Preliminary Assessment Of Methods To Enhance Arctic Char Populations In The Northwest Territories

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PRELIMINARY ASSESSMENT OF METHODS TO ENHANCE ANADROMOUS ARCTIC CHAR POPULATIONS IN THE NORTHWEST TERRITORIES

by

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EXECUTIVE SUMMARY

Sea-run Arctic char (*Salvelinus alpinus*) is an exceptionally valuable natural resource of the **NWT,** because:

1. *they are considered a gourmet food in most countries and they therefore command a relatively high market price;*
2. *they are highly prized by sport fishermen; and*
3. *they are also a **favourite** fish of local residents.*

Because sea-run Arctic char are relatively slow growing and because demand, from a variety of users, is high, a substantial number of anadromous Arctic char populations in the **NWT** have become severely overexploited and a number of others are being harvested at rates which are probably above sustainable levels. This is especially true of populations in close proximity to communities.

When char stocks become depressed or show signs of overfishing, current management practice is to close or reduce commercial quotas. This measure is taken in preference to placing restrictions on sport or subsistence/domestic harvests. Therefore, commercial fishing for sea-run Arctic char in "easily" accessible waterbodies could become more and more restricted in future years with subsequent economic losses to participants in the commercial char fishery, This is unfortunate, since Arctic char alone contribute close to 20% of the total value of the commercial freshwater fish production of the **NWT.**

The Government of the Northwest Territories tabled a document on 19 February 1990 during the legislative assembly, entitled "Building on Strengths: A Community Based Approach; Renewable Resources: Building on a Tradition". A target set and to be achieved within the next five years is to "increase char production by 33 peroent to 161,000 kg valued at $1.0 million" (page 16). This **will be difficult to achieve, because the most economically harvested char stocks in the NWT — that is, those which are close to communities and the established transportation systems — have been or are already being harvested.**

The need to investigate ways to increase production of Arctic char in the NWT is clearly apparent. This should not only include efforts to increase the harvest from unexploited or underexploited stocks, but should also include studies on how to increase production over "natural" levels and on how to speed the rehabilitation of depressed populations. Because of the above problems and the potential to apply enhancement techniques to sea-run char of the NWT, the Natural Resources Section . of the Department of Economic Development and Tourism sponsored the present study, the broad purpose of which was to assess enhancement potential of sea-run Arctic char in the NWT.

OBJECTIVES

The primary goal of this investigation was to assess practical techniques for enhancement of sea-run char populations in the Northwest Territories, This goal was pursued through the following objectives:

1. *a review of pertinent life-history characteristics of A retie char populations;*
2. *a review of methods used by the Salmonid Enhancement Program (SEP) to enhance fish populations in eastern and western Canada;*
3. *a review of methods used to enhance A retie char populations;*

4. *identification of enhancement techniques for A retie char in the **NWT;***

5. *analysis of effects of selected enhancement techniques on char population dynamics; and*

6. *provision of recommendations on **courses** of action that could promote the use of appropriate enhancement techniques in the **NWT.***

It was understood that consideration of hatcheries was beyond the scope of the present project.

METHODS AND RESULTS

Standard literature review techniques were employed during the present study; however, the information reviewed was initiated by contacting supervisors and managers of the **Salmonid** Enhancement Program **(SEP)** of the Department of Fisheries and Oceans in British Columbia, Newfoundland, Nova Scotia and New Brunswick, in addition to leading experts on the biology of Arctic char, This approach was extremely efficient in obtaining the latest information on various techniques.

Results of the study indicate that many salmon enhancement techniques are not appropriate for Arctic char, because of inherent differences in their life cycles and the habitats they occupy. A major difference is that salmon rely heavily on streams to complete their life cycle and, in most of the **NWT,** Arctic char rely more heavily on lakes. Despite these differences, a number of enhancement techniques were identified that show great promise in increasing sea-run char stocks in the **NWT.**

CONCLUSIONS AND RECOMMENDATIONS

1. Elimination of barriers to upstream fish movement has a great potential to enhance sea-run Arctic char populations in the NWT. Superficial and preliminary scanning of drainages in the NWT identified several systems which could support sea-run populations whose value to commercial fisheries would be over $100,000 per annum.

Recommendation: A program should be designed to identify the high priority drainages in the NWT for the removal of fish blocks. It should include consideration of:

- *a. size of the sea-run char populations that the new habitat could SUDDort;*
- *b. nature of the fish block(s):*
- *c. accessibility of the area to fisheries: and*
- *d. cooperative nature and desires of residents in nearby communities.*

2. "Forced **smoltification**" has an exceptionally large potential to quickly enhance depressed sea-run Arctic char populations in the NWT. This concept is new and untested.

Recommendation: An experimental program should be initiated to determine if resident Arctic char can be forced to smelt and contribute to sea-run populations.

3. Increasing the survival of young char through the use of *in situ* lake incubators in conjunction with supplemental feeding of young char has a large potential to increase the production of exploited populations of sea-run Arctic char in many regions of the NWT.

Recommendation: A pilot project should be initiated, which tests the feasibility of lake incubation and supplemental feeding for Arctic char.

4. Fertilization programs have the potential to enhance sea-run char stocks throughout the NWT if appropriate techniques can be defined. This technique cannot be applied to the NWT with any degree of confidence, because gaps exist in the basic knowledge about responses of Arctic freshwater systems to fertilization.

Recommendation: A research program should be initiated in the NWT to test the responses of lakes and, to a limited extent streams, to applications of fertilizer.

5. From 1977 to 1984, the Salmonid Enhancement Program in British Columbia cost approximately $157 million and is presently ongoing. During this same time period, approximately $12 million were expended on the Community Economic Development Program (CEDP), a subcomponent of SEP. Specific goals of CEDP were:

> '1. *To contribute significantly to salmonid enhancement.*
>
> 2. *To provide satisfying employment for people who would otherwise be unemployed or severely underemployed.*

3. *To train people in the **Bands** ond communities in enhancement and management tasks to the extent that those groups will eventually be able to provide all the **personnel** needed for enhancement works. This may involve assisting **personal** development of some individuals and increasing **their job and education** aspirations.*

4. *To contribute to community development through increased community **satisfaction**, development of community **leaders and** reduced **need for out** -migration **of capable individuals**.*

5. ***To improve Band-Fisheries** relations. "*

In an assessment of the effectiveness of **CEDP,** Rank (1982) concluded that it was notably successful in providing social benefits in terms of meaningful long-term jobs supported by comprehensive training programs and satisfying enhancement objectives. He concluded by stating that:

> *"When **comparing** the **CEDP** to other kinds of **Native** economic development **programs**, people typically call it 'the best' or 'one of the best.'"*

<u>Recommendation: The **meshing** of biological and social objectives within the SEP is viewed as one of the major successes of the **program. Similar programs** are **strongly** recommended for the NWT.</u>

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INTRODUCTION

The Northwest Territories, with its abundance of lakes and streams in many regions, supports tremendous numbers of fish, which are viewed as a major renewable resource of the region. Despite this abundance, fish of the NWT do not support large commercial fisheries in a woridwide sense. This is because many of the most plentiful species are not preferred by consumers as food fish, and do not command high market prices. This, in injunction with high transportation costs, makes harvesting of such species uneconomical at the present time.

Sea-run Arctic char (*Salvelinus alpinus*) are an exception in that they are considered a gourmet food in most countries and they therefore command a relatively high market price. For example, sea-run char are purchased by the Freshwater Fish - Marketing Corporation from fishermen of the NWT for approximateiy $8.80/kg. in mntrast, lake trout and lake whitefish, two of the most commercially important species in the NWT, are purchased for $2.00 and $1.69/kg (winter price), respectively. Because of the high price and high market demand for sea-run Arctic char, commercial exploitation of this species is occurring in the NWT at a relatively high rate. in addition, sea-run char are an extremely popular sports fish and trophy sports fisheries in the NWT attract fishermen from around the world. Local residents aiso generally prefer sea-run char over other species; therefore, domestic and subsistence fisheries sometimes take considerable numbers of char.

Because sea-run Arctic char are relatively siow growing and because demand, from a variety of users, is high, a substantial number of anadromous Arctic char populations in the NWT have become overexploited and a number of others are being harvested at rates which are probably above sustainable levels. This is especially true of populations in close proximity to communities. A few examples of such depressed sea-run Arctic char stocks include:

1. Sylvia Grinnell River near Iqaluit;
2. Salmon River near Pond Inlet;
3. Diana River near Rankin Inlet;
4. Arrowsmith River near Pelly Bay;
5. Becher River near Pelly Bay;
6. Coppermine River near Coppermine;
7. Kellett River near Pelly Bay;
8. several small unnamed rivers near Pangnirtung;
9. Tugaat River near Igloolik;
10. Rat River near Fort McPherson;
11. Big Fish River near Aklavik;
12. Hornaday River near Paulatuk;
13. Freshwater Creek near Cambridge Bay.

The above list is far from complete and it does not include populations that are being overexploited at the present time, where reduced quotas can be expected in the next 3-5 years. Hence, the problem of overexploitation of anadromous Arctic char stocks is widespread across the NWT. It will become a much larger problem in future years unless remedial actions are taken.

When char stocks become depressed or show signs of overfishing, current management practice is to close or reduce commercial quotas. This measure is taken in preference to placing restrictions on sport or subsistence/domestic harvests. Therefore, commercial fishing for sea-run Arctic char in “easily” accessible waterbodies could become more and more restricted in future years with subsequent economic losses to participants in the commercial char fishery. This is unfortunate, since Arctic char alone contribute close to 20% of the total value of the commercial freshwater fish production of the NWT.

The Government of the Northwest Territories tabled a document on 19 February 1990 during the legislative assembly, entitled "Building on Strenaths: A Community Based Approach: Renewable Resources: Building on a Tradition", A target set and to be achieved within the next five years is to "increase char production by 33 percent to 161,000 kg valued at $1.0 million" (page 16). This will be difficult to achieve, because the most economically harvested char stocks in the NWT — that is, those which are close to communities and the established transportation systems — have been or are already being harvested.

A substantial number of unexploited char populations do exist in the NWT; however, these are often in remote areas where rests of harvesting are excessively high. The need to investigate ways to increase production of Arctic char in the NWT is clearly apparent. This should not only include efforts to increase the harvest from unexploited or underexploited stocks, but should also include studies on how to increase production over "natural" levels and on how to speed the rehabilitation of depressed populations.

Modern concepts in relation to fisheries management, sustainable development and conservation include not only regulation and changes in fishing practices but also enhancement of habitat and increasing fish production whenever possible. This is a substantial departure from historic fisheries management practices, especially in the NWT. Enhancement of fish populations by manipulation of habitat or stocks is, however, an accepted management tool the world over. These techniques could play an important part in fish production in the NWT in future years.

Because of the above problems and the potential to apply enhancement techniques to sea-run char of the NWT, the Natural Resources Section of the Department of Economic Development and Tourism sponsored the present study, the broad purpose of which was to assess enhancement potential of sea-run Arctic char in the NWT.

OBJECTIVES

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3. a review of methods used to enhance Arctic char populations;
4. identification of enhancement techniques for Arctic char in the NWT;
5. analysis of effects of selected enhancement techniques on char population dynamics; and
6. provision of recommendations on courses of action that could promote the use of appropriate enhancement techniques in the NWT.

It was understood that consideration of hatcheries was beyond the scope of the present project.

METHODS

Methods used in this study were straightforward standard literature and information review techniques. Because of the voluminous nature of formal and informal reports, documents and manuscripts, etc., concerning the multimillion dollar long-term Salmonid Enhancement Program (SEP) administered and managed by the Department of Fisheries and Oceans, and the relatively small effort involved in the present study, it was decided not to use computer-aided literature searches, since these would have generated hundreds, if not thousands, of items, many of which are outdated. It was felt that a better approach was to contact supervisors of SEP on both the east and west coasts of Canada, and to contact leading scientists in relation to the latest findings on Arctic char. Thus, the study relied on verbal communication with . appropriate authorities, followed by identification of the latest written report on various subjects. The following individuals were contacted:

<u>Salmonid Enhancement - East Coast</u>

Dr. Vern Pepper
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All of the above individuals are thanked for their moderation. Special thanks are due to Dr. L. Johnson who contributed unpublished ideas in relation to char enhancement, and to Mr. Gary Logan, who was especially cooperative in relation to salmon enhancement techniques and community projects.

The following report first describes some pertinent details about the biology of Arctic char, because it is important to realize that, while somewhat similar to salmon, Arctic char life cycles differ in some important features. Therefore, all salmon enhancement techniques are not directly transferable to Arctic char.

Secondly, the report provides a summary of most salmon enhancement techniques, excluding hatcheries and "put and take" techniques, which rely on hatchery-produced fish.

Techniques that have been used in trial attempts to enhance Arctic char populations are next described, because this information is, of course, directly applicable to the present study.

Fourthly, enhancement techniques are assessed in relation to their potential to enhance sea-run Arctic char populations.

Finally, enhancement techniques that appear to be most promising in relation to sea-run Arctic char in the NWT are selected and discussed.

SELECTED CHARACTERISTICS OF ARCTIC CHAR

Arctic char have captured the attention of research scientists around the world, and consequently a considerable amount of information is available concerning different races, their distributions and various life-history patterns. Interested parties should pursue readings in "Biology of the Arctic Charr: Proceedings of the International Symposium on Arctic Charr" (Johnson and Burns 1984) and "Charrs—Salmonid Fishes of the Genus *Salvelinus* " (Balon 1980). Both books contain a wealth of information on Arctic char, A chapter in the latter, entitled "The Arctic Charr, *Salvelinus alpinus*" by Lionel Johnson, a world authority on northern fish, is particularly useful. Johnson (1989) also provides a wealth of information on a long-term study of Arctic char populations in the NWT. Much of the following is drawn from these sources.

The following material emphasizes those aspects of the biology and distribution of Arctic char in the NWT that could limit fished and unfished populations, since identification of limiting factors is a first step to enhancement of fish populations. It is not meant to be an exhaustive review.

Races and Forms of Arctic Char

Arctic char are circumpolar in distribution (Figure 1) and throughout their range they display a great variety of morphological forms, different life-history patterns, colour, growth rates, etc. In addition, sympatric stocks can occupy the same waterbody and have distinct movement patterns, growth rates, diets, etc. These complexities must be, at least partially, understood because different forms or races could have quite different habitat requirements or biological characteristics and react quite differently to particular enhancement techniques. For the present purposes, it is at least necessary to recognise that Arctic char can occur, as defined by McCart (1980), in the following forms:

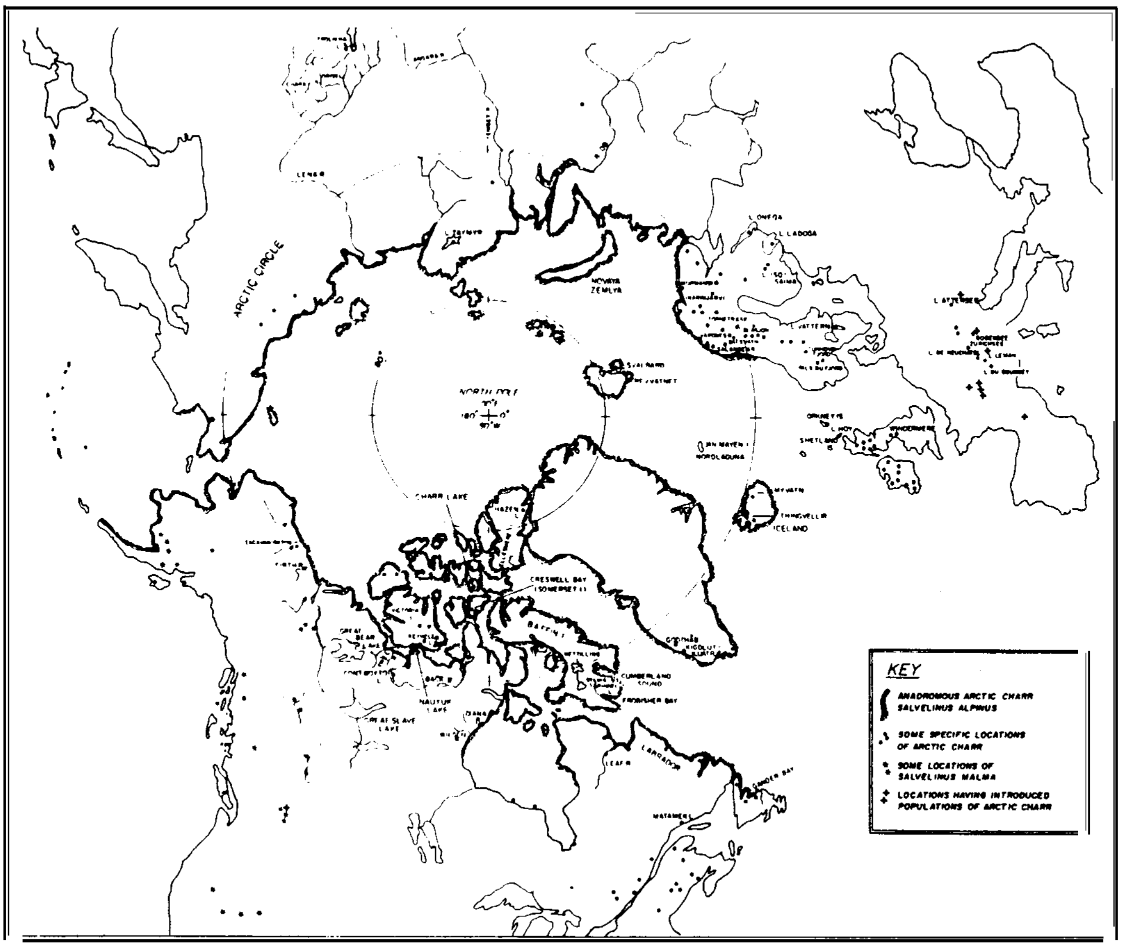


Figure 1, Sketch map of the Polar regions showing the distribution of Arctic char. The absence of marking in the Pacific basin does not necessarily indicate absence of Arctic char (from Johnson 1980).

1. Lake Resident Populations. While a few individuals may enter tributary streams on feeding excursions during the summer, these populations are almost entirely confined to lakes.

2. Isolated Stream Resident Populations. These occupy spring-fed stream channels and are isolated from contact with populations further downstream by impassable falls or other blockages to upstream movement.

3. Anadromous Populations. These have a migrant component which enters the sea to feed during the summer. Anadromous char spawn and overwinter only in streams in the vicinity of perennial groundwater sources in northwestern Canada. In northcentral and northeastern Canada they normally spawn and overwinter in lakes.

4. Residual Populations. These almost exclusively male fish are associated with anadromous populations but mature without having undertaken a sea-ward migration.

In addition, based on meristic and physiological data, there are two recognised forms of Arctic char in Canada (McCart 1980):

1. The western form has relatively few pyloric caecae (mean = 29.0; R=16-45; N=1098) and first arch gill rakers (mean =21 .3; R=16-28; N=1045) and is almost wholly associated with streams (not lakes) west of Big Fish River near the Mackenzie Delta;

2. The eastern form has a higher number of pyloric caeca (mean = 39.3; R=21-59; N=224) and a higher total gillraker count (mean = 27.4; R=19-33; N=218), and occurs mainly in association with lakes, primarily found east of the Mackenzie Delta.

