AN OVERVIEW OF NET PEN REARING ENHANCEMENT TECHNIQUE

PREPARED FOR:

SALMONID ENHANCEMENT PROGRAM

PROGRAM DEVELOPMENT BRANCH

VANCOUVER, B.C.

V6E 2P1

BY

KATHY LEAVENS

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DEPARTMENT OF FISHERIES AND OCEANS

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PREFACE

Net-pen rearing is a general term for the rearing of fish in a confining structure which allows for an exchange of water inside the pen with the surrounding environment. The purpose of this paper is to examine the use of marine net-pen rearing within the context of a salmonid[1] enhancement technique for British Columbia.

Several-thousand years ago, the Chinese were farming carp in ponds. Historically, raising fish has been a farming activity usually performed in fresh water. Net pens have only been used for the last one hundred years. Following the Second World War and the realization that stocks were declining, serious steps were taken by the North Americans, Europeans and Japanese to develop aquaculture and mariculture for salmon and trout. The practise of net-pen rearing in sea water has become increasingly popular since the 1960's.

There are at least three applications of marine net-pen rearing: farming, ranching and enhancement. Farming refers to raising fish to marketable size in captivity. Enhancement is increasing salmonid production, in this instance, by

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1 In this report, salmonid refers to coho, chinook, chum, pink, sockeye, masu and Atlantic salmon and steelhead. The Pacific salmon are coho, chinook, chum, pink and sockeye salmon. Masu salmon is used specifically when referring to Japan.

cultivating juveniles for release to the sea. Ranching is a distinct activity from enhancement when it is done by and for private enterprises. The potential benefits in all three areas have spurred research and development by many different agencies. In almost every country which has native salmon stocks and even in a few which do not, the technique has been increasingly used and refined.

While the purpose of this report is to examine net-pen rearing for its local enhancement applications, the scope must be much broader. For example, some of the knowledge gained in this area has been due to efforts to make commercial farming a success. Experimental fish farms in North America have probably contributed the most relevant information on the technical rearing aspects of net pen fish husbandry. Therefore, this report includes information on these and related topics for species other than salmonids, for applications other than enhancement, and for locations other than B.C. coastal waters. The first section of this report explains net-pen rearing in more detail and some of the advantages and disadvantages perceived at the present time. The second section deals with the management issues of net-pen rearing such as contributions to the fishery, transplant policies, and impacts on wild stocks. The next two sections describe some appropriate locations and designs of net pens and review the important biological and technicial considerations. Section V examines two successful facilities presently operating in B.C. An evaluation methodology for determining the feasibility of a proposed net pen facility, followed by some conclusions and recommendations, is discussed in the final two sections.

Net-pen rearing is becoming a well-known technique and several sites have been selected for the continuation of SEP Phase II enhancement opportunities. There is, however, little documentation of the techniques for solving particular problems. The simple methodology provided at the end of this report is intended to aid fisheries personnel in assessing a proposal for a net pen rearing project.

Another intent of this paper is to provide a documented account of net pens and to give references of more detailed sources of information. It is meant to inform but not instruct. Since the literature research and field investigation undertaken were not exhaustive, the report is also not intended to be complete, although, the author hopes that no important area has been overlooked.

I INTRODUCTION

Since the 1960's, the amount of research spent on design feasibility and pen application has increased dramatically in order to find commercially profitable or publicly cost-effective methods of raising fish. As the survey at the end of this section illustrates, the uses of net pens vary from growing chum fry for one month in a small bay, to transporting Atlantic salmon smolts down a river, to raising many species of fish to a marketable size. The wide variety of application has produced a wide assortment of net-pen designs and net-pen rearing techniques. A definition of net pens, given by Brett and Solmie (1981), is suitably broad.

> A net pen is defined to be a free-floating enclosure made of netting, supported by floats and held free from the shore and the bottom.

The netting may be rigid or flexible. The shape of the pens may be round, rectangular or octagonal. The many variations are discussed in a later section.

The definition of net-pen rearing needs to be similarly vague: Net-pen rearing is simply a technique of holding fish in net pens, for any length of time. The fish are usually given prepared food over and above naturally occurring food. The main purpose of net-pen rearing is to increase the size of the fish although not always. Herring are held in net pens without food at the Pacific Biological Station in Nanaimo, B.C. (PBS), until they have fully matured to produce a higher-quality roe for sale to the fish processors.

Since the focus of this paper is on enhancement of salmonids in B.C., the discussion in these first two sections will try to stay close to relevant issues. For all applications in B.C. by SEP and SEP-related projects, salmonids are raised for a specified period of time to increase their size and are then released. The objectives of the projects differ but the common rationale is that increasing the size will increase the chances for survival, and so, rather than releasing young salmon immediately, they are grown in net pens. Table I-1 illustrates present and past net-pen facilities and their objectives.

There are other objectives involved such as providing local employment and teaching facilities. These factors may be as important and should be considered separately after needs and feasibility are established.

TABLE I-1

Net Pen Facilities in B.C.

Facility	Objective(s)	Remarks
Sechelt - CEDP (SW)	- establish local sport fishery - increase local commercial catches	- too soon to tell how sucessful
False Creek - CEDP (SW)	- children's fishery - experiment to see if False Creek can support fish populations	- successful - successful
Indian Arm (SW)	- establish local sport fishery	- unsuccessful
Pallant Hatchery (SW)	- increase chum survival and therefore returns to commercial fishery	- too soon to tell

SW - seawater

FW - freshwater

CEDP - Community Economic Development Program

TABLE I-1 cont'd

Net-Pen Facilities in B.C.

Facility	Objective(s)	Remarks
Pacific Biological Station (SW)	- experimental fish farm	- successful
Keogh Pilot Study (FW)	- raise juvenile steelhead for transplants	- too soon to tell
Nanaimo Hatchery - CEDP (FW)	- raise hatchery excesses	-successful

Once the need for raising fish has been identified, the type of rearing facility is examined for feasibility and cost-effectiveness. Net pens offer several advantages over conventional, land-based facilities. A list of advantages in point form is presented, followed by a look at the disadvantages.

Advantages

1) Net pens have lower capital investment costs.
2) The system is modular and can easily be expanded, subject to site constraints, to accomodate large numbers.

3) The facility can also be operated on a small scale to involve community groups or to test site feasibility.
4) All salmonid species can be reared in the pens although some have higher mortalities than others.
5) Pens can be used in either fresh or sea water.
6) For sea pens, water quality is normally stable. Tidal action performs good flushing.
7) Pens can be placed anywhere the environment is acceptable so that imprinting on a particular release site is possible.
8) Fish held in sea pens can be released later to establish a local sport fishery.

Disadvantages

1) Fish-husbandry is difficult as many have found. Experience and knowledge are important qualities in a facility manager.
2) Marine and freshwater fouling are difficult to control.
3) Predators are a significant problem.
4) Conforming to acceptable site characteristics limits the places where net pens can be located.
5) Returning net-pen reared fish may stray further or more frequently.
6) High maintenance and replacement costs (Kerr et. al., 1980).

The first four disadvantages can be overcome with proper precautions. The low capital costs may outweigh the high maintenance costs, particularly if the project is not intended as a permanent facility. Straying occurs in wild B.C. stocks and the significance of additional straying is difficult to assess. The implications of these issues are discussed in the next section.

The advantages of net-pen rearing are being increasingly recognized in many countries. A list of applications throughout the world is given in Appendix A. Modern developments are usually restricted to developed countries with the exception of the pen culture of milkfish in the Philippines. The main constraints to wider application seem to be lack of adequate financing, suitable feed and technical support (FAO, 1976).

Net-pen rearing is an enhancement technique suggested for eight projects in the latest Enhancement Opportunities List for SEP Continuation. They are located at Capilano, Indian Arm, Kennedy River, Lower Cowichan River, Hemming Bay Creek and Nieumiamus Creek. Most proposals are possible satellites for hatcheries - either as lake net-pen rearing facilities or estuary-pen rearing facilities.

Some projects, previously proposed, have been rejected for a variety of reasons. Table I-2 gives some examples.

TABLE I-2

Reasons for rejection proposed sites[1]

Location	Reason
Saanich	Water temperatures too high for coho.
Belize Inlet	Suitable for coho but not a management priority; not a good commercial fishing area and chum are black, where commercial fishery takes place.
Kemano	Fresh-water supply is unsuitably cold; exposed bay; possible pollution from marina and logging activities.
Indian Arm	Problems with warm-water temperatures.

1 The information in the table was provided by B. Shepherd, personal communication, 1982.

II MANAGEMENT CONCERNS

There are some important issues concerned with net-pen rearing which need to be addressed before, during and after a feasibility study for a proposed project. Rearing and releasing fish to interact with the external environment has possible effects on the wild stocks through a variety of influences such as straying and contributions to commercial and sport fishery. There is also a question of quality of net-pen fish compared to the quality of wild fish. Thirdly, transplanting is a topic of concern, in part due to the popularity and feasibility of net-pen rearing. In addition to concerns about individual projects, Fisheries Management also needs to consider the issues of private farming and ranching made desirable by recent advances in net-pen rearing techniques. An attempt is made in the next few pages to explore these issues.

A. Contributions to the Commercial Fishery

In some projects, the releases of net-pen reared fish are expected to make a significant contribution to the commercial fishery. As with any enhancement method, problems with a mixed stock fishery arise if there is a wild stock component following similarly timed migration routes. The best alternatives seem to be:

i) locating net pens and imprinting to a site where there is a very small chance that local stocks would be affected. (The purpose of the project would likely be to establish either a new run or a terminal fishery); and

ii) using net pens to raise juveniles from local brood stocks with the goal of improving natural runs by increasing numbers of resident spawners.

Conflicts in managing mixed enhanced/wild stocks may be academic if the smolt-to-adult survival rates of pen-reared fish are not high. Studies reviewed by D.B. Lister and Associates Ltd. (1981) have shown that releases within the same river system or in streams within 120 km of the native stream will not necessarily reduce smolt-to-adult survival.

In B.C., the effects of pen rearing on rates of return have not been satisfactorily determined. It is too soon to tell whether the Pallant Creek hatchery-reared chums held in pens at Deer Bay will exhibit higher than natural survival rates. The only useful data so far have been the returns of the 3-year-old chums in 1982. Based on the 1978 brood-year age composition, the expected rate of return (to escapement) is about 1%. The calculations of this rate appear in Appendix B. The rate is very low, particularly when compared with some hatchery-reared coho with survival rates of 20 - 25%. These results can hardly be considered conclusive.

Experiments conducted by Heard and Cone (1976) examined adult returns of adult coho raised in estuarine pens in Little Port Walter, Alaska. They estimated that 12.3% of 261 smolts released in 1970 with an average weight of

13.5 g., returned to the area as adults in 1971. The next year, 16.4% of 4000 smolts released, weighing an average of 11.0 g., returned to the area. Five of nine marked jacks were also recovered in 1971 but are not included in the percentage of released smolts. Both samples are non-accelerated coho taken as fry from their natural habitat. The researchers concluded that the size, timing and rate of return were the same for pen-raised and wild smolts. At the present time, B.C. net-pen facilities have not been in place long enough to adequately assess adult survival.

