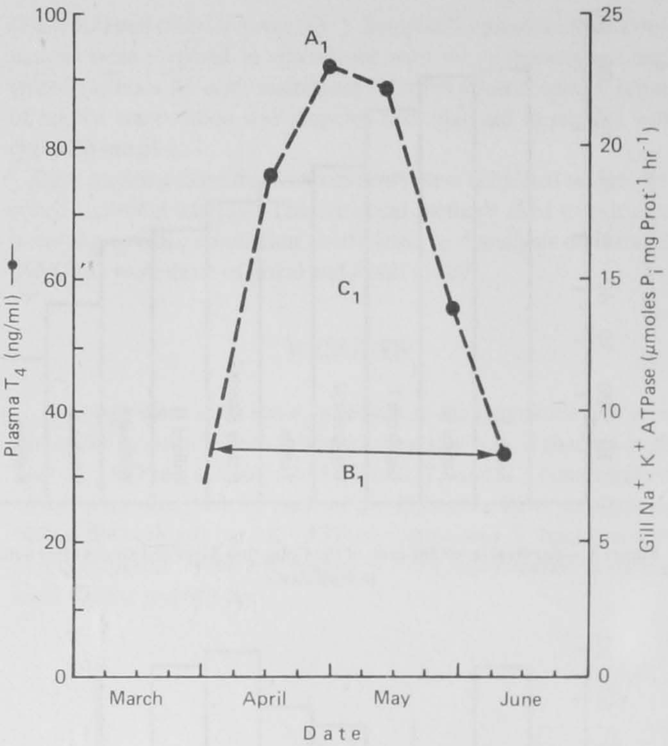

Figure 8.—A representative graph of plasma T_4 concentrations from Columbia River coho salmon in freshwater. Letters indicate aspects (parameters) of the curve which can be measured for analysis.

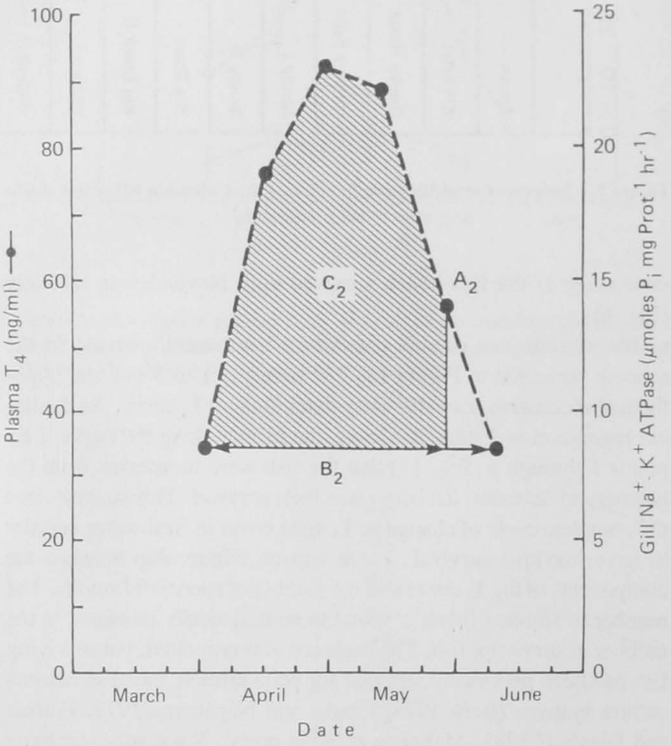

Figure 9.—A representative graph of plasma T_4 concentrations from Columbia River coho salmon in freshwater. This graph shows the effect of the hatchery release date on the measurements shown in Figure 8.

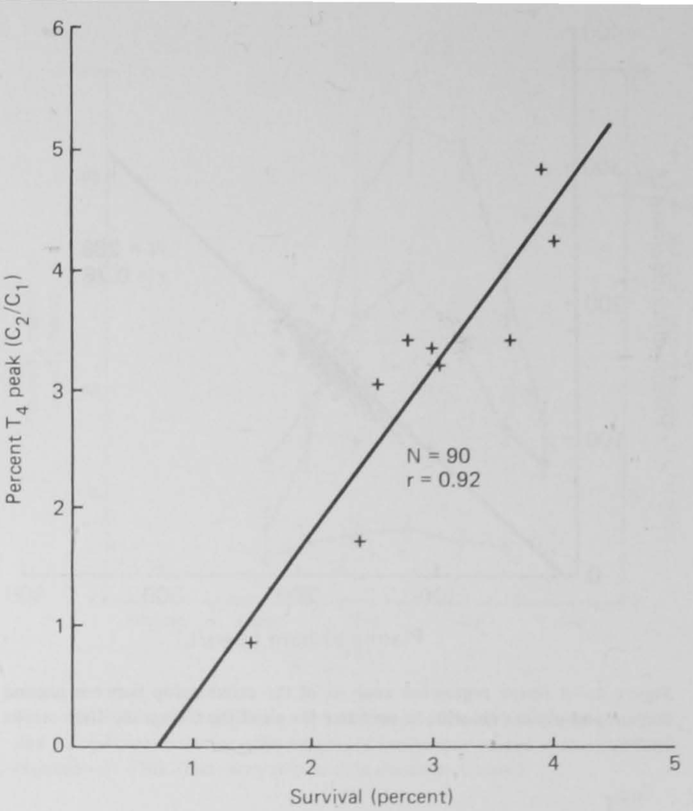

Figure 10.—A linear regression analysis of the relationship between percent survival and the percent of the integrated area of the T_4 curve (C_2/C_1) which had transpired at the time of release for each of the 9 Columbia River test stocks.

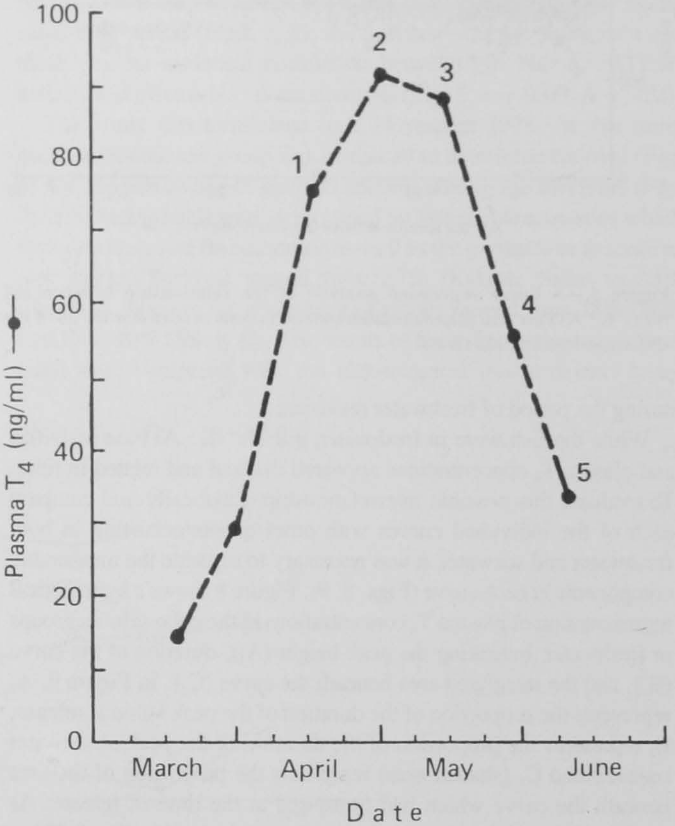

Figure 11.—A representative graph of plasma T_4 concentrations in freshwater showing hypothetical serial release dates.

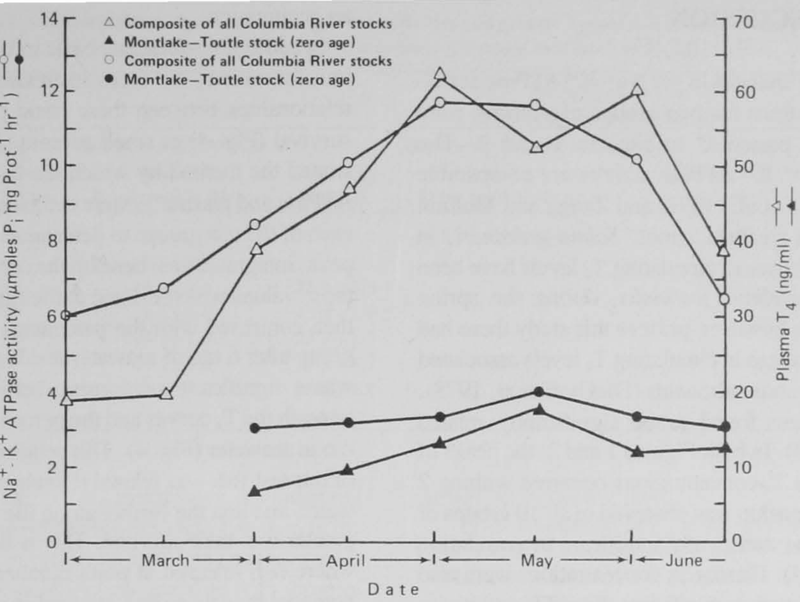

Figure 12.—A comparison of gill Na+ – K+ ATPase and plasma T_4 concentrations in three groups of coho salmon (Montlake-Toutle 0-age, and a composite of 10 groups of Columbia River yearling fish).

smolts. There were no other significant relationships between any of the other measurements (T_3, Na^+, K^+, Cl^-) obtained and the percentages of surviving or smolted fish.

