FISHERIES RESEARCH BOARD OF CANADA

MANUSCRIPT REPORT SERIES

No. 1015

Research Programs Concerned with Methods of Increasing Salmon Populations

by

P. A. Larkin, J. McDonald, R. R. Parker, F. Neave, H. Godfrey and W. E. Ricker

Biological Station, Nanaimo, B.C.

February 1969

FISHERIES RESEARCH BOARD OF CANADA

MANUSCRIPT REPORT SERIES

No. 1015

Research Programs Concerned with Methods of Increasing Salmon Populations

by

P. A. Larkin, J. McDonald, R. R. Parker,
F. Neave, H. Godfrey and W. E. Ricker

Biological Station, Nanaimo, B.C.

February 1969

FOREWORD

by

K.R. Allen

In 1966 the Director of the Nanaimo Biological Station was requested by the Fisheries Research Board to prepare a report on research required to provide a basis for the enhancement of the salmon resource. At the request of the Deputy Minister of Fisheries, a parallel report was to be prepared by the Department of Fisheries regarding the possible progress which could be made by the application of existing techniques. The report prepared by the Nanaimo Biological Station was presented to the Western Advisory Committee at its fall meeting in 1966. Since this report was a document for consideration by the Western Advisory Committee and the Board, it was not made generally available at that time. It constitutes, however, probably the most compact and comprehensive summary which has yet been prepared of our present state of knowledge of those aspects of the biology of all five species of Pacific salmon which could be relevant to the enhancement of populations. It therefore contains a great deal of material which is valuable in the development of salmon research programmes and in the assessment of priorities, and its value for this purpose would be increased by making it more generally accessible. With this end in view it is now being included in the Manuscript Report Series.

The main body of the report consists of four sections, each dealing with one species of salmon (coho and chinook are considered together for this purpose). Each of these sections was prepared by a member of the Station's staff who had long experience of work with that species. At different times summaries of the report and the recommendations for future research were prepared by the then current Directors of the Nanaimo Station, Dr. P.A. Larkin and Dr. W.E. Ricker. Since these summaries were written from somewhat different viewpoints, and with some difference in emphasis, it seems useful that they should both be available. They have, therefore, been included in the Manuscript Report as sections VI and VII, respectively. From these two reviews, certain common points stand out clearly. The first is, of course, the need for continued basic research on a wide range of problems relevant to the enhancement of stocks. Related to this is the fact that the species of salmon differ sufficiently in their life history, environmental needs and pattern of exploitation to require individual study, although, in many areas, basic studies on one species will provide a starting point for work in another. Also evident is the importance of conducting field experiments and evaluations to test in practice the effects and practical possibilities of techniques suggested by experimental studies. Such field experiments may be expected, of course, to raise, in turn, further problems in basic biology.

In the two years since this report was written, a number of developments have occurred, both in our knowledge of the possibilities of enhancing salmon stocks and in the research programmes of the Nanaimo Biological Station. In the former category the cooperative studies by the United States and Canada on the evaluation of the U.S. coho and chinook hatcheries have shown that substantial contributions to the catches of these species in the waters adjacent to Washington and southern B. C. are being made. At Babine Lake, scientific studies conducted by the Fisheries Research Board and the Department of Fisheries have demonstrated that the Fulton River spawning channels are producing the anticipated quantities of sockeye fry and that, at least up to the time of departure from the lake, they appear to be as viable as naturally produced fry.

At the Nanaimo Biological Station a number of the programmes suggested in the report have been put into effect. These include new studies on salmon migration behaviour, genetics and hybridization of salmon, and the productive capacity of streams for coho salmon. Large-scale field trials have also been inaugurated to determine the survival in the sea of pink salmon fry produced by new hatchery techniques based on earlier studies of the behaviour and environmental requirements of developing fry.

CONTENTS

I. INTRODUCTION

by

P.A. Larkin

This report has been prepared by the staff of the Fisheries Research Board's Biological Station at Nanaimo, at the request of the Deputy Minister of Fisheries and the Chairman of the Fisheries Research Board. It is concerned with the first portion of the following terms of reference which were recommended by the Western Advisory Committee of the Board.

1. The Committee recommends that a report be prepared summarily outlining the state of the art of artificial salmon enhancement, delineating the noteworthy areas of ignorance and specifying programs of research which will reduce those areas and lead to the development of the ability to enhance those populations.

2. The Committee recommends that a special committee be established, including a representative of the Nanaimo Station of the Fisheries Research Board and a representative of the Department of Fisheries, Pacific Area, to examine and report on the extent to which the salmon resource can be enhanced through application of techniques at present available and the approximate capital required for the program envisaged, and an approximate time-table.

3. The Committee further recommends that the Department of Economics of the University of British Columbia be invited to work with the Special Committee in assessing the economic aspects of various possible means of increasing salmon stocks.

4. The Committee had hoped originally that this report of the Special Committee would be ready by the time of its fall meeting, but now recommends strongly that the highest possible priority be given to it, so that it will be available before the time of the Committee's spring meeting in 1966.

The report comprises sections on each of the five species of salmon, and a summary commentary containing recommendations.

A second report concerned with the second portion of the terms of reference is being prepared by the Resources Development Branch of the Department of Fisheries under the direction of a committee of two - the Area Director of Fisheries and the Director of the Biological Station.

On completion, both reports are to be referred to economists for comment as outlined in the third portion of the terms of reference.

II. SOCKEYE SALMON

by

J. McDonald

The purpose of this report is to examine ways in which the sockeye salmon resource may be enhanced and to outline productive areas of research.

Essentially, there are three ways of enhancing sockeye. These are: (1) by producing desirable changes in quality (e.g. form, flesh color, oil content, etc.), (2) by increasing the size of individuals, and (3) by increasing the amount of surplus (catch) through increased production from existing stocks or by the introduction of new ones.

These approaches are the same as those followed in the long-established and successful husbandry of farm and domestic animals. Here, progress has been dependent upon a large measure of control of both the animal and its environment. Desirable production levels - in terms of numbers and rate - are achieved by regulating the size of the breeding stock and, by environmental control, reducing natural mortality rates. Form, flesh quality, and reproduction and growth rates are regulated by selective breeding together with control of food supply.

It can be expected that sockeye enhancement will involve the same methods. Their application, along with other means which the peculiarities of the sockeye allow, are discussed below.

1. Regulation of breeding stock size

This is a prerequisite for either the effective cropping of a wild animal or for the management of a cultivated one. The breeding stock should be of a size to most efficiently utilize the environment available - be it natural or enhanced. This is the principle upon which present sockeye management is based. In practice, however, the optimum escapements for the stocks are not yet well defined and present regulatory techniques are still too gross to provide desired escapement levels with precision.

Any enhancement program which should proceed will require a better measure of control if it is to be fully effective. For example, the sockeye development program now underway at Babine Lake will require close regulation of the number of spawners to the Fulton River and to Pinkut Creek so that the optimum number will be provided both the natural spawning grounds and the artificial spawning channels located there. Should these channels prove effective, and if this technique is applied more generally, then the necessary precision in regulating catch and escapement may demand major changes in future fishing methods and fishing regulations.

2. Selective breeding

Results from selective breeding of animals, including some fishes, reveal that a considerable potential for sockeye enhancement exists in this field. The advantages gained with live stock are well recognized. For fishes, less has been accomplished and results are not as well known. The breeding of carp is a good example of the advantages made possible by selective breeding. New varieties of carp have been produced to meet market preferences for size, color, and degree of scaliness (Hickling, 1962).

A very small amount of work has been done on Pacific salmon. Much of the work on cross-breeding within Oncorhynchus has been summarized by Foerster (1966). Results are sufficient to demonstrate that many crosses will produce viable fry and that at least in the case of reciprocal crosses of sockeye and chum, the hybrids are fertile.

Although the influence of heredity on particular sockeye characteristics is not well defined, past work does suggest the amount of control which may result from selective breeding. Donaldson (1961) claims to have developed a "race" of fast-growing and early-maturing chinook salmon within a few generations. Foerster (ibid.) reviews the work of several Russian workers. Pavlov reported that chum-pink hybrids returned chiefly as two-year-olds and at a size intermediate to pink and chum. Kamyshnaia reported that pink and chum hybrids matured at two and three years of age and showed fast growth, early maturity and excellent edible qualities. This study corroborates the earlier evidence of Smirnov. He claimed that pink-chum hybrids exhibited a shorter incubation period, a more complete hatch, and more rapid larval growth than either of the parents.

Results of chum-pink hybridization studies carried out by the Washington State Department of Fisheries are summarized in this department's 1964 Annual Report. It was reported that:

(a) hybrids from chum male and pink female crosses appeared to have a higher fresh- and saltwater survival than normal artificially propagated pinks;

(b) mature hybrids had both chum and pink characteristics;

(c) the hybrids matured at two and three years of age and the two-year-olds carried more pink qualities than did the three-year-olds;

(d) flesh color appeared to be a darker pink than either chum or pink.

These results indicate that heredity may have a considerable influence on such sockeye characteristics as form, flesh color, age at maturity, and growth and survival rates. Foerster (1935), as long ago as 1935, recognized the potential of selective breeding of salmon: "Such ideas may appear entirely impractical and visionary, but the benefits derived from such practices in the field of agriculture - in plant and livestock breeding - cannot be gainsaid." Later (Foerster, 1966) he states, "As, in the spread of civilization along our rivers, the use of water for other purposes, the deterioration in its quality, and so forth, the conditions for the natural propagation of salmon become less and less favourable, and the stocks decline, it may become necessary to develop, by selective cross-breeding, new varieties which will be able to thrive in the changed situations and contribute to a healthy fishery and provide a high-quality food product".

It must be pointed out that success of selective breeding of livestock has only been possible by maintaining close control over the animal and its environment. Most intensely bred animals can only survive or produce well under the umbrella of protection we afford them. Diet supplements, housing or shelter from the weather, disease and predator control are only some of the controls used. Selective breeding of sockeye, if it is to be fully effective, must go hand in hand with appropriate environmental controls.

3. Environmental control and reduction of natural mortality

Since man first became acquainted with salmon he has been fascinated by the fishes' great potential for reproduction. He saw that only a very small percentage increase in survival of the several thousand eggs carried by a female could increase the catch manyfold. Subsequently there has been much interest and work in measuring mortality rates at different life stages and in determining the causative factors. An excellent review of this work in sockeye is offered by Foerster (ibid.). He concludes that the following mortality rates are more or less representative of a typical sockeye stock:

1.	loss from potential egg deposition to entry of fry into the lake	88%
2.	loss during lake residence	92%
3.	loss in the ocean	90%

The sockeye during all three major life stages are met with a high and comparable rate of mortality. Some of the causal factors operating in fresh water have been identified. These include extremes in water quality (temperature and oxygen content) and quantity (freshets and extreme low flow), overpopulation of spawning beds, predation, and inadequate food supply. No doubt many causal agents remain to be revealed.

So far, salmon enhancement projects have been limited to attempts to control factors operative on spawning adults and through to the fry migrant stage (hatcheries, artificial spawning channels, and incubation channels). In addition there have been a few experiments and observations of incidental events which indicate the possibility of control at other life stages. Nelson (1959) reports on an attempt to increase sockeye production in a small Alaskan lake by adding chemical fertilizers over a period of four years. Following treatment, he claims an increase in phytoplankton, an increase in the size of sockeye smolts produced and in their subsequent survival. A very marked increase in the growth rate of "land-locked" sockeye (kokanee) has occurred in Kootenay Lake, B.C., in recent years. This change is believed to have resulted from the introduction of a new food organism (Mysis) and/or from the introduction of nutrients supplied from industrial wastes dumped into the drainage.

Foerster (ibid.) describes the effect of an experimental predator control program at Cultus Lake, B. C. He concludes that the measures applied resulted in a greater efficiency of sockeye production from the standing crop of plankton in the lake and a greater survival of smolts and hence of returning adults.

There are many opportunities for control during the sockeye's stream and lake stages. Here, the animal is fairly accessible and some measure of control over the stream bed, water flow and quality, and over competing or predatory fishes is technically possible. The main problem lies in determining the kind and degree of control which will be advantageous. The sockeye is a complex animal, interacting with its own kind, other fishes, and with its total environment. Steps to reduce mortality at one point could very easily result in a compensating mortality at another point. For example, there is every reason to expect that reducing the abundance of a competitor population would increase the sockeye's food supply and thus increase their growth and survival. Such, however, may not be the case if the competitor also served as a buffer against predation on sockeye. The final result could be a greater sockeye food supply but increased predation and no net gain - or even a loss - in sockeye production.