Until more research proves otherwise, it appears that raising coho in net pens will not increase survival rates over and above those of natural stocks. One might expect comparable rates with those of hatchery-reared coho (25% according to Bilton (1981)) but so far there is no evidence to support or deny this. This is not to say that pen-reared coho will not contribute to the commercial fishery. The coho will contribute to this fishery to the same extent as natural stocks. Hence, it seems that if the object is to restock streams, then net-pen rearing may accomplish the task with little disruption to the fisheries management priorities of maintaining escapement.

On the other hand, if the sole objective of pen raising is to create a terminal fishery and only a few spawners are required for replenishing the stocks, then the net pens should be placed in an area where the chance of interfering with natural stocks is small.

B. Contributions to Sport Fishery

Experiments in Puget Sound, Washington, on the delayed releases of coho resulted in new migration patterns. The coho remained in the Sound instead of migrating to the sea and thus established a local sport fishery. Attempts have been made in B.C. to duplicate this phenomena in the Georgia Strait, Sechelt Peninsula and Indian Arm, but so far have not been successful (Brett, 1982). It is believed that the particular size and shape of the Puget Sound allows for the unique occurrence.

The experimentalists in Washington began using net pens to study the feasibility of culturing coho and chinook for the market. Fish from the pilot farm were made available for studies of releases. The results do not consistently show that pen rearing is the most efficient method. One study in 1975, estimated that the total recovery from hatchery release of coho, was 8.4% compared to the recovery estimates of pen reared coho for 6 days (17.0%) and 45 days (5.3%). All three groups weighed between 23.9 g. and 25.2 g. on the average at different release times spanning 33 days. Another experiment with 1971 brood fall chinook found that total estimated recovery of pen-reared chinook rose with the size of the juvenile or length of delay. Even so, the maximum total recovery was only 4.1%. Examination of the distribution of the recoveries reveals that the local catch components at sea and in Puget Sound compared to B.C. and Oregon catch components are enormously affected by the time of release.[1]

C. Straying

Straying becomes a management concern when the fish released from net pens are not indigenous to the location of the facility. Even if they are, if the purpose of raising smolts is to increase survival and replenish stocks, then the technique of net penning may still produce a larger number of strays which might have adverse effects on the surrounding stocks. A review of some of the studies done on homing, straying and survival, (D.B. Lister and Associates, Ltd., 1981) contains some observations of within-system releases, transplants and releases into saltwater. Without going into much detail, a summary of the relevant conclusions is presented here.

1. Within-system releases and straying.

Smolts released at sites away from the rearing site tend to stray at considerably higher rates than those released directly from the rearing facility. The rate of straying increases with decreasing distances between release and rearing sites. A high proportion of the straying is back to the rearing site. Transplanted sockeye in two studies retained a strong attraction to the initial rearing site within the same system.

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[1] The results from these experiments are taken from a summary prepared by A.J. Novotny for book: J.E. Thorpe, Editor, 1980. Salmon Ranching, Academic Press, London, pp. 325-370.

2. Life stage and release

The length of exposure to the release stream influences the strength of imprinting. Weyerhauser Ltd. operates a coho salmon ranch in Oregon where the fish are imprinted for two weeks. The rate of return is about 1.5%. This number does not include coho caught by commercial and sport fishermen but is thought to be extremely low, possibly due to the short period of imprinting. Only two percent of the returns strayed into rivers up to 30 miles from the catch release site. The strays which came from accelerated and normal smolts, made up to 50% of the spawners in the Yaquina River system (Meggs, 1982).

3. Available spawning area

Observations of chum at Blaney Creek in 1977-78, showed that the available spawning area appeared to influence straying; i.e. straying increases with limited spawning area.

4. Releases into saltwater

The rate of straying for coho released into Seaward Lagoon to streams in Resurrection Bay, Alaska, was equal to or less than the rates documented for stream releases of smolts. Coho experiments by Heard showed high straying back to rearing site when the distance was 3 km from release site. The authors gave four reasons for this observation. The two reasons preferred were that there were not suitable spawning streams near the release site and that partial imprinting occurs to more than one stream. The conclusion was that when sites are widely separated, very little exposure to a freshwater source may be required to achieve a higher degree of homing.

5. Imprinting

There are various opinions concerning the necessary steps required to assure a high rate of homing to an off-station release site, although length of exposure to the release location appears to be a factor. A reliable imprinting method is necessary for transplants and there is evidence that a short relocation distance will result in a higher percentage of strays. There are two theories on how imprinting occurs, i.e. sequentially or singly. The Swedes tried to strengthen the homing cues of their hatchery salmon by towing them down the river in net pens.

6. Genetic influence on homing

D.B. Lister and Associates Ltd. (1981) felt that there was little direct evidence to show that homing was determined by genetics.

7. Wild stocks

There is not enough existing data to indicate the magnitude or variation of straying among wild stocks. Electrophoretic studies of coho have indicated that because there is little variation between stocks, there is either extensive straying, or a number of streams which constitute a stock (M. Birch, personal communication 1982) (Transplant Information File). There is evidence that natural strays are a certain genotype. The Transplant Committee for B.C. has speculated that strays may not contribute to the population unless they are a suitable phenotype.

D. D.F.O. Policies and Priorities

The informal transplant policy for the South Coast of B.C. sets up some guidelines for selecting donor stocks for transplants. The purpose of transplanting is to colonize barren streams but the transplant policy applies to all facilities where salmon are released from locations other than their natural rearing stream. This includes those stocks intended for a terminal or sport fishery. The committee's primary concern is to maintain genetic diversity. The present policy permits transplants within a 20-mile radius of the major hatchery supplying the eggs or juveniles. Recent studies suggest that ecological and biological characteristics may be more important than geographical distance when considering transplants. Recent investigations by Withler (1982) into transplants of Pacific Salmon found few instances of successful colonization except by removing or circumventing physical barriers.

It has been a practise in B.C. hatcheries to take an excess number of eggs from brood stocks "in case anything happens". Because the hatcheries have no room to raise the young for release, they are willing to sell them to private farmers and donate them to enhancement projects. Sometimes without regard for DFO's transplant policy. Net pen enhancement has also been seen as a technique for adding additional fish to the fishery when the fishery cannot take place at the hatchery site.

In B.C., all growers are required to get their eggs from a hatchery. Some fish farms are learning to raise their own brood stocks. A number of small local groups have expressed interest in having their own fish stocks. Even so, the idea is catching on and the demand for hatchery fish eggs is increasing. Hatcheries have had to limit numbers to off-site facilities.

The size and maturity of the commercial catch is a management concern. Delayed releases of coho and pinks have been shown in some instances to produce smaller fish (Novotny, 1980). Accelerated coho have a higher proportion of jacks.

Net-pen rearing and similar enhancement techniques may be an effective method of keeping streams from real-estate developers. Unfortunately, with a manpower shortage, the Department of Fisheries and Oceans (D.F.O.) would have to rely on volunteers who are limited by the distance which they could be reasonably expected to cover in order to look after the facility.

Protecting the long-term gene pool of native salmon, as alluded to previously, is high on the list of D.F.O. priorities. The fear is that genetic diversity will disappear and weaken the health of stocks. Two different stocks could have a different number of chromosomes and produce sterile stocks. On the other hand, controlled experiments have been and are being conducted to improve the desirable qualities such as size and resistance to diseases both in pen culture and in nature. For example, sterile coho and coho treated with hormones to produce a high proportion of females, have been released from the Capilano Hatchery. The hope is that sterile fish will not return to the hatchery but remain feeding at sea and grow to much larger sizes. Some experimentalists are crossing the species of salmon to produce strains more valuable to the fisherman and/or the fish farmer. Others are crossing stocks of the same species to change migration patterns and timing and in general improve quality or size (Meggs, 1982).

E. Farming and Ranching - Present and Future

The private farming and ranching industries are becoming more financially profitable as more research is directed toward improving techniques and more attempts are made by private enterprise. Net-pen farming is making a significant contribution to markets in Japan, Norway, the U.S. and to a lesser extent B.C. The economic, social and political impact of ranching is gaining recognition in many of these same regions.

Most government enhancement facilities practise a form of ranching. However, increased production is intended for the public use and the only conflicting interest is ensuring optimum levels of escapement. Ranching in the private sector puts those people/companies who release large numbers of salmon (usually straight into the sea), in direct competition with the commercial fisherman for the adult returns. Farmers are not involved in the allocation of returning adults but are interested in the market.

Both salmon ranchers and farmers are required to invest in the incubation and rearing facilities. Operating costs for the farmer will be much higher per kilogram of fish produced since food is an expensive item and the fish are fed until they are sent to the market. Ranchers send their fish to the ocean to feed for a year or more after feeding them for up to two years. A good farmer could realize high survival rates of 90%. The rancher would be very profitable to see 5% of the releases return to the release site. In 1981, Ore Aqua

(Weyerhaeuser Corp.) in Oregon had a 1.5% rate of return (Meggs, 1982) for coho. The managers at Ore Aqua expect that, in 1983, 25% of the troll catch in Oregon, or about 100,000 fish, will be Ore Aqua production. At a 1.5% rate of return this is 33% of the total returns. The company expects that 50-75% of their returning adults would be exploited by the commercial fishing fleet. But, they also calculate an expected return of 5% and hopefully 10% of smolts released.

Net-pen farming has proven to be difficult and risky in B.C. However, there is at least one profitable farm operating near Powell River. The farm is owned by Brad Hope. The successful operations in Washington (Domsea Farms), Norway and Japan are further proof of the viability of a fish farming industry.

At the present time, private ranching for profit is legal only in Oregon. B.C. and Washington are talking about it but not allowing it. California has a pilot project privately operating. In Alaska, non-profit operations are permitted. In many cases these are owned and operated by the fisherman. There appears to be a fair bit of conflict between ranchers and fisherman which is not surprising given the low returns. Oregon trollers feel that the government methods of managing stocks reflect the interest of the ranchers. Bill McNeil, the manager of Ore Aqua Foods, sees inevitable victory for his Company and its concept and is quoted by Geoff Meggs:

"What we're looking at here is a classic transition of public policy away from a hunting-gathering economy to more of a farming philosophy. The whole thing is being propelled by a requirement for more production out of the ocean. We're not getting it through hunting and gathering.

"Fishermen feel threatened by it because they're the hunters and the gatherers. We've got them frightened all the way from northern California through Alaska.

"Look at the history of agriculture and forestry. What we're looking at is more need for protein from that system out there and the only way we're going to get it, frankly, is to exercise more control over the system. We do that in forestry; we do it in agriculture."

Will fishermen go the way of the buffalo hunter?

"It's an inevitable economic transition as long as population pressures continue."