Unless otherwise specified, the following material refers to anadromous populations of the eastern form of Arctic char, since this form occurs over much of northern Canada and only anadromous stocks are targets for enhancement.

Overwintering

Although few studies have documented the limitations on fish distribution and production that are imposed by a severe Arctic climate, the availability of unfrozen water in winter is of obvious crucial importance to fish survival. Excluding lake resident populations, the distribution of Arctic char in the western Arctic (i.e., west of the Mackenzie River) corresponds closely with the occurrence of major sources of perennial springs (McCart 1980). This is because even major rivers in the area cease to have surface flow in winter and stream resident char depend entirely on groundwater sources. As the groundwater cools, it gradually freezes and forms extensive areas of *aufeis*. Overwintering fish survive in isolated, sometimes quite small, areas of free water until they are released from this habitat by the spring thaw. Such spring areas are exclusively associated with mountainous regions in northwestern Canada and Alaska.

Large rivers may sometimes have isolated pools of free water in their beds throughout the winter or, as is the case with unusually large rivers such as the Mackenzie River, they maintain flow throughout the winter. The western form of Arctic char apparently does not generally use such habitat for overwintering, Char have not been reported in winter catches from the Mackenzie River, In addition, intensive winter studies reported by Schmidt et al. (1989) in lower portions of the Sagavanirktok and Colville River, Alaska, which included under-ice SCUBA diver observations, revealed the presence of several species of whitefish, cisco and sculpin, but Arctic char were not present. These drainages, however, harbour overwintering char in several spring areas in their upper reaches (McCart 1980).

As previously discussed, the eastern form of Arctic char overwinters (and spawns) mainly in lakes, although the large river-lake systems in, for example, the Keewatin, sometimes make it difficult to distinguish lake from river, In addition, few detailed studies have been performed in much of the range of the eastern Arctic char of the NWT. In any event, overwintering habitat is much more abundant in the northcentral and northeastern portion of the Canadian mainland and in more northern regions such as Victoria Island, Boothia Peninsula and the Foxe basin area. This is because of the abundance of lakes in the region. Overwintering habitat again becomes much more limiting along the northeast coast of Baffin Island, and in the Central and High Arctic Islands. This region is typified by relatively small drainages which are dewatered for much of the year; relatively few lakes occur in the region.

Food

We assume that food while sea-run char are at sea is overabundant and does not limit growth of individual fish. In mntrast, food in their freshwater environment may be in very short supply and play an extremely important role in limiting growth and even survival of individuals during stressful periods, such as overwintering. Although anadromous populations may escape the food-limiting nature of their freshwater environment by smoltification and annual visits to the sea, food in fresh waters is still very important to sea-run stocks. This is because the young of anadromous char populations spend several years in fresh water before their first visit to the sea. Furthermore, there is some evidence (Johnson 1989) that smoltification depends on size, which in turn is dependent on the growth produced by the freshwater food supply.

In addition to the above, it is commonly accepted that food during the first feeding periods of alevins is critical to their survival, Food of the correct size and quality must be available within a very short time period, or excessive mortality occurs. Food may also affect overwintering survival of young char. Hunt (1969) found that larger brook trout fry had higher first winter survival than smaller specimens.

Spawning

Some populations of Arctic char maybe limited by spawning substrate. In much of the central Canadian Arctic and throughout the Arctic Islands, spawning is restricted to lakes, because rivers are frozen solid in winter. Johnson (1980, 1989) described spawning beds in Willow Lake, Kent Peninsula, as occurring in 3 to 6 m of water, Redds were prepared in limestone gravel, 5-7 cm in diameter. Vegetated, silty areas were present between individual redds and spawning generally began in the second week of September.

In late summer and fall, the eastern form of Arctic char often occurs in concentrations in lakes near the mouths of inflowing streams (pers. observations). . These regions are normally characterised by outwash fans of gravel and cobble that are carried into the lake by freshets. Catches from these concentrations indicate that they were composed entirely of ripening spawners of the year. It is suspected that such areas may by commonly used as spawning grounds because of the availability of relatively clean, loose substrate of suitable size. Such conditions would promote water permeation through the “gravel” with consequent oxygenation of the eggs.

The western anadromous form of Arctic char spawns in streams, usually but not always in the approximate area of their overwintering grounds. Suitable spawning substrates range form pea gravel to 2-10 cm gravel-small cobble areas (Yoshihara 1973; McCart 1980). The former author noted that in the Lupin River, Alaska, a redd was located in water 20 cm deep with a surface velocity of 0.6 $m.sec^{-1}$. It measured about 3.5 m long and 1.2 m wide and contained several individual nests. McCart (1980) noted that heavy growths of filamentous algae commonly occur on substrates in spawning areas.

Migrations

Waterfalls and Velocity Barriers

Unlike salmon, Arctic char are not strong swimmers (or jumpers) and they are limited in their upstream movement by relatively low waterfalls and velocity barriers, Beamish (1980) concluded a study of char swimming performance by stating that Arctic char appeared to be better adapted for migration in lakes than for moving at high speeds through fast-flowing waters. Anadromous populations of Arctic char are therefore often severely limited by barriers to migration. Such barriers often prevent large populations of Arctic char from developing in otherwise optimal conditions.

Low water Conditions

Low water in streams or even large rivers can prevent or hinder upstream movement of anadromous Arctic char. Power and Barton (1987) reported that 18 of 46 systems studied along Ungava Bay had areas which hindered upstream movement of Arctic char in recent years. They attributed the increasing frequency of years in which char are reported to have had difficulty in returning to overwintering lakes to:

1. climatic changes (cooler, drier summers); and
2. an expanding caribou population, which
   a. has substantially reduced vegetative cover in the region, which in turn
   b. decreases water retention time within drainages, and
   c. produces periods of both higher and lower than normal water levels (the latter generally mrrespond to periods of upstream char migration).

Because of naturally low precipitation, thousands of drainages in the NWT have poor connections to the sea in late summer and fall. This is especially true in the Central and High Arctic, where catchment basins tend to be smaller.

Increasing the amount of freshwater habitat available to sea-run fish by removal of barriers to upstream migration is one of the commonest, most economical and successful ways to enlarge (or create) sea-run populations of valuable fishes. This technique has been used throughout the world and is commonly used in British Columbia, Newfoundland, Nova Scotia and New Brunswick to enlarge salmon populations. As will be shown in later sections of this report, the NWT has an exceptionally large potential to expand sea-run char populations simply by removal of obstacles to upstream migration,

Intraspecific Competition

it is commonly recognised that competition is most intense among individuals of the same species, intraspecific competition for food, overwintering space and specific . nest sites for spawning, etc., is presumably intense in unexploited Arctic char populations. As shown in Figure 2, a bimodal length frequency distribution is the norm for "populations" of Arctic char in the "adult" size range, and size of the individual is not highly correlated with age in all cases (Jenness 1922; Yoshihara 1974; Sekerak et al. 1976; Craig 1977; Johnson 1980, 1989). it has been suggested that recruitment into the larger mode is controlled by density-dependent factors as well as environmental factors (Johnson 1976, 1980, 1989). Such a situation can be likened to a forest where larger trees overshadow the small, and limit their recruitment into the larger size range, However, it should be noted that the exact factors governing Arctic char population dynamics are not known. Johnson (1980) emphasised that Arctic char exhibit a great number of forms, and have exceedingly complex iife cycles, and their population dynamics are far from understood. in any event, it is important to note that unexploited populations of Arctic char are probably severely limited by intraspecific competition, since they have few predators and mmpetition from other species is iow. This may be especially true of Arctic char populations in the northern portion of their range where few, if any, other fish species occur.

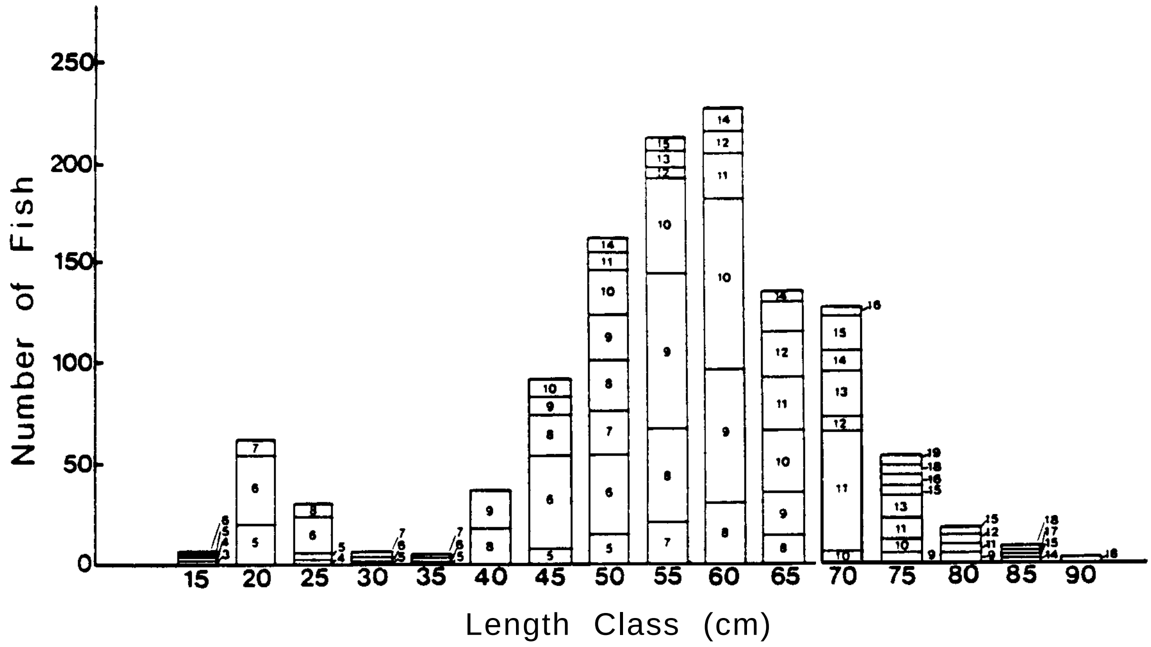


Figure 2. The length-frequency distribution of the downstream population of Arctic char at Nauyuk Lake in 1974, showing the age composition of each length class (from Johnson 1980).

Age at Maturity

Anadromous populations of Arctic char mature slowly; individuals normally mature after 10 to 15 years of age, although much eider immature individuals have been recorded (Table 1). This is in great contrast to many other fish; for example, Pacific salmon, ail of which complete their life cycle within 5 to 6 years.

Frequency of Spawning

Female Arctic char of anadromous stocks in the NWT do not spawn every year. Johnson (1980) is of the opinion that even alternate year spawning may be more uncommon than previously expected. For example, his studies of anadromous char in the Nauyuk Lake system found that only about 29% of the mature female stock spawned in 1976. Hunter (1976) reported 33 years as the maximum age for char in the Sylvia Grinnell River and Sekerak et al. (1976) reported char over 25 years old in Cresswell Bay, Somerset Island. Therefore, if individuals spawn every 3 to 4 years and mature in their teens, each female might spawn oniy 6-8 times over its entire life span.

Fecundity

Potential reproductive capacity of Arctic char is determined by the number of eggs produced by the female in addition to frequency of spawning and age at maturity. The number of eggs produced is, in turn, mainly dependent on size of the female, since final size of healthy ova (from 4,0 to about 5.3 or 5.5 mm in diameter) remains much the same. Common practice is to express fecundity as the number of eggs per spawning female or the number of eggs per 100 g of spawning female. A number of useful indices have been deveioped to obtain estimates of the number of eggs, without

Table 1. Information on maturity and fecundity for some anadromous Arctic char stocks in the NWT.

Locality	Age at Maturity	Length at Maturity (mm)	Mean Weight at Maturity (9)	Mean Number Eggs/Fish	Number Eggs/l 00 g	Reference
Cumberland Sd. Baffin Island (River A)	11 to 19 mean-l 5.6	400-600	615-2050	2000-4700	229-325	Moore 1975
Sylvia Grinnel R.	14 to 22	450-695	1950	3520	176	Grainger 1953
Creswell Bay Somerset Island	13 to 25 mean-19	383-570	559-2047	953-2126	153-170	Sekerak et al. 1976
Mackinson Inlet Ellesmere Island	12 to 16	447-463	850-925	1465-1711	158-201	Peet 1975
Nauyuk Lake Kent Pen.	10 to 18	620-803	2415	4781	140	Johnson 1980

going through the laborious process of counting each individual egg. For example, Glova and McCart (1 974) determined for Arctic char in the Firth River, Yukon, that:

log Fecundity =2.8169 log Fork Length -4.0125

In this population, mean egg production per female (mean length 529.6 mm) was 4954 ± 463 eggs or 365 eggs.100 g^{-1} of female. As shown in Table 1, each female sea-run Arctic char typically produces a few thousand eggs, generally between 1000 and 4000. This corresponds roughly to 140 to 345 eggs.100 g^{-1} of spawning female,

Reproductive Potential of Populations

It is apparent that the reproductive potential of Arctic char, which produce a few thousand eggs per female, is quite low. For example, burbot commonly produce 100,000s of eggs per female (Scott and Crossman 1973) and many other fish species produce equally large numbers. However, the reproductive potential of Arctic char populations is even lower than suggested above, because:

1. spawning does not occur every year; and
2. maturity is attained relatively late in life.

Thus, although large populations of char may occur, most of the biomass of the population at any one time is represented by immature specimens, adults that are resting between spawning seasons and senescent individuals who may not spawn again. Johnson (1980) reported that none of the largest Arctic char (≥ 900 mm) of the Nauyuk Lake system were ever observed in spawning rendition, and that in 1975 only 198 females spawned from a population of 9,672 individuals. Thus, total reproductive potential for this population was, at a maximum, only 792,000. Egg production in exploited stocks is even lower, since fisheries selectively remove large mature fish,

Mortality

Egg to Fry Mortality

Nothing is known about mortality in very early life stages of Arctic char and very few data are available on this subject for other members of the genus *Salvelinus.* It is commonly accepted that mortality is very high in the early life of most fishes. For example, it is generally held that about 75% egg to fry mortality occurs with salmon eggs in British Columbia streams where flow is relatively stable and spawning conditions are good (Stream Enhancement Guide S.E.G. 1980). This increases to about 90% mortality in streams where conditions are less than ideal.

Bacterial and fungal diseases attack and kill fish eggs and account for many unhatched eggs. In addition, the period of first feeding is known to be an especially critical phase in the life of many species of fish (May 1974), During this period, food of certain sizes and qualities must be available or heavy mortality can result. Latta (1969) demonstrated, in a unique study of brook char survival, that starvation was a probable chief cause of mortality during the alevin stage,

First Winter Mortality

Yet another period of high mortality for Arctic char could be their first overwintering period. Hunt (1969) found that first winter survival of brook trout was in-dependent of density but was correlated to size. Even small increases in size increased survival. Exhaustion of fat reserves during the winter was thought to be the prime reason of mortality of the smaller brook char. This factor could be of extreme importance to young Arctic char, since their overwintering period is considerably longer than for fish in more southern regions.

Juvenile Mortalitv and Mortalitv in Older Aae Classes

Juvenile mortality in young salmon can be quite high as a result of inter- and intraspecific competition for food and space, and predation. Smoltification is also considered to be a critical period in the life cycle of salmon, We again have no information on the mortality rates of juvenile Arctic char from anadromous populations, from age 1 + to the smelt stage, at about age 4+ to 6+.

It is generally accepted that as char become larger, their mortality rates become quite low, since they occupy habitats with few predators (L. Johnson, pers. comm., July 1990), This is especially true in the northernmost part of their range, where they are often the only fish species present, and very few, if any, vertebrate predators are present. In 1962 and in 1975, mortality in the sea-run portion of the char population from the Union River into Cresswell Bay was estimated to be about 10 to 12% (Sekerak et al. 1976; Johnson 1980). Mortality in the mid-sized length groups of sea-going fish in the Nauyuk Lake system was estimated at less than 20% (Johnson 1989). Moore (1975) estimated that the weighted average total annual mortality for populations of char in Cumberland Sound was about 16%. Such estimates affirm the belief that mortality in older age classes of char is relatively low.

Post- Spawning Mortality

Spawning is stressful to many species of fish, especially to females, and considerable numbers of individuals die during, or more likely, after the process. Johnson (1980) estimated that spawning mortality in the Nauyuk Lake system was about 13% for females and 5% for males. This mortality could also be a significant factor that limits the reproductive potential of Arctic char populations, since it is likely additive to other mortality and it acts selectively towards females.

Conclusions

Although a substantial amount of knowledge has been obtained in recent years on the population dynamics and natural history patterns of Arctic char, very little is known about the reactions of Arctic char to natural or unnatural perturbations or, for that matter, factors that actually limit production in exploited and unexploited populations. It Is important to realise that limiting factors could be, and probably are, quite different for fished and unfished populations. On the one hand, unfished populations might be limited by habitat, food or interactions with other biological components of the system, Such limitations are often density-dependent and exert more force the greater the size of the population.

In contrast to the above, production in fished populations is more likely to be limited by innate biological traits of the fish species themselves. Although traits such as fecundity and age at first maturity can be altered somewhat by general health, which in turn depends on abundance of food, living space, etc., fecundity is largely set by genetics of the species. There is little one can do to alter this trait, without intense selective breeding/genetic engineering programs. However, with the realisation of this possible limitation, we can focus our efforts toward producing maximum numbers of harvestable char from finite numbers of eggs. Modern-day hatcheries often do nothing more than this by:

1. optimizing renditions for incubating eggs;
2. providing ideal feed and feeding renditions for young **alevins;**
3. rearing young to the maximum size possible before release,

METHODS USED TO ENHANCE SALMON POPULATIONS

Removal of Barriers to Migration

Salmon enhancement projects in Canada, Alaska, Washington and in countries around the world have long recognised that one of the most cost-effective ways to increase sea-run stocks is to increase their freshwater habitat by eliminating blocks or hindrances to upstream fish migration. For example, R. Cutting, Head, Stock Assessment and Enhancement Section, Department of Fisheries and Oceans, stated that most past Atlantic salmon enhancement projects in Nova Scotia have focused on increasing habitat by removal of barriers, construction of fish ladders and annual trapping and trucking operations **(pers. comm.** June 1990), This is because this method proved to be most cost-efficient for the initial phases of the salmon enhancement project. Such individual programs vary in magnitude from relatively simple efforts to remove log jams and beaver dams or deepening of stream channels, to multi-million dollar developments and construction of permanent **fishways.**

Waterfalls and rapids can often be modified so that fish can navigate them with relative ease, In order to do this most efficiently and economically, it is necessary to understand the capabilities of the various species of fish in terms of swimming performance and the manner in which fish take advantage of stream hydraulics. For example, Figure 3 illustrates how fish use the upward thrust of water in a plunge pool below a waterfall and the importance of a deep plunge pool close to the waterfall.

Water flowing over smooth, steeply inclined bedrock can quickly attain velocities which negate upstream passage of fish, especially when plunge pools are absent, These velocity barriers can sometimes be broken with plunge pools which give the fish the added energy necessary to surmount the obstacle. Figure 4 is an example of such a situation which was modified by blasting to form a simple pool and step access which salmon could easily negotiate.