Figure 12 represents a comparison of the developmental changes (gill Na^+-K^+ ATPase activities and plasma T_4 concentrations) observed for the zero-age fish versus a composite for all yearling fish from the Columbia River hatcheries. Peak values occurred during the first 2 wk of May in both groups; however, both the Na^+-K^+ ATPase and T_4 peaks were significantly lower in the zero-age fish than in yearling fish.

Figure 13 presents the percentage of surviving fish from each of the zero-age seawater serial entries compared with the seawater survival of the Toutle Hatchery yearling fish. The percentage of survival was based upon the number of fish remaining on 1 November 1978. The survival of the Toutle Hatchery yearling fish was greater than all of the zero-age groups, which ranged from 13 to 49%. Survival was greatest for those zero-age fish which entered seawater during July.

Figure 14 shows the percentage of smolted fish from each of the zero-age seawater serial entries compared with the percentage of smolts in yearling fish from the Toutle Hatchery. The percentage of smolts was based on the number of fish surviving on 1 November 1978. The percentage of smolted yearling fish from the Toutle Hatchery was much greater than any of the zero-age groups which ranged from 10 to 47%. The groups with the highest percentage of smolted fish were those which entered seawater from late June through early August.

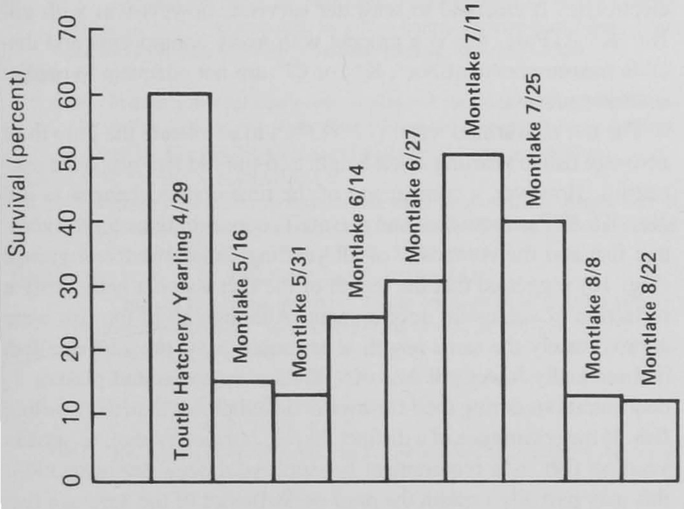

Figure 13.—A comparison of survival rates between the serial releases of Montlake-Toutle 0-age fish, and Toutle Hatchery yearling fish. (Seawater entry dates are shown within individual bars.)

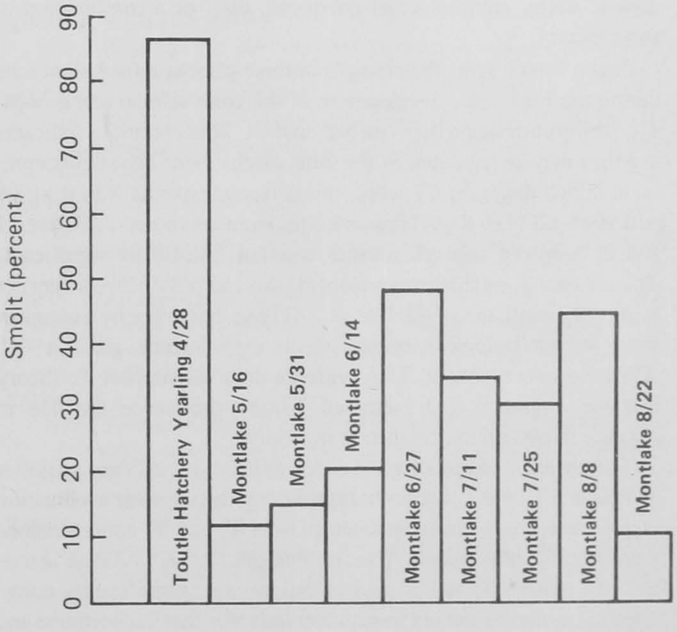

Figure 14.—A comparison of smolt success between the serial releases of Montlake-Toutle 0-age fish, and Toutle Hatchery yearling fish. (Seawater entry dates are shown within individual bars.)

DISCUSSION

Representative time course changes in gill Na^+-K^+ ATPase activities and plasma T_4 concentrations for two groups of yearling coho salmon in freshwater were presented in Figures 1 and 2. The observed increases in gill Na^+-K^+ ATPase activity are comparable with those reported by Adams et al. (1973) and Zaugg and McLain (1972) for coho salmon and steelhead trout, *Salmo gairdneri*, in freshwater. Also, gradual increases in circulating T_4 levels have been reported in brook trout, *Salvelinus fontinalis*, during the spring (White and Henderson 1977); however, prior to this study there had been no previous reports of a surge in circulating T_4 levels associated with smoltification in anadromous salmonids (Dickhoff et al. 1978). Both plasma T_4 and T_3 were found to be significantly related ($P<0.01$, $r = 0.12$, $N = 483$). In both Figures 1 and 2, the peaks of enzyme activities and plasma T_4 concentrations occurred withing 2 wk of one another. This relationship was observed in all 10 groups of fish tested and was found to be statistically significant by correlation ($P<0.01$, $r = 0.17$, $N = 534$). Plasma T_3 concentrations were also found to be statistically correlated with gill Na^+-K^+ ATPase activity ($P<0.01$, $r=0.29$, $N=523$). There are several possible explanations for this relationship. Thyroid hormone has been reported to regulate Na^+-K^+ ATPase activity in a number of mammalian tissues (Ismail-Beigi and Edelman 1970, 1971, 1974; Valcana and Timiras 1969), amphibian epidermis (Kawada et al. 1969), and in nurse shark gill and kidney tissue (Honn and Chavin 1977). Also, there may be involvment of other hormones acting synergistically with thyroid hormone. Production of prolactin and cortisol is regulated by environmental salinity, and both have been demonstrated to affect kidney Na^+-K^+ ATPase. Prolactin stimulates kidney Na^+-K^+ ATPase in freshwater, while cortisol stimulates gill Na^+-K^+ ATPase activity in seawater (Epstein et al. 1971; Pickford et al. 1970). It is also possible that the simultaneous increase in gill Na^+-K^+ ATPase activities and plasma T_4 concentrations are independent but responding to the same stimulus, or that they are not causally related. The observed changes in gill Na^+-K^+ ATPase activities and plasma T_4 concentrations at different hatchery locations appeared unique in both timing and pattern for all the groups tested. This uniqueness may be attributable to the genetic strain, environmental conditons, diet, or a combination of these factors.

Figure 3 represents the changes in three plasma monovalent ions during the freshwater development of the coho salmon test groups. The strong correlation between Na^+ and Cl^- concentrations indicates that they may be regulated by the same mechanism. The slight depression in both Na^+ and Cl^- concentrations corresponds with the time period of gill Na^+-K^+ ATPase activity increase shown in Figures 1 and 2; however, this relationship was not statistically significant. These data suggest that monovalent plasma electrolyte levels may not be directly regulated by gill Na^+-K^+ ATPase, but rather by a complex series of physiological events which may include gill Na^+-K^+ ATPase as a component. This evidence does not support the theory that the migration and increased salinity preference are due to changes in plasma ion balance in freshwater.