The very limited success of hatcheries to enhance sockeye is due to our lack of appreciation of the complexity of the situation we attempt to control. In terms of egg-to-fry survival, hatcheries have been very successful. However, the abnormally low rate of subsequent survival of the fry demonstrates that the controls exercized resulted in a compensating mortality at a later time. Hatchery operation, to be successful, must either produce fry which are in all ways comparable to wild fry in their ability to survive, or control must be extended past the fry stage to cover the period at which the compensating mortality occurs. These are the goals of current enhancement programs. Artificial spawning channels represent an attempt to produce fry comparable to the wild type by providing a more natural environment than do hatcheries but at the same time providing sufficient environmental control to increase egg-to-fry survival. Hatchery operations tend to be moving in the other direction and the period of control is being extended. The fry are raised to a later stage in hopes of increased survival. The success of either approach has yet to be assessed.

4. <u>Opportunities for enhancement offered by the reduction or elimination of the effects of dominance</u>

Major Fraser River sockeye stocks are managed on the basis of dominance, i.e. that a relatively large run is possible only every fourth year, and that this large population suppresses the abundance of the others. The possibilities and advantages of eliminating dominance and having a "cycle year" every year on the Fraser have been entertained by many over the years.

Very little is known about this phenomenon. Although "dominance" is accepted as a principle for management of the Fraser runs, its existence in fact has not been demonstrated nor have causal factors been identified. Several ideas have been advanced to account for the cyclic nature of the Fraser sockeye. These include depletion of freshwater food supply by the dominant stock and interaction of stocks in the sea. Recently Ward and Larkin (1964) examined the available evidence and concluded that dominance in the Adams River run results from the interaction of sockeye with a predator population in the lake nursery area.

The causal factors must be clearly demonstrated before control of dominance can be considered.

Discussion of progress to date and future needs

Sockeye enhancement projects carried out thus far have attempted to reduce mortality during the stream phase, or to supplement existing stocks or create new ones by egg and fry transplants. After sixty or more years, the record of achievement is a dismal one. There is little to show for the money spent and perhaps more importantly, for the time spent. Transplants are still a hit and miss proposition (mostly miss) and very little new information has been provided by past transplants to increase the chances of success. The limitations of hatchery production were demonstrated nearly thirty years ago. But since then very little has been done to reveal the weaknesses of hatchery procedures so that further progress can be made.

The chief reason for this poor record lies in our pre-occupation with the fishes' large reproduction potential and the apparent ease of increasing the production rate by artificial fertilization and egg incubation. This has led to oversimplification of the problem and undue optimism regarding the results. Enhancement projects have gone ahead mainly on a "production basis" with little or no critical and objective examination of the results. Consequently we have been left with a poor indication of the effectiveness of any particular technique and therefore with a poor basis for improvement and development. Progress in the field of sockeye enhancement will depend upon a more rational and objective approach than that followed in the past.

Future work should follow along two lines: (1) studies to show the effects of environmental factors on salmon production so that appropriate controls can be decided upon; (2) tests of promising techniques followed by application if practicable.

1. Studies of environmental factors

Emphasis should be on the freshwater phase as it provides the best opportunities for control. Our ignorance of sockeye ecology is vast and work in almost any discipline would be valuable. Listed below are some particular areas of study which are considered important at our current stage of sockeye enhancement.

(a) Studies of salmon genetics. Some degree of selective breeding will be an essential feature of future enhancement projects. Studies of the influence of heredity on sockeye quality, growth, reproduction, and age of maturity are needed along with a look at the possible advantages of cross-breeding with other *Oncorhynchus* or other salmonids.

(b) Studies of nutrition and disease. As sockeye management is intensified, fuller use will be made of available water, natural and artificial spawning grounds, and nursery areas. Disease and nutritional problems associated with high fish densities must be expected. This has been a long-time problem in many hatcheries. As a first step, it is suggested that a comprehensive survey be made of the prevalence of disease and nutritional deficiencies in natural populations.

(c) Studies of the sockeye's requirements during spawning and the egg-to-fry stage. Results would be directly applicable to improvement of spawning grounds, hatchery operation and construction and operation of artificial spawning channels. Attention should be given to the quality of young produced (size, vigor, behaviour - all aspects which bear on survival) as well as to numbers produced. In particular we need to know more about the physical conditions and fish density required for successful maturation and spawning and more about best gravel composition, water flow and temperature for development. Also important is some knowledge of the effects on sockeye of plants and other animals in the gravel. Improved conditions for sockeye may prove even more beneficial for other life. Almost nothing is known of the role of insects which are found closely associated with salmon eggs. The fact that some larval forms are carnivorous makes predation on sockeye a possibility. A bloom of plant live following stream improvement could impede flow and reduce gravel permeability and soon reverse conditions for sockeye.

(d) Studies of dominance. The potential for increasing sockeye production by the control of dominance should not be overlooked. A direct attack on this problem is warranted. Studies of predator-prey relations at Shuswap Lake should be carried out to follow up Ward and Larkin's work. Also a study of the interaction of sockeye populations in the Adams River should be initiated.

(e) Study of homing. More must be known about homing before transplantation will be a useful tool. A study to determine the precise time or stage of development at which "home" becomes fixed would be worthwhile. Studies of the mechanisms involved should continue.

(f) Studies of predation. The results of the predator control experiment carried out many years ago at Cultus Lake justify further work. Other means of controlling predation, besides reducing predator abundance, should be explored. These could include: releasing fry into the lake at a larger size, creating sockeye populations in lake areas where predator populations are small, providing alternate food organisms.

2. Testing of promising techniques

As more information is obtained, improved or new techniques of enhancement will become apparent and testing should proceed. Currently, artificial spawning channels are considered one of the most promising techniques. Some channels (for sockeye, pink, and spring) are already in operation in B. C. Others are under construction or being planned. In general, provision for testing the effectiveness of these facilities appears inadequate because in most cases no clear distinction between adult production from channels and from nearby natural spawning grounds appears likely. The need for thorough evaluation has been well demonstrated by our past experience of enhancement projects. Without knowing the result of techniques applied, there is no opportunity for improvement nor rational grounds for expansion.

References

1. Hickling, C. F. 1962. Fish Culture. Faber and Faber, London.

2. Foerster, R. E. 1966. The sockeye salmon, *Oncorhynchus nerka* (Walbaum), of the North Pacific Ocean: the extent of knowledge after fifty years of study - 1913-1962. Bull. Fish. Res. Bd. Canada, in press.

3. Foerster, R. E. 1935. Inter-specific cross-breeding of Pacific salmon. Trans. Royal Soc. Canada, V, Ser. 3, 19: 21-33.

4. Donaldson, L. R. 1961. Selective breeding of chinook salmon. Trans. Amer. Fish. Soc., 90(2): 160-164.

5. Nelson, P. R. 1959. Effects of fertilizing Bare Lake, Alaska, on growth and production of red salmon (*O. nerka*). Fish. Bull. U. S. Fish and Wildlife Service, 60(159): 59-86.

6. Ward, F. J., and P. A. Larkin. 1964. Cyclic dominance in Adams River sockeye salmon. Int. Pac. Sal. Fish. Comm. Prog. Rept., No. 11.

III. PINK SALMON

by

R.R. Parker

Pink salmon, like other successful species, have been selected, in the course of their evolution, for their ability to exploit a particular set of environmental opportunities and to withstand the accompanying set of environmental hazards. Their numerical level is a dynamic balance between mechanisms which tend to increase and those which tend to reduce their population density. Reproductive capacity is usually ample, in the long run, to provide population growth in the face of depensatory and extrapensatory sources of mortality. Some vital attribute of the environment always becomes limiting, and precipitates self-regulating sources of mortality which are compensatory in effect.

Commercial exploitation can, theoretically, substitute for or replace part or all of the compensatory mechanism of population control without ill effect. If fishing mortality persists at levels in excess of this, the population will demonstrably decrease to extinction.

It is immediately apparent that several courses of action are open to those seeking to improve the yield of pink salmon. These are:

(1) Manipulate the catch to replace compensatory sources of mortality. This is the maximum yield position in numbers of fish.

(2) Maximize the yield in weight by fishing close to the critical size.[1]

(3) Increase fecundity which in turn would increase the maximum yield position.

(4) Reduce depensatory and extrapensatory sources of mortality. These must then be replaced with fishing mortality or compensatory mortality will obviate the gains.

(5) Increase the available environment where it is limiting, i.e. the basis of compensatory mortality is raised to a higher population level.

(6) Maximise the economic yield through considerations of economic efficiencies in conjunction with biological necessities.

These areas of possible enhancement are not mutually exclusive. Interaction among the categories is anticipated.

It is almost certain that the life cycle of pink salmon is invariably of two years duration, therefore even- and odd-year breeding lines have no genetic

---

[1] The position, in terms of average size of individuals, where losses in biomass from natural causes balance gains in biomass from growth of the individuals.

exchange and must be considered as incipient species. It is anticipated that these lines will exhibit different biological and behavioural characteristics and adaptations. Each line is composed of several stocks, usually identified by the stream used for spawning. A strong homing tendency is acknowledged, and again biological and behavioural differences among the stocks are anticipated. There appears to be some degree of genetic exchange within lines, at least straying is known to occur among stocks associated with a particular "home" area. Therefore, intraline variation is expected to be less than between lines.

Because of these probable differences among lines, and stocks within lines, successful management practices should be tailored, wherever possible, to particular stocks or groups of stocks. Biological relationships cannot be generalized from the particular without careful consideration of possible stock differences.

Maximum yield through regulation of catch

Theory and principles of regulation for maximum yield of pink salmon are generally recognized. In application, however, a basic requirement is a series of observations relating numerical levels of parental and filial generations. At best one would anticipate the large number of fluctuating environmental conditions and relationships would obscure a relationship based primarily on a single density dependent mechanism of control. In practice there are few, if any, stocks that are enumerated with sufficient accuracy to provide even such basic requirements as catch and escapement. The degree to which other than terminal fisheries intercept the migrating runs of particular stocks has been appreciated only recently, e.g., Johnstone Straits fisheries on Fraser stocks, and Milbanke and Laredo Sound fisheries on Bella Coola stocks.

It is apparent that regulation for maximum yield is in a primitive stage of development primarily from lack of specific information on the circumstances under which the fishery is prosecuted. Significant opportunities are available in this area of management for sustained increases in physical yield. Therefore, it would seem imperative that studies be initiated to provide means for an accurate and continuing assessment of at least numerical catch and escapement for the major British Columbia pink salmon stocks.

Critical size

Fisheries Research Board studies have indicated that Central Area pink salmon continue to grow until they enter the enclosed coastal waters during the adult migration. The average natural mortality rate during the oceanic and returning stages of life is less than the growth rate, indicating that critical size is reached only when the fish re-enter the inner coastal waters. Uncertainty remains, however, for the argument is based upon average natural mortality rates. Within the total natural mortality rate, calculated for the final 13-14 months of sea life, the distribution of mortality is not known. It is important to discover this distribution in order to achieve the maximum weight per unit of catch within Canadian fisheries. In view of the developing international offshore fisheries this need for more knowledge is underlined.

Increased yield through increased fecundity

If the same number of eggs deposited in a given salmon stream can be achieved by fewer fish then more fish become available for yield. Our present level of knowledge in this area is restricted to a few observations and relationships obtained from two relatively minor stocks: McClinton Creek in Masset Inlet and Hook Nose Creek in Fisher Channel. A basic size-fecundity relationship exists: the larger the female - the more eggs contained in the ovaries. Parameters of this relationship are not constant among the years, however. Females of the same average size may, in different years, produce different numbers of eggs.

For an average, the fecundity of pink salmon may be taken as about 1,700 eggs per female. Average counts as low as 1,450 and as high as 1,940 have been obtained for different years, and individual counts have ranged from 750 to 2,500 eggs.

One might suppose that environmental opportunities for growth influence fecundity by affecting adult size, which would be a form of compensatory mortality. However, the basis for observed size-fecundity relationships, and the basis for observed size distribution of a returning stock, must lie in the inherited characteristics of the stocks. Therefore significant opportunities exist for enhancement of yield by selection for these two apparently linked characters. It would appear useful to study and experiment with this aspect of population biology. The basis of such a study would have to be a knowledge of pink salmon genetics.

It is quite possible that the present pattern of fishing is adversely affecting the breeding stock in this regard by selecting the larger members.

Increased yield through decreased natural mortality

Since we are dealing with a life cycle which has no real starting point (and we hope no end) any reduction of natural mortality, of any type, and at any stage of development, will eventually lead to an increase in numerical yield provided a new compensatory mechanism is not automatically precipitated. In discussing sources of mortality we will begin in the cycle with the fertilized egg in the redd. Studies at Hook Nose Creek have revealed that during the approximately 7-month period of incubation and larval development in the gravels, survival has varied from about 6% to greater than 31%. A strong density dependent relationship has existed which suggests that the number of exclusive spawning sites available to a stock imposes the main, and perhaps only, effective compensatory limiting mechanism. Stemming from this suggestion is the corollary that either the "adults on behalf of the eggs" or the embryos must then be competing for a limited resource. Study along these lines has demonstrated that improved subsurface flows have resulted in better survival, presumably by providing more oxygen to the embryo and enhancing the removal of waste metabolites. This relationship is intensified by the tendency of the adults to occupy less favourable spawning sites at high spawning densities.