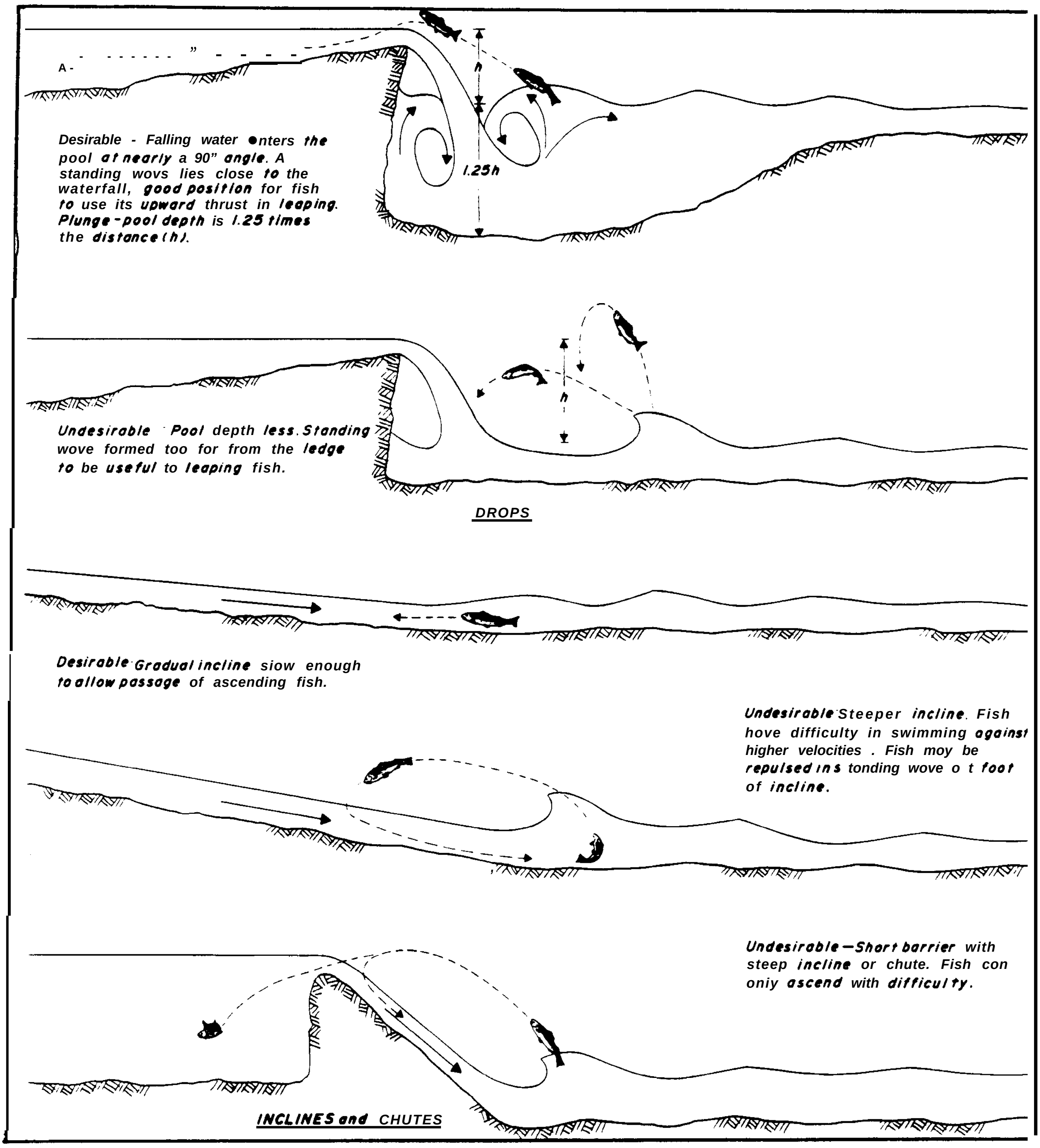


Figure 3. Movement of fish over natural and manmade obstacles (from S.E.G. 1980),

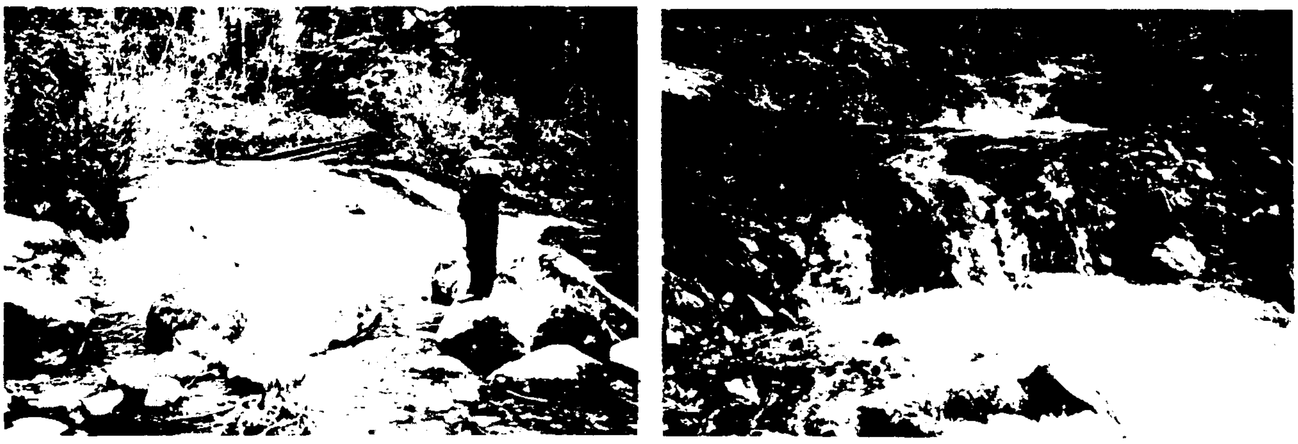
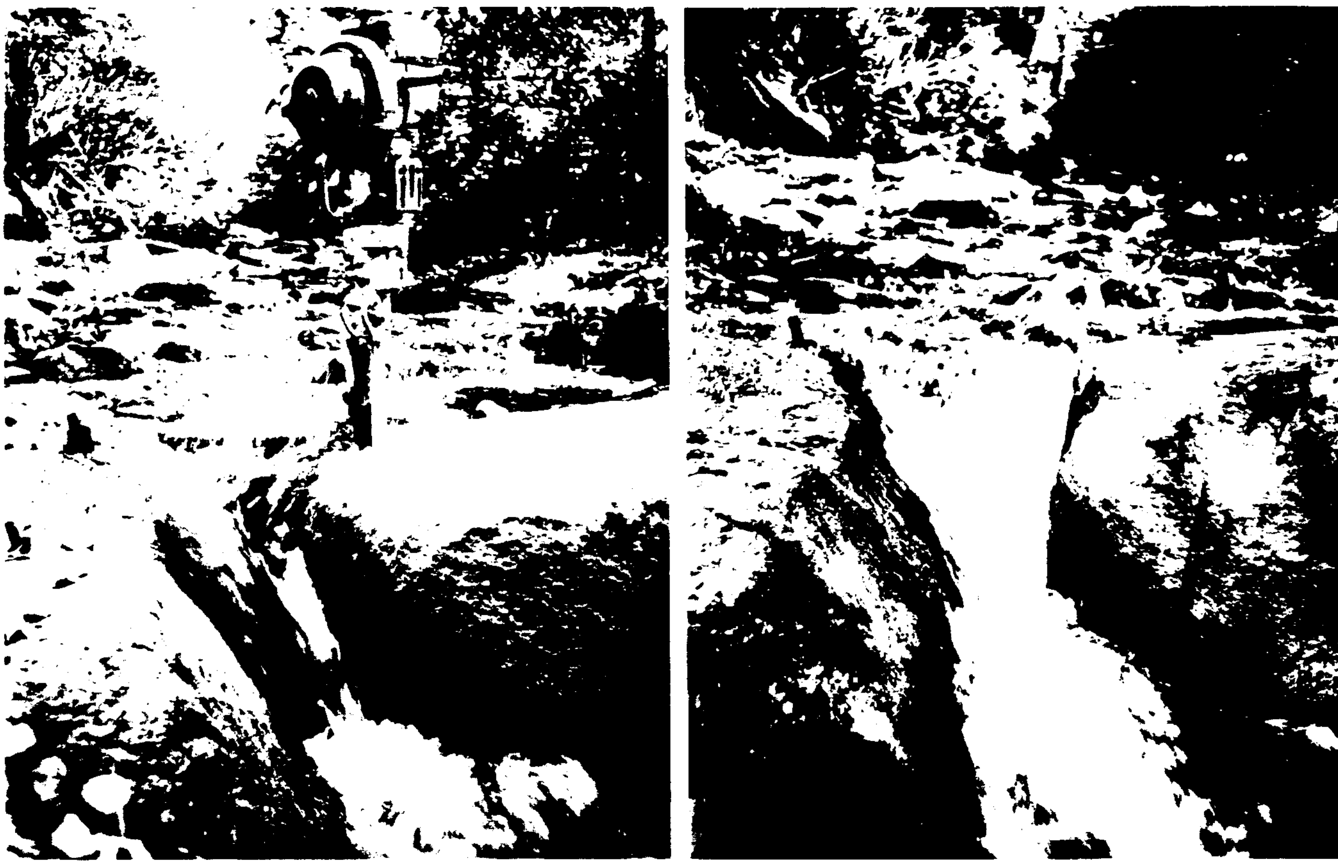


Figure 4. (A) A natural obstruction to migrating salmon (the high velocities developed over the steep bedrock made fish passage impossible at all flows). (B) The same section of stream with a simple pool and step access blasted into the bedrock to improve fish passage (from S.E.G. 1980).

Many obstacles, although effective fish blocks, can be removed with relatively little effort. Figure 5 shows a narrow, rock-controlled velocity barrier which was modified with a portable gasoline-powered rock drill and rock splitting tools.

Such streambed modifications can be performed with carefully placed and controlled explosive charges or by breaking rock. Both techniques usually involve drilling holes to contain charges or wedges. Breaking and fracturing can also be achieved with non-explosive outward pressure. Portable rock drills are common tools for either method. If possible, blasting is done in dewatered portions of the streambed at a time when it is least likely to harm existing fish populations in the waterbody.



BEFORE *AFTER*

Figure 5. Narrow notch in stream channel forms a velocity barrier to migrating fish. Fish passage was improved by drilling three holes with a gasoline-fuelled rock drill and splitting the bedrock which formed the sides of the notch (from S,E.G. 1980).

Debris (rockslides, logs, brush, etc.) sometimes blocks upstream fish passage, Hand tools are sometimes effective in clearing these obstacles, although heavy equipment is often used to clear major landslides and log jams.

Fishwavs

It is sometimes more effective to build a fishway around an obstacle than to remove the obstacle itself. Many types of fishways have been designed and their use depends on site-specific characteristics and the fish species involved. Relatively simple pool-weir designs can often be constructed by local workers (Figures 6, 7 and 8) with suitable supervision. In some cases, culverts can be modified to form effective fishways by placing concrete baffles on the bottom. Figure 9 illustrates the basic design of two types of fishways that are commonly used. Figure 10 illustrates a relatively simple design which takes advantage of natural bedrock to form the walls of the passageway. All but the simplest fishways require considerable expertise from hydrologists, engineers and biologists for proper functioning.

Figure 6. Simple pool and weir fishway on the Millstone River, Vancouver Island, constructed by a fish and game club. Steps were formed by selectively drilling and blasting the natural bedrock formation in the stream channels (from S, E, G. 1980).

Figure 7. Modified pool and weir fishway at Nib Falls on the Puntledge River, Vancouver Island, The flume section was carefully excavated in solid rock. Concrete baffles with narrow vertical slots were used to form the weirs (from S. E, G. 1980).

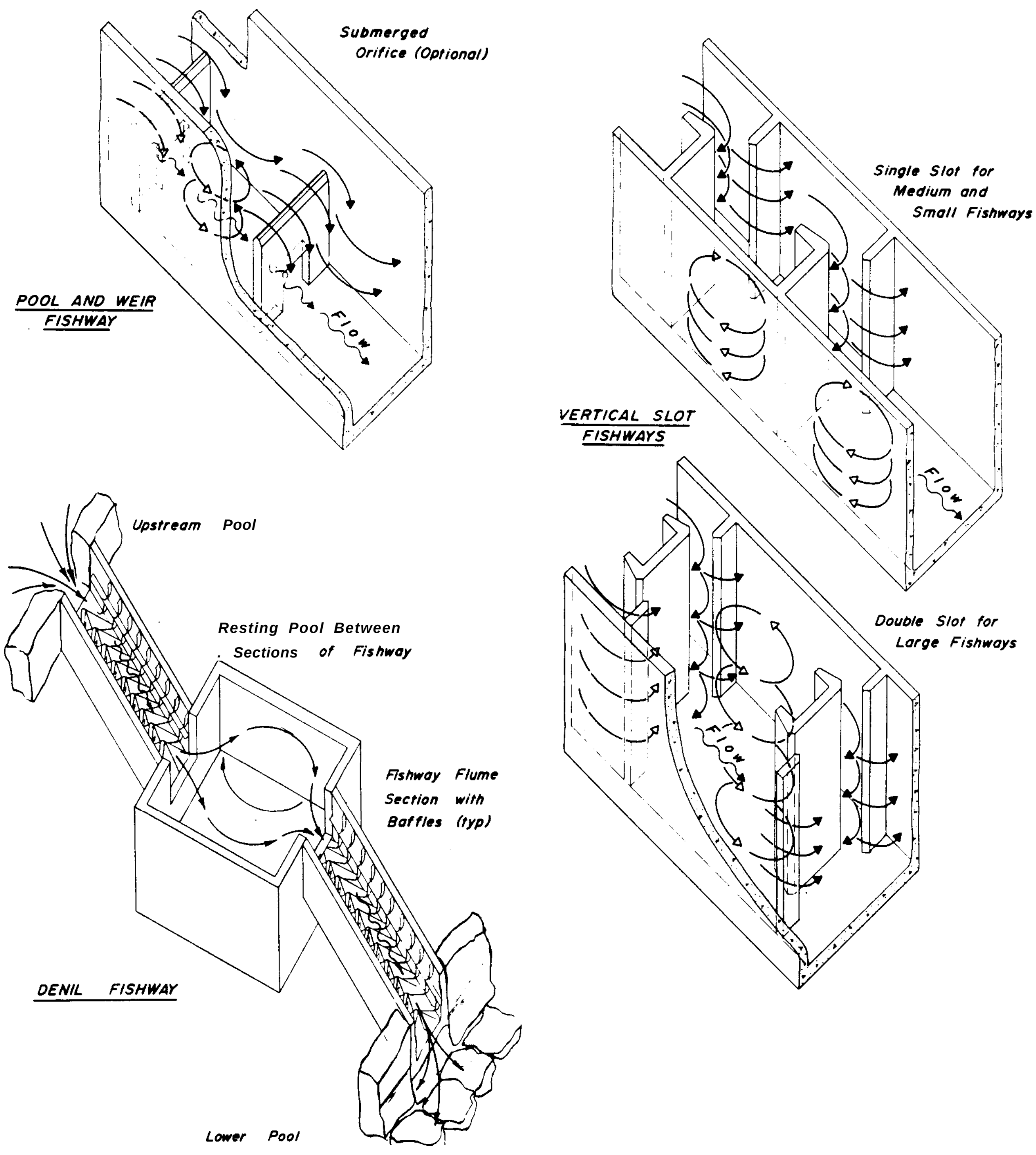


Figure 8. General outline and operational characteristics of pool and weir, vertical slot and Denil fishways (from S,E.G. 1980).

Figure 9. (A) Concrete rectangular culvert with offset baffles bolted to the floor. The baffles were made of treated timber, Without them, water velocities would be too high and the depth too shallow during fish migration. (B) Corrugated metal culvert with reinforced concrete baffles, Reinforcing dowels are welded to the floor of the culvert to anchor the baffles (from S.E.G. 1980).

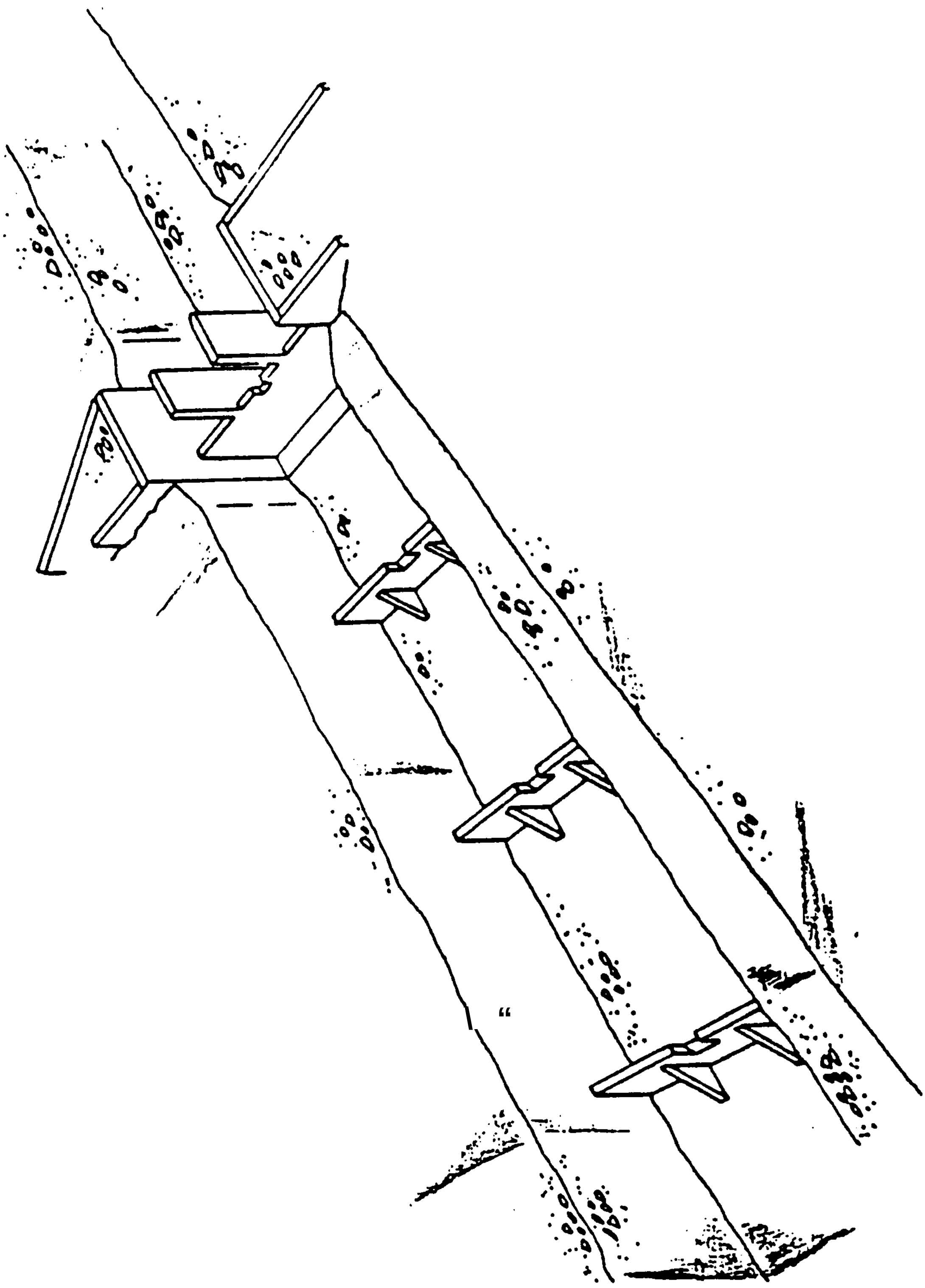


Figure 0 Schematic of a portion of the Liscomb River fishway h wı g the natural bedrock wa and the 0.6 m baffles (from O'Neil 1989 in Bielak 1990).