The argument is fairly clear and, without taking other factors such as genetic diversity and ocean capacity into account, seems to make sense. The transition looks a little messy, however and as yet, Weyerhaeuser Corp. has not proved that ranching is more efficient than farming in the short or the long run. One can see commercial fishing and farming coexist but not ranching and commercial fishing. Society needs to decide on the value of the fishing life-style to Canadians versus its costs (i.e. to stocks etc.). If the transition is inevitable, as Bill McNeil said, then the transition would be so much easier if fishermen were participating as owners of ranches and/or farms.

Looking at the broader picture, there will come a time when the capacity of ocean food supplies for salmon from all North Pacific Rim countries will reach its upper limit (some believe we have already). Then the interested parties will negotiate quotas-probably based on their present output. Therefore, it is in Canada's interest to increase its smolt output to claim a bigger share at that time.

Aquaculture using "floating-pen" type technology has been addressed by interested parties outside the fishing industry. Reports prepared for the B.C. Department of Economic Development, i.e., Fin Fish Aquaculture in B.C. - A Review of the Prospects (1975) have revealed the economic feasibility of certain types of aquaculture. An article by R.C. McCutcheon (1976)[1] shows ways in which the existing law could be altered to encourage farming. McCutcheon raises issues such as the allocation of the ocean's surface among the various users and the conflicts likely to arise.

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1 McCutcheon, R.C. 1976. Aquaculture: Problems of Implementation Under Existing Law. U.B.C. Law Review, Vol. 10. p. 289.

With the advent of successful forms of net-pen rearing, the demands for farming and ranching rights by private concerns will increase. The Canadian government's present policy is to allow farming subject to numerous regulations. The provincial government is ear-marking suitable coastal sites for future farming potential. The federal government is the only legal rancher in B.C. but Senior Management is considering a pilot project proposed by the B.C. Development Corporation for ranching coho in Kennedy Lake, (Schutz, pers. comm. 1982). The government is also studying the feasibility of terminal fisheries at inland hatcheries where commercial fishing has proven to be an inefficient method of exploiting hatchery-produced fish.

Net-pen rearing has introduced viable, alternative production methods to counter dwindling resources. As an enhancement technique it is one of many; as a commercial rearing technique it has helped make several new industries, farming and ranching, economically feasible.

III LOCATION & DESIGN OF NET PENS

Section III covers some of the important considerations for selecting sites and designing net-pen facilities. A complete treatment of the subject has filled several reports and the reader is urged to go to other sources such as the references following at the end of the section for more detailed information.

The issues involving location of net-pen facilities are covered in sub-sections A and B. The points raised under Site Selection are very relevant to the early planning stages of a facility. A short discussion of predators follows which has some relevance to the design of the net pens so that problems can be prevented. In all the projects researched, predation was brought under control eventually, but sometimes only after several years of work and thousands of fish had been lost to predators.

The various designs of net pens are examined in the last three sub-sections. The physical aspects are outlined under Structure and Nets. Maintenance of the pens is also examined because frequently there are trade-offs between the location, design and the amount of maintenance required.

A Site Selection

Potential sites are selected for a variety of reasons:

(i) the site is close to hatchery i.e. Pallant Creek Hatchery;

(ii) it is close to a stream where natural stocks don't exist;

(iii) it is located in seemingly protected areas; or

(iv) it may be close to a stream with a seriously declining indigenous population.

Whatever the reason, a detailed survey of the locale is required before a decision is made as to whether the site is suitable. It has been recommended that the area be observed and sampled for a minimum period of 1 year. (B. Shepherd, pers. comm. 1982; Kerr, 1978). Table III-1 contains a fairly-extensive list of factors to be considered and their specifications. The specific site requirements are gathered from several sources. Where the sources disagree, the recommended guidelines used by D.F.O. biologists are quoted.

TABLE III-1

SITE SELECTION

Factor	Specification (Methods)	Methods (i)	Authority
1. Minimum Ocean Depth	Approx. 3m below bottom of pens at lower end of tidal flux range.	Marine charts; shallow sounding surveys	Shepherd
2. Maximum Ocean Depth	Approx. 10m at higher end of tidal flux range. (Limited by anchoring method.)	(see above).	Shepherd
3. Sedimentation Erosion	Prefer minimal chances.	No formal check recommended, simply be aware of noticeable changes while performing other checks.	Shepherd
4. Meteorology	Max. wind speed: 9-12 m/s Ensure adequate shelter from prevailing winds.	Record min. and max. Air temperatures, wind speed and direction.	

TABLE III-1

SITE SELECTION (cont'd)

Factor	Specification (Methods)	Methods (i)	Authority
5. Water Temperature	Range: 5.5 - 15°C	Should be measured for 1 year period at varying depths.	Shepherd
6. Salinity	Range: 10 - 30%	See above. Vertical survey (4 times/year) will detect freshwater lens.	
7. Dissolved Oxygen	Range: 90-100%	See (5)	
8. Wave Height	Maximum height 1m - if exceeded even occasionally, floatation & anchoring could be expensive.	Historical records; periodic observations	Kennedy

TABLE III-1

SITE SELECTION (cont'd)

Factor	Specification (Methods)	Methods (i)	Authority
9. Chemical Analysis	Normal ranges for concentrations of Zn, Cd, Hg, Cu, Fe, Nitrate/Nitrite, Phosphate	Samples taken over 1 year period.	Shepherd
10. Current Direction	Ideally not cyclical. Maximum speed - 100cm/sec. Minimum period of slack - 0.5 cm/sec. Ideally - 10 cm/sec.	Measurements should be taken hourly for a complete tidal cycle-neap & spring tides (Kerr, 1980)	Shepherd/ Kennedy
11. Fauna & Flora		Qualitative survey of benthos and intertidal zone.	Kerr/ Shepherd
12. Land Area	Topography, elevation and access should be suitable	General survey.	Kerr/ Shepherd

TABLE III-1

SITE SELECTION (cont'd)

Factor	Specification (Methods)	Methods (i)	Authority
13. Situation	Availability of fresh water and electricity, existence of commom glazings, rights of way, conserved land, piers, present and potential users. Particularly critical is determining potential pollutants from mills or domestic sewer outfalls and identifying other uses such as log booming and marinas, marine traffic.	Observation and investigation	Shepherd/ Kerr
14. Legal Requirements	Foreshore rights.		

(i) "Methods of measurement are well documented" (FAO, 1976; Ingham, 1976; Landles and Edwards, 1976) Kerr et.al., 1978.

It is possible that a few site characteristics will not fall within the specifications but these problems may be overcome by taking extra measures for example, building a more expensive but stronger floatation and anchoring system (Kennedy). However, there appear to be many problems in net pen technology and exceeding the boundaries of the recommended guidelines in these studied areas will only increase the risk of failure.

Some further considerations due to effects of implementing net-pen rearing are:

(i) Local hydrography can change when large structures are placed in shallow water and act as barriers. Floating breakwaters act as efficient wave modifiers. (Kerr et al.)

(ii) Offal-type diets may change the ocean bottom environment due to accumulation of solid wastes where current scour is limited.

B Predators

The design of the net-pen facility will be influenced by the type of predators in the area. A survey of the location for local fauna will help prevent significant losses in the first few years. The aspects of the design which consider particular predators will be discussed in future sections. However, Table III-2 presents a list of predators which have caused problems at various facilities.

TABLE III-2

Predators

Location	Predator	Remedy/Remarks
1. Fox Island, Washington	blue herons	elevated cover nets
	western grebes	-
	mallards & ravens	liked fish food
2. Pacific Biological Station, Nanaimo, B.C.	otters, seals, minks	webbing laced over top of of pens or sheds
	gulls, herons	white cover nets
	people	guard dog
	dogfish	net bottoms fully extended horizontally and in good repair
3. False Creek, Vancouver, B.C.	dogfish, cormorants, grebes, loons, merganzers	predator net
	people	solid, locked covers

C Structure

The five components of the support structure for net pens are:

(a) breakwater

(b) mooring

(c) design

(d) floatation

(e) frame

The major considerations of each category are discussed in turn. Cost studies were not undertaken so that if cost is a consideration, the alternatives will need to be investigated further.

(a) Breakwater

A breakwater is only necessary if the site that has been selected has heavy waves. "Ideally, net pens should be located in a place where a small boat could be safely moored regardless of wind direction or force" (Kennedy, 1978). If a breakwater will accomplish this task, the following considerations gathered from several sources should be explored in deciding the type of breakwater required:

(1) a floating versus a fixed breakwater will affect the cost and life of the project;

(2) length of the breakwater depends on the length of the unit to be protected (1 1/2 times as long) and the refraction of incident waves at the ends;

(3) an alternative to log breakwaters is car tires linked by synthetic-rubber conveyor belting as described by Kerr et al (1980).

It should be noted though, that none of the net pens observed for this paper was located in sites requiring a breakwater, except those at P.B.S.

(b) Mooring

The major criteria for proper mooring are strength, flexibility, small vertical load on floats, durability, and ease of replacement. The various alternative systems, all of which were suggested by Kennedy, are as follows:

(1) A small operator could lease space at a marina and this eliminates the need for a distinct mooring system.

(2) Anchors, preferably two or more to prevent swinging caused by currents and winds, could be used. (Kennedy recommends that the anchors be 1-ton pieces of concrete.)

(3) Cables and stifflegs were found to work satisfactorily at the P.B.S. fish farm. However, as Kennedy (1978) points out, this method is only suitable where the water is deep near the shore.

(4) Net pens could be tied to a series of walkways which are held in place by pilings.

(c) Design

The design is based on the required number of pens of a particular desirable size which is determined by desired production levels.

The Pallant Creek Project handed their design specifications over to an engineering firm which then drew up detailed plans. It is not the intention of this report to cover the details of such planning. However, a general discussion of the basic considerations follows. This discussion is a condensed summary of Kennedy's suggestions with additional information obtained from other sources.

The most common shape of the net pen is square for probably obvious reasons: nets can be oriented in any direction; multiple groupings are easily designed; and fish generally swim in a circle. A solid walkway on all four sides is standard. Kennedy (1978) suggests that the space for the pen be 5% larger than the pen (except when the pen is under a roof) to keep out predators like otters. Kerr (1980) discusses alternate designs used for flat fish cages.

The problems of fouling and erosion of nets are receiving more attention by acquaculturists around the world. In Germany, this problem has been overcome by the use of rotating, globular cages (FAO, 1976).

The most common construction material is wood, chosen for its buoyancy, flexibility and ability to withstand waves. Many sites incorporate a small building on the float to store supplies or shelter workers.

The recommended distance between pens varies depending on the source, but the basic idea is to ensure adequate flushing by tidal fluctuation to all pens. Thus, a single row of pens presents no problems, although, if many pens are required, maintaining a relatively constant depth may be not possible. The sites at Nanaimo (P.B.S.) and Sechelt (C.E.D.P.) arrange two rows of pens side by side with a walkway ($\sim$ 5 ft) between them. The fish in the pen have not suffered from a lack of flushing action.

(d) Floatation

Floatation is required to support the frames, the nets when hauled from the water, the walkway, and the people working at the site and work areas.

