BULLETIN No. 114

Salmon research and hydro-electric power development

By

J. R. BRETT

Fisheries Research Board of Canada
Biological Station, Nanaimo, B.C.

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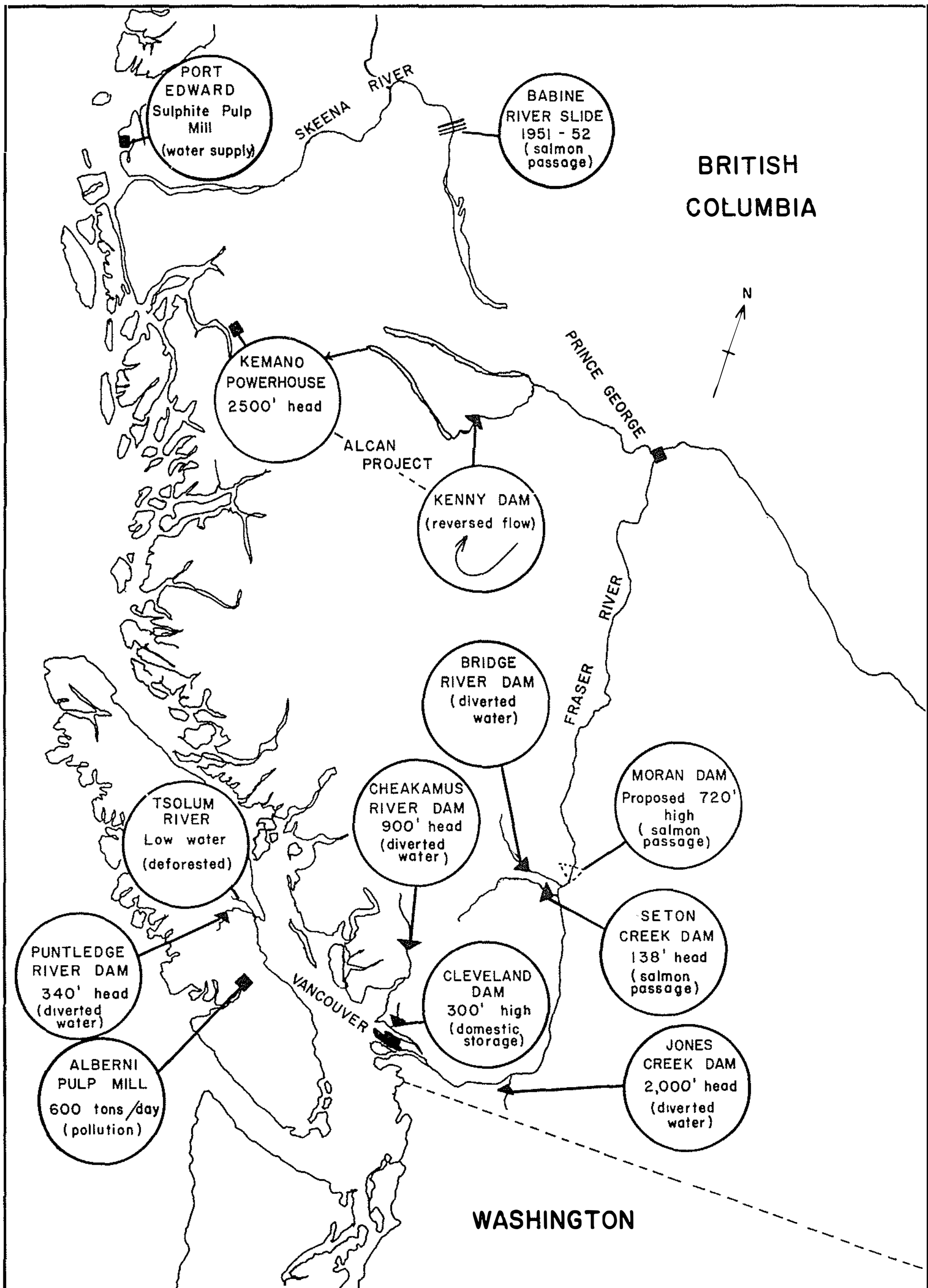

Map of British Columbia depicting typical locations where problems to migrating salmon occur, and referred to in text. The examples shown represent only a fraction of the existing or potential sites where power or other industrial developments could have serious effects on salmon.

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W. E. RICKER
N. M. CARTER
Editors

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91691—2

CONTENTS

91691—2½

FOREWORD

The purpose of this review is to outline the salmon problems which are created by hydro-electric power developments, to set forth some of the basic principles for biological research, to summarize the research in this field conducted by the Fisheries Research Board of Canada, and to indicate specific lines of study with their requirements.

The urgency and magnitude of the biological task can hardly be overemphasized. There is an inescapable conclusion that a great deal of biological research on salmon must be conducted before even judgement on many of the problems can be made, aside from the major undertaking of finding solutions.

Since the problem is both multiple and complex, no delusions should be entertained concerning the possibility of some quick or simple solution. Any new mechanical contrivance expected to aid salmon at some point in their migration will create new biological problems. It is the *lack of knowledge of salmon that is the great handicap.* This handicap can only be surmounted by a thorough program of research directed at the fish first, from which the problem *may* be resolved, wherever possible.

The program should involve an integrated study on fundamental and applied salmon biology.

It should be pointed out that large sums of money are being devoted to solving the problem in the United States, and a solution may be forthcoming, but at present there is no clear indication that such can be expected in the near future, despite the fact that segments of the research show promising advances.

There seems to be one fundamental limitation which has pervaded much of the earlier approach, mainly as a result of the pressure applied to solve imminent, vital problems. The research has been designed to solve some predetermined aspect of the problem, and entirely hinged to this aspect, *not* to the basic principle of finding out something about salmon and seeing where this new knowledge can be used.

The prime purpose of this report is to point out the necessity of learning more about salmon, and to give some direction as to how this may be channeled into pertinent lines.

I. INTRODUCTION

The dependence of Pacific salmon on a suitable freshwater environment during migration and early stages of development has placed them in direct competition with other multiple uses of water. Through hydroelectric power developments, water storage, irrigation, and waste disposal, fresh water is dammed in flow, de-energized by velocity change, depleted in volume and altered in quality. The problems of maintaining anadromous stocks of fish in the face of such changes are many. Their solution, where possible, depends in large measure on a thorough understanding of the behaviour of salmon, the limits of environmental change which salmon can tolerate, and in devising means whereby salmon can be successfully by-passed around obstacles in the path of migration.

Multiple use means multiple change, which, in turn, means a variety of new conditions and stresses applied to salmon. Not all of these need be considered adverse[1], but many of them undoubtedly are and some are obviously lethal. The need for concentrated research is implicit in the fact that it is nearly twenty years since the completion of Grand Coulee dam on the Columbia and it is still doubtful whether any different conclusion could be drawn now than was made then—that the introduction of the 350-ft. Grand Coulee dam meant the end of anadromous salmon in the upper Columbia River[2]. Considerable advances have been made and much effort is at present being expended in the Pacific Northwest towards a solution[3]. The fact that the problem has not yielded to these efforts signifies the magnitude of the undertaking. A report composed in 1951[4], dealing with problems to be studied, listed over one hundred discrete aspects requiring investigation. Two comprehensive reports have recently been made, one dealing with the consequences of building ten dams on the Fraser-Thompson system (Anonymous, 1955) and the other with the general problems created in fisheries by power developments (Larkin, 1956). There is no need to add further emphasis to the multiplicity of the problems detailed in these reports. It is this very multiplicity which calls for a classifying of the problems in an effort to find common denominators, thereby clarifying the path and basis for biological research.

To anticipate the deductions drawn in the course of this review, the themes of research fall into categories dealing with (1) physiological energy release and

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[1] Moffett (1949) records that below Shasta Dam on the Sacramento River, conditions were "greatly improved for the natural production of salmonoid fishes". However, the same dam prevented salmon from having access to long reaches of suitable water upstream.

[2] Fish and Hanovan (1948) estimated that approximately 1,140 lineal miles of spawning and rearing grounds were cut off above Grand Coulee Dam.

[3] "During 1955, over $3,000,000 was spent in the Pacific Northwest on study of the phases of the fish power problem" (Larkin, 1956).

[4] Mimeographed report, August 21, 1951, Portland, Oregon: "A program for determining the means of successfully passing both upstream and downstream migrants of anadromous fish over dams".

conservation, (2) the capacity of the fish to meet cumulative stress and remain active, and (3) the mechanics of migration with its concomitant sensory relations and particular behaviour patterns.

In the final analysis, the object of all research should be to permit adult salmon to reach the spawning grounds in fit condition, and to make it possible for healthy young migrants to pass into the sea. Anything short of this is a compromise likely to result in declining stocks of salmon.