Establishing Populations

When a barrier has been effective for long periods of time, the downstream salmonid population may not have developed behaviour patterns which promote further upstream migration, In these cases, it can be beneficial to artificially establish populations above the obstacle to upstream movement after the obstacle has been removed (S.E.G. 1990). This can be accomplished by transporting adults to upstream areas or by planting eggs or fry in suitable upstream regions. Stock for these introductions should originate within the drainage, since such stocks are genetically fit for specific renditions within the region, This process can speed up natural coionisation of new areas.

in some cases, such introductions can be performed annually even when obstacles are still present in the stream. in these instances, it is beneficial because the resultant young move downstream and eventually contribute to adult stock, The unused upstream habitat is utilised with annual heip from the enhancement program.

Water Control

Many salmon and trout enhancement programs have focused on stabilizing stream flows, because wideiy fluctuating discharges due to drought, heavy rains, destruction of water retention capabilities of drainages, etc., are very detrimental to fish production in streams (Dompier 1980), Stabiiisation is most commoniy achieved by storing water during periods of high runoff, with subsequent release during periods of unwanted iow water. Additional water is normally stored in lakes or newly created reservoirs by damming the outlet stream. However, in some circumstances, lakes can be drawn down below their natural low water level by installation of water release structures below the natural iake outlet or by siphoning, The relationship between storage and discharge is:

$1 m^3.sec^{-1}$-days = area X depth X 0.116

where $1 m^3.sec^{-1}$-day = flow of 1 $m^3.sec^{-1}$ for 1 day
area = area of waterbody in hectares
depth = storage depth in metres

Hence, a live storage of 1.5 m on a 53 hectare lake could maintain a flow of 1 $m^3.sec^{-1}$ for 9.22 days or 0,1 $m^3.sec^{-1}$ for 92 days, etc. In most instances, rather modest increases in flow can dramatically improve juvenile fish habitat during dry periods. Considerably larger flows are usually necessary to improve conditions for upstream migrations,

A number of small projects in British Columbia have used water control structures to improve stream habitat. Figure 11 illustrates a small dam constructed of stream-side boulders and concrete. This structure stores sufficient water in the upstream lake to improve summer rearing habitat in the outlet stream for juvenile cutthroat trout and coho salmon (S.E.G. 1990). Figure 12 illustrates a larger project which improved summer rearing habitat and also provided sufficient water for upstream migration of adult salmon. The latter was achieved by releasing 0,5 to 1.0 m^3/sec for 4 to 6 weeks. The entire project was completed in approximately 6 weeks with a 3-4 person crew. It has been operating for over 14 years with minimal operation and maintenance costs (S.E.G. 1980).

Improving Rearing Habitat by Providing Cover

Rearing habitat for juvenile salmon is commonly recognised as a factor which limits many populations. Cover for juveniles is often critical to their survival. Nearly all efforts of the salmon enhancement programs have focused on enhancing stream rearing habitat and little information is available on potential ways to enhance lacustrine rearing habitat. Many stream enhancement techniques introduce heterogen-

Figure 11, A three foot high dam constructed of hand mixed concrete and boulders. The dam provided storage in 27 ha (69 acre) Matheson Lake, Vancouver Island, to increase summer flows for rearing juvenile coho and trout (from S.E.G. 1980).

Figure 12. A small flow control structure provides increased flows during the summer and early fall to improve spawning and rearing habitat for who and steelhead juveniles. The left photograph shows the initial instruction stages of an open cut channel which was blasted through bedrock to allow water to be drawn from the lake. The right photograph shows a simple, reinforced concrete wail installed with a manually operated sluice gate to control the discharge from the lake (from S.E.G. 1980),

city into the stream channel. Thus, pools and runs can be created in otherwise straight channels by using deflectors (Figure 13), or boulders can be placed in streams to create turbulence which creates pools and pockets. Cover can also be increased by placing and stabilising various types of objects in the stream (Figure 14).

Pond Rearing

Pond rearing of Atlantic salmon fry has proved to be an effective salmon enhancement method in Newfoundland (Pratt 1984; Pepper et ai. 1985). This technique normally involves obtaining fry from stream-side incubators or hatcheries and outplanting to natural ponds and small lakes. While it appears that these habitats are not intensively used by wiid fry, Atlantic salmon can be "coaxed" into lacustrine rearing by planting fry into ponds or in inlet streams beside the pond. Survival is generally good once fry use this habitat. Pratt (1984) estimated that pond-rearing enhancement projects could increase the commercial catch of Atlantic salmon by about 216,000 and the sport catch by 33,000.

"In situ" Incubators

Many different types of in *situ* incubators have been developed on the principle of providing ideai conditions for developing fish eggs in containers which are placed in or beside streams or lakes. This is done with the express purpose of increasing egg to fry survival rates and the technique is very useful to heip depressed populations recover, The technique is especially useful for "small-scale" enhancement projects which involve relatively inexperienced labour in remote areas.

To obtain fertilized eggs for the incubators, adult fish in spawning condition are often captured and held in pens or enclosures until ripe. Sex products are then stripp-

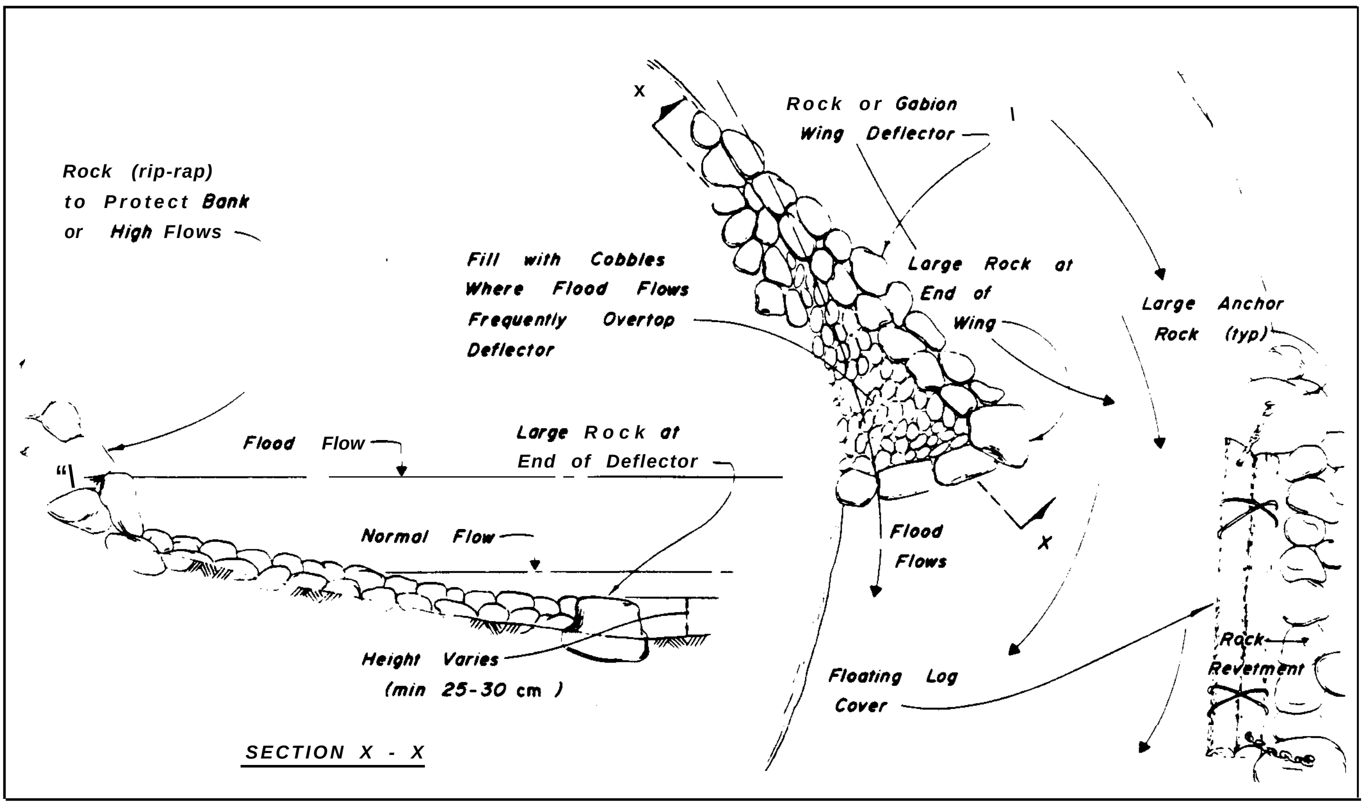


Figure 13. Typical wing deflector constructed from rock. The current will scour a deeper pool on the opposite bank. Two logs lashed together with cable provide floating rover. Anchor cable must be located to avoid snagging debris (from S.E.G. 1980),

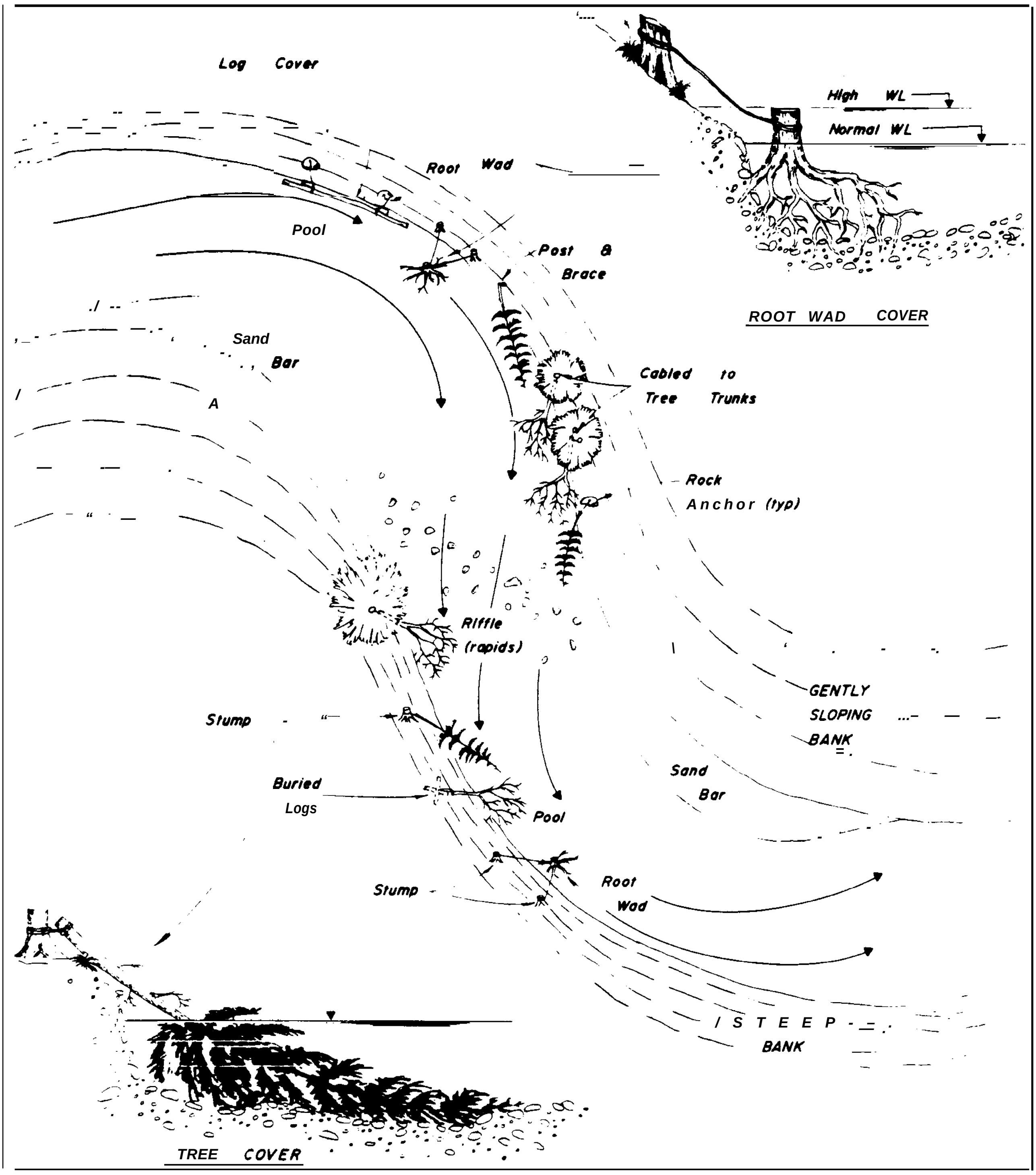


Figure 14, Examples of where trees, logs and root wads can be located to provide cover for rearing salmonids. These devices are secured to bank with cable, Stumps, trees, large rocks and buried logs can be used as anchors. Butt ends of trees must be kept above flood level to avoid snagging debris. Cable should be kept as short as possible, but approximately 0.6 m should be provided for free play and changes in water level, Regular maintenance and replacement are required for all items shown above due to natural decay (adapted from White and Brynhildson 1967 in S.E.G. 1980)-.

ed from the fish and eggs are fertilized in stream or lake-side containers. Fertilized eggs are then ready for placement into various types of incubators. Eggs must be handled shortly after fertilization, because they become very sensitive to shocks and vibrations about 24 hours after fertilization.

Stream Incubators

A basic stream incubator design used with many modifications for 100al conditions consists of a plywood box coated with non-toxic paint or fibreglass. Gravity fed water is piped into the bottom of the box and percolates upward through the gravel containing the developing eggs. Styrofoam can be used in cool climates to insulate the box and prevent freezing. (However, such incubators have never been used in Arctic conditions.) Boxes are usually equipped with a grate placed about 5-10 cm from the bottom so that fresh water is evenly distributed. Fertilized eggs are placed in the box between layers of gravel to a maximum depth of about 0.6 m.

Figure 15 illustrates a relatively large incubator box that is capable of holding about 50,000 salmon eggs. Such an installation is placed beside the stream to be enhanced in a suitable location for the gravity-fed water intake, collection of adults, access, etc. Pepper (1984) described a deep-substrate incubator designed for stream-side incubation of Atlantic salmon eggs. This unit used artificial turf instead of gravel and had a capacity of 300,000 to 500,000 eggs. Smaller units that work on the same principle can be buried in the stream where they remain undisturbed throughout the development period. Figure 16 illustrates a 15 X 9 X 6 cm Whitlock-Vibert box that is designed for the latter purpose, It is commonly constructed of plexiglass. As shown, an upper chamber holds developing eggs, Alevins descend into a large chamber as they hatch and resultant fry escape from the chamber through 11.5 X 3,3 mm slots in the sides. This size box has a capacity of 200-300 salmon eggs.

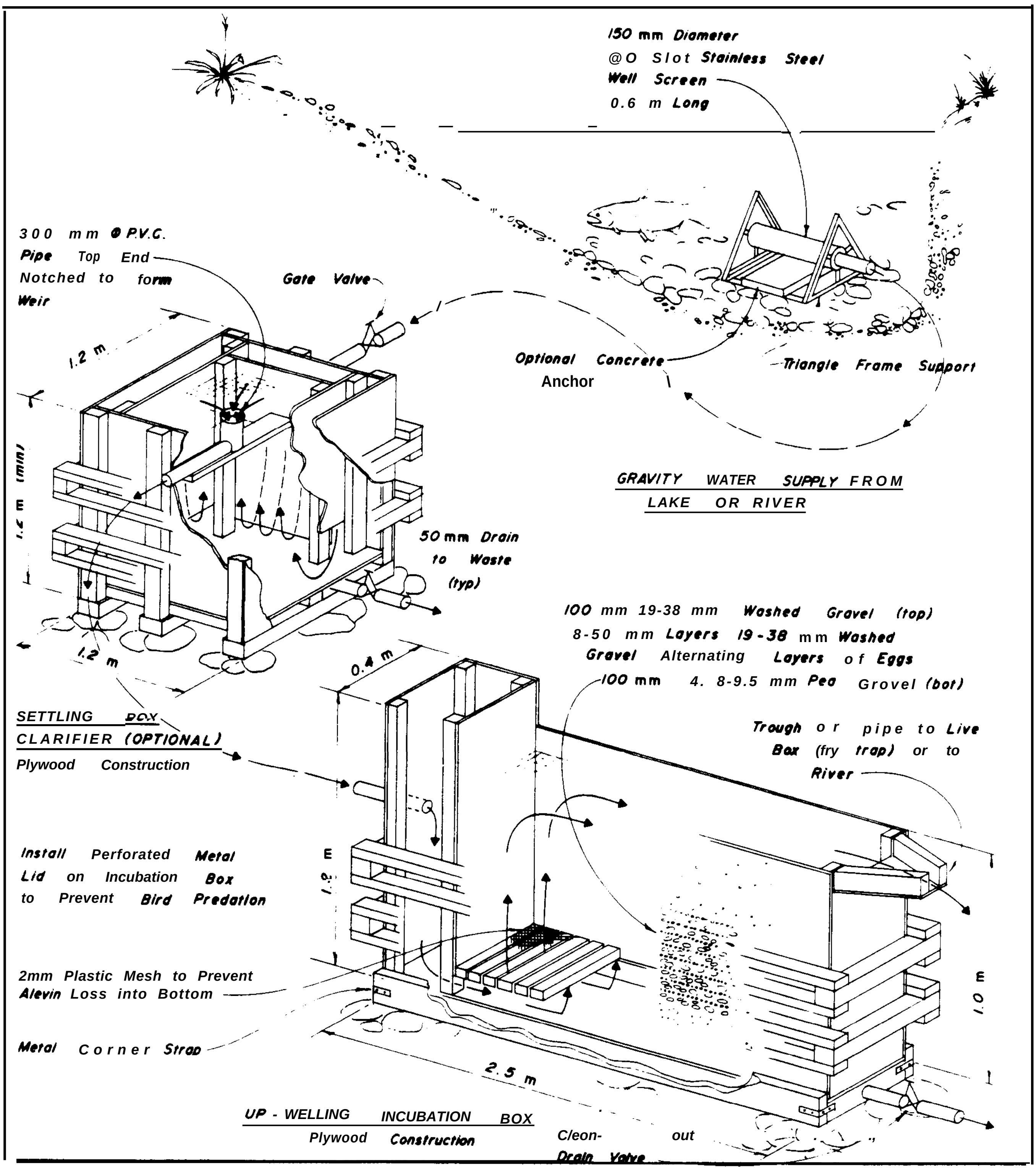


Figure 15. 50,000 egg upwelling incubation facility. The settling box clarifier is not required for lake installations. Incubation and settling boxes should be insulated in cold climates. Fibreglass and aluminum can be used as alternative construction materials (from S.E.G. 1980).