Other density dependent mechanisms may be envisioned. These are epidemics of disease or fungus organisms, or subsequent exposure or disturbance of embryos by succeeding waves of spawning pink salmon. Little concrete data is available regarding these latter relationships.

Other sources of mortality during this period may be listed. Severe fluctuations in water levels may alter the stream bed or expose the redds to dessication or unfavourable temperatures and flows. Silting may occur from damaged watersheds. This aspect of mortality is under continuing study in southeastern Alaska. Insect larvae and sculpins may prey upon the embryos in the gravel. This facet is also under study in southeastern Alaska. Other species of salmon may subsequently use the same spawning sites, thus reducing the survival of pink salmon.

All of these sources of mortality may be reduced by various means. The density-dependent sources may be reduced, by increasing the number and quality of spawning sites available, either in natural or artificial situations. In artificial spawning channels and hatcheries the embryos may be protected from predation, changes in physical flow and disease, although hatchery operations, because of the crowded conditions, may precipitate epidemics of disease. Such attempts as have been made at hatchery propagation have not produced encouraging end results. The causes of these failures are not understood. However, the quality of fry produced appears to be a significant factor.

Scientific studies to define the characteristics of pink salmon fry that affect their successful return as adults, and the environmental factors that affect these characteristics,are a necessary prerequisite to manipulation of the population by artificial culture techniques. We are almost totally ignorant in this area which encompasses physiology, behaviour, parasitism and disease.

In several areas of British Columbia one or the other lines are completely or very nearly absent. Two general facts appear relevant: (1) in the majority of spawning streams both lines are present and apparently compatible, (2) from the very existence of one line, reproductive potential of the stream is proven for the other. Attempts to establish the missing line have all ended in failure.

It is suggested that establishing a missing line in a natural situation and establishing a run in an artificial spawning channel (such as the Robertson Creek attempt) have failed for a common reason. Each stock of pink salmon has evolved to meet a particular set and sequence of life history events, and this, to a large degree, must involve innate patterns of behaviour. Past failures have not materially altered the attractiveness of the original proposition, in fact survival to the migrating fry stage has been encouraging. Again we have simply come up against a barrier of ignorance which must be broken before further gains can be made. Scientific study of innate behaviour of pink salmon and interstock comparisons, involving the mechanisms of orientation, migration and homing is indicated as a necessary, prerequisite to the successful transplanting of pink salmon.

In the shorter streams, such as Hook Nose Creek, the fry emerge and migrate out of the stream in a few hours. In the estuary, in daylight, they form into schools and commence feeding. It has been estimated that during this short exposure in the stream, between 23 and 85% of the fry population is lost to predators, mainly cottoids and coho salmon. These species are non-obligate predators of pink salmon and their numbers are probably not affected by the size of the pink salmon populations. The number of fry eaten is largely a function of the number of predators present. This type of mortality, then, is depensatory, and the effect is relatively greater at low pink salmon stock levels.

In the longer streams, such as the Bella Coola, it may take individual fry several days to reach the estuary; hence the exposure time to predation is relatively long. The fry form schools and are exposed in the fresh water during daylight hours. It is suggested that relative losses to predation in these situations may be more severe than those recorded for the Hook Nose Creek stock. The prospects of enhancing commercial yield through predator control are exciting but we are, at present, generally ignorant about predator-prey relationships. This problem will receive initial study on the Bella Coola River in 1966.

One often hears of mortality of fry when entering the marine environment associated with failure to adjust to the different osmotic conditions. From our experience in direct transfer of fry from fresh to salt water holding pens this does not appear to be a serious proposition.

Pink salmon fry, upon entering the sea at Bella Coola, are initially shore-oriented. They form a narrow band which follows the shores of North Bentinck Arm and extends into Burke Channel. With growth, the affinity for the shore is lost and the fingerlings occupy more pelagic positions. During this early stage growth is rapid. Weight increases at about 7% per day. During four years of observation growth did not appear to have been inhibited by limitation of food supply. Changes and differences among years in respect to fat content have, however, been noted.

At the end of May, after about 40 days of sea life, the fingerlings form into tight schools which then actively migrate out of the enclosed coastal waters to the more exposed waters of Queen Charlotte Sound. Variations in routes followed have been noted among the years. A characteristic of this migration is an abrupt drop in average fat content. In this regard, and because of the migratory behaviour, this would appear to be tantamount to a "smolt" stage of pink salmon.

During this 40-day period from fry to smolt, rather severe losses occur.

In three years of observations survival varied from 23 to 45% (average 34%). Sources of mortality are not yet determined and understood. It is known that predation by coho salmon is severe, and squid also feed on pink salmon fry. Other known possible sources of loss are to parasitic copepods and internal parasitic worms. Fisheries Research Board scientists are presently studying these relationships.

After migrating from the enclosed waters the movements of this stock are not known. It is suspected, from observations made by the Fisheries Research Institute and the U.S. Fish and Wildlife Service scientists, that the Central Area juvenile pink salmon move north in Hecate Strait. The main body then moves through Dixon Entrance although some may enter southeast Alaska channels. Along this route they are undoubtedly mixed with other stocks from northern British Columbia and Alaska. The migratory route then appears to be along the coast of southeast Alaska for some unknown distance. Fisheries Research Institute seining during the July-September period has disclosed a well-defined band of juvenile salmon within 15 miles of the coast moving in a northwesterly direction along the coast of southeast Alaska. Where and at what time the central British Columbia pinks leave this band and move further offshore is not known.

Central Area pink salmon have been encountered in April and May by Fisheries Research Board longline fishing in a fairly discrete region along the coast of Washington, Vancouver Island and Queen Charlotte Islands and within 300 miles of the coast. They then return to enter the coastal fisheries in late July and August and spawn mainly in September and early October.

During this oceanic period of 13-14 months, survival during a three-year study has ranged from 6 to 22% (average 13%). No breakdown of mortality into shorter time intervals is yet possible, but it is suggested that the major part of this mortality occurs immediately following the initial sea period, i.e. during the coastal migratory period following the "smolt transformation". Studies on growth, survival, behaviour and ecological relationships of the Bella Coola stock during this early oceanic stage of life history are both feasible and necessary to our understanding of life history and the critical size problem.

For the Bella Coola stock, it has been estimated, for the 1961-1963 brood years, that Areas 7 and 8 fisheries took from 79 to 85% of the returning runs. Available evidence suggests that Areas 6 and 9 fisheries also make significant catches of this stock. It is quite possible that other fisheries are also involved. These unaccounted catches are included in "natural mortality" estimates and therefore the oceanic survival figures given are underestimates of the true survival rates.

A further source of mortality is known to occur and is included in natural mortality estimates. Particularly in gill-net gear, fish become temporarily entangled but drop out of the net before they are landed. Some of these "drop-outs" are already dead, others are injured or perhaps fatigued to a degree from which they cannot recover. Some fraction survive and are noticed in the spawning escapements as net-marked fish. The importance of these drop-outs has not been assessed. Both United States and Japanese scientists are currently studying the problem and this would seem a profitable area of study for Canada. Mortalities associated with that part of the life history from return to the coast to spawning are generally recognized but vary with the situation. Losses occur to predation, molesting by sports fishermen, fungus, unfavourable water flows, stream blockage, and other unspecified causes. In some particular instances these losses reach alarming proportions but are more in the nature of sporadic and unpredictable loss than part of a foreseeable relationship.

Thus, it is possible to state that the yield from a stock of pink salmon can be greatly enhanced provided an understanding of natural mortality is first at hand. There is always the possibility that by increasing the level of one restricting attribute of the environment the population will then become restricted by another. The removal of one source of mortality may, through the biological chain, simply intensify effects of another agent of destruction. By increasing stability of a spawning ground one may inadvertently also increase the population levels of a predator. By removing or controlling a predatory species of fish, pressure may be removed from insect populations which would then be a serious factor to egg and alevin survival. These and other possibilities serve to underline our need for a more complete understanding of ecological relationships before remedial action is attempted on a large scale. At our present level of knowledge it is important to classify remedial action as experimental, and speculative. It should therefore be carefully documented and designed as a research tool so that success or failure become equally valuable as contributions to our understanding of the species.

In summary, it is suggested that it is possible to increase the yield of pink salmon along several lines: (1) by making the best use of existing stocks under prevailing conditions, (2) by substituting catch for natural mortality, (3) by improving the genetic qualities of the stock along lines of reproductive capacity, growth rate, resistance to parasitism and disease, (4) by raising the physical limitations to stock densities, and (5) by creating new stocks through transplants and cultural techniques.

It has also been suggested, for each line of approach, that serious gaps in our knowledge must first be filled, either preliminary to, or concurrent with, attempts to increase yield. Natural mortality must be recognized, defined, and the agents studied. The biology and behaviour of the fish must be studied in relation to the physical and biological environment in which it lives. The role of environmental factors as modifiers of innate capacities must be understood. Thus descriptive and experimental studies are considered as a necessary and preliminary step toward enhancement of yield.

Summary of recommended research

1. Mortality studies. The whole spectrum of natural mortality must be described in detail. Agents of natural mortality must also be understood and biological interrelationships looked for. I would recommend approaching the problem from the mortality schedule of a particular brood year rather than generalizing over several stages of life history, i.e. an egg-to-egg study of a particular brood year. Otherwise latent effects of varying mortality will be missed.

2. Studies on the fecundity of pink salmon leading to selective breeding for improved stock characteristics. One should bear in mind other stock qualities such as resistance to disease, parasitism, timing, etc.

3. Studies on migration. This to include mechanisms, i.e. innate behavioural characteristics and the modifications of the environment.

4. Studies on parasitism and disease, to include descriptive work and the effects of these organisms on the host.

5. Ecological studies of pink salmon, leading to an understanding of the species as it lives in its various physical and biological environments.

6. Changes in edibility and quality of product as fish mature. This study has relevance to the critical size problem.

7. The "drop-out" problem. Presently part of our unrecorded fishing mortality.

8. Problems of assessment, catch and escapement. These statistics are basic to population dynamics.

IV. CHUM SALMON

by

F. Neave

The quantity of the salmon resource is represented by the number and size of the fish available for capture. This quantity is determined by factors and processes which can be labelled: Birthrate; Growth; Survival. Enhancement of the resource must involve an increase in at least one of these categories and, obviously, such increase must not be accompanied by a corresponding decrease in other categories.

Birthrate and Growth

The birthrate is considered here as being the number of eggs deposited by a female salmon.

At Hook Nose Creek (King Island) and Nile Creek (Vancouver Island) the average number of eggs produced by a female chum, as counted in samples taken in a number of years, was about 2,700. A similar average seems to have prevailed at Minter Creek, Washington (Wash. Dept. Fish., Ann. Repts.). Samples taken at a few Asian localities showed averages varying from 2,000 to 4,300 (Rounsefell, 1957). Although data on the egg-production of chum salmon are very scanty, they indicate that there is much variation (a) between different watersheds, (b) in different years within the same watershed. For example, at Hook Nose Creek the average in different years varied by at least as much as 700 eggs per female.

The possibility of enhancing the resource by increasing the fecundity of spawning salmon is closely related to problems of growth, survival and length of life. Spectacular increases in both egg-production and size of fish, through selective breeding, have been claimed for rainbow trout at the University of Washington (Donaldson and Olsen, 1957) where the fish were held in ponds until mature. Some of the pitfalls of selective breeding, however, were demonstrated in other experiments by Millenbach (1950). In this instance, selection was made for early age of maturity. This result was successfully achieved but egg-production was low, the eggs were small and the fry were slow to start growth. Selective breeding of anadromous salmon, such as the chum, would of course be at a disadvantage in comparison with rainbow trout because of the problems of getting, and recognizing, a sufficient return of selected fish from the sea.

There is at present no information on which to base a technique aimed at increasing the chum salmon resource through selective breeding. Before intelligent selection could be practiced, information would be needed on the relationship between egg-number, age and size of fish, the survival-value of eggs of different size, and the ability of the parent to deliver eggs to propitious locations.

While it would be optimistic to think that selective breeding can appreciably augment the resource in the near future, the gathering of information along the above-mentioned lines would undoubtedly help in diagnosing the problems faced by different stocks at the present time. Information might well be sought on the possibility that non-beneficial selection is already occurring, or might occur, through the operation of the fishery, if the latter tends to take a higher proportion of certain size- or age-groups. Although statistical data on the age-, size-, and sex-composition of commercially caught salmon are being obtained annually, present studies do not deal with the escapements of specific watersheds, nor do they include observations on fecundity.