Kennedy (1978) recommends hollow or styrofoam floats with impervious covers sufficient to support one tonne per side. The walkway should be floated 20-50 cm above the water. Kerr (1980) suggests using polystyrene or polyurethane. A commercial product used currently on the West Coast is sold by Topper Floats Ltd. Their styrofoam-filled tires are expensive but effective.

(e) Frame

Kerr (1980) provides a list of materials used to make the pen frames which includes fibreglass, galvanized steel, European Larch etc. On the B.C. coast however, a solid framework is not the accepted practice. Most sites used rigid poles at each corner to attach the corners of the net to. The general shape of the net is achieved by hanging weights, again at each corner, inside the net. The method is detailed in Kennedy (1978) along with several other methods less preferred by operators in B.C.

D Nets

A net-pen operation requires two or three different types of nets. One type has a small mesh to contain the fry when first introduced. A second type can have a larger mesh size to retain the growing juvenile. Some facilities also need a predator guard net.

The most common netting material used in B.C. is a stretch knotless nylon. Kennedy (1978) recommends a knotted web for its strength but the P.B.S. farm now uses and recommends knotless webbing for its less-abrasive properties (Solmie, 1982). Kerr et.al. (1980) mention some other material including a semi-rigid, woven mesh made of 9:1 copper-nickel alloy. They found that the alloy resists corrosion and fouling 2 to 3 times more than the nylon. A detailed examination of a fouling-resistant cage system is presented by Huguenin et. al. (1981). The problem of fouling may be alleviated by treating the nylon nets with a copper or tin-based resin. The possible deleterious effects on the health of the fish from either the resin or the stiffer nets may be less stressful than frequently changing the nets. P.B.S. has experimented with a commercial tin-based antifoulant made by Sydel in Vancouver. They found that it worked but are still not sure of the long-term effects on the nets or the fish (Solmie, 1983).

Since smaller-mesh nets impede water flow and foul more quickly, the largest mesh which will still retain the smallest size of fish is chosen. The appropriate sizes of mesh and fish are related in Table III-3 (Shepherd, pers. comm. 1982).

TABLE III-3

Mesh Sizes

Mesh Size (mm)	Fish Weight (g)
3	.5
10	2.0
13	3.0
19	10.0
25	35.0

As mentioned in the section on design, the shape of the pens is generally rectangular or square, however their depth will vary depending on the size of the fish and their preference for cooler water temperatures or higher salinities. For example, the chum fry at the Pallant Creek net pens preferred to be nearer the surface and so the nets 5 m in depth were replaced by nets 3 m in depth. For the deeper nets, the problem of keeping the bottom taut can be eased by tapering the sides.

The choice of the overall size of net depends on the mesh size and the amount of fouling which occurs at the chosen site. Smaller nets are easier to change and if disease breaks out, the number of fish which suffer is smaller. On the other hand, the larger the nets, the less maintenance and capital investment. The project manager needs to balance these trade offs. For more detailed information, the reader can look up sources mentioned at the end of this section.

Predator guard nets should be made from a heavier, wider-mesh netting material. Fish, debris and diving birds sometimes get caught in large-mesh nets. Small-meshed nets may foul and impede water flow. Three designs of guard nets are:

(i) complete enclosure of net pens
(ii) a maze of panels hung between pens
(iii) a long net which surrounds the pens and reaches the ocean floor

Guard nets should never touch the pens since predators could still get close to the fish and bother or attack them.

Most facilities cover the pens with nets to keep out birds such as blue herons (D. Mills, 1977). The cover must not touch the surface of the water enclosed. A dark colour worked well at Fox Island but Kennedy (1978) suggests that white netting both for pens and for covers best discourages diving birds from attacking. Pens which are not covered with nets are covered with sheds or boards.

E Maintenance

Both the floats and the nets need periodic maintenance checks to keep fish from escaping.

The life of rearing nets can be prolonged and chances of getting holes reduced by using only plastic or nylon objects for keeping the nets in place, by storing nets in a covered place, and by cleaning pens when necessary. Nets should be checked often and any holes found mended immediately. Pens should be cleaned only when necessary since the process will stress the fish. If fouling occurs only near the tops of the nets, then, they can be left. If fouling is heavy enough to prevent adequate water circulation then nets can be brushed or sprayed with water from a pump, pulled up above water line one side at a time to be dried or changed.

Fouling is worse at certain times of the year, usually in the summer, although algae blooms can have unpredictable timing. Shading the nets will slow algal growth and help to keep them clean. At the Pacific Biologicial Station, a virulent algae bloom in September is prevented from harming the fish by allowing mussels to accumulate on the nets over the summer. These mussels filter feed on the algae and so keep most of it from entering the pens.

The float should be inspected once or twice a year by a scuba diver. Sea urchins will burrow into stryofoam and should be removed and the anchor lines also need to be carefully checked. A diver should check especially deep pens which are not regularly changed and inspected for holes. Neither this procedure nor the alternative of pulling nets up for inspection is satisfactory although Kennedy's (1978) design involving a system of pulleys will make the latter method simpler. Many facilities have lost thousands of fish through very small holes before they were detected.

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IV CONSIDERATIONS FOR NET PEN FISH REARING

Net-pen rearing is an aquaculture technique that has been in existence for many years. Southeast Asian fish farmers were using pen enclosures in ponds and lakes over one thousand years ago. Since the Second World War, the number of programs for rearing and releasing salmon has increased all over the world. This interest has led to technical refinements learned through research and experience. For some aspects of aquaculture, such as time of release and optimum growth patterns, experimental research is just beginning to answer the important questions. For other aspects, such as transfer procedures and optimum salinity, sufficient information is available for applying the technique successfully.

This section is somewhat arbitrarily divided into seven aspects of net-pen rearing which were thought to be the major considerations of the technique. These aspects, in order of discussion, are disease, transfer (to sea pens), density, salinity, growth, feeding, and release.

A Disease

There are several diseases which seriously affect the survival of North-Pacific salmon in net pens. The control of disease has a high priority among net-pen salmon rearers. Coho and chinook have similar susceptibilities to disease but pink and chum are the most susceptible.

Three major diseases will be discusssed in turn: Vibriosis, furunculosis and bacterial kidney disease (B.K.D.). In addition to these three, other diseases which affect juveniles in net pens are outlined. Finally, since it is much better to never contract a disease in the first instance, a few paragraphs are included covering the prevention of infectious diseases.

1. Vibriosis

Vibriosis is caused by the bacteria Vibrio angullarum. Outbreaks occur only in salt water and usually at warmer temperatures. The bacteria enter the body where scales have been lost. An early symptom is a reduced appetite.

The disease can be treated with either internal medication or a sulphonamide bath. Most facilities add terramycin, an antibiotic, to the fish food.

It is becoming very common to vaccinate against vibrio before transferring the juveniles to the sea pens. Kennedy (1978) discusses three methods of innoculating the fish and recommends the immersion technique as opposed to oral or injection techniques.

2. Ferunculosis

The bacterium which causes furunculosis is Aeromonas salmonicida. The symptoms are very similar to vibriosis but the treatment is different so proper laboratory diagnosis is necessary. The diseases may occur simultaneously. The fish become infected in fresh water and carry the bacteria with them to the sea. An outbreak usually occurs when water temperatures are greater than 12° C. The disease is successfully treated with Furox-50, a medication containing 11% active furazolidine which is added to the food. The sulphonamides sometimes cure the disease.

3. Bacterial Kidney Disease

B.K.D. is caused by Cornyebacterium Spp. which seems to be more prevalent in soft water (Roberts, 1974). The disease prevails in the winter, usually appearing in the fish's first year in the saltwater pens (Novotny, 1974). It is beleived that B.K.D. is also contracted in fresh water. Its symptoms are distinguishable from those of the previous two diseases and symptoms of all three are described by Kennedy (1978).

A satisfactory treatment for B.K.D. has not been found. Sulphamerazine is recommended by some authorities although it did not control B.K.D. at the Pacific Biological Station (Kennedy, 1978). Novotny (1974) has suggested that pencillin is partially effective.

4. Other Diseases

There are several other diseases worth noting in this section. Juvenile salmon are susceptible to tail and fin rot under unsanitary conditions. Although the skin problem is not lethal, it weakens the fish and increases their chances of catching one of the more serious diseases.

Piscine erythrocetic necrosis (P.E.N.) is a fatal disease recently diagnosed in chum and pinks. It is caused by an unknown virus and there is no known treatment.

Non-infectious diseases can cause serious problems like the one encountered at the Pacific Biological Station. At the net-pen site, a thorny phyto-plankton blooms in the early fall and causes damage to the gills of the growing salmon. The infection damages the fish's gills and raises their susceptibility to other diseases. The section on maintenance discusses how the station has overcome this problem.

A deficient diet has also been known to cause major problems at some facilities (see Section V, False Creek Net Pen Facility and Kennedy, 1978). With a correct diagnosis, usually only possible at a well-equipped laboratory, the treatment of adding vitamins and/or minerals to the diet can be administered.

5. Prevention of Infections Diseases

There are a number of methods for preventing diseases. One is to vaccinate fish against the disease as is done for vibriosis. Most of the juveniles are now vaccinated at the hatchery before transfer to a sea pen. Unfortunately, there are no vaccines for furunculosis, bacterial kidney disease or Piscine erythrocetic necrosis.

A second method is to ensure that juvenile fish are free from infection before the transfer. This means that eggs should come from disease-free adults and that the hatchery water supply should be clean.

A third method is to apply good fish-husbandry techniques, i.e. avoid over-frequent handling, overcrowding, dirty pens, poor diet, inadequate oxygen supply or water flows, and spreading of pathogens. In general, anything which causes stress to the fish will increase their susceptibility to disease.

Finally, should a disease be suspected, an immediate treatment appropriate for the observable symptons could prevent disaster. Kennedy (1978) recommends that a tentative diagnosis be made and treatment started before the disease is confirmed by the lab[1].

B Transfer to Sea Pens

Careful steps must be taken during the transfer process to ensure high survival in the net pens. First, the fish must be ready to enter the new environment. Second, stress on the fish should be minimized to avoid an outbreak of vibriosis.

A general rule for deciding when fish are ready to be transferred is given by Novotny (1971) and summarized in Table IV-1.

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1 The Diagnostic Services in the Fish Health Program located at the Pacific Biological Station in Nanaimo, diagnose of fish diseases for private and public facilities.

TABLE IV-1

Transfer of salmon to 100 percent seawater

Species	Average Weight	Number of fish/lb.	Comments
Chum	.5 g	850 - 900	better to wait until 400/lb.
Pink	.5 g	850 - 900	better to wait until 400/lb.
Coho	12.0 g	35 - 40	without acclimation
Chinook	5.5 g	80 - 90	95-99% survival if sea water temperature is below 10° C.
Sockeye	2.3 g	200	acclimation is in stages

The Pacific Biological Station always acclimates their juveniles in two stages. Their procedure of vaccination, medication and acclimation prior to and during the transfer process are documented by Kennedy (1978).