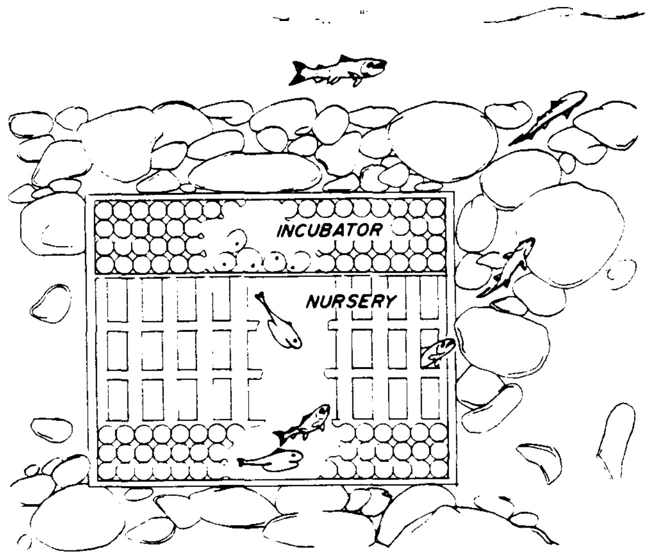


Figure 16. The Whitlock-Vibert box, used for egg plants in the stream gravel. Eggs are place in the upper mmpartment. On hatching, alevins drop through to the lower compartment, where they remain until their yolk sacs have been absorbed (from S.E.G. 1980).

Another plexiglass instream incubator has been designed and tested in British Columbia by Jordan (1988). As shown in Figures 17 and 18, this unit holds fertilized eggs in separate chambers where they develop and hatch. An appropriate sized escape hole is present for the fry. Each "unit" contains four sections (Figure 19) each of which contains 100 eggs. Advantages of this type of construction are:

1. Disease is not easily transmitted from one egg to another;
2. They are fully portable;
3. They are reusable;
4. They require no maintenance after planting; and
5. They significantly increase egg-to-fry survival of at least coho and chinook salmon.

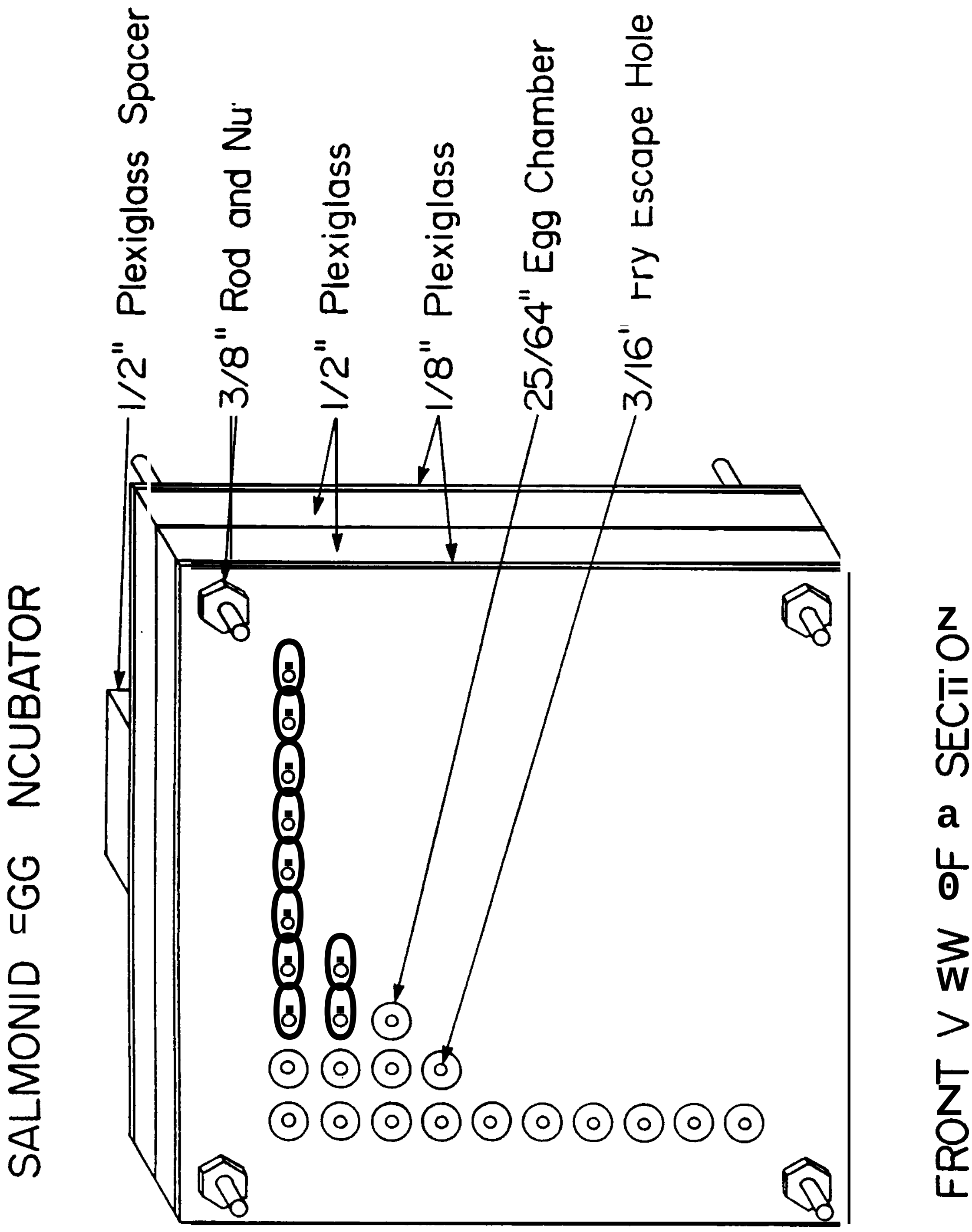


Figure 17. Salmonid egg incubator - front view (from Jordan 1988).

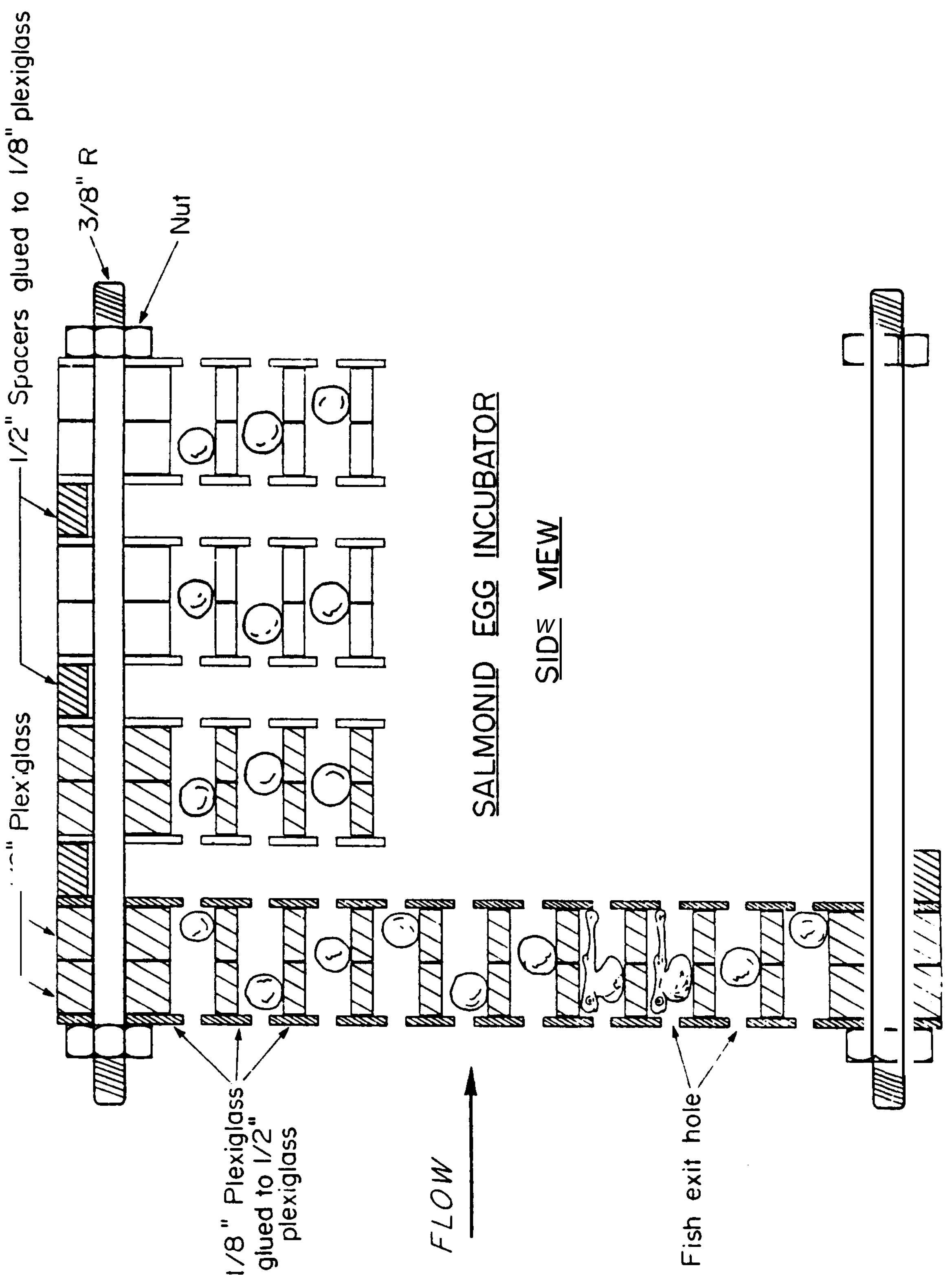


Figure 18. Salmonid egg incubator - side view (from Jordan 1988).

Jordan (1988) reported survival of chinook and coho eggs to be 91 .5% and 85,9%, respectively, in experimental laboratory conditions and in plants in a natural stream in British Columbia. Natural egg-to-fry survival of these species is generally about 20%.

One economical instream incubator design is a simple mesh (2 mm) flat-bottomed basket (15 cm in diameter and 100 cm high), filled with clean gravel and 200-300 fertilized eggs. Holes are dug in the streambed to contain the baskets which are flagged for later recovery.

Lake Incubators

The above units have been most commonly used in streams where natural water flow continually bathes the developing eggs. *In situ* chambers have been used less often in attempts to enhance lake spawning populations but there is some information that this technique can be effective in lakes, as well as in streams. Most lake incubators are simple horizontal trays (Figure 20) and are submerged in areas where there is a slight current if possible. They can be suspended or placed on the bottom (Figure 21).

Foy (1984) summarized results of experiments using lake incubators and noted that coho, chinook, chum, sockeye and pink salmon and rainbow trout have been successfully hatched in lake incubator trays. In good conditions, survival to emergence is at least 90% and survival over 95% is not uncommon. He further noted that:

1. care must be taken to prevent shock, especially if the incubator has surface floats;

2. algal growth can cause screen blockage and subsequent mortality to eggs due to reduced water exchange in the incubator;

3. loadings for salmon should not exceed 3,000 $eggs.ft^{-2}$;

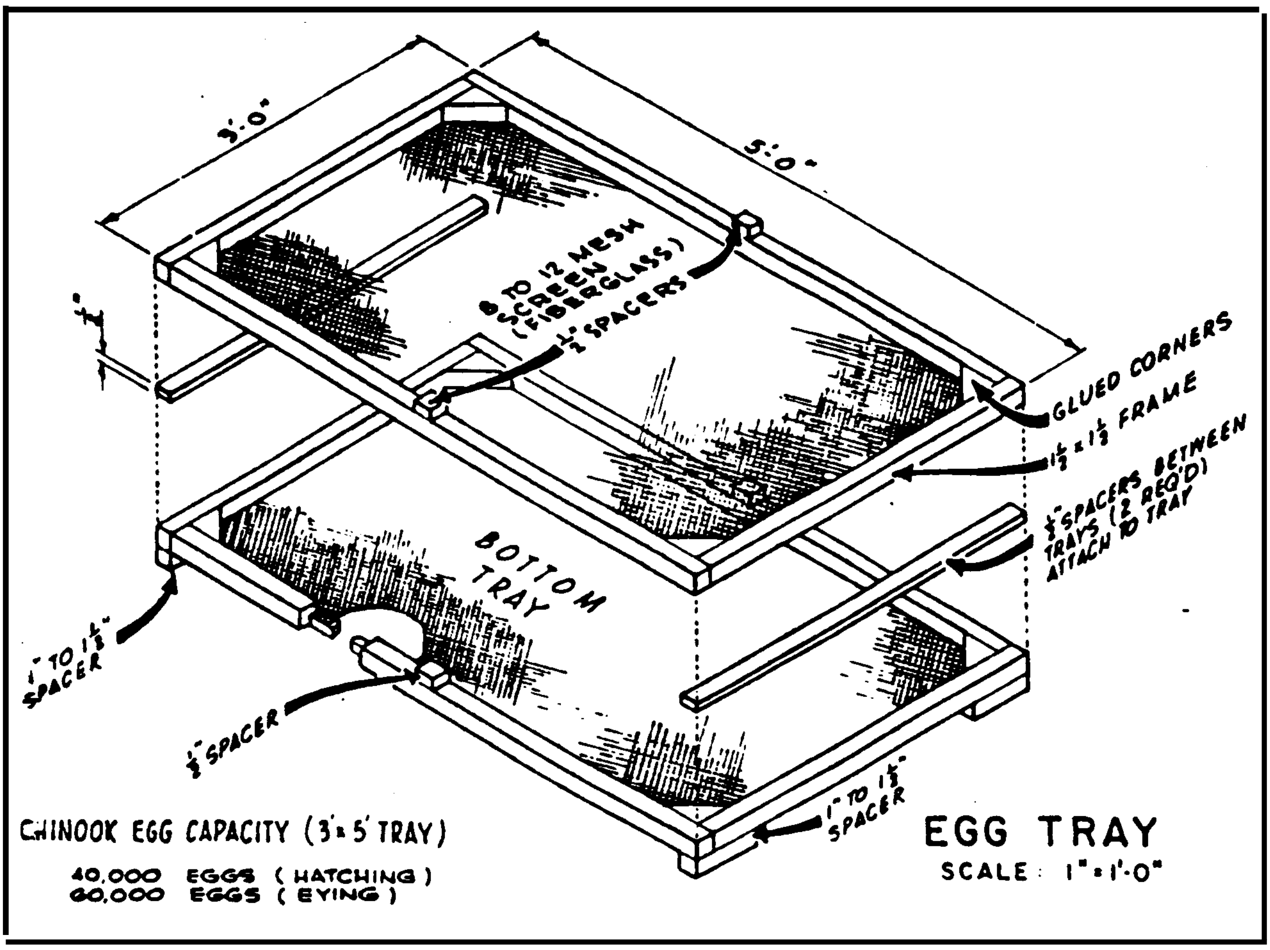


Figure 20. Schematic of egg tray for pond incubation.

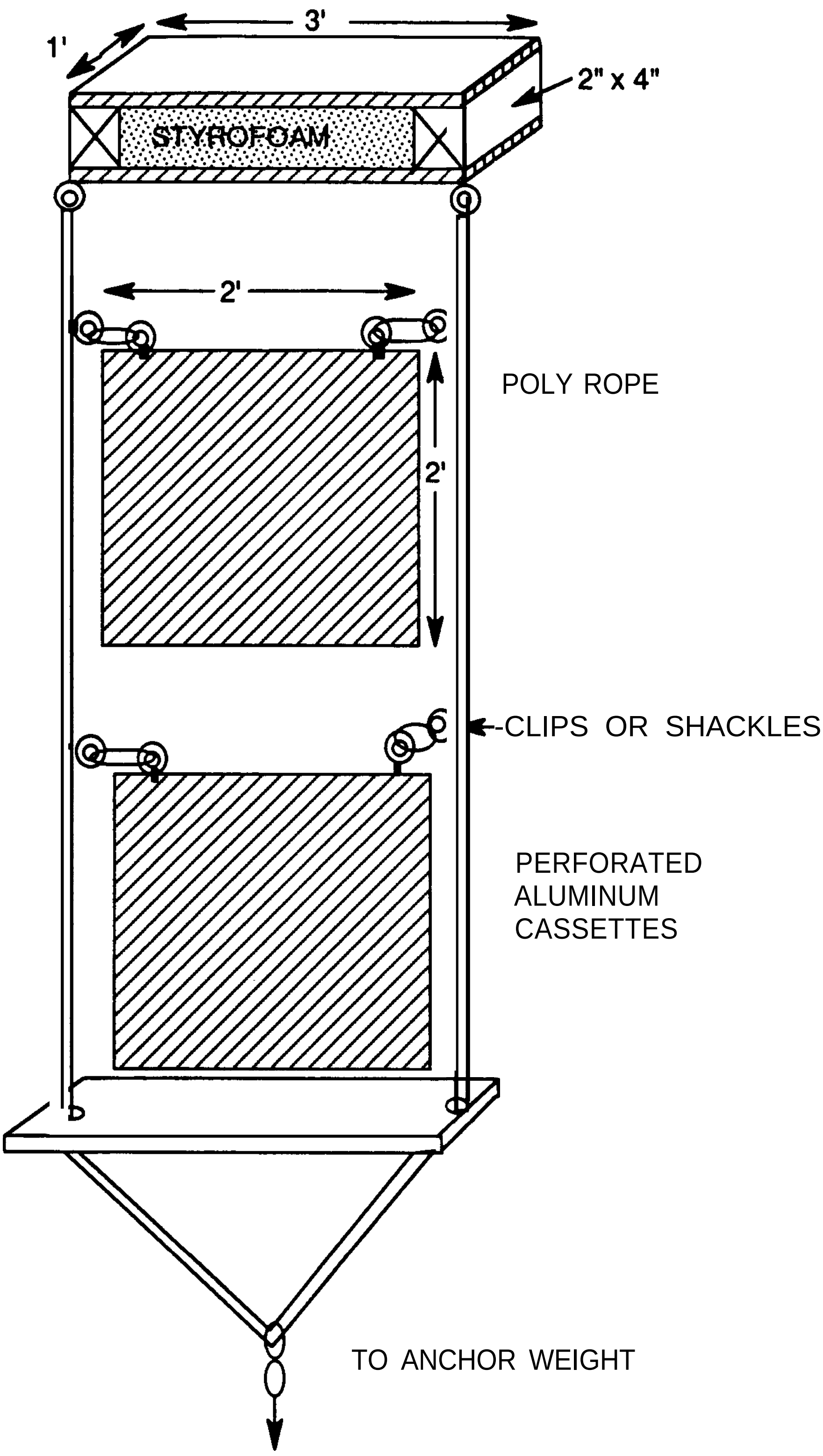


Figure 21. Schematic of suspended lake incubator.