II. SALMON PROBLEMS

The following outline of the factors affecting migrating salmon has been made, not in an attempt to deal in detail with the various factors, but rather to cover in broad terms the general problems which arise. They are considered in order, commencing at the estuary where the adult salmon leaves salt water, passing upstream to a point beyond the influence of hydroelectric power or other development, and the subsequent downstream migration of the young. Typical examples of where such problems exist have been drawn mainly from cases in British Columbia, supported by a few of the many other instances which exist elsewhere in the Pacific Northwest.

STAGE: ADULT MOVING UPSTREAM

1. *Delay* in leaving the estuary or moving upstream in fresh water because of low discharge.

This occurs in nature during dry years, and it can also result from upriver storage of water. The question which arises is, how long can delay in salt water or fresh water occur without affecting the ability to move upstream and to spawn effectively?

EXAMPLES: Cleveland Dam (Capilano River)[5]; Tsolum River[6].

2. *Changes* in freshwater quality from increased temperature, reduced flow and/or the addition of sewage or industrial wastes.

Temperature affects activity[7], behaviour, resistance to disease[8] and rate of maturity, while pollutants can be toxic, reduce the oxygen content and possibly act as a deterrent to upstream migration.

EXAMPLES: Any dam or disposal of wastes results in such changes. The Alcan and Puntledge River projects[9] are examples of the former, while the Alberni canal problem (Waldichuk, 1954) exemplifies the latter.

3. *Diversion* of "home-stream" water provinding a false or impassible passage either downstream from the "home-stream", or upstream from it.

This can result in the diverting of salmon into passages for which there is no access to adequate or "home" spawning beds, or persistent attempts by salmon to enter the false path of the diverted water, which is released from an impassible source (e.g., draft tube of turbines). The consequences are either poor spawning or no spawning.

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[5] Hourston and Larkin (1955) have published a full report on the problems involved in the Cleveland Dam project.

[6] See news item, "Drought brings death to salmon", Prog. Reports of the Pacific Coast Stations, Fisheries Research Board of Canada, No. 88, p. 72, 1951.

[7] The general principles of temperature and activity are discussed by Fry (1947). See Sections IV and V for experiments on young salmon.

[8] Fish (1948) attributes the great losses in Columbia River sockeye during 1941 to high temperatures causing an epidemic bacterial disease.

[9] Clay and Hourston (1955) have reviewed Canadian "Fisheries problems related to major industrial projects on the Pacific coast, 1949-1955". These projects and others given as examples herewith are outlined in their review.

EXAMPLES: Jones Creek[10], Seton Creek, Puntledge River, Cheakamus River. This is the most common and pressing problem in British Columbia at the present time.

4. *Obstruction* of passage by dams of varying height with a built-in by-pass system (ladders, elevators, locks). The problems associated with such structures involve the question of whether salmon will find and enter the by-pass, and do this without excessive delay[11], injury, fatique or loss of energy from attempting to fight the spill water or enter the draft tubes[12]. If the by-pass is entered, there may be delays in passing through because of behaviour inconsistencies resulting from inadequate by-pass design.

EXAMPLES: Any mainstream dam such as those proposed for the Fraser River (Anonymous, 1955) and already present in the Columbia River.

5. *Passage* upstream through reservoirs of varying length, depth and storage.

Here again, the problem of delay in passing upstream to former or new spawning grounds can occur in the reservoir. In this instance it is a behaviour delay. The increased temperature and possible stratification may act as deterrents[13], or the reduction of flow may remove a directive factor. The former environment is altered vastly, and behaviour responses in the salmon are involved. The five salmon species have different migratory and spawning habits which must be satisfied by the right environmental conditions. When a dam floods out the spawning grounds of the salmon, any directive odour from them would be effectively lost.

EXAMPLES: The proposed Moran Dam on the Fraser River would have a reservoir of about 165 miles in length. Pink salmon spawning grounds would be flooded out by dams in the Thompson River.

6. *Final migration* upstream with completion of efficient spawning.

Having surmounted the obstacles and covered the distance from estuary to spawning ground, the adult salmon must be in fit condition to carry out the final act of spawning and egg deposition.

EXAMPLE: The spawning efficiency of the salmon that got over the Babine River slide in 1951 was seriously impaired (Godfrey *et al.*, 1954). In 1955, some Stuart Lake sockeye were reported to be either not making the journey or were dying "exhausted" on the spawning grounds. These occurences resulted from

[10] The Jones Creek project (Neave and Wickett, 1955) is more properly a problem of reduced flow, although diverted head-water is involved. If salmon had spawned in or above Jones Lake, this problem probably would have arisen.

[11] Delay effects are considered to be one of the most problematical aspects resulting from dam constructions. Repeated reference appears in "A report on the fish facilities and fisheries problems related to the Fraser and Thompson River dam site investigations", Anonymous, 1955. Direct evidence on the proposed dams is obviously not available. Reference to the deleterious effects of delay at Hell's Gate has been made by Thompson (1945). This is valid where delay from turbulent, high velocity water occurs, accompanied by fatigue and injury. If the delay is strictly from behaviour relations (fish holding in pools of ladder, etc.) the Hell's Gate conditions cannot be considered applicable, since the fatigue or injury question may not be involved. Where fish are found to fight the spill water a comparison with Hell's Gate might be made. The problem of delay where behaviour only is involved can become serious if it persists to the point of advanced maturity and decreased energy reserves, either one of which could reduce the chances of spawning. Delay at Bonneville Dam has been reported by Schoning and Johnson (1956).

[12] It is now standard design on major dams in the Columbia River to build a collecting device across the downstream face of the powerhouse (see Holmes, 1940).

[13] Despite the fact that salmon in the Columbia have ascended over 60 feet of head by passing through the Bonneville fish-ladders, there are unexplained losses between this point and Rock Island, and no increase in the rate at which salmon travel through the reservoir over that for normal river velocities (Anonymous, 1955).

"natural" obstacles, and are indicative of the problem. There are some unaccountable losses between the major dams on the Columbia River. The answer may be altered behaviour, disease, or possibly an exhaustion state.

Stage: Fry, Underyearling or Yearling Moving Downstream

7. *Passage*: downstream through reservoir.

The differences between the species of salmon pose three distinct problems at this stage. 1. Chum and pink salmon fry usually migrate in streams and rivers moving directly downstream to sea. It is questionable whether they will migrate through large bodies of relatively still water (MacKinnon and Brett, 1955). 2. Coho and chinook (spring) salmon inhabit streams as underyearlings and use this area for early development. The loss of former stream habitat may therefore occur. 3. Sockeye normally move through lakes in the spring of the year and thermal stratification is thought to curtail their migration. Addition of another large body of water may result in a second year's residence in fresh water, or they may never go to sea[14].

Examples: One or more of the above effects are involved in the power developments on Seton Creek, Bridge River, and the Puntledge River, as well as at the proposed Moran dam, etc.

8. *Passage* over or through dams used for power, storage or irrigation, without a by-pass.

Losses and impaired function are involved resulting from pressure changes in turbines, impact on runners, entrance into irrigation intakes, abrasion on the spillway surface, or from turbulence at the base of the spill (see general discussion by Clay, 1955).

Examples: Cleveland Dam, and Puntledge River power plant.

9. *Entrance* to by-pass and *transportation* to downstream release point.

To date, the only downstream by-pass which has been built at a large dam is at Bonneville on the Columbia River[15]. The number of migrants using it is negligible. The problems of leading the fish to the by-pass, their entry and safe passage through the by-pass are all part of adequate conservation measures. These become all the more involved when changes in spill and forebay level occur.

Examples: Common to most high dams where a by-pass is desirable, but only Bonneville now has a by-pass.

10. *Condition* and *vulnerability* of young salmon in the tailrace.

The manner of release of migrants, their condition, the re-establishing of normal behaviour following passage over or through a dam or by-pass, and any accumulation of predators in this area, each and all can affect survival.

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[14] Ward (1927) describes the occurrence of large numbers of "landlocked" or "residual" sockeye in the Baker River system after a high dam was constructed. Foerster and Ricker (1952) report that 80% of Cultus Lake coho remain as residuals and do not contribute effectively to the spawning population. Ellis (1956) is conducting an experiment on carrying young fish through some of the Columbia River reservoirs by barge, and will be comparing survival of returning adults with controls liberated upriver.

[15] There are a number of small by-pass facilities for power take-offs where the discharge is comparatively low—e.g., Bull River, Oregon, and Columbia Cellulose water supply, Port Edward, B.C. These depend on rotating screens for diverting the migrants.

91691—3½

11. *Changes* in quality of downstream water through which young salmon pass to reach the sea.

As in the case of the adult salmon moving upstream, so the downstream migrant must not be subjected to toxicity, decreased oxygen and raised temperature to such an extent that seriously reduced activity or losses are sustained.

EXAMPLE: Somass River development and Alberni canal.