The transport procedure from hatchery to rearing pens located some distance from the hatcheries is more complicated. A method used many times by Apex Bio-resources, a commercial fish farm operating in the Port Alberni Inlet, is documented by Stavrokov (1979). In his covering letter, Stavrakov states that the procedure can be used to transfer up to 10,000 1.5-gram fish per 20-gallon bucket over a period of four hours and suffer losses of less than 0.1%.

There is one final note to be made. The numbers of fish transported and placed in each pen should be carefully enumerated. This is because keeping track of the number of fish per pen is usually done by subtracting the number of dead fish found each day from the number originally placed in the pen. Kennedy (1978) describes methods for counting the fish in the pens but emphasizes that the procedure causes additional stress to the the fish and should therefore be used as little as possible.

C Density

Dissolved O_2 levels limit the maximum number of fish kept in a pen. Optimum density will be site and species specific.

Although densities for each site will vary, the literature does provide some ranges and upper limits. A list is provided in Table IV-2.

Morgan (1981) reported on several experiments investigating the effects of density on growth and survival of seapen-reared chinook. He concluded that for maximum growth, the density should be lower than if maximizing number is the objective. So far, his studies have examined densities up to 8.5 kg/m^3 and he recommended that future studies should examine higher densities.

D Salinity

Because all salmon begin their lives in fresh water, a transformation or smoltification must occur before survival in salt water is assured. When the transfer is made, the salinity of the water must be suitable for the fish's physiology.

TABLE IV-2

Densities for Net Pens

Species	Density	Comments	Authority
Chinook	15.5 kg/m^3	juveniles in Clam Bay, Wash.	Novotny (1971)
Chinook	13.9 kg/m^3	adults in Clam Bay, Wash.	Novotny (1971)
Chinook	8-12 kg/m^3	acceptable range at False Creek, Vancouver, B.C.	Morgan (1981)
Steelhead	8 kg/m^3	at Cowichan Lake, B.C.	Sparrow (1981)
Cutthroat	8 kg/m^3	at Cowichan Lake, B.C.	Sparrow (1981)
Herring	8 kg/m^3	recommended	Brett and Solmie (1981)
Chinook and Coho	16 kg/m^3	maximum density	Kennedy (1978)
Chinook and Coho	7 kg/m^3	recommended density for small fish	Stavrakov (1981)

Smolting is highly correlated with the size of fish and the following table illustrates some typical sizes.

TABLE IV-3

Average Size of Juveniles at Smoltification

Species	Size
Chum	1 - 2 g.
Pink	1 - 2 g.
Coho	15 g.
Chinook	5 g.

Several studies performed in the early 1970's have shown preferred salinities for juvenile-coho rearing. Clark (1979) discusses this subject and the necessity for a freshwater lens at the Sechelt net-pen rearing project. The major points are:

(i) The upper lethal salinity level increases from May to February at which time highly saline water is tolerable;

(ii) Larger fish survive better than small fish in high salinities;

(iii) Salinity tolerance was increased by exposure to dilute salinities;

(iv) High salinities inhibited growth in coho presmolts.

From these studies, it was concluded that a freshwater lens is advisable until January when the coho will smolt.

Most of the studies which examine effects of salinity on growth and survival have been performed on coho. Pink and chum fry will adjust to salt water almost immediately after swim-up. Chinook can be transferred directly to sea water after the first year. Wild coho often spend more time in an estuarine environment before going to sea. Hence, it is better to provide some gradual transition to salt water. Some facilities, such as P.B.S., will acclimate all species over an extended period of, for example, two weeks (Kennedy, 1978). Some facilities may have no need for a freshwater lens since their pens are in low-salinity waters (see Section V, False Creek Net Pen Project). Other facilities are able to provide a freshwater lens, either by natural or engineered means, for some or all species. This lens may be necessary for ensuring proper imprinting.

A natural lens may be present if the pens are located near the mouth of a stream or river or near a sufficient source of local surface run-off. An example of a man-made lens is given in Section V under Sechelt Indian Band Net Pen Project. The Sechelt lens can be removed when no longer needed. Otherwise, deep pens would be required so that fish could avoid the lens after smolting. There have been studies which show that coho will revert to a parr condition if they are not transferred to saline water after smolting (Brett, pers. comm. 1982).

A final note to be made concerning salinity is on a study performed by Clark and Blackburn (1977). They showed that the plasma concentration of sodium could be a sensitive index of smolting. They found that a measurement of sodium concentration below 170 mM/l correlated with an ability to grow well in sea water. Salinity has an important influence on growth and will be discussed further in the next subsection on growth.

E Growth

Most of the studies relating to growth have referred mostly to coho and some to chinook. The various government agencies, i.e. Fisheries & Oceans Canada and the Washington Dept. of Fisheries (W.D.F.), have chosen to look at these species because private farms and ranches are interested in raising them. Also, many SEP projects use the net-pen rearing technique for enhancing these particular species.

The study of growth has focused mainly on attaining a maximum growth in the shortest period. Thus, balancing the trade-offs between maximum growth and maximum numbers of juveniles for release or harvest is an issue that has been set aside on the premise that, where enhancement is the goal, larger juveniles released have a better chance for survival. The purpose of the following discussion on growth is to review some of the findings of the researchers which have a bearing on net-pen rearing as an enhancement technique.

Heard and Cone (1976) observed a seasonal shift of coho fry to deeper, high-salinity water in their estuarine pens in Little Port Walter, Alaska. They postulated that juveniles attain greater growth in estuaries for two reasons. One reason is that the temperature is more favourable throughout the year. Another is that the osmoregulatory effect is reduced. They also noted that the low-salinity, surface lens in the estuary which was naturally created by water from Sashin Creek, was sufficient to imprint the smolts to the creek.

Experiments on underyearling coho have shown that varying the temperature, salinity and photoperiod will strongly influence the patterns of growth. Chinook grow faster than coho at higher temperatures but slower than coho at lower temperatures (Kennedy, 1978). Changing the daylight period is necessary for the sychronization of normal growth and development (Clark and Shelborne, 1980). Rearing in 10 - 15% saline water will prevent parr reversion and reduce the toxicity of nitrogenous wastes, but excessive salinity will stunt coho growth (Clark, Shelboun and Brett, 1981). The fastest growth of coho can be attained by rearing in heated water, 11 - 14°C. When the juveniles are to 16 - 20 g. they are transferred to salt water at the peak of the photoperiod (Novotny, 1975). However, at this late date, the small coho will revert to parr or die. Some experiments on growth hormones are being undertaken by the Pacific Environment Institute in West Vancouver.

An unexplainable phenomenon occurs in all pens of coho and chinook. There always seem to be a few fish growing more quickly than the average fish. It is believed that these larger fish eat the smaller ones. For this reason, it is advisable to grade the fish about once every three months.

F Feeding

The type of diet used for rearing salmon is an important consideration. As was previously discussed, vitamin or mineral deficiencies can cause severe problems. Feed is possibly the highest operating cost of the facility since the prepared food is expensive and the food conversion ratio (weight of food/weight of increased size) can be as high as 3.6:1 for coho (Novotny, 1975).

There are many commercial food suppliers. Kennedy (1978) lists eighteen companies which were expected fish-feed producers for 1979. All suitable feed comes in the form of pellets of various sizes appropriate to the size of fish. Until recently Oregon Moist Pellet (OMP) was the most popular commercial feed since there seems to be no trouble teaching the fish to eat it.

OMP is awkward, however, to maintain because it is a moist pellet and therefore has to be kept frozen. Various facilities, (PBS and False Creek), have switched to a dry pellet with no problems.

An alternative fish food used in both Japan and Norway is frozen blocks of marine animals caught by local fishing fleets. For example, in Japan a mixture of anchovy, small horse mackeral and/or sandlance results in a food conversion ratio of 8:1 by weight (Kennedy, 1978). In Norway, frozen blocks of capilin, sprats, shrimp wastes, fish meal, and possibly vitamins are mixed on site with a grinder.

None of the diets used alone is able to provide the carotinoids necessary to produce the reddish flesh colour of wild salmon. Thus, fish farmers will want to incorporate something like carophyll red[1] into the feed pellets to produce a more marketable salmon.

Most large facilities have automatic feeders for the obvious labour-saving advantages. Kennedy (1978) strongly advises that the fish be hand fed at least once per day to check the condition of the fish. Reduced appetite is often the first sign of a disease outbreak. In Norway, computerized feeders are used at some net pen facilities (Shepherd, 1979). With the electric feeders, smaller but more frequent feedings are possible. It has been shown that this type of feeding schedule results in

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1 Carophyll red is a registered trade name of a carotinoid suggested by Kennedy (1978, p.53)

increased growth. Salmon will feed only during daylight hours and when these are longer than working hours, electric feeders are necessary. The Japanese have been experimenting with demand feeders and showing some success.

As the fish get larger, the food conversion ratio also increases. For example, Novotny (1975) found that the ratio for chinook climbed from 1.8:1 to 2.4:1 by weight on an diet of 85% OMP and 15% shrimp waste. For coho, an OMP diet produced food conversion ratios from 1.4:1 to 3.6:1 by weight. The final ratios are for marketable-size fish of one to two pounds.

A technique for teaching young chum to feed is to crowd them into a small area about 1/9 the size of the pen. This method is being applied at the Pallant Creek net pens on chum introduced to the pens just six days after emergence.

Clark and Shelbourne (1980) have looked at the returns of coho whose growths were accelerated by presmolt rearing in heated water. They found that smolting could be induced in seven months rather than the normal 12 to 16 months. They found that the rate of return was lower for the accelerated fish and that the number of 2-year-old adults returning was much higher. They postulated that there may be negative effects of acceleration on adult metabolism and maturation.

G Release

The timing of releases of smolts from the net pens has been examined for several particular cases. The main objective for investigating release times was to find the weight which produced the most efficient adaptation to the sea water by reducing the extent and duration of changes and thus reducing the susceptibility to predation.

Clark and Shelbourne (1980) found that the ideal release time was more restricted for accelerated coho than wild coho. Senn and Hager (1976) concluded from their studies that there was no difference in growth between rearing chum in fresh water or in sea water with an 18% salinity but doing so would increase their survival to maturity over no rearing period at all. They also found that chum not reared before release were larger when they returned.

An interesting experiment involving delayed releases in Puget Sound, Washington, showed that a delay could change the migration pattern (Moring, 1976). There is evidence to show that resident coho were established in the Sound from the late releases. Similar studies have been performed in Georgia Strait but the results are not yet published (Brett, 1982). An attempt was made to establish a local sport fishery in Indian Arm in 1979 but the project was not a success. There is not enough information at present, to establish whether the technique of delayed releases will establish local fisheries anywhere other than Puget Sound.

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V DESCRIPTIONS OF SUCCESSFUL OPERATIONS

There are several on-going facilities located in B.C. coastal waters which have successfully raised juvenile salmon in net pens for release. The author visited sites at PBS, Sechelt and False Creek. A description of the facilities at these sites follows:

Valuable information was obtained on two trips to the Pacific Biological Station in Nanaimo. However, because the operations at PBS are well described by Kennedy (1975, 1978), only a very brief description is included at the end of this section. Unfortunately, the net pens located in Deer Bay, for rearing Pallant Hatchery chum, were not visited. What little is known about their operations is included in the appropriate sections of the rest of the report.