There were no correlations between gill Na^+-K^+ ATPase activities and plasma T_4 and T_3 concentrations during the seawater acclimation phase, however, as in freshwater, plasma T_4 and T_3 concentrations were significantly related. The fact that gill Na^+-K^+ ATPase activities and plasma T_4 and T_3 concentrations were significantly correlated in freshwater but not in seawater indicates that the hormone and enzyme relationship may be a freshwater developmental phenomenon which serves to prepare the fish for seawater entry rather than T_4 acting as a regulatory mechanism of Na^+-K^+ ATPase during seawater acclimation.

In addition to obtaining basic information relative to the parr-smolt transformation, we were interested in any statistically significant relationships between these basic physiological measurements and survival (Fig. 4) or smolt success (Fig. 5). Figures 6 and 7 demonstrated the method by which the freshwater curves for gill Na^+-K^+ ATPase and plasma T_4 were evaluated. The curves were analyzed for each of the test groups to determine maximum value, duration of the peak, integrated area beneath the curve, and the proportion of each of those values which existed at the time of release. These values were then compared with the percentage of survival and smolts of each group after 6 mo of seawater residence. As shown in Figure 8, there was a significant relationship between the proportion of the area beneath the T_4 curves and the percentage of the fish which survived 6 mo in seawater (Fig. 4). This relationship suggested that the survival of our test fish was related to their respective date of transfer to seawater, and that the further along the curve they were transferred, the greater was their survival. This is depicted graphically in Figure 9, where fish released at point number 5 should have greater survival potential than those fish released at points 1 through 4. There was no relationship between the T_4 peaks in freshwater fish and the percentage of smolts in the population. There were no relationships between any of the T_4 measurements taken in seawater and survival or smolt success. There was no relationship between the T_4 peaks in freshwater fish and the percentage of smolts in the population. There were no relationships between any of the T_4 measurements taken in seawater and survival or smolt success. Plasma levels of T_4 and T_3 were significantly related in both freshwater and seawater. At the present time, we cannot report whether this relationship is due to simultaneous hormone synthesis and release, or a uniform conversion rate of T_4 to T_3 in peripheral tissue.

Treatment of the gill Na^+-K^+ ATPase data in a similar manner showed no statistical relationship with either survival or smolt success after 6 mo of seawater residence. Survival and smolt success were also unrelated to any gill Na^+-K^+ ATPase measurements taken in seawater. Our results suggested that gill Na^+-K^+ ATPase is important as an integrated component of smoltification, but as a single discrete measurement did not predict the potential success of seawater acclimation in net-pen culture of coho salmon.

There were no statistically significant relationships between any of the plasma electrolyte measurements and 6-mo seawater survival or smolt success. The maintenance of a proper balance of body fluid electrolytes is essential to seawater survival; however, as with gill Na^+-K^+ ATPase, this is a process with many components and discrete measurements of Na^+, K^+, or Cl^- are not adequate to predict seawater success.

The use of warmed water (12°-13°C) to accelerate the growth of zero-age fish to yearling smolt length as 6-mo-old fish was quite successful. However, a comparison of the time course changes in gill Na^+-K^+ ATPase activities and plasma T_4 concentrations for the zero-age fish and the composite of all yearling Columbia River groups (Fig. 10) suggested that the length of the fish was not necessarily a reflection of successful development. Although all of the fish were approximately the same length at seawater entry, the zero-age fish had markedly lower gill Na^+-K^+ ATPase activities and plasma T_4 concentrations during their freshwater development than did yearling fish. If the occurrence of a distinct thyroid hormone surge, as seen in yearling fish, is a requirement for successful seawater adaptation, this may partially explain the poor performance of the zero-age fish in terms of survival (Fig. 11) and smolt success (Fig. 12).

The relationship between gill Na^+-K^+ ATPase and plasma T_4 in the zero-age fish was similar to the yearling fish in that there was a

Table 1.—A comparison of gill $Na^+ - K^+$ ATPase activities and plasma T_4 concentrations in 0-age and yearling coho salmon after 8 d in seawater. All values expressed as $\bar{X} \pm SE$.

	0-age		Yearling (ranges for 10 Columbia River stocks)	
Seawater entry date (1978)	Gill $Na^+ - K^+$ ATPase (μmoles P_i/mg protein per h)	Plasma T_4 (ng/ml)	Gill $Na^+ - K^+$ ATPase (μmoles P_i/mg protein per h)	Plasma T_4 (ng/ml)
5/16	8.9 ± 2.3	4.1 ± 0.2	14.6 ± 1.7-27.2 ± 5.4	12.5 ± 2.2-38.2 ± 2.7
5/31	14.0 ± 2.2	13.5 ± 1.1		
6/14	14.3 ± 1.1	23.0 ± 2.5		
6/27	9.1 ± 0.9	15.2 ± 1.9		
7/11	14.1 ± 1.6	23.9 ± 1.7		
7/25	20.1 ± 3.8	19.9 ± 1.7		
8/08	13.8 ± 2.5	6.6 ± 1.0		
8/22	no data	no data		

significant correlation in freshwater but not in seawater. Although gill Na^+-K^+ ATPase activities were lower in the zero-age fish than in the yearling fish in freshwater, five of the seven zero-age serial seawater entries had gill Na^+-K^+ ATPase activities comparable with those of yearling fish after the period of seawater acclimation (Table 1). Likewise, five of the zero-age serial seawater entries had plasma T_4 concentrations comparable with those of the yearling fish after seawater acclimation. These results suggest that there are qualitative differences between the increases in gill Na^+-K^+ ATPase activities and plasma T_4 concentrations of fish in freshwater and those observed in seawater. The increased enzyme activities and hormonal concentrations in seawater adapted fish appear to be a reflection of the marine environment, and it is possible to induce these changes in fish prematurely transferred to seawater. Our measurements in seawater acclimated fish indicated that the zero-age fish were as well developed as normal yearling fish; however, our measurements in freshwater acclimated fish clearly indicated that the zero-age fish were not as well developed as the yearling fish. Although we cannot make a valid comparison without the data from the yearling cohorts of the zero-age fish, we have tentatively concluded that the poor seawater survival and the high incidence of seawater parr in the zero-age group were related to incomplete development in freshwater, rather than the inability of the fish to adapt to seawater.

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The Use of Soybean Meal in Trout and Salmon Diets[1]

RONALD W. HARDY[2]

Worldwide demand for protein supplements used in animal feeds is increasing and, as a result, the prices of these ingredients are rising. Fish meal, either herring or anchovy meal, has traditionally been the major protein supplement in trout and salmon diets. There has been a slight decrease in the worldwide production of fish meal during the last few years. The production of high quality herring meal needed for some salmon diets has decreased markedly as herring meal has shifted from a primary product to a by-product of the herring roe fishery.

There are some protein supplements that appear to be promising candidates to replace part or all of the fish meal portion of trout and salmon diets. From the perspective of worldwide supply, soybean meal is the principal alternative. In recent years, its production has increased approximately 9%, with continued expansion of production predicted. Soybean meal is less expensive than fish meal and, except for methionine and lysine, contains a higher level of all essential amino acids (on a percent of protein basis) than does herring meal.

It has been known for over 50 yr that soybeans contain undersirable compounds. When young rats or chickens are fed diets containing raw soybeans, the following effects have been noted: decreased growth, decreased absorption of fat, decreased metabolizable energy value of the nonfat portion of the diet, increased pancreatic size, increased gallbladder contraction, increased excretion of bile salts, lowered intestinal proteolytic activity, and altered methionine oxidation (Scott el al. 1969) (Appendix 1). Fortunately, these problems can be corrected for most animals by proper heat treatment and supplementation of soybean meal, but trout and salmon may be more sensitive to the antinutritional effects of soybean meal.

The use of soybean meal as a feed ingredient for trout and salmon presents problems that reduce its value. These problems include deficiencies of amino acids, unavailability of phosphorous, presence of antinutritional factors, alteration of trace mineral availability, and possible palatability complications (Appendix 2). These problems have been researched by investigators throughout the world. However, the researchers have not reached unanimous agreement on the effects of supplementation or processing on the nutritional value of soybean meal. Part of this may be due to differences in the sources of soybean meal, a variable commodity. Part is due to differences in experimental design, in size and species of fish used, and in other experimental conditions. In other animals, the effects of antinutritional factors and deficiencies are greatest in the very young. Soybean meal diets that would be toxic to the young, however, can be tolerated by older animals. There is no research to suggest that age affects the nutritional value of de-fatted soybean meal in rainbow trout or salmon.