In addition, the effects of multiple dams and the particular problems arising during construction are numerous and cumulative. No further listing is required here, but the significance of the increased problem should be stressed.

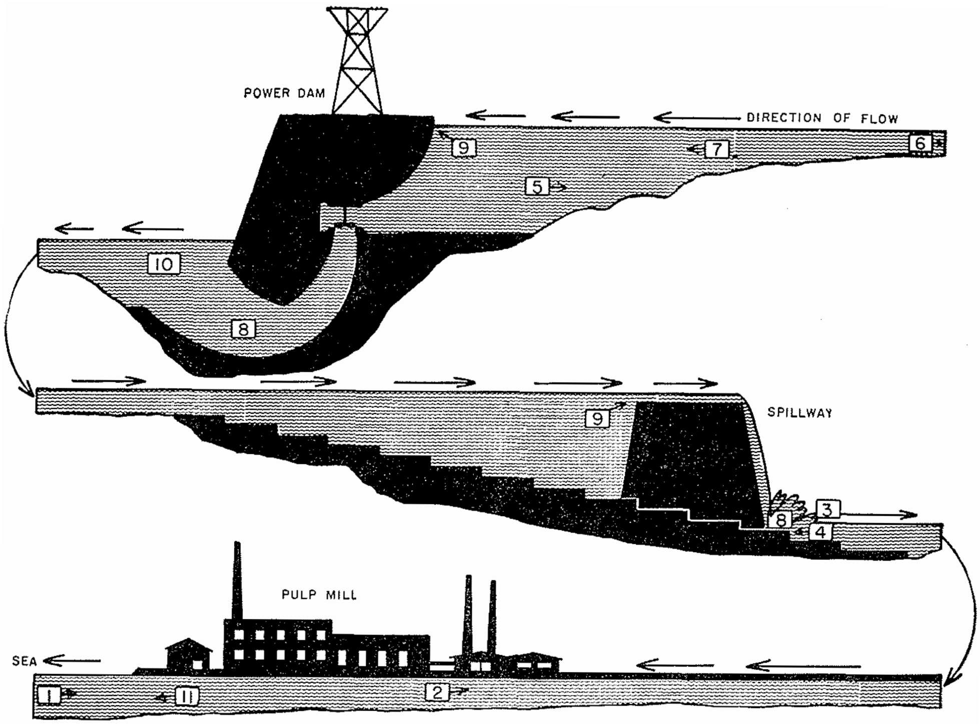

FIGURE 1. Diagrammatic representation of problems created for salmon by multiple water use.

Upstream Migrant

1. Delay from low water.
2. Pollution and raised temperature.
3. Diverted "home-stream" water.
4. Blocked passage and by-pass delays.
5. Passage through reservoir, and flooded spawning grounds.
6. Final spawning efficiency.

Downstream migrant

7. Passage through reservoir, and habitat limitations.
8. Mortalities in turbine or spill.
9. Guiding and by-pass problems.
10. Predator accumulation.
11. Changed water quality.

III. RESEARCH PRINCIPLES

The diversity of the above problems is very great. Only through integrated research, embracing the whole complex of migration, can systematic advances be made. In 1951, the focus of research attention swung to methods of getting young salmon safely downstream. By 1955, the prospect of a multiple dam development on the Fraser-Thompson system brought out the lack of adequate knowledge available for ensuring the safe passage of large numbers of adult salmon upstream; and the fact remains that the prime problem in British Columbia at the present time is what to do about water diversion.

The first question is, how should the total research be formulated? Undoubtedly, it must be framed around the responses and capabilities of the fish, but not every capability and every response. Urgency requires that the research be along the most expedient lines. An inspection of the series of problems facing salmon during migration shows recurring type problems. The question of *delays*, of ability to withstand *stress* of one form or another, the effects of *changed environment*, and the problem of altered or misdirected *behaviour*—these are prominent in the whole scheme of events. Within such limited catagories, the basis of research can be laid. Some of the principles will be discussed under the following headings (to which has been added the type of problem outlined in Section II).

Category	Number relative to Section II
A. Energy dissipation	1, 2, 3, 4.
B. Stress and activity	1, 2, 4, 5, 6, 8, 10, 11.
C. Hormonal state	1, 2, 4, 5, 6.
D. Behaviour and sensory perception	2, 3, 4, 5, 7, 8, 9, 10, 11.
E. Interaction	A × B × C × D.

A. Energy Dissipation

By the time the adult salmon has reached the estuary, it has become, in essence, a conveyor[16] of a mass of developing eggs or sperm, to be transported to a suitable location where spawning can occur, Since there is no food intake[17] for the balance of its life, the salmon must be equipped with enough fuel in the form of stored fat and convertible protein and carbohydrate to cover the distance and engage in spawning and defensive activities. Excessive demand on these stores from activity directed in false passages, prolonged delay[18], or continued high temperature resulting in fuel depletion means death before spawning. Total fuel requirements, allowing for some reserve, must not be exceeded.

[16] It should not be thought that it is a *simple* conveyor. The eggs are maturing within the subtle medium of the nutritional and hormonal complex of the ovary.

[17] Incidentally, this is a great asset to experimentation, since no complications of energy intake and efficiency of food conversion are involved, and no feeding during experiments is required.

[18] Natural "delays" may occur for considerable periods of time, but these usually take place in lakes or in relatively quiet portions of rivers. At Lakelse Lake, B.C., a period of 2 months is spent in the lake while the adults mature.

Salmon take an average of 33 days to cover the 365-mile journey from the sea to Babine Lake (altitude 2,200 feet) against a current velocity of about 3 m.p.h. Assuming they do not receive mechanical aid from the energy of moving water[19], they must burn enough fuel to cover the distance, and maintain basal metabolic demands for that period at whatever temperatures are present in the river. They must also have enough additional fuel to last until fully mature (possibly another 30 days) and dig the necessary redd.

The most fundamental basis, then, is the balance and exchange of energy. Without adequate fuel, there can be no spawning success. An assessment of fuel consumption, energy demands (under normal and changed environmental conditions) and the limits of supply, must be made for salmon in general[20], and must be applied to specific cases.

The principle of energy dissipation and its limitations is the basis from which to proceed.

B. Stress and Activity

STRESS. Whether in terms of natural or unnatural factors, the environment imposes an overall stress on an animal. Temperature, salinity, acidity, predators or competitors—all physical, chemical and biotic elements, bring some demand on the animal to face up to and meet its total environment. Survival is the measure of success, but "bare" survival is not enough. At any one time, it must be survival of an animal still capable of meeting the balance of environmental experience, including reproduction.

For salmon, the differential between the salt concentrations of blood and of fresh water imposes an osmotic stress. It must do work to maintain internal balance, resulting in an increased metabolic load and reflected by an increased rate of oxygen consumption. A rise in temperature steps up every bodily chemical process and likewise calls on energy release. Any environmental or internal stress places a demand on the fuel supply. There is a quota for the load from the sum total of stresses. This quota is set by the amount of fuel within the animal's system *less* that amount for all activities from swimming to spawning.

The above applies to stresses which have not reached the lethal limit. A measure of the lethal limit of any of the environmental stresses is a consideration in itself (e.g., temperature, pressure, toxicants) and obviously sets the extreme limits of enviromnent tolerance.

A distinction can be made between two types of stress, *discriminate* and *indiscriminate*. A discriminate stress is here defined as one which applies at any time to certain individual fish within a population, but not to every fish. Thus,

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[19] Salmon have been observed "gliding" in fast water without any noticable swimming action. Back eddies exist and could be used by migrating salmon. This requires study.

[20] Studies on the physiological and biochemical changes in adult salmon during spawning migration have been reported for chinook salmon by Greene (1915, 1926) and for pink salmon by Davidson and Shostrom (1936). In the chinook salmon, fat reserves at spawning time were depleted to 2% and less of their initial level, and muscle protein fell by 30%.

Currently the Fisheries Department of the State of Washington, and the International Pacific Salmon Fisheries Commission working in conjunction with the Fisheries Research Board of Canada, are both conducting investigations on the depletion of salmon energy-reserves, in the Columbia and Fraser Rivers respectively.

Some measurements of glycogen metabolism have been made by Fontaine and Hatey (1953) on Atlantic salmon. These suggest that glucose balance is maintained but do not treat the subject thoroughly enough to be conclusive.

predation and fishing can be considered discriminate stresses, exterminating individual fish without affecting the "escaped" fish. Fishing can remove 50% of a population and the balance proceed unaffected to spawning grounds. The status of the remainder may even be improved in some respects, if competition on spawning grounds has been removed.