4. still water systems (lakes and ponds) provide enough water movement for successful incubation if screens are clean;

5. fry of good quality can be produced with lake incubators; and

6. use of subcompartments prevents the spread of fungus.

Improvements to Spawning Habitat

Stocks of salmonids are often limited by the availability of suitable spawning substrate. When this limitation is identified, it is often beneficial to place gravel in lakes or streams at appropriate locations; to manipulate water flow, so that gravel beds are maintained; or to place objects in stream beds to promote formations of gravel areas, In extreme case, completely new, elaborate spawning channels can be constructed, In the latter case, water flow, temperature, substrate size and composition, and fish spawning densities are strictly controlled. Suoh optimal habitat often leads to extremely high rates of hatching and survival of young alevins.

Gravel Recruitment

Gravel can be recruited to certain areas by placing objects in streambeds which trap desired types of substrate in specific areas. Figure 22 illustrates use of a concrete highway curb to stabilise gravel above and below the structure. If this type of structure extends completely across the stream, it is often necessary to notch a portion of it to promote fish passage during periods of low water, In remote areas, rock-filled gabions can be used in a similar fashion. Large boulders and concrete blocks can also be used,

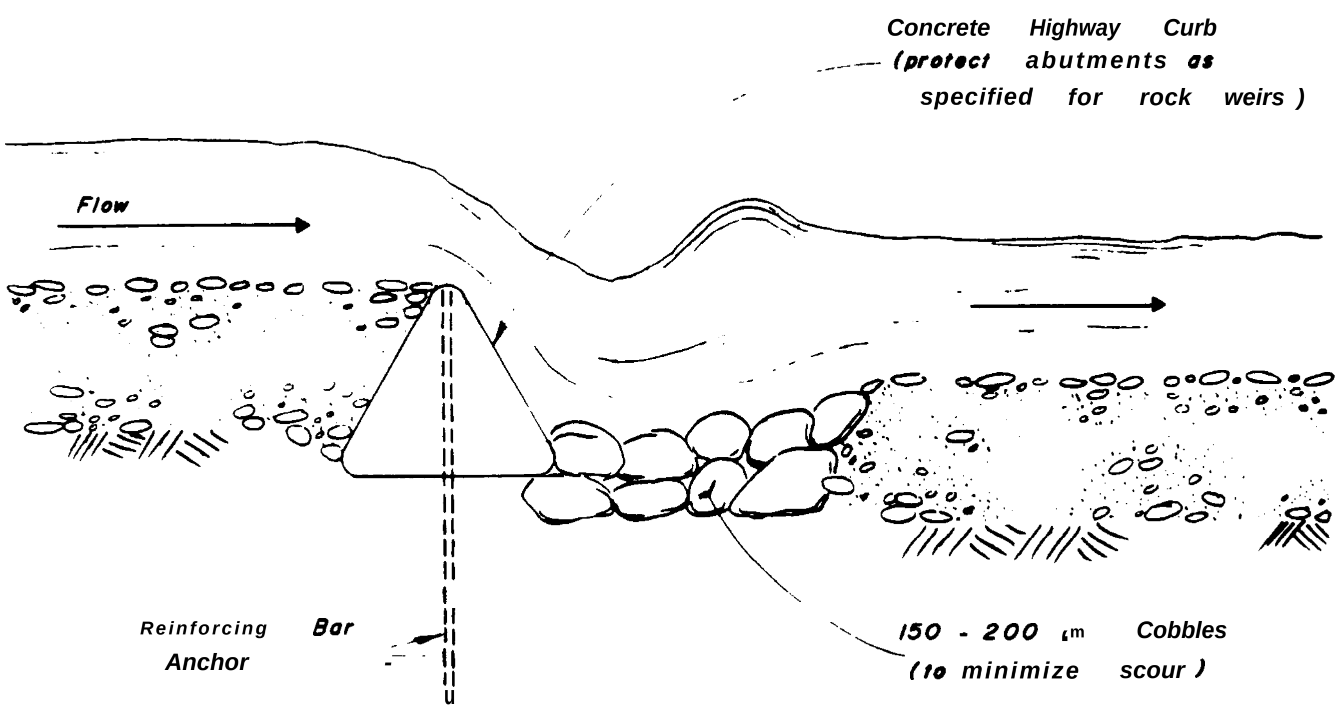


Figure 22. Concrete highway curb used to stabilise gravel and maintain channel grade. The weir can be sloped towards the centre to facilitate fish passage at low flows. This type of weir is ideal for drops not exceeding 230 mm and for streams where large rocks are not plentiful (from S.E.G. 1980).

Gravel Placements

The above method only works in streams which transport relatively large quantities of gravel as a normal part of their hydrology. Some streambeds are devoid of gravel because of the composition of the streambed and surrounding material. Spawning may be promoted in such streams by obtaining clean gravel, placing it in the stream in such a manner so it becomes a relatively permanent feature of the stream bed.

Gravel Cleaning

In some cases, gravel beds have become clogged with silt and are unsuitable for incubating fish eggs. Artificial cleaning of such gravel beds can significantly improve egg-to-fry survival rates in such cases, This technique has been mainly used to clean gravels in artificial spawning channels. It has limited application in natural streams because of the short duration of its benefits, Cleaning of gravel beds in lakes is more lasting.

A number of methods have been used to clean gravel in streambeds, including mechanical scarification and hydraulic flushing. The former involves excavating and exposing substrate to the flushing effect of the stream. Excavation can be accomplished with all manner of tools from shovels and rakes to bulldozers. Hydraulic flushing involves forcing water or air through the streambed. Fines are transported out of the gravel into the current, where they are transported downstream. Portable high--pressure water pumps (designed for fire-fighting) are widely used to clean relatively small areas.

Spawning Channels

Construction of spawning channels are normally large-scale complex operations. The channels themselves range from straight and relatively small systems to complex configurations several kilometres in length which double back on themselves. Water flow in channels is strictly controlled and settling basins are often constructed to minimize the amount of silt entering the channel. In-channel structures control water velocity and depth. Rounded gravels of various sizes (depending on fish species) are used, Holding pools and cover are sometimes provided for prespawning adults and counting fences are often an integral part of the downstream portion of the structure.

Despite their relatively high cost, spawning channels have been instructed in several regions of British Columbia. In this area they are primarily used for species of salmon where young have a short residence time in the stream, mainly sockeye, pink and chum salmon. This is important, because the stream normally does not have sufficient habitat to rear the large numbers of young produced from the spawning channel. West and Mason (1987) estimated that spawning channels of the Babine Lake Development Project have resulted in an average commercial catch of 825,800 adult sockeye salmon worth more than $6.2 million annually for a benefit cost ratio of 3.02:1. Several other large-scale spawning channels are present in British Columbia.

Food

Several ways have been devised to increase the food supply of young salmonids in their freshwater habitats. As will be shown below, most effort has gone into lake fertilization with inorganic nutrients, although some research has been performed in relation to streams and other types of nutrient sources,

Lake fertilization

Whole lake fertilization experiments to increase primary and secondary production and eventually size of juvenile sockeye salmon have been studied extensively in British Columbia under the Salmonid Enhancement Program (Stockner and Hyatt 1984; Hyatt and Stockner 1985; Stockner 1987). State of present technology and knowledge at Department of Fisheries and Oceans research facilities in British Columbia in relation to lake enrichment is considered to be world class. Lake enrichment stems from the simple concept that nutrients normally limit production of plant and, indirectly, animal biomass in many aquatic systems. Addition of nitrogen and phosphorus increases production throughout the food chain, with the end result of hopefully producing more or larger fish species that are of value to man. In British Columbia, sockeye salmon rear for a number of years in freshwater lakes. Increasing their food supply **(zooplankton)** can increase survival within the lake, but it also produces larger smelts which have a higher survival rate during their oceanic existence,

Stockner and Hyatt (1984) summarised lake fertilization state-of-the-art as follows. Lakes are usually treated with aqueous solutions of inorganic nitrogen (N) and phosphorus (P) made from commercially available ammonium nitrate and ammonium phosphate fertilizers in a ratio of about 15N:1 P (based on atomic weight). Fertilization rates vary according to lake type, flushing rates, etc. In British Columbia lakes, fertilization rates range from **2.5** to 15.6 mg $P.m^{-2}.wk^{-1}$, **which** is about 60% of the natural load.

In normal circumstances single lakes can be most economically treated by boat (assuming that there is road access), but aerial application is most economical if a number of lakes are to be treated. In some cases, nuisance blue-green algae blooms occur. These unwanted effects can usually be controlled by adjusting the N:P ratio toward nitrogen.

A simplified diagram of the concept of lake enrichment is shown in Figure 23. **Phytoplankton** biomass and production typically increases dramatically in fertilized lakes (Figure 24), Composition of this community is important, **because picophytoplankton** forms a better food source for **zooplankton** than the larger diatoms and blue-green algae. Examples of responses of the **zooplankton community** to this increased food supply are shown in Figure 25. Composition of the **zooplankton comm-**

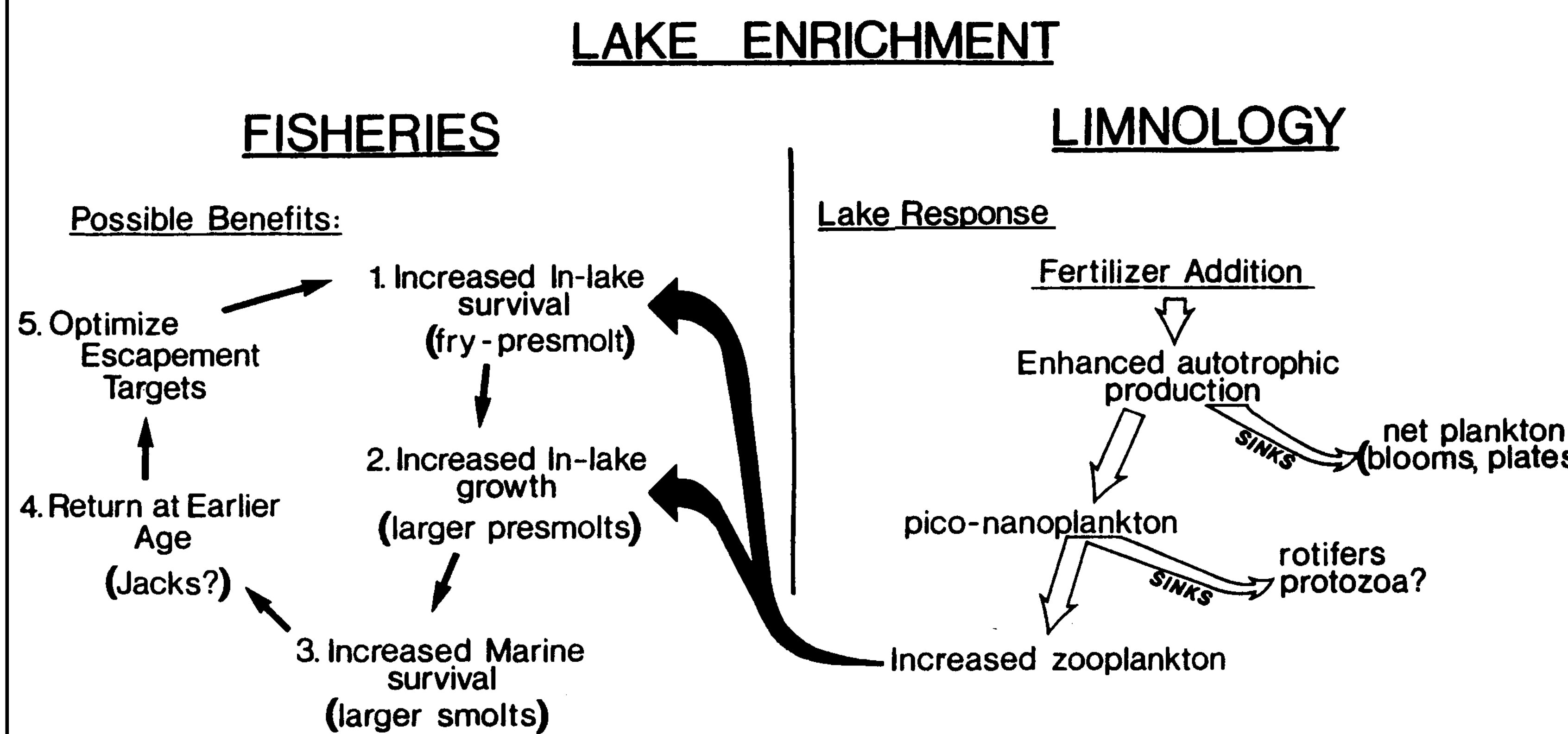


Figure 23. Components, objectives and expected benefits of British C mb a Lake Enrichment Program (from Stockner and Hyatt 1984).

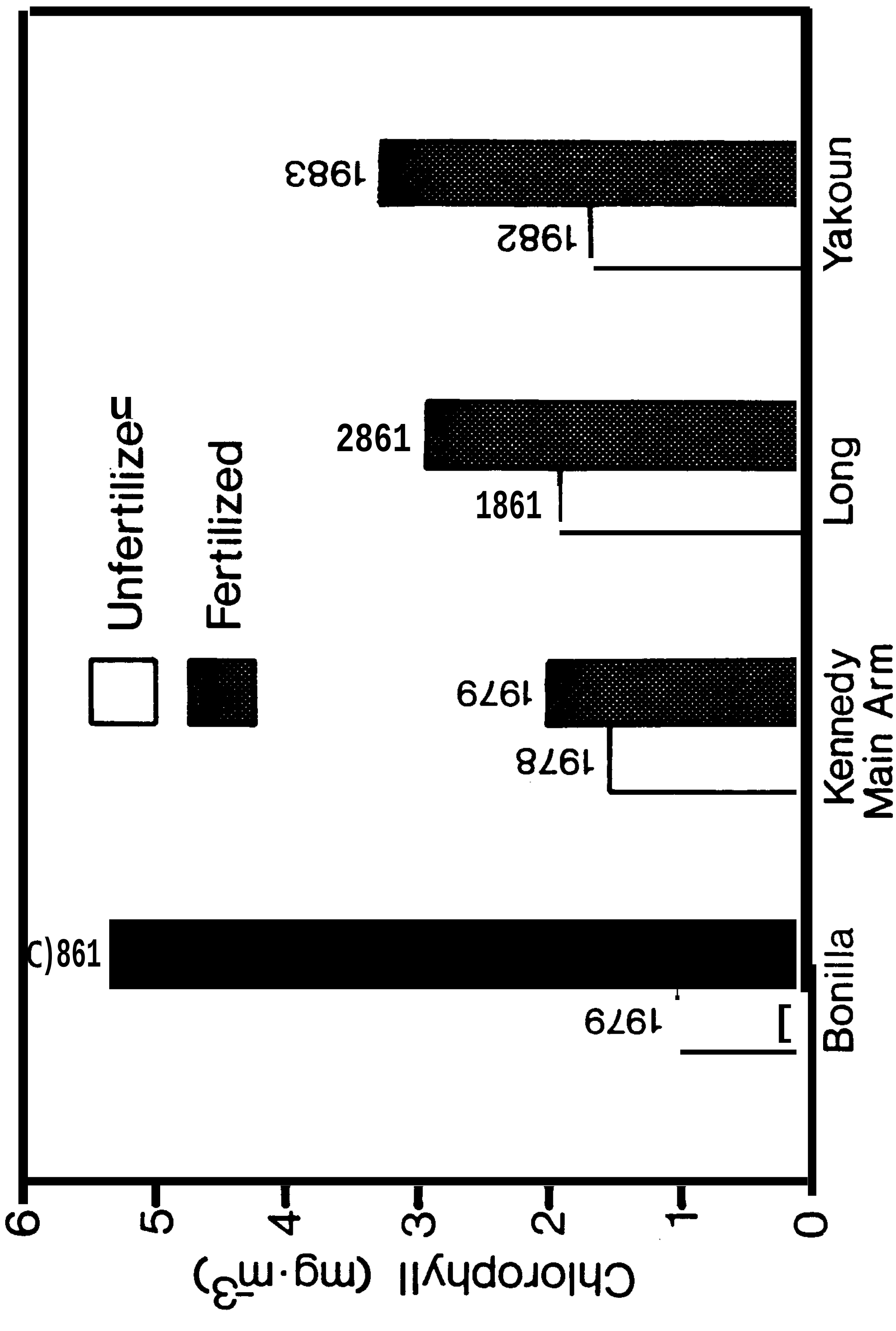


Figure 24. Seasonal average chlorophyll concentration (mg.m-3) in several coastal lakes in the year preceding and year of first fertilization (from Stockner and Hyatt 1984).

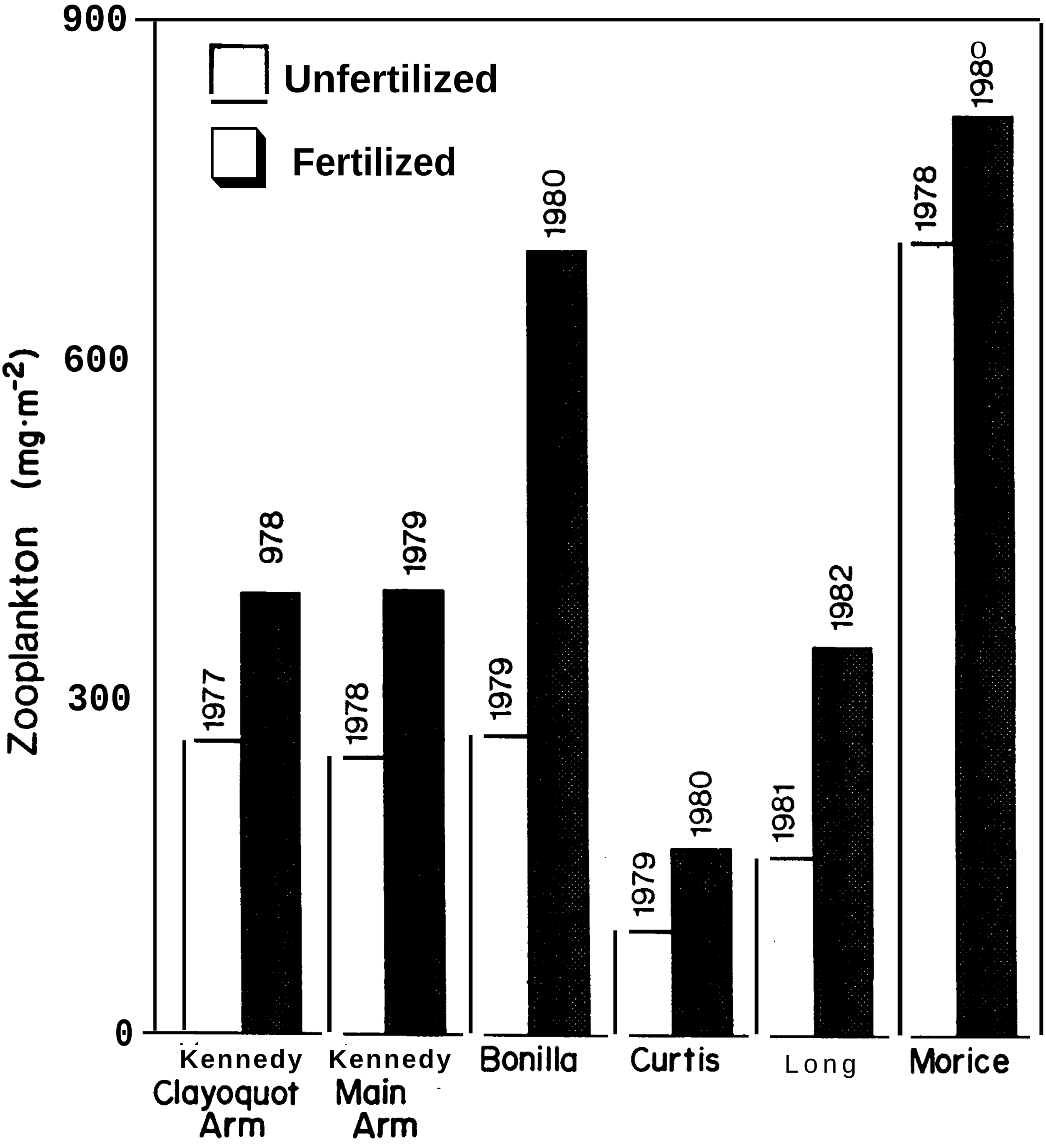


Figure 25. Seasonal average zooplankton biomass (mg.m-2) in several coastal lakes in the year preceding and year of first fertilization (from Stockner and Hyatt 1984),

unity is again important, because some groups, such as **rotifers,** are little used as food by fishes, while others, such as large **cladocerans** and **copepods** are highly **favoured.** Increased sockeye salmon smelt weights of from 39% to 102% (at densities of 500 to 3000 **fish.ha^{-1}** have been documented and attributed to lake fertilization.