Using a diet containing 80% commercial de-fatted soybean meal (Table 1), Rumsey and Ketola (1975) investigated the effects of amino acid supplementation on the growth of rainbow trout. The experimental diets were supplemented with crystalline amino acids to meet the reported requirement of chinook salmon for methionine and cysteine. There was no growth improvement over the unsupplemented control diet (Table 2). Other degrees of supplementation to duplicate the amino acid levels in trout carcasses did not improve growth. When combinations of amino acids were added that raised the dietary levels to those found in trout egg protein or in isolated fish protein, a growth response was seen. The fish were 9 g at the start of the experiment and gained about 50-70% of their starting weight after 6 wk of feeding. Two problems with this work were the lack of a standard diet to compare fish growth during the experiment, and the lack of a supplemented control, whereby a nonessential crystalline amino acid was added or removed to maintain constant protein and crystalline amino acid levels in the diets.

Table 1.—Percent composition of the experimental diet (from Rumsey and Ketola 1975).

Ingredient	Percent
Soybean meal (49% protein)	80.0
Dextrin, tapioca	6.5
Herring oil	10.0
Carboxymethyl cellulose Vitamin premix Mineral premix	1.0
NaCl	0.5
Amino acid supplement	0.3–3.8

Table 2.—Weight gain of rainbow trout fed the experimental diets for 6 wk (from Rumsey and Ketola 1975).

Dietary supplement	Percent added to diet	Weight gain (g)[1]
None	0	4.2 a
LYS	0.7	3.4 a
HIS	0.3	4.2 a
MET	0.3	4.6 a b
HIS+LYS	1.0	4.5 a b
HIS+LYS+MET	1.3	4.4 a b
LEU	0.7	4.4 a b
MET+LEU	1.0	4.8 a b
MET+LEU+LYS+VAL+THR	2.0	6.0 b c
MET+LEU+LYS+VAL+THR +HIS+TRP+TUR	3.8	6.4 c

[1]Values not followed by the same letter are significantly different at the 5% level.

Nearly the same experimental diet was used by Ketola (1975a) to study the effects of supplemental dicalcium phosphorus and ash on fish growth. The ash supplement was prepared by burning fish meal in a muffle furnace. The level of mineral supplement was adjusted to equal the level of mineral supplied by an appropriate dietary level of herring meal. Soybean meal contains about one-third as much phosphorus as does herring meal, but much of that may be bound as phytate-phosphorus and thus may be biologically unavailable. Supplementation of the basal diet with either 6% ash or dicalcium phosphate resulted in a statistically significant ($P<0.01$) growth response in the 5-wk feeding trial (Table 3). None of the fish grew

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[1]Contribution No. 589, School of Fisheries, University of Washington, Seattle.

[2]School of Fisheries, University of Washington, Seattle, WA 98195.

Table 3.—Growth and food conversion of rainbow trout fed a soybean meal-based diet supplemented with dicalcium phosphate and ash (from Ketola 1975a).

Dietary supplement	Final weight (g)[1]	Food conversion[1]
None	3.50 a	3.33 a
Ash	3.87 b	2.63 b
Dicalcium phosphate	3.85 b	2.61 b

[1] Values followed by different letters are significantly different at the 1% level.

very well on any of the diets, however. Though the diets were supplemented with trace minerals, lysine, and methionine, the fish gained only 30% of their starting weight on the basal diet and 43% on the supplemental diets.

In a similar study conducted with Atlantic salmon, Ketola (1975b) found that supplementation of a 70% soybean meal diet with graded levels of inorganic phosphorus resulted in a stepwise increase in weight gain and a similar decrease in food conversion (Table 4). Fish were again fed for 5 wk. The basal diet contained 0.7% phosphorus, all of plant origin. About one-third of the phosphorus in plants is generally considered to be available to young chickens. If trout can absorb about the same amount of plant phosphorus as poultry, the dietary phosphorus requirement of 6.5 g Atlantic salmon would be about 0.8%. However, growth of fish on a commercial diet was significantly higher after 5 wk of feeding, indicating that the experimental diet, supplemented with trace minerals, calcium, salt, and methionine, was not nutritionally competitive with a commercial nonsoybean-based diet, even when phosphorus was added.

Table 4.—Weight gain and food conversion of Atlantic salmon fed a soybean meal diet supplemented with inorganic phosphorus (from Ketola 1975b).

Dietary supplement	Weight gain (g)[1]	Food conversion[1]
None	2.0 a	2.75 a
.15% P	2.6 b	2.49 a
.30% P	2.7 b c	2.06 b
.45% P	2.9 c	2.04 b
.60% P	3.2 d	1.84 b
.75% P	3.3 d	1.69 b
.90% P	3.2 d	1.80 b
Commercial diet	4.5 e	1.24 c

[1] Values not followed by the same letter are significantly different at the 5% level.

Identification of the nutritional deficiencies of soybean meal and diet supplementation to correct these deficiencies improved the growth of young rainbow trout and Atlantic salmon but did not bring growth up to the levels obtained with practical fish meal-based diets. Obviously, there were other factors at work lowering the nutritional value of soybean meal below its expected value. Researchers turned to modified methods of processing in an attempt to make the soybean meal more biologically valuable. They tried to destroy antinutritional factors or break disulfide linkages, thus improving digestibility.

Smith (1977) reported that, for rainbow trout, heating full-fat soybeans greatly improved their nutritional value over commercial dehulled, de-fatted soybean meal (Table 5). Steam-cooking was superior to dry roasting, and reconstituting commercial meal with soy oil did not improve growth. Smith heated raw soybeans for various lengths of time and at various temperatures using dry heat or steam, and he measured the digestibility coefficient of the crude protein fraction and the metabolizable evergy level for rainbow trout. He found that relatively high roasting temperatures were needed to increase digestibility and metabolizable energy (Table 6) and that some combinations of heating time and temperature resulted in promising values when the soybean meal was force-fed to trout held in metabolizable energy chambers. When diets containing 80% full-fat soybean meal were fed to small rainbow trout for 20 wk, excellent growth was reported (Table 7). Methionine and cystine supplementation improved weight gain over an aspartic acid-supplemented control. Heat treatment of the meal at 232°C improved weight gain over heat treatment at 204°C. Smith (1977) speculated that the improved growth was due to the destruction at higher temperatures of trypsin inhibitors which interfere with protein digestion.

Table 5.—Percent weight gain of rainbow trout fed diets containing 80% soybeans for 8 wk (from Smith 1977).

Processing	Percent gain
Full-fat dry roasted	86
Full-fat steam cooked	101
Extracted and reconstituted with soy oil (steam cooked)	93
Commercial meal, dehulled, solvent extracted, reconstituted with soy oil, no additional heating	50

Table 6.—The effect of heat treatment of soybeans on the digestibility and metabolized energy (ME) for rainbow trout (from Smith 1977).

Heat treatment			Digestion coefficient	
° C or pressure (lb)	Time (min)	Steam (S) or dry (D)	crude protein (%)	ME (Kcal/g)
232	5	D	75.2	4.25
[1]232/200	8	D	71.8	3.96
205	10	D	78.2	4.21
[1]204/190	12	D	73.0	3.93
[1]204/190	12	D	75.5	4.22
[1]204/176	8	D	71.8	3.96
127	10	D	45.4	3.08
15 lb	10	S	61.6	3.22
10 lb	10	S	80.1	4.16
5 lb	15	S	71.1	3.55
5 lb	5	S	39.2	2.28

[1] Second figure is approximate temperature of beans when removed from oven.

Table 7.—Final 20-wk weights of rainbow trout fed diets containing 80% full-fat soybean meal given three different heat treatments and four amino acid supplements. Starting weight 0.64 g (from Smith 1977).

Heat treatment					
Temp.	Time	Met+Cys	Met	Cys	Asp
232° C	8 min	29.49	18.75	14.55	12.64
204° C	12 min	15.97	16.40	13.13	12.38
204° C	8 min	11.30	10.18	7.56	1.50

PR-8 control (practical diet) 15.66g (20-wk weight).
H 440 control (purified diet) 20.58g (20-wk weight).

Poston et al. (1978) autoclaved isolated soy protein at different pressures and fed diets containing this material to rainbow trout. A growth response was observed as autoclaving pressure of the isolated soy protein increased (Table 8). Methionine supplementation greatly improved growth at all levels of heat treatment.

Table 8.—Effect of autoclaving and methionine supplementation of isolated soy protein on percent gain of rainbow trout (from Poston et al. 1978).

Autoclave pressure	Methionine supplementation	
(lbs)	None	0.9%
0	39	540
8	117	620
16	190	680

A long-term diet study using full-fat soybean meal as the major protein source (Table 9) was conducted by Reinitz et al. (1978), who fed these diets to rainbow trout for 35 wk. During that time, the fish grew from 26 g to about 175 g (Table 10). Compared with fish fed a practical control diet, these fish gained more weight, had a lower food conversion, and had similar cumulative mortality (5%). Additional supplementation of the test diets with dicalcium phosphorus, lysine, or trace minerals did not improve weight gain.