An indiscriminate stress is one which applies to every fish and is not selective in its effect. Stresses like high temperature, low oxygen or toxic effluents spare no individual entering or inhabiting an environment with such characteristics. There are differences between individual fish in their ability to resist the stress, these resistances frequently being normally distributed throughout the population. Thus, if an indiscriminate stress removes 50% from a population, it means that the balance are suffering though surviving, and that very little additional stress can tip the scales against them. Ability to continue normal activities will be temporarily or permanently impaired. Even a stress involving a small percentage loss indicates that the balance of the population is under duress.

The assessing and prescribing of safe levels for toxic materials (bio-assay) is usually done by determining incipient lethal dosages. Inherently this approach is wrong for our purposes, since the load imposed by, say, a half-lethal dose or stress, cannot be determined. An analogy might be taken from the effects of alcohol on man. If intoxication were to be measured in terms of lethal doses, in the absence of a better criterion, a half-lethal dose might be prescribed as a safe level for driving—a rather unlikely proposition.

The complete elimination of mortalities in downstream migrants from a a turbine or spill does not mean the problem is removed[21]. It merely means that the stress is no longer lethal. A recurrence of the same stress from multiple dams could be lethal, or the addition of a second stress in the form of industrial wastes (considered non-toxic by experiments with normal controls) could bring unexpected mortalities.

The problem posed by indiscriminate stress is consequently quite different from that of discriminate stress. Any indiscriminate stress must be measured at all levels of that stress, and the measuring stick should be the effect on performance and/or metabolism. By systematically determining the amount of reserve which salmon have to meet the environmental stresses, limits can be placed on the extent to which the normal environment can be altered without affecting the spawning success of the adult, or the downstream migrant's chances of establishing itself in a saltwater environment. Figure 2 is a schematic representation of the principles involved.

ACTIVITY. The environment affects activity through metabolism (Fry, 1947). This is a highly significant principle. It means that the environmental effect on activity (swimming, growing, digesting, etc.) can be assessed by a study of metabolism, and that measures of activity can be used to determine environmental stress. When the effects of temperature, for instance, are assessed by measuring metabolic demand (rate of oxygen uptake) a level of

[21] The losses resulting from sudden pressure change, equally applied to all fish passing through a turbine, are indiscriminate. In addition, there could be a discriminate stress as a result of the runner striking individual fish.

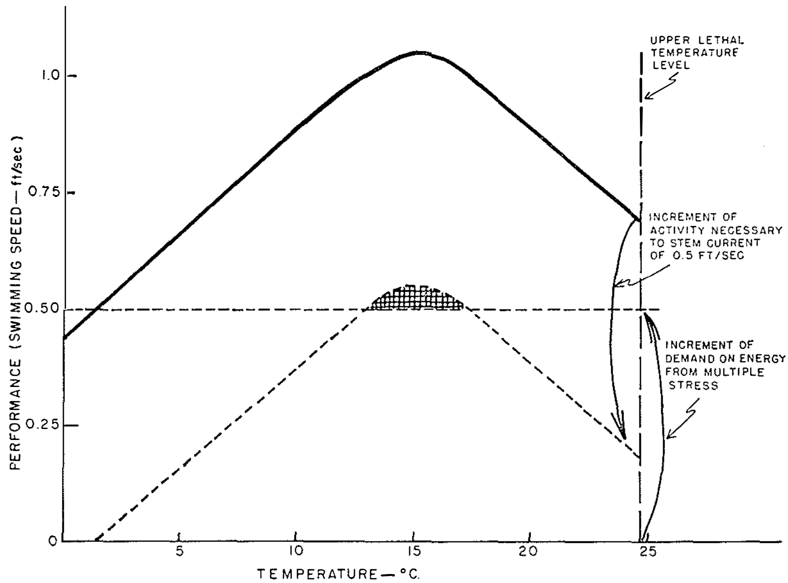

FIGURE 2. The relation between performance (ability to swim) and temperature for young sockeye. The top arrow indicates the increment of performance necessary to stem a current of 0.5 ft./sec. The raised "base line" has been drawn to suggest the possible effects of increased demand through stress on the available energy output of the fish, by an amount equal to that consumed by swimming at 0.5 ft./sec. Only between temperatures of 13°C. and 17°C. could the fish meet this combination (cross-hatched area in figure).

temperature is reached where the difference between active and resting metabolic rates is maximal. This is the point for greatest scope for activity and defines the level at which optimum energy release can occur. In this sense, it defines the level at which the stress has least effect on the fish. It also defines the level at which maximum activity can take place. The measurement of activity (swimming speed) and metabolic rates (oxygen uptake) forms a basis on which to judge the effects of stress. By determining the amount of free energy which must be available at any one time to permit bursts of activity (jumping, ascending rapids, etc.) the permissible levels of stress from the balance of the environment can be determined and limits set.

C. Hormonal State

Up to this point the energy-stress-activity concepts have been considered. The relations which must be satisfied in the fish's successive progress to and from the spawning grounds are like links in a chain. No link can be eliminated without disrupting the whole phenomenon. Maturation, as indicated by colour changes, snout growth in the male and changes in body form, is the sign that gonads are ripening, and this process is coupled with the appropriate release of hormones (gonadotrophic hormone) as are other activities like jumping (adrenaline) and growing (thyroxine). There is a time limit for maturation processes which is proportional to the rate of physiological development and, in turn, a product of *temperature* $\times$ *time*. Increased temperature shortens the time to ripening. Some control from the central nervous system can be expected, but the order is not known. While this can modify the process, it does not defeat the problem that time is running out and delay can be fatal if maturation to the point of egg release precedes arrival on the spawning grounds.

For chum and pink fry in their seaward migration, the apparent stress of remaining too long in fresh water is reflected in the "exhausted" state of the thyroid gland (Hoar and Bell, 1950). A time factor also appears to be present, steadily reducing the chances of survival as freshwater life is prolonged beyond normal limits[22].

The hormonal state and its effects are complex[23]. The point which is made here is simply that time can run out. This is, in itself, a serious factor and should be investigated.

D. Behaviour and Sensory Perception

Migration is not just a matter of enough fuel to make the course, enough resistance to meet the stresses and enough time to complete maturation. It involves a series of perception-response activities which carry the fish from point to point in its environment (no matter how devious the course) and which collectively result in its movement from estuary to spawning ground. They are a part of the total behaviour pattern of the fish and, when sorted in their correct series, constitute the mechanics of migration. Alterations in the normal environment can affect the behaviour by providing false cues, by changing the internal state of the fish, or by masking the natural environment. This results in delays or misdirected activities, even to the point (in the adult) of return downstream. The behaviour problems are many and complex. It is not possible to work out *all* the behaviour responses in salmon; it becomes a matter of identifying the significant aspects which relate to migration, and determining the extent to which environmental changes can alter these to a significant and possibly detrimental degree. The key to research is locked in the express question of what are the environmental requirements which satisfy the internal drives of migration and culminate in successful spawning.

Since there are probably more opinions and more diverse research involved in this aspect than in any other, it requires good direction to narrow the research possibilities into effective channels if pertinent answers are to be had in the next decade.

There is a logical sequence which research can follow. The fact that migration is a series of directed responses implies that one or more senses are involved, either singly or in combination, or possibly in sequence. The identification of

[22] This probably accounts for the difficulties sometimes encountered in the culturing of pink and chum fry in fresh water.

[23] Hoar (1953) has reviewed the problem of physiological control and general timing of fish migration. It is a subtle combination between environmental impressions which changing light, salinity and temperature impose on the developing fish, coupled with internal responses, culminating in directed activity (migration).

the particular sense (e.g. olfactory) or combination (e.g. olfactory plus lateral line) could confine the problem of behaviour research to responses which are dependent on these particular sensory endings. As an example of the significance of establishing the sensory relations involved in stream orientation, it was found that sockeye and coho downstream migrants orient themselves by sight, in the presence of light and in the absence of turbulence. This knowledge has been applied in guiding experiments which used a curtain of moving cables for deflecting the migrants (Brett and Alderdice, 1956; see p. 26). In this instance, the behaviour problems were channeled into those which related to sight.

A point which also would appear to be of fundamental importance in defining the nature of the studies is the definition of the perceived environment of the fish. From a sensory approach, the environment can be divided into the *perceptual* and *non-perceptual*. The perceptual defines that part of the environment to which the fish can respond and over which its capabilities can exert some influence. It obviously cannot respond to the non-perceived environment. Much of behaviour is a demonstration of selection made from the perceived environment (with the exception of "releasers" when an internal drive is not consummated). Until the perceived environment is defined, the manner of selection and the basis for much of behaviour must go uninterpreted, like a disease without diagnosis.

Perception can be masked and is probably subject to interaction. The difference in response to a current of water in darkness and in light may be simply the absence of visual cues in the dark, rather than any diurnal change in behaviour. The effect of white water below a falls or spill must be equivalent to partial blinding.