A kind of selective breeding which has been tried experimentally in both North America and Asia consists in the hybridization of various species of Pacific salmon. Foerster (1935) showed that many interspecific crosses produced good hatches of apparently healthy fry. More recent experiments have concluded the production of chum-pink hybrids in the USSR, Japan and Washington. In experiments conducted at the Kalininsky hatchery, Sakhalin (Pavlov, 1959), normal development and excellent survival to the fry stage resulted from the crossing of male chums and female pinks. Many hybrids subsequently returned to the river, mostly at an age of two years and at an average weight much greater than pink salmon. The reciprocal cross (male pink × female chum) was not successful. The implication that by hybridization a fish approximating the size of an average chum can be produced within the shorter life period of a pink salmon would provide a starting point for larger-scale attempts to enhance the resource if it could be shown that birthrate and survival are not adversely affected over a series of generations. The subsequent history of the Sakhalin experiments is not known to me, but a recent experiment at the Hood Canal hatchery of the Washington Department of Fisheries is not reassuring on this point. In 1961, 222,564 pink salmon eggs were fertilized with chum salmon sperm at this hatchery. The resulting fry (92% survival from the eggs) were held in a pond for 61 days and the survivors (75.4%) were released in salt water. A return of 2995 two-year-old hybrids and 332 three-year-olds was reported, representing a high survival (2.1% of the number liberated). Interbreeding of the hybrids, however, gave very poor results, the mortality exceeding 90% from eggs to free-swimming fry.

In Japan (Horonai River, Hokkaido), Hikita and Yokohira (1964) reported excellent survival to the fry stage of chum-pink hybrids. In this instance both crosses were successful, chum male × pink female giving 81.8 to 91.5% survival, and pink male × chum female giving 93 to 94.5% survival. 176,600 hybrids were released in 1962 and 149,200 in 1963. Returns were not yet due at the time when the report was written.

While interesting further results can be expected from hybridization experiments, the present outlook for increasing the salmon resource through application of this technique remains quite uncertain.

Survival

Most of the attempts which have been made to increase the available quantity of Pacific salmon have been concerned with reducing the death rate at certain stages of the life history. Since the average mortality from eggs to maturing fish is well over 99%, it is obvious that an increased survival to this stage of only one per cent would more than double the population. Opportunities for reducing the death-rate, however, are restricted to the freshwater or very early saltwater phases of the life history, - which leaves a long period in which gains can be dissipated before reaching the fisherman.

Survival of chum salmon, under natural conditions, from potential egg deposition to arrival of fry migrants at some downstream counting point, has been found to range from as low as 0.1% to as high as 22% in investigations made in British Columbia (Nile Creek, Hook Nose Creek and Qualicum River). These figures therefore include losses incurred both during development in the gravel and during at least the early stage of seaward migration. Estimates of survival to time of emergence at Nile Creek in several years ranged from 0.2 to 18% (Wickett, 1952) and at Hook Nose Creek from 5.7 to 31%* (Hunter, 1959). Survival of fry during their migration to the sea, or other downstream counting point, was estimated to be from 35 to 56% (Nile Creek) and from 15 to 77% (Hook Nose Creek)*. Losses during migration were attributed to predation by other fishes and percentage survival tended to be greater when fry runs were large.

Relatively high survival estimates (67 to 74%) from egg-production to the fry stage were quoted by Pravdin (1940) for the Bolshaia River, Kamchatka, and other USSR streams. In a spring-fed spawning area of about 9 acres, adjacent to the Bolshaia River, Semko (1954) estimated that in different years from 16 to 80% of the emerging fry (chums and other species combined) escaped predation before entering the main river.

The losses suffered during the incubation period can often be ascribed to such factors as: displacement of eggs or alevins by flood or by the digging operations of fish; asphyxiation, due to insufficient water supply or to reduction of oxygen content of the water; drying of spawning beds; unfavourable temperature for development; fungus or disease; predation; exposure of eggs to salt water. Unfavourable conditions of these kinds can readily be ameliorated by artificial methods. Historically this has been the role of hatcheries. These institutions have commonly reported survival of 75 to 90% or more from eggs to free-swimming fry. In British Columbia, hatcheries have never been used extensively for chum salmon but the rearing of this species presents no special problems. In Hokkaido it is claimed that a majority of existing chum salmon populations are derived from hatchery-produced fry. From figures given by the Washington State Department of Fisheries (Ann. Rept., 1964) it appears that 36,847,000 chum eggs were collected in the state during the six years 1957-1962 and that resulting liberations amounted to 32,218,000 fry and young fingerlings,- an overall survival of 87.6%.

This figure is considerably higher than the best values reported for chum salmon eggs and fry developing under strictly natural conditions. The drawbacks and uncertainties of hatchery operations lie in the costs involved, in the fact that only a small proportion of the spawning potential can ordinarily be handled, and in the serious doubt as to whether the gains achieved by the hatchery are maintained after liberation of the young fish.

---

*Hook Nose Creek figures are for chum and pink salmon combined.

The effectiveness of hatcheries in circumventing the heavy losses incurred during downstream migration no doubt depends in part on the place and manner of liberation. If the journey to the sea is eliminated or shortened, some of the perils of migration must be reduced but it is possible that such benefits might be offset by disruption of normal timing and behaviour patterns associated with migration and entrance into the sea. An illustration of what can happen to planted fish (in this case in their native spawning area) is provided by Semko (loc. cit.). At the spring-fed spawning area mentioned previously, chum salmon in one year were not permitted to spawn naturally. Instead, a small liberation (50,000 - 70,000) of hatchery-raised chum fry was made at the normal season of fry emergence. Whereas in previous years the survival of natural fry populations of this species in this area had been estimated at from 32 to 84%, the planted fry were reduced to about 1% before escaping to the river. This result was attributed to the presence of a large population of predators which had only a relatively small number of fry to feed on. Whether, in addition, the hatchery fry were more vulnerable to predation than "wild" fry is apparently not known.

The protection afforded by the more recently employed technique of controlled water flow (in conjunction with either natural or artificial incubation areas) covers much the same period of the life-history as is dealt with by the hatchery. Much of the mortality which under natural conditions is associated with severe changes in water volume and current can be eliminated. In addition, the fry can emerge from the gravel and migrate downstream at times of their own choosing. Also, it is sometimes feasible to exclude all or some predators from the controlled section of streams, thus reducing mortality in the initial stage of downstream migration. Data on the survival of chums in controlled streams are as yet quite limited. In three years prior to the institution of water control on the Qualicum River the number of fry migrants represented from about 5 to 20% of the potential egg deposition. In the two years following the introduction of water control it was about 26%. At Jones Creek (Fraser River system), fry migrants have represented from 30 to 60% of the eggs deposited by parent fish in the controlled channel. These figures, although less spectacular than those reported by hatcheries, are higher than the percentages hitherto reported for uncontrolled streams in British Columbia. Possible advantages over hatcheries are seen in lower operating costs, in elimination of the handling of eggs and fry, in reduced vulnerability to epidemic diseases and in the production of fish better able to survive after leaving the man-controlled environment.

Attempts to extend the benefits of artificial conditions over a somewhat longer period of the life-history have been made, notably in the Puget Sound region, by holding small chums in saltwater ponds or lagoons for some weeks or months after the time of normal migration to the sea. The capacity of ponds is of course limited to relatively small numbers of fish and these require continued feeding. Although survival figures for these experiments are not immediately available, it is understood that considerable problems of disease and in the provision of suitable diets have been encountered. In certain natural lagoons, providing areas up to 25 acres, with provision for tidal exchange of water but with access of fish to the sea prevented, the fish have relied mainly on natural food supplies but have been protected from underwater predators by prior treatment of these waters with rotenone. Plantings of up to 2 million fry or small fingerlings have been made in such areas. A very favourable growth rate has been reported for chum salmon held for 3 months in one such lagoon. Predation by birds appears to have seriously reduced survival in some instances. Data are as yet insufficient to show whether these enterprising experiments will point the way to significant augmentation of chum salmon stocks in the near future.

Remarks

In general, it may be said that artificial methods have been effective in increasing the percentage survival of chum salmon on the quantitative levels and at the immediate stages of the life-history to which they have been applied. Their effectiveness in promoting a widespread enhancement of the resource will depend on evidence (a) that the increased survival achieved during the periods of human control is not offset by correspondingly increased mortality in subsequent periods, (b) that artificial methods can be applied to much larger segments of the salmon populations than have hitherto been dealt with.

There are as yet few data to show whether increased survival of young salmon actually results in greater numbers of returning fish. In certain related species (e.g. cutthroat trout [Miller, 1954]) there are indications that artificial protection of eggs and fry permits the temporary survival of fish which are unlikely to be successful under more rigorous conditions in later life. If this is the case some of the apparent gains recorded by present methods of artificial culture will be illusory. In general (and this applies in good measure to chum salmon), little is known of the number of salmon which actually survive to maturity as a result of artificial manipulation. Necessary information must be obtained both from the fishery and from escapements. Evaluation of the current Qualicum River programme may be a very important step in this direction. It may be added that information on the survival of natural populations of chum salmon in British Columbia is confined to a very few streams and these may not be representative of the condition of other stocks. Wider knowledge of the workings of natural propagation would provide a better basis for assessing the directions in which artificial techniques should be developed.

Studies recommended

1. Studies on the relationship between egg number, age and size of fish survival value of eggs of different size and ability of adults to deliver eggs to propitious locations; as a basis for selective breeding of more fecund stocks of chum salmon.

2. Studies of possible adverse selection by the fishery of particular strains of salmon.

3. Studies of salmon hybrids.

4. Studies to indicate whether increased survival achieved during periods of human control is offset by increased mortality in subsequent periods and whether it is possible to use cultural methods on much larger segments of natural populations than heretofore.

5. Studies designed to give wider knowledge of the workings of natural propagation as a basis for assessing directions in which artificial techniques should be developed.

References

Donaldson, L. R., and P. R. Olson. 1957. Development of rainbow trout brood stock by selective breeding. Trans. Amer. Fish. Soc. 85: 93-101.

Foerster, R. E. 1935. Inter-specific cross-breeding of Pacific salmon. Trans. Roy. Soc. Can. 29(V): 85-95.

Hikita, T., and Y. Yokohira. 1964. Sci. Repts. Hokkaido Salmon Hatchery, 18: 57-66.

Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Bd. Canada, 16(6): 835-886.

Millenbach, C. 1950. Rainbow brood-stock selection and observations on its application to fishery management. Prog. Fish.-Cult., 12: 151-152.

Miller, R. B. 1954. Comparative survival of wild and hatchery-reared cutthroat trout in a stream. Trans. Amer. Fish. Soc., 1953, 83: 120-130.

Pavlov, I. S. 1959. Experiments on the hybridization of Pacific salmon. Fish. Res. Bd. Canada Translation Series No. 263.

Pravdin, I. F. 1940. A review of investigations on the Far-Eastern salmon. Fish. Res. Bd. Canada Translation Series No. 371.

Rounsefell, G. A. 1957. Fecundity of North American salmonidae. Bull. U.S. Fish and Wildl. Serv., 57: 451-468.

Semko, R. S. 1954. A method for determining the consumption by predators of the young Pacific salmon during the early stages of development. Fish. Res. Bd. Canada Translation Series No. 215.

Washington State Dept. Fisheries Ann. Repts., 1957-1964.

Wickett, W. P. 1952. Production of chum and pink salmon in a controlled stream. Prog. Rept. Pacific, 93: 7-9.

V. COHO AND CHINOOK SALMON

by

H. Godfrey

In British Columbia coho and chinook salmon support a large proportion of the troll fishery, virtually all of the sport fishery, and primarily for this reason are commonly lumped together in fisheries investigations. Nevertheless they show many important differences in their biology which warrant their separate consideration with respect to possibilities of enhancing their production. In this report the species are treated separately, but to avoid repetition it is noted in the discussions of problems concerning one species where the remarks are also applicable to the other.

This report is not entirely comprehensive because much of the material which is relevant is relatively inaccessible or is in the process of being compiled. Various United States agencies presently hold a vast amount of information relating to the artificial propagation of these two species, which at this time at any rate is not readily available to Canadian workers. In particular there are many case histories and other accumulated data of hatcheries and fish farms. Also, besides data in the files, these agencies have many multilithed reports which have had very limited distribution but which might be acquired upon request. One single example is given in the last section on coho salmon in this report. As a further example, a few days ago reports were received of a study of the achievements to date of the Washington State fresh- and saltwater fish farms (which has not been examined yet, but which contains the basic data for Crutchfield's 1965 economic evaluation of these farms).

Thus, useful material exists which was not available for this report, but might be later. Such material should also be particularly useful in assessing the economic aspects of the different techniques, and of similar techniques employed in various situations under different conditions.

The stages in the life cycle of Pacific salmon are relatively discrete, and may take place in different environments, and there is obvious merit in presenting the discussion by life history stages as is done in this report.