Table 9.—Percent composition of experimental soybean diets (from Reinitz et al. 1978).

Ingredient	Percent
Full-fat soybean meal	72.7
Anchovy meal	4.9
Blood flour	4.9
Brewer's yeast	4.9
Dried whey (delactosed)	4.4
Vitamin concentrate	0.2
Durabond	2.0
Other variables	7.0-8.0

Table 10.—Weight gain and food conversion of rainbow trout fed soybean diets for 35 wk (from Reinitz et al. 1978).

Dietary supplement	Weight gain (g)[1]	Food conversion[1]
1. MET (1%) NaCl (1%) Trace minerals (1%) Dicalcium phosphorus (1%)	149.7 a	1.58 a b
2. MET (1%) NaCl (1%) Trace minerals (1%) Dicalcium phosphorus (2%)	147.0 a	1.57 a
3. MET (1%) NaCl (1%) Trace minerals (1%) Dicalcium phosphorus (1%) Lysine (1%)	148.7 a	1.60 a b
4. MET (1%) NaCl (1%) Trace minerals (2%) Dicalcium phosphorus (1%)	146.8 a	1.61 b
5. Practical diet (control)	129.5 b	1.71 c

[1] Values not followed by the same letter are significantly different at the 5% level.

Spinelli et al. (1979) replaced 50 or 100% of the fish meal in a moist diet with commercial soybean meal and fed these diets to rainbow trout for 210 d. After 90 d, 50% of the fish receiving 100% soybean meal had died, and this treatment was discontinued. Those fish receiving diets in which 50% of the fish meal was replaced with soybean meal exhibited about 80% of the growth observed with no soybean meal in the diet (Table 11). When the phytin was enzymatically removed from the soybean meal, a slight growth response was noted. Blood samples of trout fed the 100% soybean meal diet were analyzed for calcium, copper, iron, and zinc. A significant reduction in serum zinc and iron levels was seen (Table 12) and an elevation of serum copper was observed. Removal of the phytin in soybean meal partially restored the mineral levels in the blood to control levels. The authors suggested that materials other than phytin that interfere with mineral metabolism might be present in soybean meal.

Table 11.—Relative growth and relative feed conversion of rainbow trout fed moist diets containing soybean meal substituted for 50% of the fish meal (from Spinelli et al. 1979).

Diet	Relative growth (%)	Relative food conversion (%)
Control	100	100
Commercial soybean meal (no treatment)	80	77
Steam heated	82	77
Steam heated and dephytinized	87	84

Table 12.—Calcium, copper, iron, and zinc content (ppm) in the blood of rainbow trout fed diets in which 100% of the fish meal was substituted with soybean meal and dephytinized soybean meal (from Spinelli et al. 1979).

Diet	Calcium	Copper	Iron	Zinc
Control	71	1.5	213	14.8
100% soybean meal	73	2.2	141	9.1
100% dephytinized soybean meal	66	1.7	190	10.1

Results of research on the use of soybean meal in salmon diets have been less promising than those with trout (Table 13). As soybean meal levels increased in the diet, weight gain decreased (Fowler and Banks 1976). Supplementation with DL-methionine, phosphorus, and trace minerals did not improve growth at the tested levels (Table 14) for chinook salmon, but it seemed to improve weight gain at the lowest level of replacement. Full-fat soybean meal diets were not accepted by chinook salmon and failed to support adequate growth in coho salmon.

Table 13.—Final weight of chinook salmon fed varying levels of soybean meal for 20 wk (from Fowler and Banks 1976).

Percent soybean meal in diet	Final weight (g)[1]
0	25.0 a
9.5	22.6 b
14.3	21.2 c
19.1	20.5 c
23.8	21.0 c

[1] Values not followed by the same letter are significantly different at the 5% level.

Table 14.—Growth of chinook and coho salmon fed diets with different levels of soybean meal (48.5% protein) (from Fowler 1980).

Diet	Chinook final weight (g)	Coho final weight (g)
Control	39.9	32.3
Control + DL MET + trace minerals + sodium phosphate	36.5	32.3
12.7% soybean meal	32.2	31.0
25.8% soybean meal	23.8	29.5
32.3% soybean meal	18.4	24.7
80% full-fat soybean meal	discontinued	

Fowler (1980) attempted to duplicate the work of Smith (1977) using different roasting temperatures for full-fat soybeans and feeding different levels of meal in the diet (Fig. 1). Final weight of chinook salmon decreased as the soybean meal level of the diet increased. Higher heating temperatures did not improve the nutritional value of the meals. Although all diets were supplemented with dicalcium phosphorus, DL-methionine, and trace minerals, no group of chinook salmon receiving a diet containing any amount of soybean meal weighed as much as the control group. Cumulative mortality increased as the percent of full-fat soybean meal in the diet increased (Fig. 2).

Our understanding of the factors that affect the nutritional value of soybean meal for fish is clearly inadequate. Although the nutritional deficiencies of soybean meal for poultry and rats have been elucidated, research with trout has indicated that more severe problems exist that those which can be calculated from feed composition tables. The antinutritional factors that have been identified may interfere with nutrient utilization in fish at a much lower dietary level than occurs in birds and mammals. It is likely that the growth benefits observed by Smith (1977) and Poston et al. (1978) which resulted from heat treatment of soybean meal were due to inactivation of antinutritional factors present in soybeans rather than changes in protein structure which resulted in increased accessibility to proteolytic digestive enzymes and increased nutritional availability. Poston et al. (1978) observed that trout fed autoclaved, isolated soy protein had greater trypsin activity within the pyloric caeca than trout fed untreated soy protein.

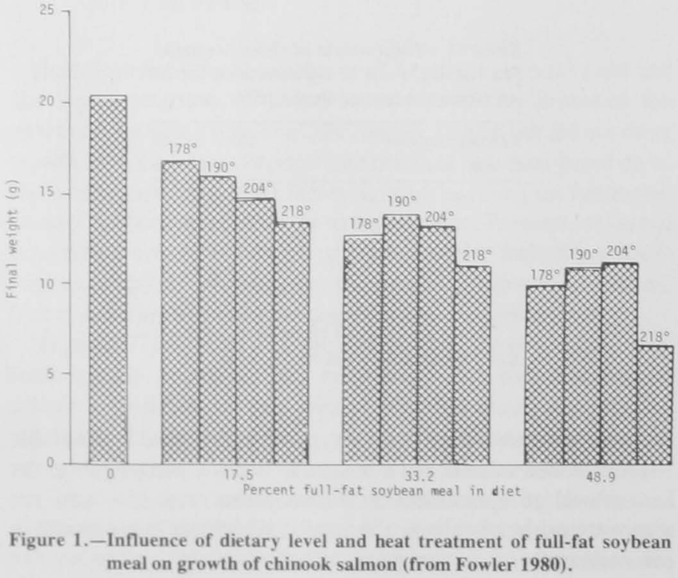

Figure 1.—Influence of dietary level and heat treatment of full-fat soybean meal on growth of chinook salmon (from Fowler 1980).

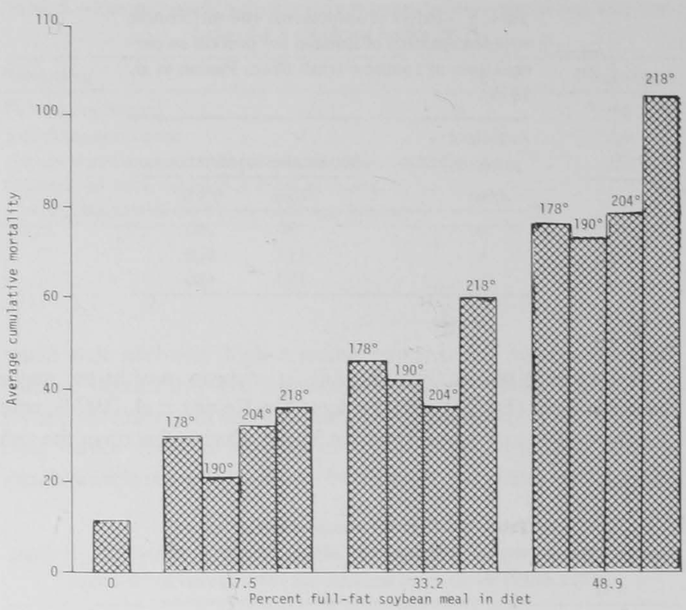

Figure 2.—Cumulative mortality of chinook salmon fed full-fat soybean meal (from Fowler 1980).