The significant feature of the non-perceived environment is the fact that the animal is denied any directed response. The consequences may be severe. This is annually demonstrated in man by cases of unintentional death from carbon monoxide poisoning. For fish, the presence of non-perceived toxicants can be equally destructive. There appears to be no direct perception of oxygen concentration, only a violent distress internally from cellular response to its lack. Man has overcome the problem of non-perceived environment through the use of instruments. The determining of the natural navigating "instruments" of salmon is a prime task in the study of behaviour.

E. Interaction

One last point can be made concerning the research fundamentals. This concerns the interaction of factors affecting migration. The example chosen is that of stress × activity × behaviour. Black (1955) has demonstrated clearly that if the stress of extreme exercise is applied to young salmon, their ability to be active is reduced during a recovery period lasting 6 to 8 hours. In addition, their schooling behaviour is temporarily abandoned. The significance of a severe stress, although applied for a comparatively short time, can have lasting effects. It means that this should be avoided whenever possible; and that, if applied, multiple effects can be expected.

IV. STUDIES CONDUCTED BY THE FISHERIES RESEARCH BOARD, AND THEIR PRESENT STATUS

The experimental studies which commenced in 1952 as a part of the Fisheries Research Board program were directed at two levels in the problem of fish and power—fundamental studies and applied field tests. More knowledge was required on the capabilities and responses of salmon to environmental factors in general. Laboratory experiments to determine lethal levels of temperature, oxygen and toxicants were commenced, in conjunction with studies on the swimming speeds and light sensitivity of young salmon.

The field work was aimed at contributing to the most pressing single problem confronting the successful passage of salmon up and downstream, namely, the *directing* of fish into safe by-passes. In the case of adult salmon, the problem of ready entrance into ladders, lifts or locks has often been a difficult one. For young salmon, if by-passes were to be of value, the importance of efficient directing and local concentration was even more pressing, since adequate by-passes had never been designed, nor could they be considered unless the young fish could be guided away from spillway or turbine. In consequence, more effort has been devoted to the problem of directing downstream migrants than upstream adults.

A. Guiding Migrating Salmon

1. Adult Salmon and Odours

The object of this research has been to find some odour which could be used in directing adult salmon away from unsuitable water flows and into safe passages. During the course of testing, a strongly repellent odour was discovered, associated with the skin of mammals. Since this discovery an effort has been made to extract the active component, to describe its properties, to isolate it, and to learn more about odours and salmon.

Some striking results have accrued. The substance is a fairly simple polypeptide, probably involving the amino acid serine in its composition. Aqueous, concentrated skin extracts can be preserved under refrigeration, or with added antibiotic, for at least three months. Dried preparations also remain active.

When applied continuously in the Stamp Falls fishway, a complete cessation of migration results. This induced delay does not last beyond 40 minutes.

The threshold of sensitivity is approximately 1:80,000,000,000 parts of a concentrated extract in water. It is obviously reactive at the molecular level. This result has importance since it is one of the first demonstrations on unconditioned fish of a natural odour detected at such a dilution. It provides additional support to the suspected sensitivity and use of the olfactory organ in "homing".

STATUS. Isolation of the active component is being pursued in the interests of identification, technique development, and overcoming the rather laborious extraction process now involved.

In practice, it could be used for short-term dispersal of fish, but is unlikely to be of value in the continuous diversion of fish from a false passage containing "home-stream" water. It may be of use in "labelling" toxic water which salmon have occasion to enter.

It is intended to investigate further the extent of salmon dispersion which can be achieved in time and area, and attempt to learn something of the practical limitations in the use of extracts at present on hand.

PUBLICATIONS: Brett and MacKinnon (1952, 1954); Alderdice, Brett, Idler and Fagerlund (1954); Idler, Fagerlund and Mayoh (1956).

2. Guiding Downstream Migrants

(a) YEARLING SOCKEYE AND COHO. The significant findings in this avenue of research relate to the use of a moving curtain of cables, suspended vertically in the water, and effective in guiding yearling sockeye and coho in the Lakelse River. The combination of an interval of not more than 6 inches between ¼-inch diameter cables, moving at not less than 8 inches per second, and with low illumination, has been found to be sufficient for sockeye. The addition of a low electric charge (1.25 volts per inch) is required to deflect coho at the 90% level or better.

A fundamental principle which has evolved in this problem is the importance of providing a means of ready orientation without alarming the fish. In the case of young salmon, the sensory relation which appears to play the major role in its stream orientation, and everyday behaviour is *sight.* Feeding, avoiding of predators, schooling, stream position and avoidance of obstacles or moving objects are primarily dependent on vision (in the presence of adequate light and absence of turbulence). This relation can be exploited for guiding purposes, as has been done with the moving curtain. It can be further used in by-pass design.

An experimental by-pass built in the Lakelse fence to receive deflected smolts incorporated a series of cross-reflecting mirrors lining a plywood chute. It was designed to minimize all visual or otherwise sensible cues (e.g. points of turbulence) while accelerating the incoming water to exceed the swimming speed of the fish. With the exception of the approach to the by-pass, which inclined upwards and appeared brighter owing to a fill of fresh gravel, schools of sockeye readily moved down the chute and were swept into the trap. Dim light at the entrance was more effective than bright light or no lighting, when the deflector was floodlit. Coho, which usually swam at a lower level in the water than sockeye, were not as readily captured. Future designs would be modified to meet these limitations. The general principles applied in this first effort proved to be of significant value and were a contributing factor in the high levels of deflection achieved.

(b) CHUM AND PINK SALMON FRY. Results of recent experiments conducted at Hooknose Creek, Port John, indicated that none of the techniques developed for yearlings were of value in guiding fry. Their relatively strict behaviour of swimming rapidly downstream, normally under cover of darkness, was disrupted but not directed by light or electric charges, and hardly affected by moving cables. Pronounced movement to the bottom of the stream and collecting in small groups at the surface occurred, but no systematic lateral displacement was achieved.

STATUS: The status of the research now stands at the point where new approaches must be sought for the fry problem. It would appear that one way to divert fry is to divert the water in which they are travelling. The problem then becomes how to concentrate fry in, say, the surface water only, and redirect the path of this water into an appropriate by-pass.

For the yearlings, a large-scale test is the most logical next move to determine the effectiveness of the established methods under conditions which are considered to be representative of the present proposed power developments in British Columbia.

PUBLICATIONS: Brett (1953), Brett and MacKinnon (1953), Brett, MacKinnon and Alderdice (1954), Brett and Alderdice (1956, 1958).

3. Swimming Speeds of Young Salmon

Cruising speeds of fish were measured by determining the maximum sustained steady-rate of swimming, maintained for at least one hour. They constitute a measure of two fundamental aspects of fish performance: (1) the actual physical ability to swim, and (2) the capacity of the animal to do sustained work, i.e., metabolic performance (which may or may not be directed into the act of swimming).

These measurements are of value in determining the rate of flow of water which does not exceed the capacity of a fish to stem the flow. In cases where water is screened for irrigation, or for turbine use, or any other use which is potentially destructive to fish, the velocity at the intake must not exceed the cruising speed of the fish if they are to be directed laterally out of the path of water. Information of this nature has been almost entirely lacking.

Present experiments demonstrate that for salmon underyearlings the rates are less than 1 ft./sec. (0.7 m.p.h.) in almost all instances (see Fig. 2). At temperatures of 5°C. and less, the cruising speeds average about 0.5 ft./sec.

As a measure of metabolic performance, the highest cruising speeds have provided an index of the temperatures at which the fish are most likely to succeed, and consequently the temperatures at which they are most likely to be found. This has been borne out by the studies on coho and sockeye. Coho show an optimum in the vicinity of 20°C. and maintain a high level of performance even approaching the lethal level. They are found in streams, and in inshore shallows of lakes in mid-summer. Their activity is greatly reduced by low temperatures.

In contrast, young sockeye display their optimum at about 15° to 16°C. and have a greater ability to perform at low temperatures than do coho. The fact that sockeye tend to be offshore in deeper waters, and only move into the streams during the early spring, supports the proposition that the swimming speeds are a profitable laboratory measure of ecological temperature relations. Measurements of lethal temperatures and preferred temperatures have not distinguished so clearly the fundamental differences between these species.

STATUS: This work forms a basis from which to proceed in determining the effects of stress on the performance of young fish. As such, it is likely to be one of the most useful "tools" in research. Its chief limitation is the time taken to do a test—about 3 hours for each fish.

PUBLICATIONS: The general principles have been reviewed by Brett (1956). In preparation: "The effect of temperature on the cruising speed of young sockeye and coho salmon".

B. Environmental Factors

1. Temperature Lethals

The limits of tolerance to extremes of high and low temperatures have been determined for the fry of all species (except low lethals for pink fry). Since temperature tolerance depends on acclimation, there is no single end-point, so that high and low temperatures can be lethal over a range of about 21.5°C. to 25.0°C. and 7.0°C. to −0.1°C. respectively, depending on species and acclimation.