FALSE CREEK NET PEN REARING FACILITY

Background 1978 - 1982

1978 - 1979

In July, 1978, a pen-rearing facility for chinook was established in the False Creek area. In December 1978, this project was contracted to BCIT for site development, operation and management. The college's main objective was to provide a training site for students in mari-culture techniques associated with ocean ranching. The project also serves several other purposes; i.e.

(1) to see if salmon could be successfully reared in False Creek

(2) to carry out experimental research on fish rearing and fish biology

(3) to provide fish for a children's fishery in the spring

In 1978 approximately 5,000 chinook were obtained from the Capilano Hatchery and raised in 10 pens (4' x 5' x 6' and 5' x 6' x 10') located next to the "Granville Dolphins" under the northeast end of the Granville Street Bridge. Prior to this move, a detailed survey was not carried out, but during this year and subsequent years, relevant data was collected.

The fish were fed on OMP according to the OMP charts. They were treated with terramycin, and malachite green. (Vaccinations against vibrio were given at the hatchery before the transfer.) By March 7, 1979, the total number of mortalities was 446. One thousand of the juveniles were coded-wire tagged and the remaining fish were to be tagged before their planned released in

July, 1979. Unfortunately the water temperature rose quickly to 17°C in June and to 18°C in July. Because of this factor coupled with seasonal low tides[1] and low salinities (13-14 ppt), the fish were highly stressed and mortalities were high. There was no children's fishery in 1979 and the 1319 chinook were released for test fishery purposes. Two tagged precocious males returned to the Capilano Hatchery in the fall of 1980.

1979-1980

In September 1979, 9,600 juvenile chinook from the Capilano hatchery were transferred to the False Creek net pens following vibrio vaccination and coded-wire tagging. They were put in a new pen with 6 - 10' x 10' x 10' nets. The old pens were used for the overflow when densities reached .75 lb/ft^3, (about 9 kg/m^3).

Bio-assays which were performed regularly in the previous years were only done when the general condition of the fish was abnormal. Up to Feb. 29, 1980, the major cause of mortalities, (79% of 533 dead) was predation by American grebes and Brandts cormorants. By June 30, the number of mortalities had climbed to 1955. Again, warmer water temperatures induced stress and Bacterial Kidney disease. From this, it was decided to hold next year's children fishery in May to avoid these high temperatures and resulting high mortalities.

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1 The pens were located in shallow water and at very low tides, the water depth in each pen was halved, thus doubling the density.

The children's fishery was held on two weekends, May 31, and July 1, 1980. The pens were towed to Alder Bay where a net blocked the entrance and approximately 7,000 chinook were released in two batches. When the fishery ended, the net blocking the entrance was removed and the remaining chinook were allowed to escape.

1980-1981

In September 1980, 15,308 juvenile chinook were transferred to False Creek from the Capilano Hatchery following vibrio vaccination and coded-wire tagging. The pens had been moved to a new site in False Creek, by the northeast corner of Granville Island which offered land access and deeper water. The minimum depth at the new location was ten feet. A new float was added which held 6 - 10' x 10'x 10' pens and had much wider walk areas and more flotation. The new structure was intended to accomodate a class size of 20 and/or the interested public.

During the winter, mortalities remained at 20% due to tailrot and the zinc-and-calcium deficient OMP feed.

Approximately 6000 chinook were released for the children's fishery held on two weekends at the end of May and beginning of June, 1981.

1981-1982

In the fall of 1981, approximately 16,000 chinook smolts from the Capilano Hatchery were taken for the project.

In 1981, dogfish appeared for the first time causing about 8,000 salmon to be lost through holes in the net.

Present Operations

BCIT is now responsible only for maintaining the pen facilities and rearing the fish while SEP manages the children's fishery. Approximately one-third of the salmon reared are caught in the fishery and the rest are released. So far, only four adults have returned to the Capilano Hatchery and none to False Creek. One or two have been caught by fishermen in the Juan de Fuca Strait.

Location and Design

One of the reasons the project was chosen was to see if fish could live in False Creek. No survey was undertaken, although it was believed that the area has become cleaner in recent years. The project has shown that the fish can be raised quite successfully in this area even though oil stains on the water surface are noticeable. These oil stains are imperfectly visible in Plate 1. With a proper survey, the water temperature problems would have been detected, and the fish would have been released sooner in the first two years. By keeping the fish only until May, difficulties due to high-temperature stress have apparently been overcome.

The newest float is made from treated yellow cedar. The surface is deck-coated. The means of floatation are about 30 styrofoam-filled, 45-gallon, plastic drums which are strapped on with metal strips.

The surrounding houseboats and the wharf serve as a breakwaters. The floats are secured to a large barge. Plate 2 shows the entire facility. The pens in the background are the newest.

BCIT has been given permission from Canada Mortgage and Housing to use the present mooring without paying any rental fees.

The newest float holds four pens in a row with about five feet between them. These pens are covered with locked wood panels to slow down growth of algae and keep out vandals. Plate 3 shows a close-up of a pen with one panel removed for feeding. By covering them, the nets only have to be changed twice a year. BCIT also keeps its two older floats for holding overflows as the size of the fish increases and for the students' experimental sample pools. The pens are shown in Plate 4. These older pens have smaller mesh nets 3/8 inch mesh and so hold the newly arrived smolts from the hatchery. After 4 to 5 weeks the fish are divided into the 4 new pens with 5/8 inch mesh nylon nets.

Each net is weighted down by 8, 15-lb, sand-filled, polystyrene jugs. Plate 5 shows three such jugs beside a pen. A guard net surrounds the whole float. Originally, this net was 10 feet deep but did not adequately keep the predators such as the diving birds away. Now this net is 20 feet deep and lead-lined. At high tide, maximum depth is about 20 feet.

Environment

The False Creek facilities have such predators as dogfish, cormorants, grebes, loons and merganzers. With the new guard net, these animals are no longer a problem.

The tidal fluctuations in False Creek are smaller than would be found elsewhere but appear to provide adequate flushing of excrement and food, so there is no excess growth under the pens. Algae growth on the nets is slower than that at other sites examined. For example, the nets that are uncovered are changed once every five-to-six weeks and the covered nets are changed twice per year. The sea water does not flush well into the bay, so with the run-off from the surrounding city the salinity remains low, at an average of 14 ppt. There is no freshwater lens. Selected environmental data are shown in Appendix C.

The aquatic animal life is noticeably improving in False Creek. Juvenile chum and coho, herring and anchovy schools, crabs and dog fish have been seen in the bay lately.

Fish Rearing

In November, 1982, the net pens held the following:

(1) 3,000 coho from the Seymour River Hatchery in one pen

(2) 16,500 chinook from the Capilano Hatchery split into two pens.

(3) an unspecified number of cutthroat from the Abbotsford Trout Hatchery

The coho were transferred to False Creek because there was no room to raise them at the hatchery and because the people involved in the project want to see how well coho grow in the area. They were not transplanted until late October, so for this reason and other bioligical differences, they are not expected to grow as large as the chinook. The chinook size at the time of release ranges between 100 g. to 300 g with an average near 160 g.

The staff ensures that the density in any pen remains less than 10 kg/m^2. In May, each pen will hold about 2,000 chinook. Until November, 1982, the fish feed used was the Oregon Moist Pellet (OMP) and the feeding schedule followed the OMP charts plus .2%. Then a switch was made to Western Farmer Dry Feed which seems to work as well as the OMP and keeps without freezing. Two weeks before the fishery, the chinook are cut off their regular diet and fed shrimp, and krill. For the last few days before the fishery, the fish are starved.

The pens are cared for by staff from the Seymour River Hatchery, which is also contracted to BCIT. Students in the Fish and Wildlife Program work weekends at the pens, feeding the fish and collecting data. Each day someone feeds the fish and checks for problems due to stress or predation. Fish samples are sent to the Pacific Biological Station only when there are signs of poor health. A sample is also sent about three weeks before the fishery to check for polychlorinated biphenyls, heavy metals etc. The limits have never been exceeded. (See Appendix C for some data obtained from the heavy metal water analysis.)

BCIT has to go through the transplant committee to receive its fish and has never encountered any problems. There is no evidence yet that imprinting occurs at False Creek since no adults have returned to the area.

In the future, BCIT hopes to continue its operations on about the same level, although they are contemplating a steelhead rearing program. If chinook smolts become difficult to get, the project may switch to coho juveniles supplied by the Seymour River Hatchery.

The author would like to thank David Veysey for taking the time to discuss the False Creek project and for a tour of the facility.

PHOTOGRAPHS TAKEN AT FALSE CREEK PROJECT

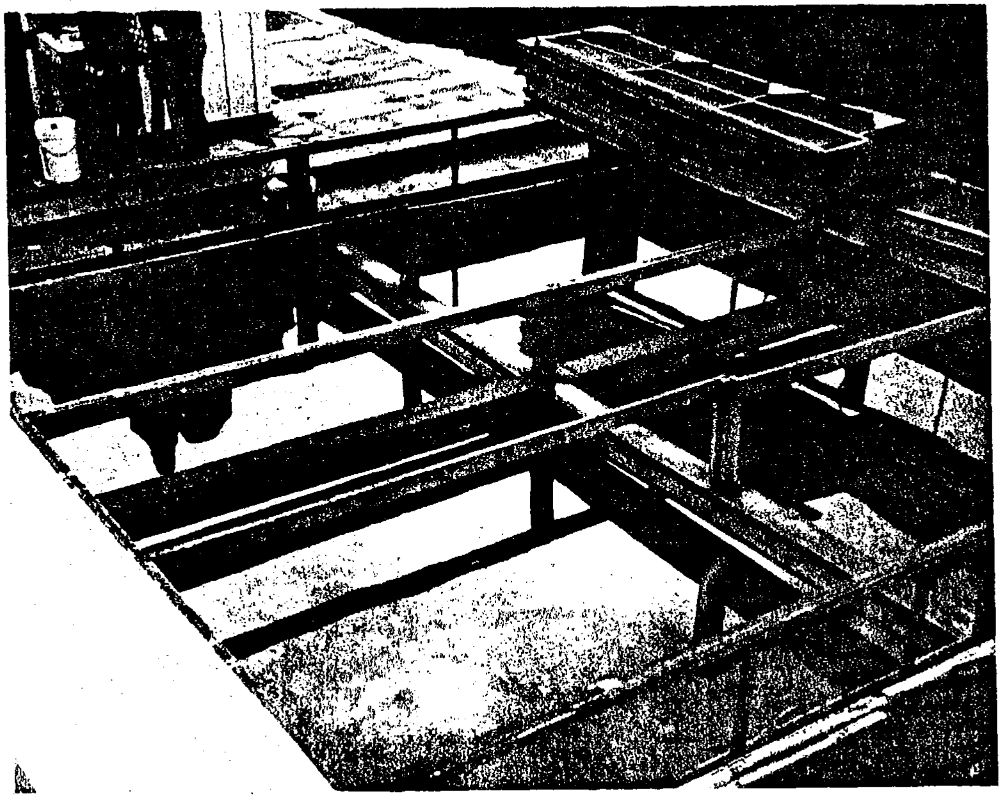

Plate 1 Oil stains on the water surface at the net pen facility in False Creek.