Three-spined sticklebacks normally occur with **juvenile** sockeye salmon in their freshwater lake environment. In some cases in British Columbia, lake fertilization has resulted in population explosions of this unwanted species and little or no effect on juvenile sockeye salmon, Reasons for this are unclear and research is continuing on this problem.

Stockner and Hyatt (1984) estimated that the lake enrichment program was responsible for more than 1,800,000 adult sockeye salmon, primarily due to the higher survival rates of larger smelts from five enriched lakes on Vancouver Island. This is a very substantial contribution, considering that sockeye salmon presently retail for between $15.00 and $30.00 per fish. **Pearse** (1982), in his in-depth study of Canada's Pacific Fisheries Policy, noted that approximately $9.0 million had been spent on lake fertilization programs within the **Salmonid** Enhancement Program, which resulted in a net national benefit of about $48.5 million, to make **lake** fertilization the most economic tool of the entire program.

Stream fertilization

Stream enrichment works on the same principles as lake enrichment and, since research into the latter has proved so fruitful, efforts are now being made to increase sport or commercial fish species in streams by adding inorganic nutrients (Johnston et al, 1990), or in some cases **organics** which break down over a relatively longer period of time. Results are promising; for example, size of steelhead trout and coho salmon fry increased substantially as a result of whole-river fertilization of the **Keogh** River, British Columbia, Peterson et al. (1985) showed that addition of phosphorus alone greatly increased growth of attached algae in the Kuparuk River, in northern Alaska. Fish were not studied in this relatively short-term experiment, but the study demonstrated a very rapid response of lower trophic levels to nutrient addition in an Arctic freshwater system.

Various types of organic material, such as willow and alder leaves, grain and soybeans have been added to streams in an attempt to increase productivity (Meehan et al. 1978; Mundie et al. 1973, 1983). All of these methods are in their experimental stages of development and have shown promising results. An advantage is that, in general, organic materials break down slowly and frequent repeat applications are not necessary, as is the case with aqueous inorganic fertilizers.

Supplemental Feeding

Wild Stocks: There are some indications that wild fish in streams can benefit directly from frequent application of commercial fish food or frozen invertebrates, Mason (1974 a,b) reported that wild juvenile coho salmon feed extensively when such food was regularly and frequently applied to Sandy Creek, B.C. In this case, fish biomass increased dramatically, but was reduced to natural levels the year after because of a limited overwintering habitat.

"Hatchery" Stocks: Pond rearing and artificial feeding of Atlantic salmon fry appears to be advantageous in increasing their survival and eventual contribution to fisheries, In some cases, fry from hatcheries or stream-side incubator units are simply outplanted to lakes and ponds. However, placing fry in enclosures or relatively restricted areas and feeding them artificial food has been done in a number of circumstances with beneficial results (Pepper et al. 1987),

ARCTIC CHAR ENHANCEMENT

Although efforts have been limited, there have been a few attempts to enhance Arctic char populations, and some further projects are in planning stages. These are, of course, of particular interest to the present study and are described in detail in the following material.

Stream Channel Modifications in Quebec

Power and Barton (1987) reported that char experience difficulty in late summer upstream migrations in a number of streams in northern Quebec. Local residents supplied information on 70 rivers draining into Ungava Bay and northeastern Hudson Bay and identified:

1. 18 problem rivers, which had partial or complete barriers in at least some years; and
2. 24 rivers which were barren of sea-run char.

The commonest form of barrier was shallow, boulder-strewn channels, although beaver dams and ancient fishing weirs were also problems, Community residents further identified six rivers where dead or stranded char had been found during summers of abnormally low rainfall.

As a result of community interest, a Stream Enhancement Project was organised by the Makivik Corporation to improve upstream passageways for sea-run char in problem streams. This project focused on easing fish passages in shallow channels of streams which already mntained sea-run char populations (not enlarging habitat for sea run char by eliminating fish blocks). The project began in 1986 and continues to the present time, Results are described in Gillis and Gordon (1987) and Dumas (1987, 1989). These works identified 35 rivers where char had difficulty in upstream migrations along the eastern coast of Hudson Bay and along the shore of Ungava Bay (Table 2, Figure 26).

Table 2. Nature of obstacles to Arctic char migration, documented in Nunavik river systems.

Main Obstacle to Char Migration	Number of Rivers in which this Obstacle Prevails*
Steep climb through boulders	16
Old fishing weir	4
Shallow gravel/small rock passages	3
Sever rapids/small falls	3
Poor water flow due to diffused channels	1
Shallow access to the lake	1
Shallow passage over bedrock	1
Beaver dam	1
Insufficient water flow	1
Road culvert	1
Obstacles unknown	3

• Includes results from 1984 Ungava survey (Barton et al. 1985 in Dumas 1989).

Remedial work on these rivers continues to the present time (Dumas pers. comm., July 1990), It normally consists of moving small boulders and cobbles by hand or with hand tools to form a deeper unobstructed passageway for fish, Such work is less permanent in finer substrates because of the "levelling" effect of high water and ice movement.

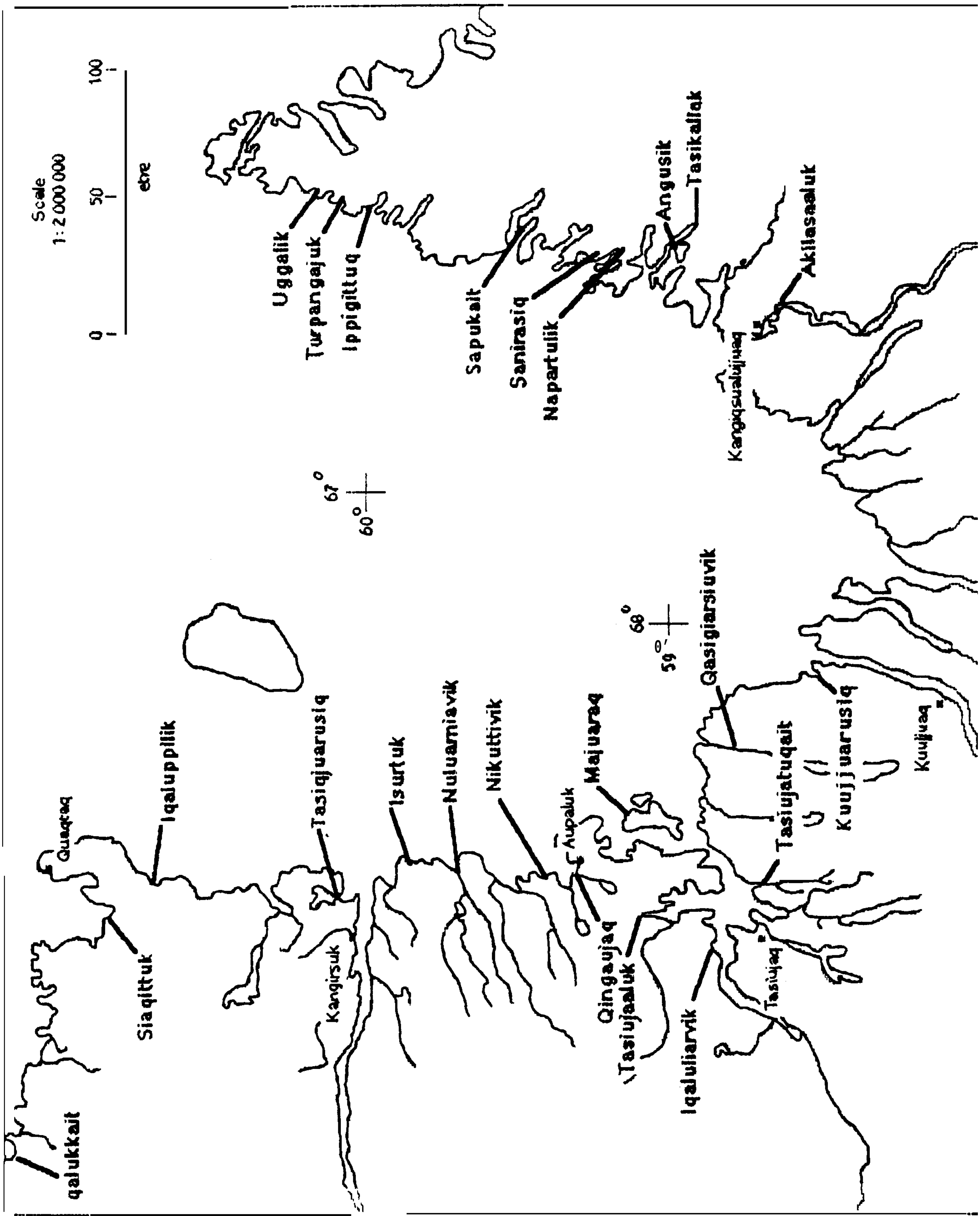


Figure 26. Example of problem streams for sea-run Arctic char in Ungava Bay drainages.

Dumas (1989) reported that the effectiveness of these efforts is uncertain at this time since intensive monitoring to document effects was not carried out simultaneously. However, increased fishing success in future years could be a measure of success. Dumas (1989) estimated that it would require about $300,000 and eight years to complete the project as it is presently planned.

Dumas (pers. comm., May 1990) stated that future efforts may be refocused toward establishing sea-run populations in large systems where they do not presently occur, This work would normally entail elimination of complete fish blocks or the construction of simple fishways.

Lake fertilization in Sweden

Milbrink and Holmgren (1984) reported results of their attempts to fertilize lakes in Sweden with the hope of producing more valued fish species, including resident populations of Arctic char. In this case, Lake Anjou, one of the many lakes regulated by hydroelectric developments in Sweden, was used as a study site. The lake was fertilized indirectly by adding nitrogen and phosphorus to an inflowing stream which entered a rather isolated bay of the main lake. Fertilizers were added continuously to the stream from June 1976 to September 1979 at a dosage of about 1 g N $m^{-2}.yr^{-1}$ and 100 mg P $m^{-2}.yr^{-1}$ to the experimental bay. Water quality, phytoplankton, periphyton, zooplankton, benthic invertebrates and fish were monitored. Samples were taken from the fertilized bay, as well as in a bay which was not fertilized, at a considerable distance from the experimental site.

Results of the study indicated that the increased nutrient supply was quickly utilised by primary producers or trapped in sediments. Phytoplankton and zooplankton biomasses in the fertilized bay were, in generai, 2-3 times and 5-10 times, respectively, those found in the unfertilized bay. Rooted vegetation increased tremendously, and in turn supported a rich **epibenthic** invertebrate community. Production rates in the system were not measured but were believed to be quite high due to the intense grazing that was occurring.

The most dramatic change in the fish populations **occurred** with Arctic char, although Arctic **grayling** were also positively affected. In 1976, no difference in fish numbers was detected in the experimental and control bays, but numbers of char and **grayling** were substantially higher in the fertilized bay in 1978 and 1979 (Table 3), In addition, the average condition of char, as assessed by **Fulton's** formula (**Ricker** 1975), increased from 0.76 in 1976 to 0.89 in 1978 and 1979, a highly significant (**p<0.001**) change. The length-weight relationships of individual char caught in the two areas is shown in Figure 27.

Table 3. **Test fishing results from parallel situations in the fertilized bay and reference bay in the late summer if 1976, 1978 and 1979, Catches of char, grayling, brown trout and burbot are included in the total weights. The number of survey nets used in each occasion is given in parentheses (from Milbrink and Holmgren 1984).**

	Fertilized Bay				Reference Bay			
	Number of Char	Number of Grayling	Total Weight (kg)	Weight/ net (kg)	Number of Char	Number of Grayling	Total Weight (kg)	Weight/ Net (kg)
1976								
13-19 Sept	8	5	2.7 (12)	022	5	10	3,5 (12)	029
1978								
22-23 Aug	9	8	3.0 (7')	0.43	1	1	1.0 (5)	020
8 Sept	15	6	4.6 (5)	0.92	-	1	0.65 (2)	0.33
1979								
27-28 Aug	5	6	2.0 (5)	0,40	-	-	0.3 (5)	0.06
5-6 Sept	19	6	5,5 (12)	0.46	3	-	1.4 (11)	0.13

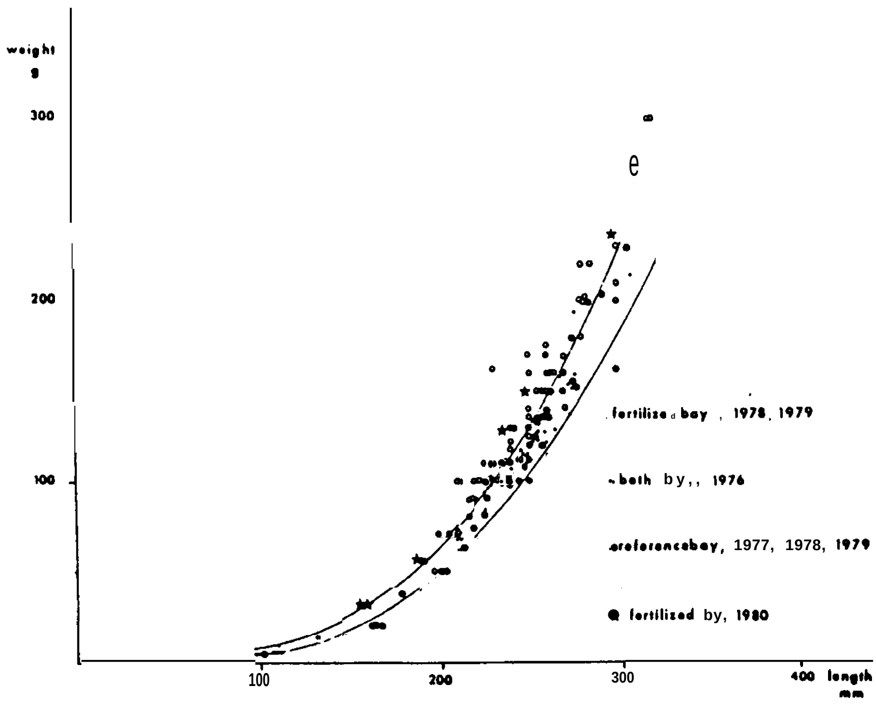


Figure 27. Length-weight relationships of char caught in August to September each year (from Milbrink and Holmgren 1984).

While the above study results are dramatic, the actual numbers of fish involved are quite small. However, it should be borne in mind that the study was performed in a hydroelectric reservoir with a large annual drawdown (9,2 m) and an exceedingly sparse fish population. In addition, most of the data presented were on fish specimens greater than one year of age. Young-of-the-year fish could have been more numerous and might have shown even more dramatic positive effects,

"Sea Ranching" Arctic Char

According to Gilles Chantigny, Northern Quebec Coordinator, Department Fisheries and Oceans, Gare Maritime, Champlain, Quebec (pers. comm., June 1990) there is interest in his department in enhancing stocks of Arctic char. Preliminary thoughts are to raise young char in a southern hatchery where costs are more economical and to plant young char in selected drainages where stocks are depressed. No actual work had been done to refine this concept but there is awareness within this DFO office of a need to enhance sea-run Arctic char populations in northern Quebec,

"Forced Smoltification"

L. Johnson (pers. comm., July 1990) indicated that there maybe factors (as yet unknown) which control recruitment to the sea-run portion of anadromous populations. Little or no recruitment occurred to this segment of the population in Nauyuk Lake between 1976 and 1987 (Johnson 1989). In contrast, in 1988 the population was dominated by recruits between 300 and 400 mm in length, Reasons for such wide variations are unknown, but it is thought that exploited populations would likely recover more rapidly if large numbers of recruits were available annually. One way to supply recruits might involve "forced smoltification of appropriate specimens from nearby landlocked populations" (Johnson pers. comm., July 1990). The potential of this untested technique to enhance sea-run char populations in the NWT is very great, because:

1. the supply of specimens from landlocked populations in the NWT is virtually unlimited;
2. grwoth to commercial size could be relatively rapid; and
3. the technique could be exceptionally cost-efficient.

SELECTION OF ALTERNATIVES TO ENHANCE SEA-RUN CHAR POPULATIONS IN THE NWT

It is obvious from the preceding discussion that the effectiveness of various enhancement techniques is largely untested for Arctic char. Therefore, any program to enhance sea-run Arctic char in the NWT will undoubtedly have to be modified to suit local conditions and stocks of char and will aiso be subject to uncertainties. However, several enhancement techniques are relatively straightforward and few, if any, reasons can be found to support arguments that particular techniques will not be successful with sea-run Arctic char.

Table 4 lists the various enhancement techniques that have been discussed and assesses their suitability for sea-run char populations in the NWT. it can be seen that several successful techniques for salmon enhancement in streams have little potential for widespread use in the NWT. This is because most commercial char populations in the NWT reside in lakes and do not use streams for spawning, overwintering, rearing, etc. This is not to say that such techniques will not work; oniy that their application will be limited.

Consideration of the biology of Arctic char, together with knowledge and experience gained through fish enhancement projects, especially the DFO Salmonid Enhancement Program, suggests that the following methods are the most appropriate for initiation of an enhancement program for sea-run Arctic char in the NWT:

1. Extension of habitat by elimination of barriers to upstream migration;
2. *In situ* incubators to increase egg-to-fry survival;
3. Supplemental feeding to increase survival of young;

Table 4. Assessment of enhancement techniques for use on sea-run Arctic char populations in the NWT.