It is important to determine the limits for any environmental factor since these provide the boundaries within which the fish are confined. Having established these, the next step is that of determining activity levels which define the capabilities within the viable range. Swimming speeds, as previously described, and growth rates are good measures of activity.

Status: Lethal levels are known only for fry (or young under-yearlings) and some yearlings. The tolerance limits for all species during egg development and for maturing adults are not known, although the International Pacific Salmon Fisheries Commission has conducted some work on low lethals in the egg stage (unpublished), and Seymor (1956) has done a thorough study on the effects of temperature on chinook salmon eggs.

Temperature has multiple effects (e.g., it governs rate of oxygen uptake, affects growth and activity, shows optimum and lethal levels). It is not a simple factor to deal with. Possibly one of the most important things which requires investigation is the temperature limits for successful spawning. Jones and King (1949) have been able to observe spawning in Atlantic salmon under artificial conditions. It is possible that temperature effects might be studied experimentally in spawning Pacific salmon.

PUBLICATIONS: Brett (1952, 1956). In preparation: "The resistance of chum fry and sockeye yearlings to temperatures below 0°C".

2. Oxygen Lethals

The work on the minimum oxygen requirements in developing salmon eggs is not directly concerned with the salmon-power problem, except possibly in the case of flooded-out spawning grounds This study has formed a part of the program concerning the production limitations in natural spawning grounds, the value of controlled flows, and the construction of artificial spawning grounds (see Wickett, 1954) It is mentioned here to point out the fact that work of this nature has been undertaken and that it should be expanded to include the requirements of young and mature salmon, when actively doing work (e.g., continuous swimming, as in migration) Shepard (1955) has determined the low lethal levels of oxygen in another salmonoid and this work forms an excellent basis for comparable experiments with Pacific salmon

PUBLICATIONS: Alderdice, Wickett and Brett (1958).

3. Toxicity of Pulpmill Effluents

Pulpmill effluents may have a direct lethal effect on fish through toxicity, or an indirect effect by reduction of the oxygen content (B.O.D.) to an intolerable level. At present, the latter is the limiting factor and adequate treatment by dilution and aeration of the effluent eliminates both effects from the lethal category.

During the determination of the toxicity of a sulphate mill effluent on young sockeye salmon (at a temperature of 18°C. and a salinity of 20‰) certain side effects indicating a sublethal stress were observed. A reduction in the fish's ability to extract oxygen occurred. It also appeared that the ability to be active was impaired, although no experiments to confirm the suspicion were conducted. This finding, and its possible consequences, are of considerable significance, since the levels of oxygen requirements have previously been set from normal fish standards, which may be unjustified

It was from some of this research that the ideas developed on stress effects and the possible inhibition of activity in conjuction with normal environmental stresses (high temperature, low salinity, etc.). It is a promising field of inquiry which can be applied extensively to the whole problem of multiple stress, activity and energy exchange in salmon.

STATUS: So far, work has been confined to young salmon of one species, at one age and under one combination of temperature and salinity. The chosen levels of these variables were those which conformed to conditions present where pollution problems have currently arisen (e.g., Alberni Canal). Apparatus suitable for exploring the significance of some of the variables and for testing the toxicity of components of an effluent is being installed. It will be serviceable for small fish only.

It is also planned to investigate the reason for distress or death from toxic elements in effluents. Knowledge of the cause may prescribe the cure.

PUBLICATIONS: Alderdice and Brett (1957).

C. Sensory Perception

1. Sight in Young Salmon

The present guiding experiments using visual orientation in smolts are conducted in the absence of any specific knowledge of the actual light sensitivity and visual acuity of the fish. Basic studies of this nature have commenced. The relation of rods and cones, and the masking effects of the heavily pigmented retinal epithelial cells, are under investigation both histologically and experimentally. Two pertinent findings have resulted to date. Young salmon require about 30 to 40 minutes to dark-adapt, and this dark-adapted stage is reached about halfway through the evening seaward migration of Lakelse salmon. This means, for instance, that colour vision, as far as it is known in fish, would be eliminated with dark-adaptation, and that a switch in spectral sensitivity occurs during migration. In addition, sensitivity to light increases while acuity decreases during an evening migration, factors of significance in the operation of a deflector based on visual perception, and affecting the entrance of fish into an illuminated by-pass.

Sensitivity to light has been tested with underyearling coho by preliminary training to feed on small crustaceans (*Daphnia*), followed by experimental reductions in light intensity to a level where feeding was impossible. Light intensities ranged from a maximum of 8300 down to 0.00001 foot-candles. In absolute darkness, no feeding occurred. At the lowest level of light, 0.00001 ft.-c., very slight feeding was recorded (3% of normal). The level which just produced a significant reduction from the normal rate of feeding was approximately 0.0001 ft.-c., equivalent to about one-third the intensity from bright moonlight. The brightest lighting did not affect the normal feeding rate of the fish. The remarkable range over which the young salmon eye can function indicates an exceptionally sensitive and adaptable eye.

STATUS: A thorough investigation of any sensory organ requires fairly elaborate apparatus. To date, rather simple experiments have been conducted with interesting returns. To delve further into the problem demands both specific knowledge and instrumentation. The type of information which has been obtained so far illustrates the value of the sensory approach, and recommends it as one of the studies basic to guiding and to behaviour in general.

PUBLICATIONS: Brett (1957). In preparation: "The structure and photomechanical responses of the Pacific salmon retina".

V. RESEARCH PROSPECTS

The course of research has been considered, both as to the principles involved and the particular research being conducted by the Fisheries Research Board, through its Biological Station at Nanaimo. In anticipation of possible expansions in the research program, as the needs dictate, and with the thought that research does not always prosper in a rush, a broad look at the problem has been taken.

There are fundamentals to develop which should not be entirely bound to the immediate tasks. Research in salmon physiology should serve as a contribution to physiology in general and provide for uses beyond the demand of solutions to the fish-power problems. On the other hand, direct research on specific items is required, and these should be undertaken with full effort. The two paths are in no way exclusive, but rather they are complementary. Through mutual exchange between fundamental and applied research, this phase of fisheries biology will prosper.

The following projects are proposed, above and beyond those already in progress (Section IV), divided into laboratory and field phases. They are merely outlined in concept, and will be pursued as time, opportunity and urgency dictate.

A. Energy Exchange

LABORATORY EXPERIMENTS

(1) The measurement of fuel depletion by analysis of fat, protein and carbohydrate reserves in adult salmon. This should be performed on captive fish held in tanks under different levels of temperature, salinity and swimming rate. A study of the weight change with periodic sampling for analysis is required.

(2) Measurements of active and resting metabolic rates in juvenile and mature salmon, and their ability to do work. The use of respirometers and activity chambers (rotating circular troughs) are appropriate to such a study.

FIELD EXPERIMENTS

(3) Weighing and sampling of salmon (for analysis of body constituents) at different stages in migration from estuary to spawning ground.

In general, these concern the question of what are the rates, limits and factors affecting fuel consumption.

B. Environmental Stress

LABORATORY EXPERIMENTS

(1) Experiments on the tolerance limits to extremes of temperature, salinity, oxygen, pressure and toxicants, and the determination of effects on activity at sub-lethal levels of each of these indiscriminate stresses, are required.

(2) The physiology of fatigue and general effects of extreme exercise (as developed by Dr. E. C. Black, U.B.C.).

(3) The determination of sex difference in ability to withstand stress and ability to perform (female salmon were blocked more than males at Hell's Gate).

FIELD EXPERIMENTS

(4) The measurement of physical and chemical state of water at points in migration, including extremes of pressure and impact likely to be encountered in turbine or spill.

(5) The collecting and *testing* of fish exposed in nature to "standard" stresses, e.g., released through turbine or over spill.

C. Hormonal State

LABORATORY EXPERIMENTS

(1) Examination of blood samples (e.g., steroids) and of the state of the glands (pituitary, gonad, thyroid, kidney—and possibly others) to be done from stress studies under B.

(2) Retention experiments on young and adult salmon to examine the effects of delay.

(3) A study of factors governing rate of maturation—e.g., temperature, light and time.

FIELD EXPERIMENTS

(4) To conduct field measurements comparable to those in the laboratory, performed on migrating and spawning salmon. Particular attention to be given to differences between races spawning near and far from the sea.

D. Behaviour and Sensory Perception

LABORATORY EXPERIMENTS

(1) To study schooling or territorial relations in salmon—how are these affected by changes in physical and chemical aspects of the environment, i.e., the use of some behaviour pattern which signifies that normal behaviour responses are or are not maintained; to develop behaviour criteria, comparable to *performance* as a means of detecting changes in metabolic output.

(2) To develop sensory studies on lateral line and current detection, audibility range and sensitivity. These require apparatus for recording nerve impulses, which would be serviceable for all experiments on sensory perception, including odour research.