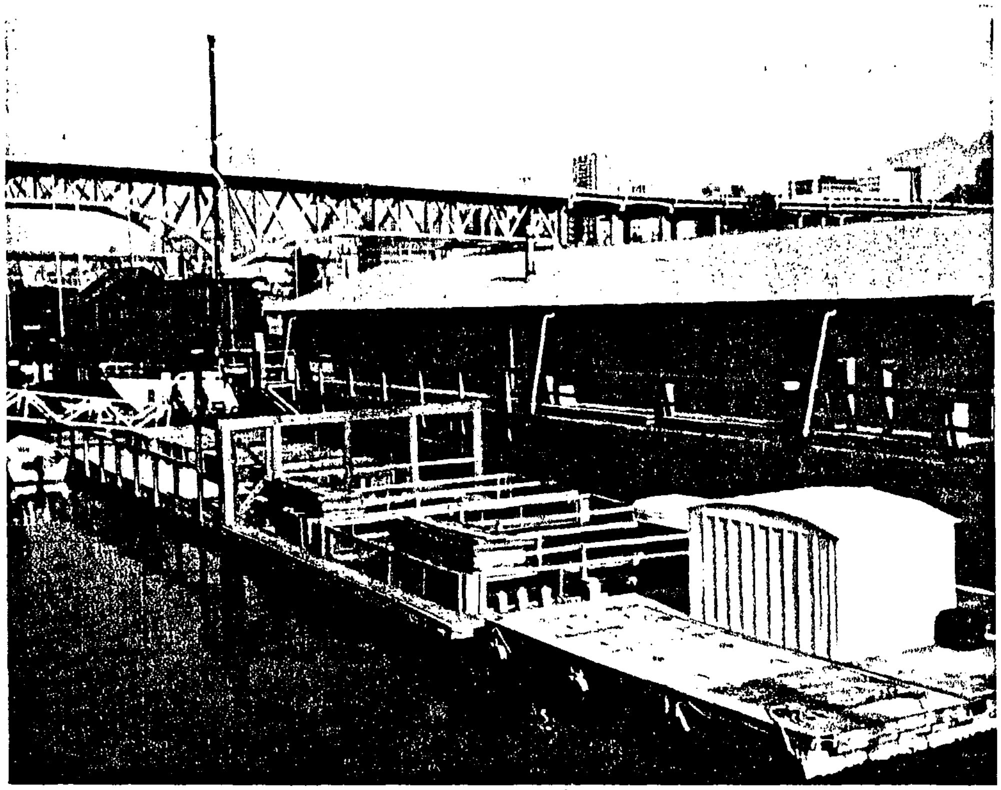

Plate 2 The BCIT net pens are shown tied up to the barge.

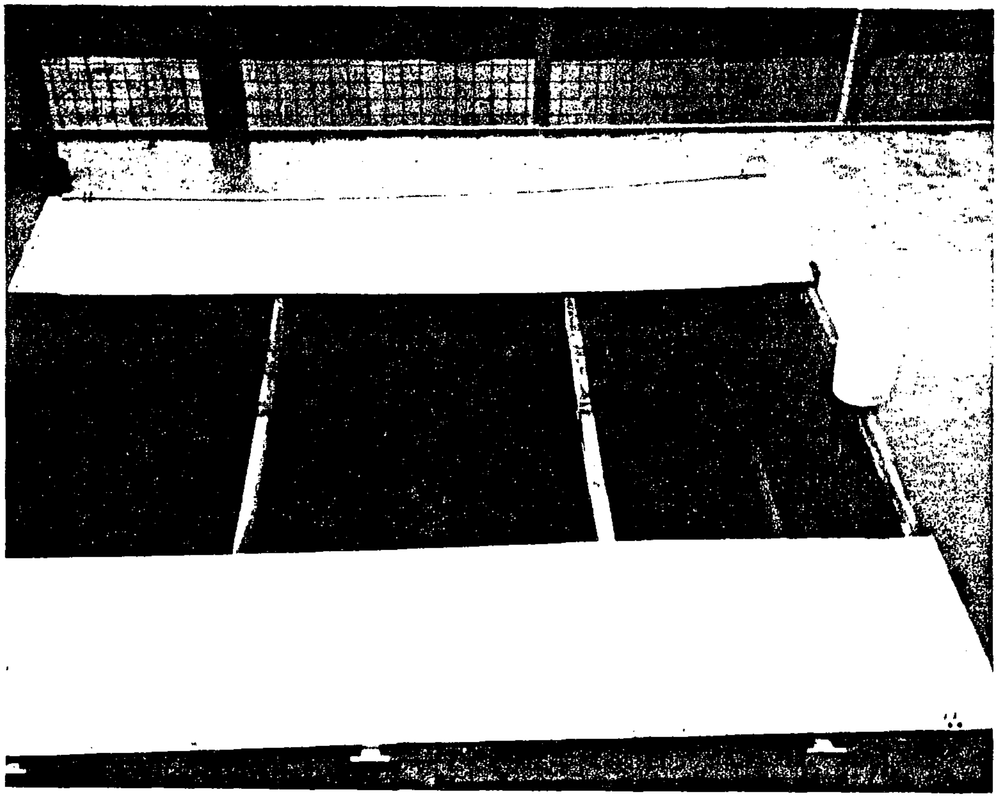

Plate 3 The newer pens at BCIT are covered with wooden panels which can be locked up.

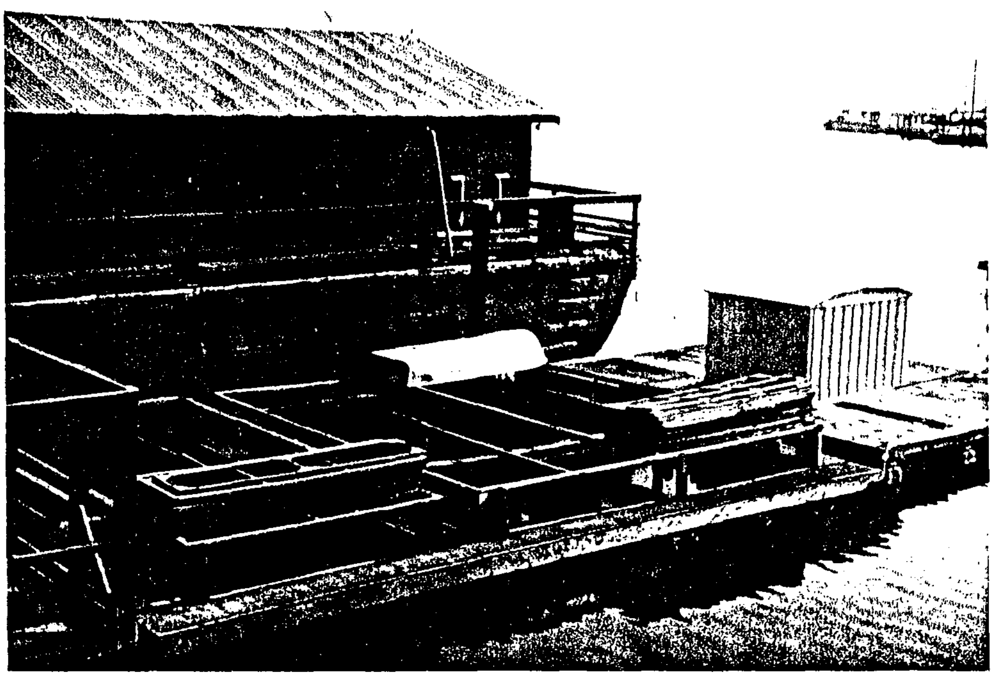

Plate 4 The two older pens are covered with screens in wooden frames. There is no public access to this area. The larger pen is separated further for isolating experimental groups of fish.

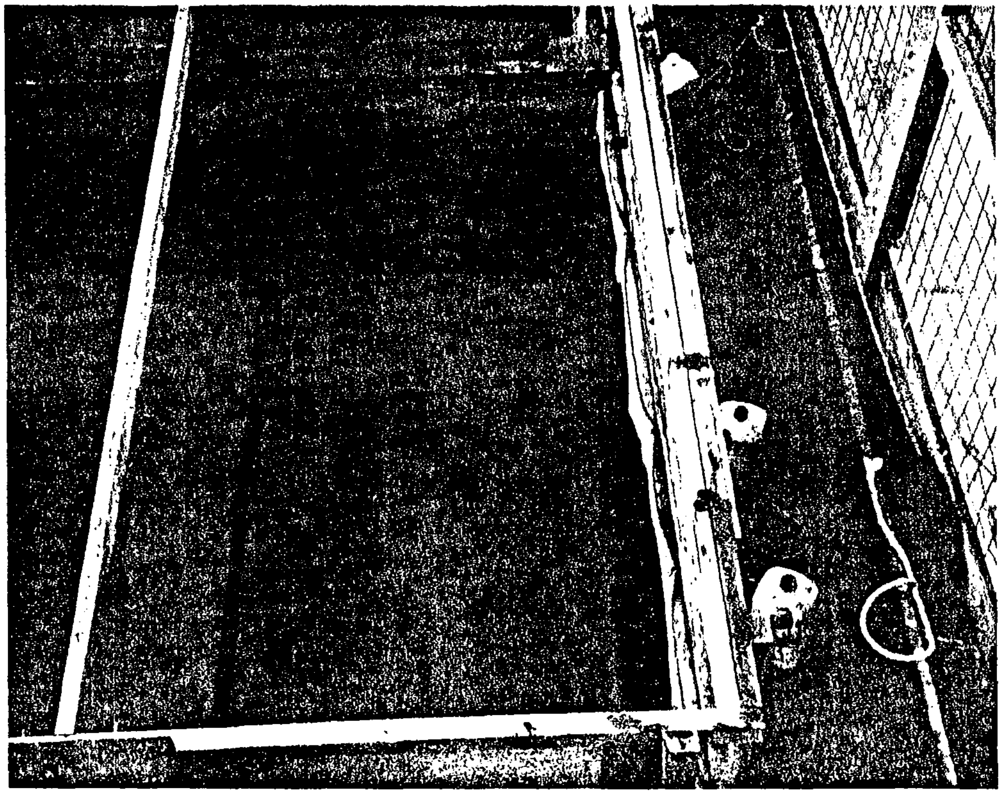

Plate 5 A closer view of a net pen on the surface.