Chinook Salmon

The eggs

Smirnov (1960) made observations on coho salmon eggs that have important implications to the transplanting of eggs to stream beds, or to the incubating of eggs in artificial spawning channels. He noted that the eggs and embryos of coho salmon possess special characteristics that enhance their chances of survival under conditions of lowering oxygen concentration - small eggs with relatively thin shells, a dense surface capillary system, an abundance of carotinid pigment and intensive pulsation of the embryo.

Comparative studies of the physiology of the eggs and embryos of Pacific salmon could provide information that might be of great importance at the very first stage of their artificial propagation. At present we are making frequent egg transplants and are establishing artificial spawning channels without being aware of the possible significance of such differences between the several species. It is hardly necessary to add that knowledge of the physiology of developing eggs and embryos is important in many other aspects of their culture as, for example, in relation to the exposure and reaction to various pathogens.

Spawning

Although chinook salmon do spawn in many coastal streams, production comes mainly from the large rivers and their tributaries (e.g. the Sacramento, the Columbia and the Fraser). In British Columbia only about 15 (10 per cent) of the total number of chinook salmon rivers contribute about three-quarters of the total spawning escapement.

"Typical" chinook salmon spawning ground consists of relatively large bottom material; the redds are larger and are more separated than those of the other species; the water over the beds is usually deep and swift-flowing, and the eggs are buried deep in the gravel. An impression is gained that these features of the spawning of chinook salmon bear a relationship to their great size. Thus, the availability of the most suitable spawning sites throughout a geographic range may be a primary factor in regulating their overall abundance. If this is so, and if it were possible to by-pass the requirements for natural spawning, by satisfying merely those for successful fertilization and hatching, then it should be possible to increase production to that stage. Although the ends sought may be the same, the rationale implied here differs from that of "improving" upon natural reproduction.

Hatcheries and spawning channels may serve to increase the utilization of the sexual products of chinook salmon, and even to improve upon it. However, with regard to spawning channels, we are at present essentially ignorant of their requirements for this species. At this time we do not know what are the important properties of "good chinook spawning ground", either in terms of the requirements of the physical environment, or in terms of the behaviour of the fish in selecting a site and building a redd. An example may be given of a recently reported case where in an artificial spawning channel for chinook salmon (in Oregon?) the fish failed to "hold" until they were ripe, and subsequently died without having spawned. It was determined later that the percolation properties of the gravel bed were at fault.

Egg survival

Appropriate data on the natural survival of chinook eggs are virtually non-existent. It can be accepted that very high rates of fry production can be achieved in modern hatcheries. However, the same cannot be assumed for artificial spawning channels, particularly in cases of their utilization over several years. It would be of great value to study the changing physical and biological properties of an artificial spawning channel for several years prior to the introduction of any fish. Concurrent experiments involving fish could, of course, also be pursued.

Fry survival

There are several kinds of early life history patterns in chinook salmon, but this report does not deal with all of them. This is not serious since emphasis will be given to certain biological principles which are common to each kind, although they might apply at a different stage in the life history.

Besides the existence of spring, summer and fall "races" of chinook salmon, and of red- and white-fleshed fish, of particular importance is the occurrence of the "ocean" and the "stream" type of chinook salmon. The former migrate to sea over a period of a few days up to some weeks after emergence, whereas the latter first winter in fresh water before they make the seaward migration. Because of this there would obviously be differences in the sequence of problems associated with the artificial propagation of one type as compared with the other. To a certain extent (but by no means entirely so) the fresh-water phase of the ocean type chinook is comparable to that of the pink and chum salmon; and that of the stream type with the coho salmon.

Only a modicum of information is available on the survival of chinook fry to the point of their seaward migration (although such data are currently being obtained through the Big Qualicum River studies of the Department of Fisheries). However, in general we can accept that the gross production varies from year to year and from stream to stream, since it is subject to the effects of environmental fluctuations and to the presence of other fish species. No doubt, under natural conditions the chinook fry incur losses from disease, predation and various other agents. Theoretically, hatcheries and spawning channels should eliminate or minimize such losses, but at this time we have very little in the way of quantitative evidence.

Of especial importance to this report is that there are, apparently, two rather distinct kinds of fry of the ocean-type chinooks. Some fry leave the stream almost immediately after emergence when they are still relatively very small. The other kind remain in the stream for a period (possibly as long as three months or more) where they feed and grow, and so migrate at a much later date (on the average) and larger size. In the case of the Big Qualicum River, and at other similar situations, the end result for both kinds of fry is direct entry into the sea. In other situations passage must be made over a considerable distance downstream before the estuary is reached, and in these cases it is possible that many of the smaller kind of migrants first take up temporary residence and grow.

It is not known at this time whether there are inherited or acquired physiological differences between the two kinds of fry, and if there are, whether such differences bear on their subsequent growth and survival. For example, it would seem important to determine whether they differ in salinity tolerance, since there are indications of the possibility that few of the smaller kind survive (Big Qualicum River studies now in progress).

The numbers and proportions of these smaller kinds of fry can be considerable, as the Qualicum data will show.

The larger fry which remain in the river and feed and grow may be considered as comparable to the "90-day fingerlings" whose production is the common objective of the fall chinook hatcheries in Washington and Oregon States. In the hatcheries the fry are reared by artificial feeding until they have reached a certain desired size - a process which usually takes about 90 days. This size, which was determined through experience, and upon evidence obtained from mark recoveries and returns to the hatcheries, is that which is considered to give the best rate of survival after release, commensurate, presumably, with the cost of production. A similar relationship between smolt size and adult return has been demonstrated in other instances, as for example by Foerster (1954) for sockeye salmon.

The early removal of chinook fry from the hatchery troughs to rear them in fresh- or salt-water ponds until they have attained the desired migratory size is a variation of the hatchery practice mentioned above. Here the secondary objective is to reduce costs, particularly those of feeding. (Some of the Washington fish farm projects have also included measures to reduce predation, to increase the natural food supply by fertilization, and supplemental feeding.) A recent study by Crutchfield (1965) has shown that most of the Washington fish farms have been ineffective and unprofitable. However, these failures did not invalidate the basic principles, and good success in two or three instances may be considered as proof of this.

Very recently the Washington State Department of Fisheries released a report by their biologists on the histories of these farms, and this should be examined later to provide a better appreciation of their potentialities for British Columbia.

If the small fry are "obliged" to leave the stream at an unfavourable size, it should be determined how and why this occurs, and whether such fish could be utilized in some way or other.

It is possible that during their period of residence in the stream the larger kind of chinook fry behave in a manner comparable to that of the resident coho fry (the survivors of which will remain until the following year). If this is the case, then an important aspect in their life history has been neglected until recently, in that the events of their emergence and seaward migration have been considered as being essentially similar to those of pink and chum salmon.

Among coho salmon a surplus of young fish is usually produced within a given length of stream. This surplus is soon displaced through the aggressive activities of the larger individuals, which thus acquire the available territories where they continue to feed and grow. Studies at Minter Creek, Washington, have shown that the annual yield of coho smolts from a given length of stream is relatively stable, its magnitude being regulated by the amount of rearing space available, and despite considerable variation in egg deposition and emergence of fry. Probably a comparable situation occurs even among ocean type chinook salmon (although there are almost certainly differences in the behavioural mechanisms involved).

In some situations the displaced smaller fry may find suitable territories where they can continue to feed before finally entering the sea. Where this does not occur it might be feasible to transplant such fish to suitable rearing areas in other streams, or to rear them to a desirable size by some other means.

Concerning the larger kind of fry, those that remain in the stream for some weeks, their situation can be examined further, particularly in relation to spawning channels and the effects of flow control in natural streams.

One of the concepts associated with spawning channels must presumably be either that the young fish will leave the channel almost immediately after emergence, or that if they remain a natural food supply will be available to them. In the case of the stream type of chinook, therefore, the situation would be comparable to the production of coho smolts in that it would be necessary to rear the fish for a period of 12 months or more. If ocean type chinooks are produced, then it should be determined what factors account for the production and displacement of the smaller kind of fry, and what factors and their mechanisms determine the survival and growth of the larger kind that remain.

Flow control in a natural stream presents an even more complex set of problems. The biological principles basic to the advocation of controlled flow as a means of enhancing natural production of salmon were originally determined and expressed in terms of a single species (or at most in terms of two or more species dealt with singly). In a natural situation it should be expected that the effects upon the production of the same species might be very different because of interaction with other species of fish that would be present. The Qualicum River, for example, is co-inhabited by large numbers of chum salmon, important numbers of chinook and coho salmon, and smaller numbers of pink salmon and steelhead and cutthroat trout. Although occasions and degrees of segregation may occur there must certainly be considerable interaction between the different kinds of fish. Furthermore, where instances of segregation have been observed, as in the Qualicum River, these have probably resulted from prior interaction. The effects of controlled flow might thus be to enhance the production of species A, or even of A and B, but at the expense of that of C, D and E. Until we determine some of these interactions, and can explain them through a knowledge of the mechanisms that effect them (predation, disease, territoriality and food supply, for example), the final results of flow control in a given situation could be very different from what were originally anticipated.

In considering these matters it appears appropriate to quote from Larkin (1956) as follows: "Freshwater environments offer comparatively little opportunity for specialization in fishes. In consequence many species have a relatively wide tolerance of habitat type, and flexibility of feeding habits and in general share many resources of their environment with other species of fish." Flow control could be expected to alter the original natural framework for interspecific competition. This is not to say, of course, that flow control is undesirable, but merely that at present its results are not predictable. At this stage we appear to be relying too much upon a trial-and-error approach for the solution of a very complex problem.

Age of return - changes following artificial rearing

No evidence on this matter is available at this time for chinook salmon; see remarks under Coho salmon.

Ocean migrations

In general, chinook salmon make extensive coastal migrations, predominantly northwards, and then, at the time of their maturing, southwards towards the streams of their origin. Columbia River and Fraser River fish are commonly taken off Southeast Alaska, and, in the past, even fish from the Sacramento River have been taken as far north as off the Queen Charlotte Islands. Probably all chinook salmon fisheries in the northwest Pacific exploit a mixture of stocks, in many cases of fish from both Canada and the United States. The troll fishery off the west coast of Vancouver Island, for example, takes fish from many Canadian streams together with both natural and hatchery-produced fish from the Columbia River and Washington State. It appears likely that some Columbia River hatchery chinooks have even been caught in such inside waters as Puget Sound and Georgia Strait.

Considering the above, it is obvious that schemes for the enhancement of the production of chinook salmon by artificial techniques must take into consideration their migratory behaviour in the ocean. This applies not only to what extent they may be taken by foreign fishermen, but also to the desired division of catch between our own commercial and sport fishermen. Furthermore, it is also necessary to be aware that the migratory behaviour of fish produced and reared by artificial means might be quite different from that of their natural parent stock (which, in turn, could be associated with changes in their quality and vigor, for example).

(An item that is relative to these points may be mentioned here. In 1964 the estimated Canadian catch of hatchery-produced (1961 brood) Columbia River fall chinook salmon amounted to roughly one-third of the total catch of those fish by all United States and Canadian fisheries.)

Selective breeding

Little has been done in this field with chinook salmon, but some studies have been reported by Donaldson and Menasveta (1961). These authors have made the claim that "Selected stocks grow faster, are more resistant to high temperatures and disease, mature earlier, and have a higher survival rate than non-selected stocks". Some of these results are certainly desirable, although not necessarily all (e.g., change in age of maturing). However, it should be stated that the data presented in the report cited do not appear to support the claim, at least, not in its entirety.

Nevertheless, such studies are most desirable and should be pursued. They have particular importance in the artificial propagation of Pacific salmon, since such techniques themselves could effect a degree of selective breeding over a period of time.

Quality of fish produced by artificial techniques

Studies in this field are also in their infancy, and arguments continue to be made that artificially-produced fish differ from natural stocks in quality, vigour, behaviour and a variety of other ways. An important element of our ignorance here is an almost complete lack of knowledge of the parameters that define the quality of natural, or "wild", fish, and little, if any, work with Pacific salmon is at present being pursued in that direction.

In the current program for evaluating the production of fall chinook salmon in Columbia River hatcheries, R.E. Burrows of the U.S. Fish and Wildlife Service is attempting to measure and compare the quality of the fish that are produced by each of the several hatcheries, and to relate the differences that he finds to their survival. Unfortunately, he has quite ignored wild fish, presumably because he is concerned only with hatchery efficiency. (An example of Burrow's studies is provided in Table I.)

Almost certainly techniques for the artificial propagation of Pacific salmon could be greatly enhanced if more were known of the factors that contribute to the quality and vigour of natural fish. Such researches should be encouraged in Canada; indeed, they might almost be considered as a pre-requisite to an expanded program of production by hatcheries and artificial spawning channels.