Currently under investigation is the alteration of the bioavailability of trace minerals to rainbow trout when they are fed soybean meal as a dietary ingredient. An understanding of the causes of this phenomenon is necessary before a sensible solution to the problem can be found.

Salmon and trout have different life histories and are physiologically different in some ways. Although they share a common freshwater existence during early life, it does not necessarily follow that diets which are successful for trout will be suitable for salmon. Chinook salmon must migrate to the ocean within 3-4 mo after they begin to feed. Size at hatchery release affects survival, to some extent, so diets must be used which allow maximum growth to occur. Dietary ingredients like soybean meal, which lower the growth rate and alter the physiological state of salmon, cannot be used in practical diets until the underlying nutritional problems are identified and solved. These problems seem to be more severe for chinook salmon than for coho salmon. Fish culturists have more flexibility with coho salmon as far as growth in hatcheries is concerned since coho spend 1½ yr in freshwater before migrating to the ocean. Usually it is not necessary to obtain maximum growth from coho during their freshwater residence in order to have large smolts at hatchery release. Nevertheless, until the extent and effect of physiological alterations of salmon fed diets containing soybean meal are known, it is unwise to use soybean meal in practical salmon diets. When these problems are resolved, soybean meal will be a valuable feed ingredient for salmon diets and a practical alternative to fish meal.

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APPENDIX 1.—EFFECTS OF FEEDING RAW SOYBEANS TO YOUNG CHICKENS OR RATS

1. Decreased growth.
2. Increased pancreatic size.
3. Decreased absorption of fat.
4. Decreased metabolizable energy of nonfat portion of diet.
5. Gallbladder contraction.
6. Increased excretion of bile salts.
7. Lowered intestinal proteolytic activity.
8. Altered methionine oxidation.
9. Cataracts (trout fed untreated isolated soy protein).

APPENDIX 2.—NUTRITIONAL PROBLEMS WITH SOYBEAN MEAL

Problems	Solutions
A. Deficiencies	
1. Methionine and cystine	1. Supplement with MET and CYS or blend with other feedstuffs
2. Unavailable phosphorus (bound with phytin)	2. Supplement with phosphorus
B. Antinutritional factors	
1. Trypsin inhibitors	1. Heat treatment
2. Chymotrypsin inhibitors	2. Heat treatment
3. Hemagglutinin	3. Inactivated by acid in stomach
4. Other unidentified factors causing decreased protein or fat digestibility	4. Unknown
C. Trace mineral availability alteration	Supplement with chelated trace minerals or dephytinize
D. Palatablity	Mask with olfactants or other feeds

Freshwater Aspects of Anadromous Salmonid Enhancement

ROWAN W. GOULD[1]

ABSTRACT

Freshwater enhancement of anadromous salmonid populations has been practiced in the United States and Canada since the late 1800's. Reduction of natural spawning habitat and increasing fishing pressure make artificial enhancement a possible alternative to declining populations.

Enhancement of anadromous salmonids involves improvement of the natural environment and reducing natural mortality. Methods of enhancement include fishways, spawning and rearing channels, stream rehabilitation, lake fertilization, environmental management, and artificial propagation techniques.

Five Pacific salmon species and steelhead trout are commonly enhanced, primarily in watersheds entering the Pacific Ocean and Great Lakes. Enhancement efforts contribute heavily to a commerical and sport industry realizing over $1.5 billion.

Artificial propagation of anadromous salmonids has been practiced n the United States and Canada since the late 1800's. Newly formed state and federal fish commissions believed that artificial propagation would eliminate declines caused by industrial development. The first anadromous fish hatchery was built in New Castle, Canada, in 1866 and was designed to take Atlantic salmon, *Salmo salar*, eggs for ntroduction into local streams (Wahle and Smith 1979). Most early Pacific salmon hatcheries were constructed to provide eyed eggs for ntroduction into east coast waters. These programs proved unsuccessful because east coast streams were generally too turbid or warm for good Pacific salmon reproduction. Eventually, west coast facilities turned to enhancement of runs on the Pacific coast.

Six species of anadromous salmonids are extensively enhanced: chinook salmon, *Onchorhynchus tshawytscha*; coho salmon, *O. kisutch*; sockeye salmon, *O. nerka*; chum salmon, *O. keta*; pink salmon, *O. gorbuscha*; and steelhead trout, *Salmo gairdneri*. All range naturally from Alaska southward to Oregon. Chinook, coho, chum, and steelhead extend further south into California. Over 3,000 streams support salmonid runs along the Pacific coast. Enhancement efforts occur predominantly in these streams with some chinook, coho, and steelhead enhancement along the Great Lakes, as a result of artificial transplants in 1964. Presently, there are in excess of 200 fish hatcheries, including newly developing private hatcheries, engaged in artificial rearing of anadromous salmonids. These facilities directly affect an extremely important commercial and recreational fishery valued in excess of $1.5 billion (E. Salo[2]). From 1960 to 1976, a total of 2.4 billion chinook, 723 million coho, 177 million steelhead, 111 million chum, 18 million sockeye, and 11 million pink salmon have been released from Pacific coast hatcheries (Wahle and Smith 1979). To date, in the case of coho salmon, these releases have resulted in juvenile to adult returns (commercial/sport catch plus escapement) of 5 to 20%, depending on the location.

Freshwater culture of anadromous salmonids is made possible by homing instincts which cause adults to reproduce in freshwater streams of their origin. Spawning for most species generally occurs from August to December. Exceptions include some chinook and sockeye stocks which begin to spawn earlier in the summer, and steelhead which are spring spawners. Fish migrate from the sea to deposit and fertilize eggs in gravel spawning redds. The eggs filter down among the rocks and are covered by the female. After a few weeks, they emerge as fry. At this point, most chum and pink salmon migrate directly to the sea. Chinook, coho, sockeye, and steelhead develop in freshwater (time depending on the species) until a process called "smoltification" occurs. Smolts, as they are called at this stage, are ready to migrate to the ocean. Further development occurs in seawater. If anadromous salmonid reproduction proceeded naturally, <1% of the fish would survive from egg to returning adult. At each life stage, the natural and man-induced losses are tremendous. Freshwater aspects of the salmonid life cycle are the most logical choices for effective, positive manipulation. Loss of habitat, increasing exploitation, and reduced water quality are ever increasing problems. Artificial culture procedures and effective enhancement of existing natural conditions reduce or eliminate barriers to survival. Several techniques have been devised.

The fishway is one successful enhancement tool to artificially restore, stabilize, or initiate salmon runs. Fishways either circumvent man-made blocks to fish migration, such as dams or diversions, or serve to increase access to previously unaccessible spawning habitats. Many states, especially Alaska, are making extensive use of artificial fishways. Three types are popular: 1) a series of consecutive open bottom weirs down the length of a channel or artificial flume (weir and orifice fishway), 2) a series of slotted weirs down the length of a channel or artificial flume (vertical-slot baffle fishway), or 3) baffles attached to the sides and floor of a channel or artificial flume (Denil fishway) (Bell 1973). All dissipate flow energy in turbulence and provide dead spots for migrating fish to rest.

Another enhancement technique used to increase the availability of natural spawning habitat is stream channel rehabilitation and clearance. Compacted gravel can be cleaned, debris removed, and resting pools created, along with other manipulations designed to increase stream spawning or rearing potential. The opening of new spawning habitat is usually coupled with fish transplant procedures. Efforts are being made to reduce the impact of transplants on existing gene pools while ensuring optimum transplant survivability.

Enhancement of food-chain organisms is a method used to increase survival of naturally spawning populations. Adding or changing bank vegetation can increase food potential for stream rearing. An

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[1] National Fisheries Research Center, U.S. Fish and Wildlife Service, Department of the Interior, Bldg. 204, Naval Base, Seattle, WA 98115.

[2] E. Salo, Professor, Fisheries Research Institute, University of Washington, Seatle, WA 98105, pers. commun. July 1979.

enhancement technique to increase food potential currently being tested is nursery lake fertilization. Sockeye salmon require lakes for juvenile life-stage rearing. British Columbia and Alaska embarked on extensive programs to enrich nursery lakes with phosphate fertilizer. The result is increased primary production of phytoplankton, thus increasing zooplankton, the main food for young sockeye salmon. Lake enrichment experiments on Vancouver Island, B.C., have resulted in substantial increases in numbers of adults, both in returns to commercial and sport catches, as well as escapement to the spawning streams (Stockner 1977). In Alaska's Little Togiak Lake, site of another lake enrichment program, smolt size was increased but juvenile to adult survival has not been evaluated.