(3) To carry out selection experiments on choice of water quality. Hoglund (1951) of Sweden has developed interesting apparatus for this type of research.

FIELD EXPERIMENTS

(4) The study of attracting odours. Organic fractions to be extracted by resin exchangers from "home-stream" water and experiments conducted in false or unused streams to determine effectiveness. Do salmon detect and use their own odours?

(5) A study of essential senses for homing in salmon. Blocking of olfactory sacs, blinding, severing of lateral line, etc. in adult fish in inshore waters to determine effects on returning to "home-stream". It is noteworthy that Cragie (1926) did some original experiments in this field three decades ago. More recently, Hasler and associates (Hasler, 1954; Wisby and Hasler, 1954) have demonstrated the value of this approach.

(6) The use of moving, charged electrodes for guiding adult salmon.

(7) Full scale directing of yearling salmon by moving, charged cables.

(8) Transplantation experiments required from spawning grounds located far apart. Are salmon racially adapted to one geographic area to the exclusion of others, or is this a case of conditioning of developing young to a spawning area, not geographically specific?

VI. CONCLUDING STATEMENT

The three central problems which must be solved first before there is any thought that salmon and power can co-exist are: *delay* (at all stages), *by-passing* (upstream and downstream migrants) and *concentrating* salmon (by guiding). The research which is necessary to develop an understanding of these aspects has been considered, and a classification of the basic studies elaborated. Emphasis has been placed on the physiology and behaviour of salmon with a view to determining functional capacities, tolerance limits and migration mechanics. These should define what the environmental requirements are for successful maintenance.

No thought has been given to how the environment could or should be altered to fall within specific limits, where and when these are known. If energy supply is a limiting factor, then consideration must be given to how reduction of energy dissipation can be achieved. The lifting of fish over a dam must save energy consumption in the fish. However, if this operation causes delay for salmon moving into or out of the lift mechanism, then the problem shifts to the question of behaviour.

There will be "salmon water" requirements at all times. For instance, by-pass water will have to be available at discharge levels set according to the rate and numbers of moving fish, and in the best biological location (probably inshore). The design of spills might possibly be done to suit salmon requirements by staged spills at, say 20-foot intervals down the face of a 100-foot dam. This, of course, implies that the fish requirements are known with regard to pressure, impact and turbulence. Since it appears that migrants will not readily sound below a level of about 80 feet in reservoirs (Hamilton and Andrew, 1954; Pressy, personal communication) turbine design should take this factor into account.

A unified and integrated approach between salmon research and multiple water use is required. The biological knowledge necessary to assess many of the problems is entirely lacking. The problems are new and biologically complex. It is fortunate that there is sufficient background now to define some of the paths of research, from which, undoubtedly, new insights and appreciation will develop. The most apparent single conclusion and recommendation which can be made is the lack of, and necessity for building up, the biological understanding of salmon.

A great deal of work will have to be done before one can be satisfied that the problems can, or cannot, be met.

VII. REFERENCES

The following list of references is pertinent to the foregoing text. Direct reference to each has not been made in every case:

ALDERDICE, D. F., AND J. R. BRETT. 1957. Some effects of kraft mill effluent on young Pacific salmon. *J. Fish. Res. Bd. Canada,* **14**(5): 783-795.

ALDERDICE, D. F., J. R. BRETT, D. R. IDLER AND U. FAGERLUND. 1954. Further observations on olfactory perception in migrating adult coho and spring salmon—chemical properties of the repellent in mammalian skin. *Fish. Res. Bd. Canada, Pacific Progress Rept.,* No. 98, pp. 10-12.

ALDERDICE, D. F., W. P. WICKETT AND J. R. BRETT. 1958. Some effects of low oxygen levels on Pacific salmon eggs. *J. Fish. Res. Bd. Canada,* in press.

ANDREW, F. S., L. R. KERSEY AND P. C. JOHNSON. 1955. An investigation of the problem of guiding downstream-migrant salmon at dams. *Int. Pacific Salmon Fish. Comm., Bull.* No. 8, 64 pp.

ANONYMOUS. 1949. Interim report on the Chilko River watershed. International Pacific Salmon Fisheries Commission, 70 pp.

1952. Temperature changes in the Nechako River and their effects on the salmon populations. Canadian Dept. of Fisheries and Int. Pacific Salmon Fish. Comm., Processed Report, Supp. No. 1, 52 pp.

1953. A review of the sockeye problems created by the Alcan project in the Nechako River watershed. International Pacific Salmon Fisheries Commission, 28 pp.

1955. A report on the fish facilities and fisheries problems related to the Fraser and Thompson River dam site investigations. Report by Technical Staffs of the Canadian Department of Fisheries, International Pacific Salmon Fisheries Commission, British Columbia Fisheries Department and British Columbia Game Commission, 99 pp., appendix and figures.

BLACK, E. C. 1955. Blood levels of hemoglobin and lactic acid in some freshwater fishes following exercise. *J. Fish. Res. Bd. Canada,* **12**(6): 917-929.

BRETT, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus. J. Fish. Res. Bd. Canada,* **9**(6): 265-323.

1953. Research in salmon migration over high dams. The nature of the biological problem. *Trans. 6th British Columbia Nat. Res. Conf.,* pp. 96-102.

1956. Some principles in the thermal requirements of fishes. *Quart. Rev. Biol.,* **31**(2): 75-87.

1957. "The Eye", Chap. 12, Part 1 of Volume 2 of "The Physiology of Fishes". Academic Press, New York (in press).

BRETT, J. R., AND D. F. ALDERDICE. 1956. Lakelse River experiments on guiding sockeye and coho salmon fingerlings. *Fish Res. Bd. Canada, Pacific Prog. Rept.,* No. 106, pp. 14-20.

1958. Research on guiding young salmon at two British Columbia field stations. *Bull. Fish. Res. Bd. Canada* (in press).

BRETT, J. R., AND D. MACKINNON. 1952. Some observations on olfactory perception in migrating adult coho and spring salmon. *Fish. Res. Bd. Canada, Pacific Prog. Rept.,* No. 90, pp. 21-23.

1953. Preliminary experiments using lights and bubbles to deflect migrating young spring salmon. *J. Fish. Res. Bd. Canada,* **10**(8): 548-559.

1954. Some aspects of olfactory perception in migrating adult coho and spring salmon. *Ibid.,* **11**(3): 310-318.

BRETT, J. R., D. MACKINNON AND D. F. ALDERDICE. 1954. Trough experiments on guiding sockeye salmon fingerlings. *Fish. Res. Bd. Canada, Pacific Prog. Rept.,* No. 99, pp. 24-27.

BRIGGS, J. C. 1950. The quantitative effects of a dam upon the bottom fauna of a small California stream. *Trans. Amer. Fish. Soc.* for 1948, **78**: 70-81.

BURNER, J. C. 1951. Salvaging salmon at Grande Coulee. *The Reclamation Era,* **37**(11): 252-255. Washington, D.C.

BURNER, C. J., AND H. L. MOORE. 1953. Attempts to guide small fish with underwater sound. *U.S. Fish. Wildlife Serv., Spec. Sci. Rept., Fish.,* No. 111, 38 pp.

CLAY, C. H. 1955. Downstream fish migrations over dams. *The British Columbia Professional Engineer,* Oct. 1955: 4 pp.

CLAY, C. H., AND W. R. HOURSTON. MS, 1955. Fisheries problems related to major industrial projects on the Pacific Coast, 1949-1955. MS Rept., Canadian Dept. of Fish., Feb., 1955: 28 pp. Vancouver, B.C.

CLEMENS, W. A. 1955. Research and fish. *Rept. Proc. 9th Annual B.C. Game Conv.,* 1955, 4 pp.

COLLINS, G. B. 1952. Factors influencing the orientation of migrating anadromous fishes. *U.S. Fish and Wildlife Service, Fish. Bull.,* **73**: 375-396.

1954. Research on anadromous fish passage at dams. *Trans. 19th North American Wildlife Conf.,* 1954, pp. 418-423.

COLLINS, G. B., C. D. VOLTZ AND P. S. TREFETHEN. 1954. Mortality of salmon fingerlings exposed to pulsating direct current. *U.S. Fish and Wildlife Serv., Fish. Bull.,* **56**: 61-81.

CRAIGIE, E. H. 1926. A preliminary experiment upon the relation of the olfactory sense to the migration of the sockeye salmon (*Oncorhynchus nerka* Walbaum). *Trans. Roy. Soc. Canada,* V, **20**: 215-224.

DAVIDSON, F. A., AND O. E. SHOSTROM. 1936. Physical and chemical changes in the pink salmon during the spawning migration. *U.S. Bur. Fish., Invest. Rept.,* No. 33, 37 pp.

DUNCAN, R. E. 1956. Use of infrared radiation in the study of fish behaviour. *U.S. Fish and Wildlife Serv., Spec. Sci. Rept., Fish.,* No. 170: 16 pp.