Coho Salmon

The eggs

See remarks given under Chinook Salmon

Spawning

The natural production of coho salmon is especially characterized by the fact that they spawn in numerous small coastal streams as well as in the tributaries of larger rivers. There are, for example, more than 1,000 coho salmon streams in British Columbia, and possibly more than 2,000 in Southeast Alaska. The overall production of the species depends upon the individual contributions of these streams, and, unlike that of chinook salmon, it is not dominated by the production of a few major rivers. In British Columbia the top 10 rivers, which form about 1 per cent of all the coho streams in the Province, account for only about 10 per cent of the total annual spawning escapement. This geographical dispersal of coho salmon streams probably favours the species with a degree of "resiliency" against the encroachments of civilization. On the other hand, because of their size and location, most coho streams are especially vulnerable to the effects of climatic variation, and of changes in the amount of precipitation in particular.

As compared with chinook salmon (see preceding section), the spawning ground requirements of the coho are more easily and adequately realized (at least under present-day conditions), and other aspects of the life history of this species appear to be of greater importance relative to enhancing their production by artificial means.

The fry and yearlings

As much as 95 per cent or more of British Columbia coho salmon that survive mature in their third year of life, having spent a year in fresh water before migrating to the ocean.

After they emerge from the gravel the fry disperse quite rapidly throughout the stream, mainly, although not entirely, in the downstream direction. Some fry may enter the sea directly after emergence, but it is believed that few of these survive (since extremely few adults with their freshwater scale characteristics have been found). Some of these early migrants have been observed moving close inshore and entering nearby adjacent streams, and it is possible that some of these are able to take up residence there and survive to the smolt stage.

The extent of the production of these early migrants is not known - that is, it has not been determined in what magnitude and with what annual variation it occurs over a wide geographical range. It is possible that these fish could be salvaged by rearing in fish farms or by transplanting to other suitable streams, and that it would be profitable to do so. However, at present this is not known.

In the Cowichan River system Neave (1949) observed an 8-year average efficiency of 22.8 per cent survival of fry from potential egg deposition. This is high as compared with rates reported for pink and chum salmon at a similar stage of development, which Neave attributed to "more stable conditions of stream flow and bottom material which were apt to prevail on the grounds selected by coho, and to less crowding of the redds".

The results of several studies on the activities and behaviour of young coho during the period of their stream life are pertinent to our considerations of their artificial propagation. Probably most important is that heavy losses soon occur among the fry from predation, cannibalism and disease, and from drying up of the streams during the summer which reduces the living space available to the resident fish. Because coho salmon spend a year in fresh water it might be expected that hatcheries or other facilities could provide means for enhancing their survival to the smolt stage (Neave, 1949; Shapovalov and Taft, 1954; and others).

From a study of the behaviour of coho fry in a natural stream in Oregon, supplemented by aquaria studies, Chapman (1962) concluded that aggressive behaviour was "one important factor causing downstream movement". Aggressive behaviour was virtually continuous; larger fry were dominant and acquired better growth opportunities in defended territories, dispersing the sub-dominant fish downstream. In Chapman's experiments, the feeding of coho fry in excess of requirements did not alter the holding capacity of artificial stream channels. (However, it should be recognized that aggression and also other normal patterns of behaviour among such fish as young coho salmon commonly break down or change under the conditions that are imposed by hatchery troughs and rearing ponds. In hatcheries fish can be reared under very crowded conditions provided they are fed adequately.)

Ruggles (1965) has also observed, and discussed the implications of, the agonistic and territorial behaviour of coho fry. He noted differences in the rearing capacities of pools and riffles in a stream, and with artificial channels determined that greatest smolt production occurred in a channel composed of one-half pool and one-half riffle.

Chapman (1965) made determinations of the net production of juvenile coho in three Oregon streams. Annual gross production was greatly different among the three streams. (Thus, hatcheries might be good substitutes for some streams but not for others.) However, net production per unit area was not significantly different among the streams - "suggesting that spatial needs and (or) food supply are involved in regulating net production".

Hartman studied the role of behaviour in the ecology and interaction of underyearling coho salmon and steelhead trout in three British Columbia streams. The distributions of these two species were similar along the lengths of the streams. However, their micro-distributions were different. At high density levels, in spring and summer, coho occupied the pools, and the trout the riffles. When numbers were lower, in autumn and winter, both inhabited the pools. The segregation that was in effect in spring and summer resulted from interaction which occurred because of similarities in environmental demands accentuated by dense populations and high levels of aggressiveness. Certain ecological demands were different in winter, numbers were lower and levels of aggressiveness were reduced.

Of particular importance in describing the survival of coho salmon under natural conditions have been the observations of Neave (1949), McKernan et al. (1950), Wickett (1951) and Smoker (1953). These workers have demonstrated the existence of a relationship between coho production and stream flow conditions during the period of juvenile freshwater residence. Low precipitation and resulting reduced summer water levels were associated with reduced yields of adult fish two years later.

The studies by Salo and Bayliff (1958) at Minter Creek, Puget Sound, demonstrated that the stream produced a fairly constant annual yield of smolts despite considerable variation in egg deposition and fry emergence. In other words, the stream had a limited capacity for the support of fingerling coho salmon.

The results of comparing natural with artificial production at Minter Creek led Salo and Bayliff to conclude that maximum natural production could be realized with about 300 female coho salmon and an equivalent number of males. They predicted that these would produce about 2250 adult fish, of which 750 would return as spawners to the creek. In contrast, the carrying capacity of the hatchery of 450,000 yearlings could be produced by 300 females; these would yield an estimated 15,750 adults of which about 5250 would escape the fisheries to return to the hatchery. They recommended that "the excess eggs and fish produced by these fish beyond the capacity for holding at the hatchery could be transferred to other hatcheries or planted in streams".

Disregarding costs, the results of the Minter Creek experiments would appear to favour the artificial production of coho salmon as a supplement to that of the stream's natural yield. In actual fact, however, the results are difficult to evaluate. There are several reasons for this, but of particular importance are those associated with the estimates that were made of total marine survival and fishing intensity. In the final analysis it can be said that a reliable comparison of the actual production by the two methods was not achieved.

The following conclusions can be drawn in reviewing these several studies. Provided that the necessary minimum amount of seeding has been effected, the production of coho salmon in a natural stream is limited in the first instance by space and food requirements. The amount of rearing space available is determined by the physical dimensions of the stream and by fluctuations in water levels. The space requirements of individual fish are expressed through their territorial and aggressive behaviour. Predation, disease and possibly other factors interact in a density-dependent manner, and effect further variations in survival. Interspecific competition for the stream's resources - space and food, primarily - has a variable effect upon the production (probably both gross and net) of a single species (e.g. coho), depending upon the numbers and kinds of the competing species. (As suggested earlier in this text, this last point is probably of particular importance when considering the possible effects upon production of flow control in a stream.)

Smolts

There is a small amount of published information on the ocean survival of coho salmon, but very little of it is pertinent or of value to this report. In cases where total ocean mortality was determined on the basis of returns to the natal streams, the fishing intensity on the stock was not known. To date, estimates based on recaptures of marked fish have been most dubious for a number of reasons, including those associated with the use of single fin marks and the associated strong possibility of subsequent regeneration; duplication of marks used in concurrent experiments, and failure to determine and correct for marking mortality.

The Minter Creek data showed an average (arithmetic mean) total ocean survival of wild smolts of 5.20 per cent, with a range over 10 years of 0.91 to 9.38 per cent. Over four years, Shapovalov and Taft (1954) obtained comparable values of 0.98 to 7.72 (average 3.55) per cent. At Hook Nose Creek in central British Columbia, Hunter (unpublished data at the Biological Station, Nanaimo) obtained rates of 6.71 to 20.24 (average 11.79) per cent.

Experiments at Minter Creek included the releases of marked fish after varying periods of rearing (i.e., at different sizes). Thus, rearing periods of 3, 8, 12 and 14 months gave average total marine survival rates of 1.06-8.33 per cent, 3 per cent, 0.06-2.67 per cent and less than 1 per cent, respectively.

Various United States agencies have much unpublished data on the production of adult coho that were raised to the smolt stage in hatcheries, but at this time little of this can be used for this report with confidence. The usual practice at these hatcheries is to rear the young fish so that they will have attained a desired size when they are "ready" to migrate. Mention will be made below of some of the consequences of so accelerating the growth of the young fish that they achieve too large a size before they migrate.

Migrations

In general, coho salmon make shorter and probably more diversified migrations than do chinook salmon, dispersing from their streams in many directions from north to south. For example, Fraser River coho have been taken along the Washington coast, as far south as off the Columbia River, as well as far northwards in British Columbia in both inside and outside waters. Coho from numbers of British Columbia streams have been taken at many points in Southeast Alaska, and also at dispersed locations in the Gulf of Alaska.

There is also considerable evidence that many coho salmon spend their entire marine life in such inside waters as Puget Sound and Georgia Strait. (The taggings by the Department of Fisheries in recent years have again demonstrated this, and they have also indicated that once the grilse size is reached the natural mortality rate is probably quite low.)

Again then, as with chinook salmon, consideration of the values of hatcheries and spawning channels for the production of coho salmon must take into account where the fish may migrate and by whom they may be taken.

Changes in age composition of hatchery fish

The information that will be presented in this section may also be used as an example of a coho hatchery (on the Klaskanine River in Oregon) for which it is claimed that many more adult fish are now being produced than were produced in the past by the natural run to the river. In this particular instance, a fishery that had been closed for over 30 years has been re-established in recent years from the production of the hatchery. The present fishery has taken an annual catch of several thousand fish, and in addition several more thousands have escaped to the hatchery. Currently the rearing facilities of the hatchery have been over-taxed, so that surplus fish have had to be disposed of elsewhere.

The data shown in Table II, and other available information, certainly support these claims. However, one is obliged to pose the question: "How large was the fishery, and what were the spawning runs that supported it during those years, more than 30 years ago, before the fishery was closed?"

Other hatcheries in Washington and Oregon have made similar claims, but comparable data are not available. As will now be described, some of these hatcheries are also accumulating evidence of changes that have occurred in the age composition of the adult fish.

Table II shows the large numbers and proportions of 2-year-old fish that have returned in recent years. The total high production since 1958 is attributed to the large size which the fish had reached before they migrated to sea, which in turn has been credited to enhanced rearing through the use of the "Oregon moist food pellet". The large production of the 2-year-old fish is attributed to over-feeding, which produces overly-large smolts that mature and return one year too soon. (However, note the high return of 2-year-old fish in 1955 which were produced from the 1953 brood, and which were not reared on the Oregon moist pellet.)

The 2-year-old "jack" coho are small fish which weigh between 3 and 4 pounds as compared with an average weight of about 10 pounds for the 3-year-old fish. More than 98 per cent of these "jacks" have been male fish.

Four tentative explanations for the excessive production of these small fish have been given: (1) there may be a very high male-to-female sex ratio at hatching; (2) the sex ratios may be different over the size range, with excesses of males at either end of the size-frequency curve, and a more equal sex ratio in the central area; (3) There may be a differential mortality rate against females which, (4) may be partly natural and partly the result of selective fishing of females, or a combination of both.

The relationship between the implications of these various facts and the objectives of this report are self-evident.

Studies Recommended

In general, the biology of coho and chinook salmon is little known and there is need for extensive study of all phases of the life history. Some particular studies relevant to artificial enhancement that this review of these species suggests are:

1. A comparative study of the anatomy and physiology of the eggs and embryos of Pacific salmon, particularly with reference to coho and chinook.

2. Investigation of the spawning requirements of chinook salmon, particularly as they relate to artificial spawning channels.

3. Investigation of the changing physical and biological properties of an artificial spawning channel for several years prior to introduction of salmon.

4. A study of the reasons for the variable age of seaward migration of chinook salmon and its relevance to increasing production.

5. A study of the effects of controlled flow on the interactions between various species of fish in stream environments, with particular reference to production of coho and chinook salmon.

6. Studies of marine migrations of coho and chinook salmon which would indicate where and when hatchery-produced fish might be caught.

7. Selective breeding studies of various strains of chinook salmon.

8. Studies of the physiology and behaviour of wild chinook fingerlings as a basis for comparison with artificially-reared salmon.

9. Studies of the effects of artificial rearing on age of return of coho and chinook salmon.

References

Chapman, D. W. 1962. Aggressive behaviour in juvenile coho salmon as a cause of emigration. J. Fish. Res. Bd. Canada, 19(6): 1047-1080.

Chapman, D. W. 1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Amer. Fish. Soc., 94(1).

Crutchfield, J. A., K. B. Kral and L. A. Phenney. 1965. An economic evaluation of Washington State Department of Fisheries controlled natural-rearing program for coho salmon (Oncorhynchus kisutch). Manuscript.

Donaldson, L. R., and D. Menasveta. 1961. Selective breeding of chinook salmon. Trans. Amer. Fish. Soc., 90(2).

Foerster, R. E. 1954. On the relation of adult sockeye salmon returns to known smolt seaward migrations. J. Fish. Res. Bd. Canada, 11(4): 339-350.