Not all lake fertilizations have been successful. Lakes respond differently to fertilization, so extrapolation of results from one lake to another is unwise. More understanding of applicable physical and biological processes is required before the technique can be employed effectively.

Spawning and rearing channels, which constitute additional techniques, are not manipulations of existing spawning habitat, but are created entirely by man. Spawning channels are artificial streams possessing ideal gravel and flow characteristics for optimum spawning. Rearing channels are also artificial streams but designed for optimum rearing characteristics. An advantage of spawning and rearing channels is minimum human intervention once they are constructed. Generally, spawning channels are used to enhance chum, pink, or sockeye salmon. For sockeye salmon, channels are built in conjunction with nursery lakes. Rearing channels are used to culture chinook, coho, and steelhead. The U.S. Fish and Wildlife Service has developed a spawning/rearing channel combination for propagating chinook salmon.

Physical modification of holding, rearing, and migration environments can be used to increase survival of natural or artificially enhanced populations. In limited cases, water temperature is being manipulated where barriers allow controlled mixing of impounded warm surface water with cool subsurface water. Controlled temperature makes possible optimum growth while minimizing diseases and physiological stresses characteristic of high water temperatures. Flows can also be manipulated. Several Pacific coast spawning streams have dams which produce hydroelectric power. Controlled discharge of impounded water with consideration for migrating fish softens the negative effects of excessively low or high natural stream flow.

The best-known technique for fishery enhancement is hatchery propagation. Hatcheries rely on the homing instinct to return adults to the hatchery or egg-taking facility. Fish culturists then artificially spawn, fertilize, and rear the fish. In the natural condition, most mortality occurs before the free-swimming stage. The first few days after fertilization eggs are extremely sensitive to mechanical shock. Changing environmental conditions or displacement by other spawning pairs can result in significant mortality. Disease and predation are also prevalent. Artificial rearing from the egg avoids many of these conditions, thus resulting in many more juveniles for seaward migration.

In the hatcheries, adult fish are held in ponds until physiologically ready for spawning. Eggs are generally removed from the female by incision and fertilized artificially with sperm from the male. With the exception of steelhead, adult fish are sacrificed. For salmon species, spawning naturally results in death. Some steelhead survive to return and spawn again, requiring nonlethal egg-take for artificial fertilization. After hatching, the fish are reared in incubators or troughs until large enough for transfer to holding ponds. They are fed from swim-up (a stage where they become free-swimming versus bottom dwelling) until released as smolts. Release times are determined by behavioral characteristics, normal wild stock migrations, and various tests to ascertain capability to withstand exposure to saltwater. Rearing ponds may be located on many streams allowing transfer and release to many watersheds (satellite concept). After the life cycle is complete, eggs can be collected from returning adults for subsequent incubation in a centralized hatchery.

Two general schools of thought prevail concerning freshwater aspects of anadromous salmonid culture. The first, production strategy, emphasizes maximum total output from each rearing facility. The second, a quality fish strategy, emphasizes smolt output designed to maximize survival after release to the wild thus increasing return to either the fishery or the hatchery escapement. All artificial enhancement techniques, with the exception of hatcheries, accomplish their goal by improving or simulating natural habitat. In the past, hatchery operations have generally emphasized production of large numbers of released fish. The trend, however, has recently switched to fish survivability. The goal of all aspects of anadromous salmonid enhancement is to provide the maximum numbers of harvestable and returning adult fish. Ultimately, it is our hope that natural and artificial enhancement will aid in maintaining this valuable and fragile resource.

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Catfish Aquaculture in the United States

HARRY K. DUPREE[1]

ABSTRACT

One of the most recent success stories in aquaculture is the development of the catfish industry in the United States. Situated primarily in the southeastern and south central states, the food fish industry has expanded from $100,000 in farm level sales in 1960 to an estimated $70 million in 1979. Commercial catfish sales for food at the retail level now exceed several hundred million dollars annually. Recreational gross income to pay lake owners, live fish distributors, and the ancilliary industries and services will approach $1 billion annually. Most sales come from the production of channel catfish, but modest returns are reported from sales of blue, white, and bullhead catfishes. Most production continues in earthen ponds, with some yield from cage, net pen, and raceway facilities. Pond areas in intensive catfish culture are estimated to be 36,400 ha in 1979, and production levels have increased from less than 1,500 kg/ha in 1960 to 4,000-7,000 kg/ha today. Feeds, disease prevention, harvesting, and marketing have improved remarkably, but water quality deterioration due to maximizing production continues to be the principal limiting factor.

One of the most recent success stories in aquaculture is the development of the catfish industry in the United States. Situated primarily in the southeastern and south central states, catfish production has moved into the west coast states, and into unlikely areas such as the heated artesian waters of Idaho. Commercial catfish sales for food at the retail level now exceed several hundred million dollars annually. Recreational gross income to pay lake owners, live fish distributors, and to the ancilliary industries and services will approach $1 billion annually.

Catfishes have been cultured for over 50 yr in the United States. Most of the early programs were state and federally supported and involved production of seed stocks for supplemental stocking in farm ponds. Commercial aquacultural production was limited to 200-400 kg/ha annually which was approximately the standing crop attainable in natural fertilized ponds. In the late 1950's Auburn University produced a significant breakthrough, determining that the feeding of pelleted formulations would increase production levels to >1,500 kg/ha. Thus, commercial catfish aquaculture was born.

A number of catfish species are adaptable in varying degrees to intensive aquaculture. The most widely used is the channel catfish, *Ictalurus punctatus*. This species readily adapts to the crowded conditions in ponds, raceways, and cages; eats a wide variety of prepared feeds; and converts these ingredients efficiently into flesh. It is tolerant to handling and shipping, and possesses excellent table qualities and human acceptance. This fish is also widely used in commercial fish-out enterprises and in public recreational programs.

The blue catfish, *Ictalurus furcatus*, is somewhat similar morphologically to the channel catfish. This species attains a larger size, and a higher dressing percentage (60-62% for the blue catfish compared with 56-58% for the channel catfish). However, at sizes up to 1 kg, the blue catfish grows slower and converts food less efficiently than the channel catfish. The blue catfish is also more difficult to spawn due to the large size of the brood fish, 10-30 kg, and the fry and fingerlings are more susceptable to infectious diseases and handling injuries. This species appears to have only limited value in commercial aquaculture, but it does have value as a large predator in lake and river management.

White catfish, *Ictalurus catus*, was studied in the 1960's and found to be inferior to the channel catfish in most aquaculture programs. Few, if any, fish producers are now culturing this species. Extensive testing and commercial production activities during that period showed that the fish initially grew rapidly, but growth rate and feed efficiency decreased rapidly when the size exceeded 0.25 kg. Dressing percentage was <55% due to the large head size but the flesh quality was comparable with the channel and blue catfishes. The white catfish is the most hardy of the catfishes and tolerates the crowding, adverse water conditions, and high water temperatures common in intensive aquaculture in the southern United States. This species is desirable in combination stockings with channel catfish for recreational fishing.

Bullhead catfishes have received attention in aquaculture with the brown bullhead, *Ictalurus nebulosus*, the most promising. Generally, the brown bullhead, yellow bullhead, *Ictalurus natalis*, and the smaller black bullhead, *Ictalurus melas*, are more susceptable to disease, but more tolerant to adverse water conditions than the channel catfish. Prices paid for bullhead catfishes are generally quite low, and consumer demand is limited. Economics of the production of bullhead catfishes are identical to those of the channel catfish, and no economic advantage exists for their production. Some production for recreational purposes may be warranted in those areas where water quality and other environmental constraints limit the production of channel, blue, or white catfishes.

The remaining catfish having aquacultural potential is the flathead catfish, *Pylodictis olivaris*. This fish is highly prized for human consumption, but due to its habit of eating only living animal food, culture of this fish is labor intensive and expensive. Culture of the fry and smaller fingerlings of this species has aquacultural potential since it is very desirable as a large predator in management of rivers and large reservoirs.

Growth of the catfish industry has been rapid (Tables 1, 2). Starting in 1960, 130,000 kg of marketable fish were produced on 160 ha. By 1975, an estimated 50 million kg of fish were produced on 30,000 ha, and production has increased to 54 million kg on 36,000 ha of water in 1979. Growth of the industry is projected to be 10-15% per year for the next 10-15 yr. In states where catfish production is already a major industry, e.g., Mississippi, annual expansion rates >30% are common. Additionally, in states that are new to catfish

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[1] U.S. Fish and Wildlife Service, Fish Farming Experimental Station, P.O. Box 860, Stuttgart, AR 72160.