Technique	Optimal Conditions for use	Suitable for Arctic Char in the NWT	Comments
Removal of barriers to upstream migration	• Large amounts of unused high quality habitat present in upstream areas • Barrier easily removed • Target fish species has strong tendency to invade new habitat • Little or no need for annual maintenance	yes	Large potential for use in the NWT
Construction of fishways	• Large amounts of unused high quality habitat present in upstream areas • Barrier easily removed • Target fish species has strong tendency to invade new habitat • Little or no need for annual maintenance	yes	Large potential for use in the NWT
Annual planting above barrier	• Large amounts of unused high quality habitat present in upstream areas • Near community • Minim altransportation costs	yes	Small potential for use in the NWT due to poorly developed transportation systems
Water control (streams) to improve summer rearing conditions	• Low cost "water control structures"	unlikely	Stream life of char unlikely to limit population in NWT
Water control (streams) to improve conditions for upstream migration	• Low cost "water control structures"	yes	Poor connections to sea preclude anadromy in thousands of drainages in NWT
Increasing Cover in streams	• Easy access	unlikely	Stream life of char unlikely to limit population in NWT
Outplanting fry/ pond rearing	• Ponds where other fish populations are low • Abundance of food	possible	Ponds may winterkill in NWT
Stream-side incubators	• Good access • Population limited by spawning success	no	Severe winter conditions would likely preclude use

Continued . . .

Table 4. Continued.

Technique	Optimal Conditions for use	Suitable for ArcticChar in the NWT	Comments
Instreamincubators	•Low cost units •Population limited by spawning success	possible	Might be used for western stream spawning populations
Lake incubators	•Low cost units •Population limited by spawning success	yes	Large potential for lake spawners in central and eastern NWT
Gravelrecruitment instreams	•"Mobile" gravel in upper reaches of streams •Low silt bad	unlikely	Most commercial populations of char in NWT are lake spawners
Gravelplacements	•Low frequency of flooding •Low sitt bad	unlikely	Spawning habitat may not limit exploited populations
Gravelcleaning	•Low frequency of flooding •Low silt bad	unlikely	Spawning habitat may not limit exploited populations
Spawning channels	•Good suppty of high quality water •Ability to control flows, temperature, sedimentation	unlikely	Most commercial populations of char in NWT are lake spawners
Lake fertilization	•Food-limited lacustrine environment •Juveniles rear in lakes	possible -limiteddata from Sweden indicate that techniques workwithchar	Reactions of Arctic freshwater systems to fertilization are poorly understood, High potential to enhance char populations if technique works, due to long period of rearing
Streamfertilization	• Relatively low flushing •Food-limited lentic environment	limited	Most commercial populations in NWT rear in lakes
Supplemental feeding	•Food-limited environment •Economical source of fish food •Easy access for repeat visits	yes-limited	Good potential for use in areas near communities
Forced smoltification	•Nearby resident char	yes	Technique has not been validated but large potential exists to enhance all types of sea-run char populations

4. **Lake fertilization to increase survival and growth of young; and**

5. **"Forced smoltification" to supply recruits to the sea-run** portion of the population.

Each of the above techniques is discussed in the following material.

Extension of Sea-run Char Distribution

Extension of salmon distribution by the elimination of barriers to upstream migrations was identified as a prime method to enhance salmon populations on both the east and west coast of Canada, and early activities of SEP concentrated on this method. The abundance of sea-run Arctic char in the NWT can almost certainly be increased dramatically if barriers to upstream migration are removed or circumvented, It is beyond the scope of this study to assess the potential of this technique across the NWT; however, a cursory examination of materials leads to the conclusion that there is a large potential to enhance sea-run Arctic char stocks by this method.

Table 5 lists a few representative systems in various regions across the NWT where sea-run Arctic char populations could be established or enlarged by elimination of fish blocks. The potential of these systems to support sea-run Arctic char was roughly assessed by simple ratios as follows:

surface area of Nauyuk Lake	= 24,329 kg (biomass of sea-run char in 1974 according to Johnson 1989)
surface area of system in question	= potential biomass of X kg of sea-run char

This is admittedly a crude estimate since "production" in other systems could be quite different from that in Nauyuk Lake, which is on the Kent Peninsula near Cambridge Bay. However, it is felt that the method is sufficiently accurate to show that a large potential exists in the NWT for increased production of sea-run Arctic char by removal

Table 5. Example of economic benefits that could accrue to the NWT by establishing sea-run char po io g m loc
Potential market value of 1 kg of Arctic char was set at the 1990 price of $8.80/kg.

Waterbody	Map Sheet	Near	Obstacle	Habitat Unused	P_te...ia. Population (kg)	P...... kg Harvest/yr* (kg)	P Market Value ($1000s)
Ferguson River	55 K	25 km SW of Whale Cove	The Canyon	Extensive 40 km lake-river system	50228	25·	$22.· o
Ayr Lake	27 F	25 km NW of Clyde River	Rapids on Kagulu R.	50 km long lake	12· 645	6082	$53.52
Maguse Lake	55 E	5 ×m N of Arviat	Rapids/waterfall on Maguse R.	> 80 km Maguse L./ Turquetil/Tootyak Lks.	60	30294	$266.58
Unnamed Lake	16 L/ 16 K	Cape Dyer - Baffin Island	Low water in fall?	2 lakes ~ 12 km long	11772	589	$5.18
Fleming Lake	48 B	50 km S of Arctic Bay	Waterfall	15 km long lake	27468	1373	$12.09
Unnamed Lake	48 B	65 km S of Arctic Bay	Low water in fall	Extensive lake system 15 km X 15 km	68278	3414	$30.04
Unnamed Lake	26 I	4 km NW of Pangnirtung	Rapids on Kolik R.	15 km long lake	14911	746	$6.56
Unnamed Lake	26 P	50 km NW of Broughton Island	Low water in fall?	10 km long lake	10202	510	$4.49

* 5% of population

Continued . . .

Table 5. Continued.

Waterbody	Map Sheet	Near	Obstacle	Habitat Unused	Potential Population (kg)	Potential kg Harvest/yr* (kg)	Potential Market Value $8.80/kg (K)
Unnamed Lk/R system N of ry	25 K	35 km SE of Lake Harbour	Rapids in river	30 km long lake/river	31392	57○	$· 3.81
Unnamed Lk/R system N of Pritzler Harbour	25 J/ 25 G	140 km SE of Lake Harbour	Rapids in river	3; km long lake/ river system		1844	$16.23
Wentzel River	76 M	150 km SW of Cambridge Bay	Rapids in river	25 km long lake	51012	2551	$22.45
Kuujjua River	87 G	150 km NW of Cambridge Bay	Rapids in river	20 km long upper lake	28253	1413	$12.43
Unnamed Lk/R NW of Wellington Bay	˜ 7 D	70 km NW of Cambridge Bay	Rapids in river	55 km long lake/river system	329619	16481	$145.03
Nauyuk Lake					24329	2· 6	Jo so 1980, 1989
* 5% of population						Total Value	$610.52

of fish blocks. Economic value of additional char produced was assessed by estimating that 5% of the biomass could be harvested annually (the 5% level of harvest is used routinely by Department of Fisheries and Oceans), and that the value of char was $8.80/kg (the price presently paid by the Freshwater Fish Marketing Corporation). As shown in Table 5, this amounts to over $600,000 of additional revenue, annually.

It is again emphasized **that all of the above estimates are preliminary and quite crude. However, the systems listed in Table 5 are a very small fraction of the number in the NWT that could be enhanced. It is apparent that this technique has a large potential to increase sea-run char production in the NWT by several millions of dollars annually.**

Due to the terrain in various regions of the NWT, certain broad regions offer more potential for use of this technique than others. For example, much of the High Arctic north of Parry Channel has few large lake-river systems, so that potential to produce fish in this area is very restricted. Rugged terrain with incised canyons and rivers with numerous obstacles are characteristic of areas adjacent to Iqaluit and the southeastern shore of Coronation Gulf, so that elimination of barriers in many of these barrier-laden systems may not be feasible. However, many other regions of the NWT appear to have numerous systems where elimination of one or two barriers would extend the distribution of sea-run char substantially. The area surrounding Foxe Basin and northeastern Hudson Bay are especially attractive because of the relatively low-lying terrain and large drainages. Considerable opportunities aiso exist on Victoria, Banks and King William Island, Boothia Peninsula and over much of the mainiand near Coppermine and Queen Maud Gulf.

Characteristics of drainages which would promote the use of this technique include:

1. Nature of upstream habitat — optimally large and of high quality; large lakes should be present with an abundance of feeder streams and gravel shoals;

2. Other fish — optimally none; this will seldom, if ever, occur since most suitable waters are at least inhabited by resident populations of Arctic char;

3. Nature of obstacles — optimally few and easily removed permanently. Waterfalls and rapids are normally bedrock controlled, so that their "removal" by **streambed** modification or the construction of fishways is often permanent. Removal of debris from streambeds or channel constrictions (to increase depth) is, in contrast, a remedial exercise that has to be repeated in many cases; and

4. Seed stock — optimally present in downstream areas; invasion of new drainages will also likely occur through straying from adjacent stocks of sea-run char.

"In Situ" Incubators

The use of relatively small *in situ* or streamside incubators has proved to be extremely successful in increasing egg-to-fry survival of salmon in British Columbia, Washington, Nova Scotia, Newfoundland, etc. Most experience has been with stream incubators which are either buried in the **streambed** or set beside the channel with adequate water supply piped to the chamber. Salmon and trout egg-to-fry survival has also been dramatically increased by placing eggs in lake incubators.

In situ incubators have not been tested for Arctic char, but there is little reason to suspect that the concept will not work, given appropriate renditions and the use of appropriate techniques. Due to the severe winter renditions and the long incubation period for Arctic char eggs, it is not considered feasible to use **"streamside"** incubators for Arctic char. In addition, since most commercial populations of Arctic char spawn in lakes, use of *in situ* stream incubators is inappropriate. However, *in situ* lake incubators appear to have considerable potential to enhance sea-run char populations, particularly those which have been severely overexploited, and where recruitment may be limited by natural egg production. Natural egg-to-fry mortality is normally quite high and can be dramatically reduced by providing better than natural conditions for developing eggs by placing them in artificial incubation chambers.

As previously discussed, Johnson (1980, 1989) estimated that about 2% of the total migratory stock of char in Nauyuk Lake spawn in any year. Thus in 1975, the entire population could have produced approximately 792,000 eggs (198 females X 4,000 eggs/female). While this number may appear to be substantial, it is in fact quite small when compared to many other species of fish. The reproductive capacity of sea-run char is believed to be quite low, especially when one considers that maturity is attained late in life and that spawning does not occur every year, Heavily exploited populations of Arctic char, such as those in Freshwater Creek, Diana River and Sylvia Grinnell River, will have a much reduced reproductive potential, because there are few relatively large mature fish remaining in these populations.

Many salmon populations experience about 75% egg-to-fry mortality in relatively good conditions for incubation. If char populations undergo similar mortalities, only about 198,000 fry would be theoretically produced in the Nauyuk Lake population in 1975. If 50% of these died each year (a conservative estimate) until smoltification at age 5, only about 6,000 potential smelts would be available for recruitment to the sea-run population, Application of Moore's (1975) estimate of 16% for the weighted average total annual mortality of char in Cumberland Sound until the age of maturity at 10+ or 15+ produces from 2,509 to 1,048, respectively, sexually mature char. These numbers are considered high estimates, because:

1. an estimate of egg production of 4,000 eggs per female is maximal; and

2. mortality in young age classes is likely to be higher.

However, if egg-to-fry mortality were reduced from 75% to 25% through the use of lake incubators and if mortality remained the same in older age groups, about 18,000 smelts could be recruited to the fishery, This potential three-fold increase in the production of smelts over "natural" levels demonstrates the advantages of enhancement in early life stages, where survival is normally very low. These preliminary analyses suggest that this technique could enhance sea-run Arctic char populations, as it has many other species of **salmonids.**

Since artificial *in situ* lake incubators have not been used on Arctic char, the characteristics of systems in the **NWT** which would promote their use are largely unknown, Some obvious considerations are:

1. turbidity and sedimentation should be low so that incubator trays do not become clogged;

2. char in spawning condition should be readily accessible;

3. sites for placement of incubator trays should be accessible; and

4. a program to monitor the success of lake incubators should be incorporated into any plans to test this technique in the **NWT.**

Supplemental Feeding.

Information has been presented which suggests that young Arctic char in their first summer may benefit from additional food, This would increase their size and their subsequent ability to survive the first winter. This technique might be especially useful in conjunction with lake incubators. If this were performed successfully, the technique would focus on young Arctic char from the egg to an age of about 4-5 months — a period of high natural mortality. This approach focuses on a period in the life cycle which has great potential for enhancement.

Food could be obtained from commercial sources; however, local sources of food should be investigated, The latter includes marine zooplankton and epibenthic invertebrates, and freshwater plankton. Feeding would best be performed with young char confined in enclosures, protected from predators such as loons and seagulls.

Characteristics of systems which would promote the use of this technique are again largely unknown. Some preliminary considerations are:

1. a source of fry should be available;
2. a source of food should be available;
3. feeding areas must be readily accessible from communities but protected from vandalism, etc.

Lake Fertilization

It is generally accepted that production in Arctic fresh waters is severely limited by nutrients and a limited amount of data suggests that Arctic char populations may benefit from additional nutrients added to the system through lake enrichment programs. However, it is also suspected that Arctic systems may be very sensitive to the types and quantities of nutrients added, and that they may respond somewhat differently than temperate lakes, For example, Arctic char have disappeared from Meretta Lake, near Resolute Bay, apparently in response to overfertilization, due to a relatively small amount of sewage entering the lake. For this reason, any fertilization programs in the NWT would very likely have to be supported by strong, well designed research programs. Due to this gap in basic knowledge and the potentially serious consequences of "overfertilization", any lake fertilization attempts in the NWT should proceed with the utmost caution.

Despite the above drawbacks, lake and stream fertilization in the NWT appears to have a good potential to enhance char populations if appropriate techniques can be developed. In British Columbia, fertilization programs have been developed through strong research efforts and the technique has been very successful with sockeye salmon, a species which is similar to sea-run char in that it rears in a food-limited lake environment for a number of years.

"Forced Smoltification"

As previously discussed, if populations, especially exploited populations, are "smolt limited", a direct supply of smelts could be extremely beneficial to speed the recovery of depressed stocks or to simply supply additional recruits for a fishery. This technique has the added advantage of speed, since the effective time between enhancement and an increase in fish available for fisheries is only a few years. To my knowledge this concept is new and originated with L. Johnson (pers. comm., July 1990). The technique appears to have tremendous potential for application to many char populations across the NWT.

CONCLUSIONS AND RECOMMENDATIONS

This study indicates that programs to actively enhance sea-run Arctic char populations would be extremely beneficial to the economy of the NWT and its residents. One major drawback in relation to enhancing sea-run Arctic char stocks is the relatively long time between enhancement and effect of enhancement on fisheries. This is due to the slow growths rates of char, However, this fact makes it even more important to initiate char enhancement programs at the earliest opportunity, so that effects will begin to be felt in the 1990s. In addition, at least one technique (forced smoltification) has been identified which muld affect fisheries in as little as 2 to 3 years. The following recommendations can be made:

1. Elimination of barriers to upstream fish movement has a great potential to enhance sea-run Arctic char populations in the NWT. Superficial and preliminary scanning of drainages in the NWT identified several systems which could support sea-run populations whose value to commercial fisheries would be over $100,000 per annum,

   Recommendation: A program should be desianed to identify the hiah priority drainages in the NWT for the removal of fish blocks. It should include consideration of:

   a. *size of the sea-run char populations that the new habitat could* ***support;***

   b. *nature of the fish block(s);*

   c. *accessibility of the area to fisheries; and*

   d. *cooperative nature and desires of residents in nearby communities.*

2. "Forced smoltification" has an exceptionally large potential to quickly enhance depressed sea-run Arctic char populations in the NWT. This concept is new and untested.

Recommendation: An experimental program should be initiated to determine if resident Arctic char can be forced to smelt and contribute to sea-run populations.

3. Increasing the survival of young char through the use of *in situ* lake incubators in conjunction with supplemental feeding of young char has a large potential to increase the production of exploited populations of sea-run Arctic char in many regions of the NWT.

Recommendation: A pilot project should be initiated, which tests the feasibility of lake incubation and supplemental feeding for Arctic char.

4. Fertilization programs have the potential to enhance sea-run char stocks throughout the NWT if appropriate techniques can be defined, This technique cannot be applied to the NWT with any degree of confidence, because gaps exist in the basic knowledge about responses of Arctic freshwater systems to fertilization.

Recommendation: A research program should be initiated in the NWT to test the responses of lakes and, to a limited extent streams. to applications of fertilizer.

Social Implications of Char Enhancement Programs in the NWT

The West Coast DFO Salmonid Enhancement Program was initiated in 1977 after preliminary considerations and decisions concerning the feasibility of increasing salmonid production to historic levels. This program remains in effect today and is one of the few iong-term programs that has survived government cutbacks and readjustments of priorities. Phase i of the program, which lasted from 1977 to 1984, cost approximately 157 million dollars. Consensus is that the program was justified in relation to enhanced salmon production in British Columbia. However, it is doubtful that the program would have survived over the past 13 years without additional benefits, namely social benefits to Native Peoples. The agreement between the Federal Government of Canada and the Provincial Government of B.C. states that:

> *". . . C& and British Columbia agree that the Salmonid Enhancement Program must be so designed as to be capable of achieving specified economic, social and environmental goals; taking into account and fully respecting the legitimate interests of other natural resource users; . . ."*

Thus, as Rank (1 982) stated:

> *" . . . while the purpose of the program is to 'preserve, rehabilitate and enhance natural salmonid stocks, ' this is considered to be a means of achieving certain specific economic and social objectives, namely—*
>
> *i) To augment national and provincial income.*
>
> *ii) To create employment opportunities for Canadians.*
>
> *iii) To improve economic opportunities for Native Peoples.*

iv) To foster development of economically disadvantaged communities and regions.

v) To increase and improve recreational opportunities. . . "

Goals ii) and iii) were achieved through the Community Economic Development Program (CEDP), a subcomponent of SEP. Specific goals of this program as stated by Rank (1982) were:

"1. To contribute significantly to salmonid enhancement.

2. To provide satisfying employment for people who would otherwise be unemployed or severely underemployed.

3. To train people in the Bands and communities in enhancement and management tasks to the extent that those groups will eventually be able to provide all the personnel needed for enhancement works. This may involve assisting personal development of some individuals and increasing their job and education aspirations.

4. To contribute to community development through increased community satisfaction, development of community leaders and reduced need for out-migration of capable individuals.

5. To improve Band-Fisheries relations. "

From 1977 to 1984 approximately 12 million dollars have been expended on CEDP projects. Thus, over one million dollars per year for seven years have been directed towards social aspects of the overall program. In an assessment of the effectiveness of the overall program, Rank (1982) concluded that CEDP was notably successful in providing social benefits in terms of meaningful long-term jobs supported by comprehensive training programs and satisfying enhancement objectives. He concluded by stating that:

'When comparing the CEDP to other kinds of Native economic development programs, people typically call it 'the best' or 'one of the best.' "

The meshing of biological and social objectives within the SEP is viewed as one of the major successes of the program. Similar programs are strongly recommended for the NWT.

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