ELLIS, C. H. 1956. Tests on hauling as a means of reducing downstream migrant salmon mortalities on the Columbia River. *Washington Dept. Fish., Fish. Res. Papers,* **1**(4): 46-48.

FIELDS, P. E., G. L. FINGER AND R. J. ADKINS. MS, 1955. The use of light barriers in the guidance of downstream migrant salmon and steelhead trout. MS, School of Fisheries, University of Washington, 9 pp.

FISH, F. F. 1948. The return of blueback salmon to the Columbia River. *Sci. Monthly,* **66**(4): 283-292.

1950. Oxygen block in the main-stem Willamette River. *U.S. Fish and Wildlife Serv. Spec. Sci. Rept., Fish.,* No. 41: 19 pp.

FISH, F. F., AND M. G. HANAVAN. 1948. A report upon the Grand Coulee fish maintenance project 1939-1947. *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.,* No. 55.

FOERSTER, R. E., AND W. E. RICKER. 1952. The coho salmon of Cultus Lake and Sweltzer Creek. *J. Fish. Res. Bd. Canada,* **10**(6): 293-319.

FONTAINE, M., AND J. HATEY. 1953. Contribution à l'étude du métabolisme glucidique du Saumon (*Salmo salar* L.) à diverses étapes de son développement et de ses migrations. *J. Phys. Comp. Oecol.,* **3**: 37-52.

FRY, F. E. J. 1947. Effects of the environment on animal activity. *Pub. Ontario Fish. Res. Lab.,* No. 68, pp. 1-62.

GODFREY, H., W. R. HOURSTON, J. W. STOKES AND F. C. WITHLER. 1954. Effects of a rock slide on Babine River salmon. *Fish. Res. Bd. Canada, Bull.* No. 101, 100 pp.

GREENE, C. W. 1915. The storage of fat in the muscle tissue of the king salmon and its resorption during the fast of the spawning migration. *Bull. U.S. Bureau Fish.,* **33**: 69-138.

1926. The physiology of the spawning migration. *Physiol. Rev.,* **6**: 201-241.

HAMILTON, J. A. R., AND F. J. ANDREW. 1954. An investigation of the effect of Baker dam on downstream-migrant salmon. *Int. Pacific Salmon Fish. Comm., Bull.* No. 6, pp. 1-73.

HASLER, A. D. 1953. Odour perception and orientation in fishes. *J. Fish. Res. Bd. Canada,* **11**(2): 107-129.

HOAR, W. S. 1953. Control and timing of fish migration. *Biol. Rev.,* **28**: 437-452.

1954. The behaviour of juvenile Pacific salmon, with particular reference to the sockeye (*Oncorhynchus nerka*). *J. Fish. Res. Bd. Canada,* **11**(1): 69-97.

HOAR, W. S., AND G. M. BELL. 1950. The thyroid gland in relation to the seaward migration of Pacific salmon. *Canadian J. Res.* (D), **28**: 126-136.

HOGLUND, L. B. 1951. A new method of studying the reactions of fishes in stable gradients of chemical and other agents. *Oikos,* **3**(2): 247-267.

HOLMES, H. B. 1940. Dams and the problem of migrating fishes. The passage of fish at Bonneville Dam. *Stanford Ichthyol. Bull.,* **1**(6): 182-192.

1948. History, development and problems of electric fish screens. *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.,* No. 53, 62 pp.

HOURSTON, W. R., C. H. CLAY, L. EDGWORTH, P. A. LARKIN, E. H. VERNON AND R. G. MCMYNN. 1955. Planning anadromous fish protection for proposed dams. *Trans. 20th North American Wildlife Conf.,* pp. 440-454.

IDLER, D. R., U. FAGERLUND AND H. MAYOH. 1956. Olfactory perception in migrating salmon. 1. L-serine, a salmon repellent in mammalian skin. *J. Gen. Physiol.,* **39**(6): 889-892.

JACKSON, R. I. 1950. Variations in flow patterns at Hell's Gate and their relationships to the migration of sockeye salmon. *Int. Pacific Salmon Fish. Comm., Bull.* No. 3, pp. 85-129.

JONES, J. W., AND G. M. KING. 1949. Experimental observations on the spawning behaviour of the Atlantic salmon (*Salmo salar* Linn.). *Proc. Zool. Soc. London,* **119**(1): 33-48.

KERR, J. E. 1953. Studies on fish preservation at the Contra Costa steam plant of the Pacific Gas and Electric Co. *California Dept. Fish and Game, Fish. Bull.* No. 92, 66 pp.

LARKIN, P. A. MS, 1956. Power development and fish conservation on the Fraser River. Institute of Fisheries, University of British Columbia, 40 pp.

LETHLEAN, N. G. 1953. An investigation into the design and performance of electric fish screens and electric fish counters. *Trans. Royal Soc. Edinburgh,* **62**(2): 479-526.

MACKINNON, D., AND J. R. BRETT. 1955. Some observations on the movement of Pacific salmon fry through a small impounded water basin. *J. Fish. Res. Bd. Canada,* **12**(3): 362-368.

MCLAIN, A. L., AND W. L. NEILSEN. 1953. Directing the movement of fish with electricity. *U.S. Fish and Wildlife Serv., Special Sci. Rept., Fish.,* No. 93, 24 pp.

MCMYNN, R. G., AND P. A. LARKIN. 1953. The effects on fisheries of present and future water utilization in the Campbell River drainage area. *British Columbia Game Comm., Management Pub.,* No. 2, 61 pp.

MOFFETT, J. W. 1949. The first four years of king salmon maintenance below Shasta Dam, Sacramento River, California. *California Fish and Game,* **35**(2): 77-102.

MOORE, H. L., AND H. W. NEWMAN. 1956. Effects of sound waves on young salmon. *U.S. Fish and Wildlife Serv., Spec. Sci. Rept., Fish.,* No. 172, 19 pp.

NEAVE, F., AND W. P. WICKETT. 1955. Transplantation of pink salmon into the Fraser Valley in a barren year. *Fish. Res. Bd. Canada, Pacific Prog. Rept.,* No. 103, pp. 14-15.

NEEDHAM, P. R. 1949. Dam construction in relation to fishery protection problems in the Pacific Northwest. *Trans. 14th North American Wildlife Conf.,* pp. 276-282.

RICH, W. H. 1940. The future of the Columbia River salmon fisheries. *Stanford Ichthyol. Bull.,* **2**(2): 37-47.

1948. A survey of the Columbia River and its tributaries with special reference to the management of its fishery resources. *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.,* No. 51, 26 pp.

SCHOENEMAN, D. E., AND C. O. JUNGE. 1954. Investigations of mortalities to downstream migrant salmon at two dams on the Elwha River. *Washington Dept. Fish., Res. Bull.,* No. 3: 51 pp.

Schoning, R. W., and D. R. Johnson. 1956. A measured delay in the migration of adult chinook salmon at Bonneville Dam on the Columbia River. *Fish Comm. Oregon, Contr.* No. 23, 14 pp.

Seymour, A. H. MS, 1956. Effects of temperature upon young chinook salmon. Ph.D. thesis, School of Fisheries, University of Washington, Seattle.

Shepard, M. P. 1955. Resistance and tolerance of young speckled trout to oxygen lack, with special reference to low oxygen acclimation. *J. Fish. Res. Bd. Canada,* **12**(3): 387-446.

Talbot, G. B. 1950. A biological study of the effectiveness of the Hell's Gate fishways. *Int. Pacific Salmon Fish. Comm., Bull.* No. 3, pp. 7-80.

Thompson, W. F. 1945. Effect of the obstruction at Hell's Gate on the sockeye salmon of the Fraser River. *Int. Pacific Salmon Fish. Comm., Bull.,* No. 1, 175 pp.

Trefethen, P. S. 1955. Exploratory experiments in guiding salmon fingerlings by a narrow D.C. electric field. *U.S. Fish and Wildlife Serv., Spec. Sci. Rept., Fish.,* No. 158, 42 pp.

Waldichuk, M. 1954. Effect of pulp mill waste in Alberni Harbour. *Fish. Res. Bd. Canada, Pacific Prog. Rept.,* No. 101, pp. 23-26.

Ward, H. B. 1927. The influence of a power dam in modifying conditions affecting the migration of salmon. *Proc. Nat. Acad. Sci.,* **15**: 56-62.

Warner, G. H. 1956. Report on the air-jet fish-deflector tests. *Prog. Fish-Culturist,* **18**(1): 39-41.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. *J. Fish. Res. Bd. Canada,* **11**(6): 933-953.

Wisby, W. J., and A. D. Hasler. 1954. Effect of olfactory occlusion on migrating silver salmon (*O. kisutch*). *J. Fish. Res. Bd. Canada,* **11**(4): 472-478.