Table 1.—Estimated hectares devoted to catfish farming, kilograms produced, and value of production.

Year	Hectares	Million kilograms (undressed)	Approximate value (million $)
1960	200	0.1	0.1
1961	200	0.2	0.2
1962	400	0.5	0.4
1963	1,000	1.1	1.0
1964	1,600	1.8	1.6
1965	2,800	3.2	2.8
1966	4,000	5.0	4.4
1967	6,100	7.5	6.6
1968	12,100	15.0	13.2
1969	16,200	20.0	17.6
1970	18,200	24.5	18.9
1975	30,400	51.0	40.0
1979	36,400	54.4	70.0

Updated from: Madewell, C. E. 1971. Historical development of catfish farming, producing and marketing catfish in the Tennessee Valley. Tennessee Valley Authority Bull. Y-38, Muscle Shoals, Ala.

Table 2.—Hectares devoted to catfish farming by states.

	Approximate number of hectares	
State	1972	[1]1978
Mississippi	5,600	10,100
Arkansas	4,200	4,100
Texas	1,600	
Alabama	1,400	4,000
Louisiana	1,200	
Georgia	800	
Missouri	300	
Oklahoma	300	
Tennessee	200	
California	200	6,100
Kansas	100	
South Carolina	100	
Others	300	
Total	16,300	

[1]Revised on basis of estimates. Recent data not available in all catfish producing states.

Source: Office of Technical Assistance, Economic Development Administration, U.S. Department of Commerce, 1972.

farming, e.g., California, the production area has increased from 240 ha in 1972 to an estimated 600 ha in 1979.

Production of catfish for direct human consumption is now influenced primarily by economic factors, whereas several years ago biological limitations were more prevalent. Acquisition of land and construction expenditures for ponds and essential facilities minimally cost $3,000/ha. Production units must usually exceed 40 ha in water surface area to be economically sound, and larger sizes are more desirable. Capital requirements of $500,000 to over $1 million are common. Annual expenditures for feed, chemicals, nets, vehicles, other equipment and supplies, and labor will normally exceed $500,000/farm to produce 0.5-1.0 million kg of fish annually. Additionally, a processing plant is usually necessary for the sale of fish produced within 100-200 km of the plant. In these plants the fish are processed for human consumption and are sold to the public directly, or indirectly through restaurants and food stores. These plants now cost $1-2 million. Feeds and equipment must also be made available to the fish producer by specialized industries.

As previously stated, feeding of pelleted formulations established the basis for commercial catfish aquaculture. The next major breakthrough was development of reliable, economical techniques for production of seed fish. Early production techniques for seed fish were labor and equipment intensive, and so unreliable that most fishery scientists and fish producers predicted little industry potential. However, this limitation in seed stocks proved not to be a problem since by the mid-1960's techniques had been developed for brood fish care, dependable spawning and hatching, and husbandry of the fry and fingerling fishes. Limitations in the availability of seed stocks are now economic rather than biological, and are due to hesitancy of seed stock producers to maintain brood fish populations and to spawn and culture seed stocks for more than their known sales.

Broodfish may be obtained from reservoirs and rivers as "wild" fish, or puchased from a catfish producer. Many of the producers in the 1960's had to rely on "wild" stock which, after several generations in the commercial hatcheries, became the basis for the industry in that area. The fish, when captured from the "wild," possessed diseases and parasites of unkown significance, but the fish either "cleaned up" in captivity, or died. The survivors thus imparted some disease resistance and other cultural characteristics to the domesticating strain. Cultured broodfish and their offspring in production systems are often better able to tolerate low oxygen levels and other poor water qualities. Presently, there are numerous domesticated strains, and broodfish are seldom obtained from the "wild" except for genetic and other research programs.

Good broodfish are essential to good fingerling production. Proper care throughout the year is necessary to insure healthy broodfish when the spawning period arrives. Minimum age for sexually mature broodfish is 3 to 4 yr. For spawning, females must be gravid, and the males must possess secondary sexual characteristics. Mature and gravid females will spawn approximately 5,000 eggs/kg of body weight, and when paired with a good male the resulting hatch will be near 100%. Fry from such a mating will be large and healthy, and an 80% survival of these fry to the 10 cm size is commonly obtained.

Fingerling producers in the early 1960's used gonadotropic hormones to induce spawning, but with the development of good broodfish maintenance techniques, this gave way to natural spawning in ponds. In this production system, cans or other types of cover are provided for the fish to pair and spawn. The egg masses can be recovered and hatched in mechanical devices, or left for the male to hatch. To increase the predictability of hatching and survival of the fry, most eggs are hatched in troughs using mechanical stirrers and the fry are stocked in known numbers in specially prepared ponds for rearing to salable size. Currently, fingerlings produced for food fish seed stocks and recreational stockings are estimated to exceed one-fourth billion annually with a value of $20 million.

Catfishes are now generally produced in earthen ponds, but raceways and cages, and more recently net pens, have been used. Earthen ponds have varied from <1 ha to >100 ha in surface area, and from 1 to 3 m deep. Generally, pond surface area has decreased to 5-10 ha since management and harvest problems are greater in the larger units. Management and operations have changed from a system of single spring stocking-single fall harvest to that of continuous stocking-monthly harvesting with draining occurring only every 2 or 3 yr. The monthly harvesting is accomplished using seines with mesh sizes which retain larger fish and allow the smaller fish to escape and grow to harvestable size. In the single stocking-single harvest program, usually 3,000-6,000 fingerling fish 10-20 cm in length are stocked, and are fed during the warm weather months at an estimated

2.5-4.0% of their body weight daily. Harvestable fish are usually obtained in 180-220 d. In contrast, the continuous stocking-monthly harvesting program maintains a standing crop of 15,000-20,000 fish/ha. The feeding scheme is similar for the two programs, and results in annual harvests of nearly 1,800 kg/ha for the single harvest program to 4,000-7,000 kg/ha for the continuous harvest program.

In cage and net pen culture, the fish are confined to only a small area of a stream or lake. The technique has potential since fish can be produced in areas not suitable for draining, seining, or intensive management. These areas could include very large lakes, strip mining pits, gravel pits and quarries, irrigation reservoirs, and even streams. Production in cages and net pens generally will not exceed the production potential of open pond culture or a given body of water, and thus the use of cages and net pens in ponds suitable for intensive management is not beneficial.

Advantages and disadvantages of cages and net pens are many, and opinions differ among scientists and producers. Obviously, fish can be produced and harvested from cages and net pens in unmanagable waters, and this is the strongest point in favor of this technique. Incidence of disease and disease control, losses to predation, losses from oxygen deficiencies and poor water quality, and behaviorial losses (fighting) vary with quality of management. However, little question remains that better and more expensive feeds are required compared with open pond culture, and that more time and labor are required. Cages and net pens are expensive but in turn the expense of pond construction is avoided. Obviously, there is a potential, though limited, for the production of catfish in these systems.

Raceway culture of catfish essentially parallels that of trout culture. However, with warmwater culture, large quantities of good quality water at temperatures of 24°-30°C usually do not exist. Ground waters are usually cooler, and surface waters (streams and rivers) often contain agricultural chemical toxicants, and parasites and disease organisms. Some studies are underway or being planned which, if successful, will enable the fish producer to re-use water economically, or to utilize surface water by removing the waste metabolites and environmental contaminants. Techniques for raceway production and suitable feeds exist, but because of limited water the production is now estimated to be $<5,000$ kg, all produced in warm artesian water in Idaho.

At the present time, good information exists on nutritional requirements and feed formulation, infectious diseases and their control, harvesting and processing, and to some extent marketing. However, very little useful information on fish genetics and selective breeding has been made available to the catfish producers. Most stocks are essentially hatchery domesticated but unselected. Water quality and water re-use studies coupled with better feeds, disease control, and management have reduced mortalities and increased production. However the farmers still continue to maximize their output, so continuing research and development are necessary in all problem areas to maintain the pace of the growing industry.

An inadequate program in technical assistance to the catfish producers has hindered development of the industry. In areas where extension and diagnostic services are available large aquaculture programs have developed. Experienced producers have been able to move into areas where no assistance was available. However, specific problems in disease, water quality, and other cultural aspects usually require the assistance of professionally trained biologists. For the most part, the catfish producers have only a few federal and state-supported groups or private individuals available for assistance. In some fish producing states there is essentially no assistance, and farmers must travel 100 km or further for aid and advice.

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