Larkin, P. A. 1956. Interspecific competition and population control in fresh water fish. J. Fish. Res. Bd. Canada, 13(3): 327-342.

McKernan, D. L., D. R. Johnson and J. I. Hodges. 1950. Some factors influencing the trends of salmon populations in Oregon. Trans. 15th N. Amer. Wildl. Conf.

Neave, F. 1949. Some fish populations of the Cowichan River. Bull. Fish. Res. Bd. Canada, No. LXXXIV.

Ruggles, C. P. 1965. Depth and velocity as a factor in stream rearing and production of juvenile coho salmon. Dep. Fish. Canada, Manuscript.

Salo, E. O., and W. H. Bayliff. 1958. Artificial and natural production of silver salmon, Oncorhynchus kisutch, at Minter Creek, Washington. Res. Bull. Washington Dep. Fish., No. 4.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (Salmo gairdneri gairdneri) and silver salmon (Oncorhynchus kisutch) with special reference to Waddell Creek, California, and recommendations regarding their management. Bull. Calif. Dep. Fish and Game, No. 98.

Smirnov, A. I. 1960. The characteristics of the biology of the production and development of the coho - Oncorhynchus kisutch Walbaum. Vestnik Moscovskogo Universiteta, Biology, No. 1. (Trans. by R. E. Foerster, FRB No. 287).

Smoker, W. A. 1953. Stream flow and silver salmon production in western Washington. Fish. Res. Papers, Wash. Dep. Fish., 1(1)

Wickett, W. P. 1951. The coho salmon population of Nile Creek. Prog. Rept. Fish. Res. Bd. Canada, Pacific Coast Sta., No. 89.

TABLE 7.

1964 HATCHERY EVALUATIONS - SUMMARY SHEET

FALL CHINOOK SALMON

DESCRIPTION OF SAMPLE		PHYSICAL CHARACTERISTICS					HEMATOLOGY				BLOOD CHEMISTRY			PLASMA PROTEIN					GLYCOGEN		PROXIMATE ANALYSIS			
Hatchery	Release Date	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Albumin	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Water	Protein	Lipid	Ash
Spring Creek N.F.H. 1st Release (Clin.)	4/20/64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Spring Creek N.F.H. 2nd Release (Raceways)	4/24/64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Klickitat Wash. Dept. Fisheries	4/28/64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Abernathy Salmon Cultural Laboratory	4/29-30/64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oxbow Oregon Fish Commission	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Spring Creek N.F.H. 3rd Release (Raceways)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Elokomin Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Big Creek Oregon Fish Commission	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Big White Salmon N.F.H.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lower Kalama Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Washougal - 1st release Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Grays River Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Upper Kalama - 1st release Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cascade Oregon Fish Commission	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Upper Kalama - 2nd release Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Little White Salmon N.F.H.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Bonneville Oregon Fish Commission	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Washougal - 2nd release Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Toutle Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Upper Kalama - 3rd release Wash. Dept. Fisheries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Range		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean								[illegible]	[illegible]	[illegible]														
Range								[illegible]	[illegible]	[illegible]														

*Unstressed
**Stressed

Table II. Coho salmon catches in Young's Bay and returns to the Klaskanine River hatchery.

Brood year	Yearlings liberated	Hatchery returns		Commercial catch[a]		Total run[a]		
		2's	3's	2's	3's	2's	3's	Combined
1953	0	<71	110	..	..	..	..	..
1954	699,000	18,368	9,740	0	0	18,368	9,740	28,108
1955	288,000	205	306	..	..	205	306	511
1956	203,000	1,312	966	..	..	1,312	966	2,278
1957	356,000	631	968	..	..	631	968	1,599
1958[b]	410,000	2,616	3,322	0	457	2,616	3,779	6,395
1959	788,000	6,918	4,086	133	2,083	7,051	6,169	13,220
1960	1,124,000	15,234	5,606	803	4,070	16,037	9,676	25,713
1961	1,122,000	6,669	8,942	2,166	11,114	8,835	20,056	28,891
1962	1,603,000	20,179	?	7,986	..	28,165	E29,210	E57,365
1963	1,718,000	..	..	..	..	E24,000	..	..

[a]Test fishing was carried out in Young's Bay in 1961. In 1962 commercial fishing was permitted for the first time in over 30 years. The commercial catch includes only those fish taken in the local fishery in Young's Bay; doubtless an additional number of fish were taken in other more distant fisheries. During the closure small numbers of fish were taken in the sport fishery.

[b]Introduction of the use of the "Oregon Moist Pellet" for feeding.

E = estimated

VI. SUMMARY COMMENT AND RECOMMENDATIONS

by

P.A. Larkin

It is notable that in the terms of reference for these reports there was the underlying inference that the research which was needed was going to be done locally, despite the considerable history of investigations which have been done elsewhere, and on other species of animals. Two comments seem appropriate:

(1) It is likely that findings in some quite distantly related field of investigation may suggest whole new areas of research which should be explored. A good example is the recent growth in understanding of mechanisms of animal orientation, which stems largely from work on insects and birds. Pursued with respect to salmon, this new branch of biology has suggested that transplants may fail if the donor stock is not endowed with orientation behaviour appropriate to its new environment. It is quite likely that some of the biology most relevant to artificial enhancement of salmon will be done by other workers on other animals.

(2) Bearing in mind that British Columbia has a smaller catch of salmon than the United States, the USSR or Japan, it seems likely that more research will be done on these problems outside of Canada than inside. Accordingly, much of our research planning should be done in relation to what's going on elsewhere. Even allowing for what is going on elsewhere the list of research questions which might be relevant is very long and implies more effort than is likely to be expended. Salmon, like all living creatures, are complex and it is no exaggeration to say that obtaining permanent and substantial enhancement may be inherently more difficult than space-age rocketry. Before embarking on any expanded research programs it should be made clear that the problem is not a straightforward assignment in biological engineering - to a large extent we are probably ignorant of the "areas of ignorance".

Coming at the problem in this way, from the direction of what is not known, it would probably be a long time before one could expect to fully justify any attempts at enhancement. Evidently, the most productive approach will be to choose research programs that seem most relevant and to periodically apply the findings to new attempts at enhancement.

<u>Evaluations</u>

It is noteworthy that the reports do not contain recommendations for immediate large-scale field trials of any current techniques. A large number of field trials of this type have been undertaken and are currently being undertaken. However, it is not an exaggeration to assert that the literature on various trial and error types of salmon enhancement contains a large measure of hearsay and anecdote [and in some cases what could be called witchcraft]; and that its major contribution has been appreciation of the difficulties of finding out just what the enhancement effort is doing to the salmon populations. A good example are salmon hatcheries, which after almost a century of experience have yet to be adequately evaluated. Incidental to their main objective, they have resulted in a valuable accumulation of knowledge on disease and nutrition, and have been useful for other types of experimentation. But they have never persistently lived up to the enthusiastic arithmetic which spawned them despite what appeared to be good results in producing young fish. It would seem (with hindsight) that if an equal investment had been made involving fewer hatcheries, better evaluation and more research, we would today have a better appreciation of how to go about building productive salmon hatcheries. The current moratorium on hatchery construction on the Columbia River and its associated very large chinook hatchery evaluation program (in which the Station is involved) is a step in the right direction. It is possible that current hatchery practice is in some instances making substantial and economic contributions, but at this juncture they are either not evaluated or in the process of being evaluated. The same is true of other current techniques such as spawning channels. Thorough evaluation of even a small project is expensive and complex. It would be unrealistic to attempt to pursue every fish cultural project with rigorous observation and controlled experiment. Obviously, only particular opportunities should be exploited for research potential, otherwise a limited effort is dissipated ineffectually. A major investment on one or two such evaluations (such as the Babine Lake development) should be emphasized to the point of ignoring other projects if necessary.

Direct experiments are also time consuming because they await the pleasure of the animal's reproductive cycle. Until recently, because techniques of marking were inadequate, it was usually only feasible to test one or two hypotheses with a year class. Recent developments give promise of a much greater variety of marks for larger numbers of fish over a greater range in individual size, with a resultant multiplication of findings per salmon generation. There seems some prospect that while direct experiments must still take time (and where genetic factors are important, perhaps several generations) they may soon be much more productive of results than previously.

Summarizing:- a number of salmon enhancement techniques have been tried, but to date there has been little if any success. At the present time several large-scale programs are under way in British Columbia and elsewhere using hatcheries and spawning channels. Thorough evaluation of a few selected projects of this kind should be a major and rewarding research enterprise. It is recommended that:

1) Emphasis should be given to an expanded program of evaluation of the Babine Development Project for sockeye enhancement.

2) Participation in the Columbia River chinook hatchery evaluation should be continued, and expanded to include the evaluation of coho hatcheries.

3) From time to time advantage should be taken of particular opportunities for evaluation of current techniques of enhancement. The number of such projects should be limited.

Direct experiments using new techniques

It would be undesirable to confine research attention and evaluation to kinds of projects that are planned by applied fish culturists. The fish culturist's repertoire is perforce comprised of techniques which appear to provide least economic risk. There remain a great many alternate possibilities which while perhaps less likely to produce more fish immediately may open the way to more possibilities in the future. These kinds of projects will be suggested with each new insight into the problems and wherever they seem worthy of a trial they should be pursued with vigor.

In recent years the Station has undertaken two such enterprises involving incubator type hatcheries, one for pink salmon at Kleanza Creek, the other for sockeye salmon at Lakelse Lake. The former studies were terminated by a fire, but indicated among other things: that evaluation was complicated by straying of adults, that departure of fry from the hatchery might be prematurely stimulated by silt and that transplants might be complicated by differences in temperature regimes of the donor and receiving streams. Appropriate research should precede further field trials. The Lakelse experiment is not yet completed, but has to date suggested that the hatchery regime did not substantially increase sockeye smolt production, and that fry produced in the hatchery were less viable than wild fry. Further experiments are indicated and are planned, particularly to indicate the reasons underlying the apparent inadequacies of hatchery fry. It seems likely that there is very much to be learned about the physiology and behaviour of young salmon before satisfactory artificial rearing techniques can be perfected.

Several other possibilities for field experiments have been suggested by various investigators. For example, a few for pink salmon: (1) it might considerably increase the likelihood of success of establishing runs in off years if sperm could be held over for a year, thus providing genetic material of a race presumably adapted to the stream; (2) similarly, with new marking techniques it might be possible to simultaneously test many donor stocks for transplanting pink salmon either to new streams or in off years; (3) massive transplants might overcome depensatory "mortality" occasioned by predators, parasites, cannibalism (by the on-year fish), the fisheries, or straying (which looks like mortality in the results); (4) fry might be moved from fresh water to well out at sea, bypassing the substantial mortality in the first weeks of sea life (but perhaps killing the fry in a different way).

There is certainly no lack of imaginative schemes for field experiment either with pink salmon or the other species, to say nothing of the possibilities in fields such as lake fertilization, lake poisoning, hybridization, selective breeding and so on. What is lacking is a sound enough body of background understanding to ensure that these schemes are really worthwhile undertaking at this time. Field experiments, like evaluations, are relatively expensive, take a long time, and must be thorough to produce results commensurate with the effort. Accordingly they should be few, well chosen and well executed.

Summarizing:- the Station should undertake field experiments which explore new kinds of salmon enhancement but the number of such projects should be kept small to ensure thoroughness. It is recommended that:

1) Studies, begun at Lakelse, on characteristics of salmon fry produced by artificial rearing techniques, should be continued and expanded.

2) Field experiments which will test new schemes for salmon enhancement should be undertaken whenever there is a sufficient body of new information to make an expensive trial worthwhile.

New knowledge

Implied in the foregoing, and evident throughout the reports by the investigators, is the recognition that our ignorance of salmon biology is vast, that attempts at enhancement have been disappointing, and that currently there is need for fresh and widened approaches to the problem. This has been true before - each cycle of disenchantment has brought greater appreciation of the size of the task, and has given rise to demands for new kinds of information.

This is certainly the pattern that has been followed in recent years in the United States where the total research and development expenditure is several times larger than in Canada. For example, associated with hatchery practice there has been substantial development of studies by laboratories devoted to disease problems, and nutrition questions. Similarly there has been a short, recent history of studies on physiology, genetics, selective breeding, attempts at lake fertilization and so on. While for various reasons progress by this large group of workers has been slow there is no question that their existence reflects realization of the many sided complexities of salmon enhancement.

There is also much relevant work going on in Europe and in Japan and the USSR.

To ensure appreciation of findings elsewhere, to provide inspiration for direct experiments, to provide advice for expanding development programs and to provide an appropriate background of understanding, it is necessary to enlarge existing programs and to expand work in all aspects of salmon biology.

Some current studies at the Nanaimo Station which are relevant in this way to questions of salmon enhancement are the following:- (1) some of the much needed studies of early life history of coho and chinook salmon, (2) research on behaviour of sockeye fry in early life history migrations, (3) studies of factors influencing age of maturity of sockeye, (4) investigations on kokanee which may have considerable relevance to the success of fish cultural efforts to increase sockeye production, (5) studies of the relation between egg size and fish size in sockeye, (6) extensive observations on the biology of pink salmon in their early sea life, (7) studies on kidney disease, a particularly important problem in the hatchery culture of chinook salmon, (8) studies on the bacterial flora of stream incubated salmon eggs, (9) extensive research on spawning behaviour of Pacific salmon.

To broaden the current activities in directions most likely to best supplement present investigations here and elsewhere and to best complement the program of enhancement of the Resources Development Branch, the following actions are recommended (and are planned for 1966-67 and in estimates for 1967-68) in addition to studies recommended above on evaluation and direct experiments:-

(1) addition of a geneticist to consider problems in heredity, selective breeding and hybridization of salmon.

(2) addition of new studies on egg physiology and behaviour to increase understanding of reasons underlying failures of current fish cultural techniques, and to suggest new techniques.

(3) expansion of studies at Burke Channel to obtain better understanding of early mortality of pink salmon in the sea.

(4) emphasis on nutrition and growth studies in physiology.

(5) addition of a stream biologist to pursue studies of wide application to enhancement techniques and pollution.

(6) addition of studies on diseases of wild populations of salmon.

(7) additional studies on parasites of salmon and their incidence and effects in natural populations.

With additional resources in future years, further activities in addition to evaluation and direct experiments mentioned above, might include several more of the lines of investigation recommended in the reports on individual species. Notable among these would be:-

(1) inclusion of more research on early life history of coho and chinook salmon for which there will be growing problems. The present studies of this investigation are in an expanding phase that should suggest many new lines of study.

(2) studies on chum salmon, particularly the early life history stages that are involved in current salmon enhancement projects.

(3) studies on spawning requirements of all species of salmon.

(4) studies on "dominance" in sockeye populations.

(5) detailed investigation of homing, particularly of pink and sockeye salmon.

(6) predator control studies particularly for sockeye salmon.

Conduct of Research

It is valuable to emphasize that while the foregoing indicates what might be undertaken in the view of the authors, that in the actual doing of the research, the investigators should decide what is to be done and how to do it. For this reason it is most realistic to outline only the problems of concern, but not to plan patterns of activities that will restrict the potential contribution of the researchers.

VII. SUMMARY AND RECOMMENDATIONS

by

W.E. Ricker

Two general types of research are recommended:

A. Increased field and laboratory studies of requirements, tolerances and causes of mortality of salmon in the context of their total environment

All five species of salmon must be studied individually. All life-history stages may receive attention, but the younger stages are particularly suitable because with them the opportunities for increasing survival are greatest. Eggs, fry, fingerlings and (for coho and sockeye) yearlings are specially involved, and early sea life must be included. Such studies make it possible to predict likely results of enhancement procedures.

B. Field trials of measures that seem promising in the light of work done to date or in future

Field trials should be conducted as tests of hypotheses, with full use of controls, so as to learn whether the predicted increase in growth or survival is actually being attained, and if not why not. In this way failures as well as successes will contribute importantly to the final goal.

Some field trials that will of necessity involve large-scale installations and operations should be discussed with the Resource Development Service to see if a cooperative effort is desirable.

A field trial can be started as soon as information is available indicating a promising line of attack. However, there will usually be required one to several years of background study at the site chosen (unless it has already been adequately studied).

These two approaches, A and B above, are at once complementary and interdependent. Detailed physiological and ecological studies will suggest promising field trials; while field trials will frequently provide unique opportunities to test tentative conclusions by observing the young fish in a new or modified environment.

A. Laboratory and field investigations

(1) Comparative physiology and embryology of eggs of the 5 species of salmon, and even of individual stocks within a species, especially their requirements in relation to temperature, oxygen and other environmental conditions.

(2) Study of spawning requirements (gravel size, depth, current, etc.) for all species of salmon.

(3) Additional study and comparison of behaviour and development of fry in gravel and under exposed (normal hatchery) conditions, and determination of their subsequent survival. Comparison of chums and pinks with sockeye in these respects; later also cohoes and chinooks.

(4) Studies of animals, plants and bacteria in the gravel of spawning streams of different types, and in controlled-flow situations. Survival of salmon eggs and fry in different natural or experimental situations involving different faunas and floras.

(5) Additional study of early sea life of pink salmon at Burke Channel and possibly other sites, to identify causes of mortality and learn if any are avoidable.

(6) Similar studies of chum salmon at a suitable site or sites.

(7) Studies of diseases of salmon in nature, especially among the younger stages.

(8) Similar studies of salmon parasites.

(9) Selective breeding of stocks (with or without hybridization) that would be better adapted to artificial conditions of various sorts (hatcheries, channels), or would have superior growth, survival or market characteristics.

(10) Study of life-history (especially causes of mortality) among stream-type sockeye salmon, to see whether their present limited distribution reflects special requirements that exist in only a few places.

(11) Small-scale experimental introduction and study of Pacific salmon of foreign species or stocks, where there seems a possible advantage in this.

The only new species available is the masu salmon, and the possible advantages of masu over cohoes (which have a similar life history) are not obvious, but could be examined. Many stocks of Asian chum salmon feed in fresh water and go to sea at a larger size than ours do. Such a stock might produce a greater surplus for catch than native stocks in some British Columbia streams.

(12) Small-scale experimental transplantations of stocks to learn more about what governs success or failure.

This project awaits the development of good fry-marking techniques so that many donor stocks can be tested simultaneously at a single site. Another very useful technical development would be storage of live sperm for a year, so that native pink salmon genes could be introduced into imported off-year runs in places where one of the two lines is missing.

(13) Detailed investigation of homing in 4 species of salmon.

This knowledge is required in relation to (11) and (12) above, and for other purposes. Only sockeye have been extensively studied to date.

(14) Assessment of the possible value of predators in maintaining large average size of the individual fish, especially among pink salmon.

It is well known that smaller sockeye smolts do not survive nearly as well as larger ones, and that the smaller smolts of a year-class tend to produce the smaller adults at any given age. Parker's recent observations suggest that the same may be true of pink salmon fry. He notes also that in a year of exceptionally good survival (1960 brood, maturing in 1962) the size of the adults was unusually small on the average, and also very variable. If these effects result from a (partial) failure of predators to knock off the slower-growing fry and fingerlings, then any scheme to increase survival of young pinks substantially would unavoidably produce small-sized adults. However, it is also possible that the sizes noted in 1962 were mainly a result of competition for food among members of the unusually large population. An experiment to test these alternatives should be carried out as soon as feasible.

(15) Control of predators during a critical life-history stage.

Life-history stages in which salmon are particularly vulnerable to predation include (a) fry during downstream migration after emergence from gravel, (b) fry in lakes near the mouths of inlet streams, (c) fry and smolts during downriver migration and in estuarial waters. All these stages last only a short while, and it is possible that destruction of predacious fishes of little value during a brief time-period could produce important benefits at low cost. The procedure proposed is to examine sites where predation on salmon seems likely to be heavy, to evaluate it quantitatively and determine the species involved, and to experiment with selective control procedures preparatory to field trials.

(16) Rearing salmon to market size in salt water, using low-cost fish as the major food.

There are at present in British Columbia three major sources of fish protein that have a low unit value: herring (used for reduction), scrap groundfish (used for mink food), and dogfish (not used except under government subsidy). All are possible hatchery foods for salmon, and conversion rates of 5:1 or better can be anticipated. Studies should be begun as soon as possible to establish appropriate diets for fast growth and (in the terminal stages), good flavour; also densities of fish that can be maintained, water flows needed, etc.

B. Field trials

The procedures listed below already show some promise of making a substantial contribution to increasing salmon stocks, on the basis of observations and research done here or elsewhere.

(1) Evaluation of the usefulness of artificial spawning channels for sockeye.

This major field trial is already underway at Babine Lake, in cooperation with the Resource Development Service. Similar work using chum and pink salmon should be planned for the near future.

(2) Evaluation of production of chinook and coho hatcheries by marking experiments, and of wild fingerlings and yearlings.

We are already assisting with a United States experiment on hatchery chinooks. It is proposed to add cohoes next year, and the project has several years to run. It would be desirable to add fish from a Canadian hatchery to the group, if one is established. Meantime we could get some additional benefit from this big recovery effort by putting out our own marked native fish - because we have almost no information on percentage contribution to the fishery and returns from the sea of wild coho and chinook young. Naturally-produced migrants should be used. A problem is the limited supply of marks available. However the micro-wire tagging technique makes the experiment technically feasible for coho smolts at least, provided a fin mark (adipose only?) is used in conjunction.

(3) Transplantation of chinook and coho adults or eggs or fry into reaches of streams above impassable barriers.

Unused stream habitats seem to offer the greatest immediate potential for increasing stocks of these two species, cohoes in particular. The experiment should be done at one or a few sites, and results evaluated by sampling downstream migrants, marking same, and collecting adults in the fishery and near the stream barrier. See (2) above for fishery recovery possibilities. Only stocks native to the stream should be used for transplantation above the barrier in this particular experiment.

If good production of adults is obtained, there will arise the question of whether it can be most economically maintained by continued transportation or by construction of a fishway.

(4) Large-scale transplant of pink salmon to a site where the off-year is blank.

It is necessary to test Dr. Neave's hypothesis that in localities where off-year pink stocks are small or absent there is a minimum stock size below which the population cannot maintain itself. The actual transplant should be preceded by at least two years' study, one of the "on"-year stock in the area in question, and one of the stream in an off year.

(5) Best utilization of surplus fry.

Sockeye and cohoes both typically live for at least a year in fresh water before going to sea. There is considerable evidence that it is Lebensraum in the fry and fingerling stages (rather than the egg stage) that usually limits the abundance of cohoes, and the same is probably true of sockeye in some lakes or parts of lakes. Under such circumstances annual or sporadic surpluses of eggs and fry are almost unavoidable in some areas, and the question arises as to whether eggs might be taken or fry captured and used to advantage elsewhere. Lakes or streams not at present used by these species seem to offer attractive possibilities.

Transplants of cohoes would be similar to those under (3) above except that the stock used would in general not be native to the stream in question.

Regarding sockeye past experiments in stocking fishless lakes, though not well documented, sometimes resulted in production of fairly large numbers of residuals as well as smolts; and in fact the situation for sockeye is really at the experimental rather than the field-trial stage. Comparison of introductions into different kinds of lakes, for example those with and without other fish, might yield critical information.

For any wide adoption of this procedure an important point will be that of establishing where surpluses of fry exist. In a few places fry are taken downstream into unsuitable waters without opportunity of return, and these should be given first consideration. More generally it will be necessary to evaluate the fry requirements of a stream or lake before deciding when the optimum number has been exceeded.

(6) Fertilization of sockeye nursery lakes.

Present-day average levels of adult fish obtained from some of the most famous sockeye nursery lakes continue to lag behind historic levels (for example, Karluk, Babine, Shuswap). What is more disturbing, the estimated maximum levels of yield from optimum spawnings also seem low in comparison with earlier times. A possible hypothesis is that the dead adult salmon are of value to their young in the lake, either by a fairly direct food chain (e.g. adult→bacteria→entomostrocans), or by less direct contribution to the lake's biological economy via "mineralization", so that with today's smaller spawning populations the lake has a reduced capacity as a nursery for the young fish. Experimental fertilization of a small Alaska lake with inorganic fertilizers increased the growth rate and survival of sockeye there for the short time it lasted.

While fertilization of a large lake would be fairly expensive, it should be compared with the value of the extra salmon produced. This <u>might</u> be much the most economical method of increasing the production of adult sockeye from some lakes. The extra adults could be obtained by increasing the <u>size</u> of the smolts, rather than their numbers, since marine survival increases rapidly as smolt size increases.

All aspects of this situation require intensive study, and a lake should be selected as soon as possible for background studies prior to experimental fertilization.

Conclusion

The research projects and field trials listed above include projects that have been discussed and advocated at both the Nanaimo Station and the Vancouver Laboratory. The exact division of labour in future can be worked out in the light of future budgets and facilities at the two sites.

To start now on all the projects listed (not to mention others that will soon be developed) would require men, resources and facilities greatly in excess of the present west-coast budget for biological salmon investigations. Thus priorities among investigations and field trials will have to be set up, related to their promise, cost, men available and so on. No important source of funds or manpower is available within the two stations without crippling other important lines of work.

If Canada is serious about increasing the salmon resource in a major way, we must think in terms of eventual annual expenditures of tens of millions of dollars for operating and maintaining the necessary facilities. In this context, it would seem desirable that research effort needed to make such facilities effective be limited "only" by our capacity to plan good programs and find good investigators, rather than by availability of money or positions.

Printed in Canada by the Canadian
Government Printing Bureau for the
exclusive distribution by Fisheries
Research Board of Canada,
Nanaimo, B.C., Canada