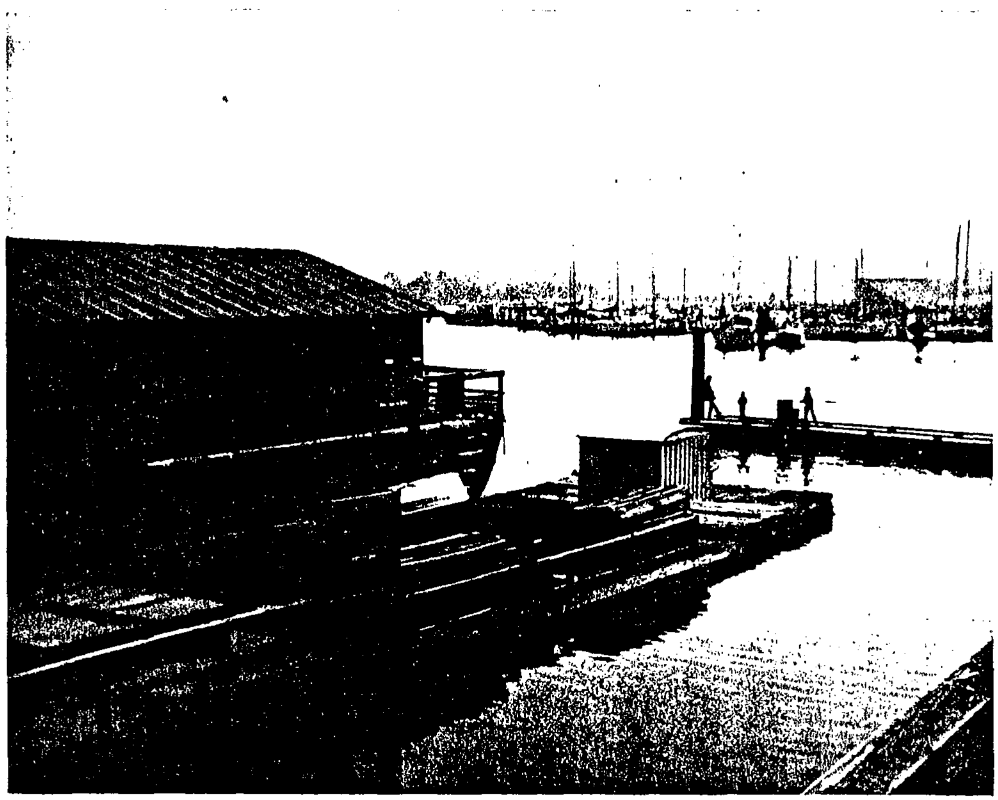

Plate 6 A view of the BCIT Net Pen Facility located in False Creek.

SECHELT INDIAN BAND NET PEN REARING FACILITIES

Background 1979 - 1982

1979 - 1980

Net-pen rearing facilities were introduced to Porpoise Bay, near Sechelt, in July, 1979. Operation of the facility was contracted to the Sechelt Indian Band by the Community Economic Development Program of SEP. The main purpose of the project was to enhance the local sport fishery. Future plans included the enhancement of nearby streams that show depreciating fish stocks.

In the first few months, six 10' x 10' pens were constructed to accommodate four nets of 3/8" mesh 10' deep. In November and December, a total of 20,000 coho smolts, 1978 brood, were transferred from the Capilano Hatchery to Porpoise Bay. A freshwater lens was placed directly into each pen via a 2,000 foot plastic hose with a two-inch inside diameter, connected to the Pacific Rim Aggregates gravel pit water line system. This system is gravity fed from a dam situated 3,000 feet up the Angus Creek watershed. Approximately 75 pounds per square inch pressure was utilized to maintain the lens until May. At that time, most of the smolts had indicated that they had adapted to the salt water by moving to the lower half of the pens.

Fish samples were sent periodically to the Pacific Biological Station to test for signs of disease. There were no indications of disease problems.

In the latter part of June and early July, 1980, 19,996 coho were coded wire tagged with the code "02-16-09" and released. In 1980 the estimated (expanded) Canadian recoveries were 7.9 in the sport catch. In 1981, the estimated (expanded) Canadian recoveries were 873 in the sport catch and 196.9 in the commercial catch. (Recovery information from a report prepared by L. Lapi, P.B.S., 1983)

1980 - 1981

In the summer of 1980, two additional 15' x 15' pens were constructed with 3/4" mesh net to hold the additional fish planned for rearing in the following year. In September, 1980, 21,139 coho from the 1979 brood year were transferred from the Capilano Hatchery to Porpoise Bay. Due to problems of predation, only 11,500 were coded wire tagged and released in June, 1981 (tag code 02-17-10). In February, 1981, an unspecified number of coho from the 1979 brood year were transferred from the Capilano Hatchery to the net-pen facility. There were 20,904 coho released in June, 1981, all of which had been coded wire tagged "02-18-14" at the Capilano Hatchery before their transfer to Sechelt.

1981 - 1982

In March, 1981, an unspecified number of 1980 brood year coho were tranferred to the Sechelt facility. Following the transfer, 18,429 were successfully coded wire tagged "02-21-11". In June, 1982, 10,400 coho were released. It is believed that warm water temperatures over the summer were responsible for a relatively low survival rate.

In September, 1981, 21,187 chinook from 1980 brood year were tagged "02-21-10" in Capilano Hatchery and transferred to Sechelt. A total of 9,604 were released in June 1982.

The Sechelt Band also captured 95 broodstock adult coho from the Sechelt area using a purse seiner, beach seining and dipnetting at local streams. The captures took place between October 23 and November 25, 1981. They experienced difficulty capturing females and only 12 adult females were used in the egg take. In all, 11,500 eggs were fertilized, incubated and picked at the Walters Brook incubation site. In March and April, 1982, 7,913 fry were transferred to a rearing trough also located by Walters Brook. Plate 7 shows the temporary rearing facilities that have been set up. The juveniles as of July, 1982 are shown in Plate 8.

Present Operations

The Sechelt Project is gradually expanding its operations. The long term objectives, as stated in March, 1982 are:

(i) to expand production capacity to 50,000 coho and 50,000 indigenous chum

(ii) to expand to other sites in the Sechelt area north of Porpoise Bay, e.g. head of Jervis Inlet.

The Band would like to see their project producing local employment opportunities and enhancing local stocks for sport and commercial catch. They are presently preparing a permanent incubation and rearing site on a piece of land near the pens. Also, they are constructing their own water-intake system on a nearby groundwater-fed creek to replace Pacific Rim Aggregates water system (Plate 9).

Location and Design

As stated previously, the pens are located in Porpoise Bay, approximately 100 feet from the shore in water 90 feet deep. Access to the pens is by a boat presently kept at a wharf belonging to the Pacific Rim Aggregates. Plate 10 is a view of the pens from a distance. On the other side of the bay, the Pacific Rim Aggregates property can be seen.

There are two rows of four 10' x 10' x 10' nets and one 15' x 15' x 10' net at the float. There are cedar decks surrounding all four sides. Near the center, a small shed was erected to store food, nets, etc. (Plate 11). Topper floats were purchased to support the pen structure. The bay is well sheltered and there has been no need for a boom to provide protection from waves. The float is held in place with two anchors at either end.

The project has recently switched from green netting to the more pliable white netting used by most facilities (Plate 12). The nets are weighted by sand-filled polyethylene jugs. The two large pens are surrounded on the inside with a tarpaulin reaching down about five feet. A hose extending from the land sends fresh water into the two pens. When the smolts no longer show a preference for the fresh water, the tarpaulin is removed. Plate 13 shows the water flowing into the pen although the tarpaulin is not visible.

Environment

The major predators at Sechelt have been otters and dogfish. Originally, a guard net surrounded the outer perimeter of the float but when expansion took place in 1980, the staff experienced problems and gave up on the predator net. The general feeling was that in 90 feet of water, dogfish who live close to the sea bottom would rarely bother the nets and otter predation could be prevented by trapping. Vandalism has also occurred in the past, causing losses of 5000 fry in 1981. Appendix D contains some environmental data collected over several years. A final note concerning the environment relates to the time of release. In 1982, there were some reports that an unknown number of net pen released fish were being caught by local herring fisherman. If these reports are true, herring fishing defeats the purpose of raising fish in net pens and some checks should be made with perhaps an alteration of the release time.

Fish Rearing

All fish are vaccinated for Vibrio at the Capilano Hatchery. When coho fry are transferred from the hatchery, they are placed in the nets with the freshwater lens. Chinook, however, are transferred directly to sea water and two or three times during the year, are graded to prevent cannibalism. Each time the fish are graded the numbers per pen is reduced as well. The fish are fed OMP according to a schedule set out in the contract. The project employs three people full-time, with a temporary crew being added during busier periods such as brood stock collections.

Both species were released at the same time in June of 1980 and 1981. The numbers released are estimated using water displacement by weight divided by average weight. Average weights at the time of release are provided in Table V-1.

TABLE V-1

Average Weights

Year of Release	Coho	Chinook
1980	27 g	-
1981	34 g	168 g
1982	40 g	146 g

Bob Baptiste and his staff were very helpful in explaining the various aspects of net pen rearing and showing the author around the Sechelt facility.

PHOTOGRAPHS TAKEN AT SECHELT PROJECT

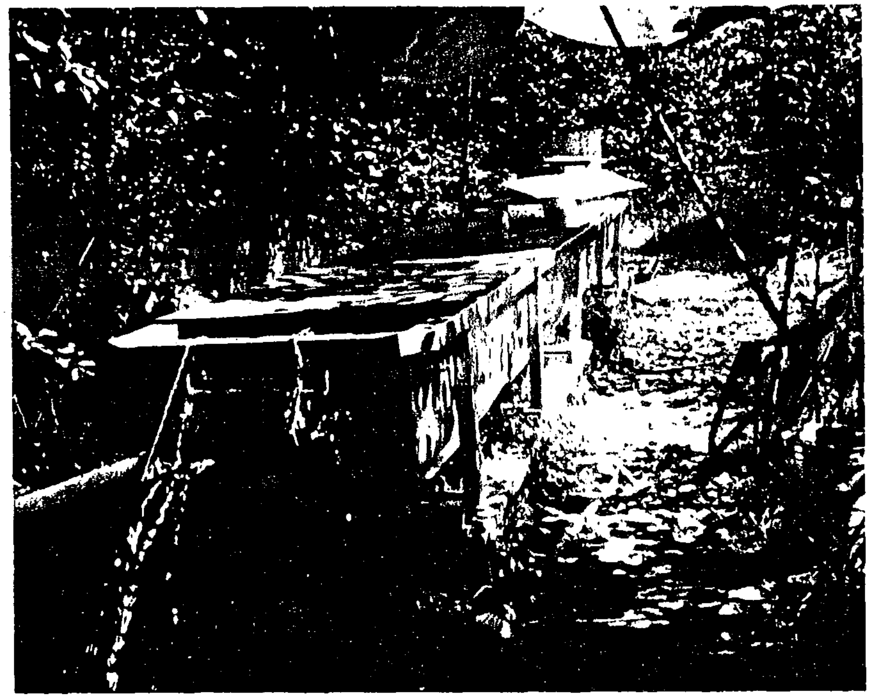

Plate 7 A rearing trough for coho located on Pacific Rim Aggregate property near the net pen facility.

Plate 8 Juvenile coho from the 1981 brood stock captured in the Sechelt area. The photographs were taken in July, 1982.

Plate 9 A new water intake system on Angus Creek under construction.

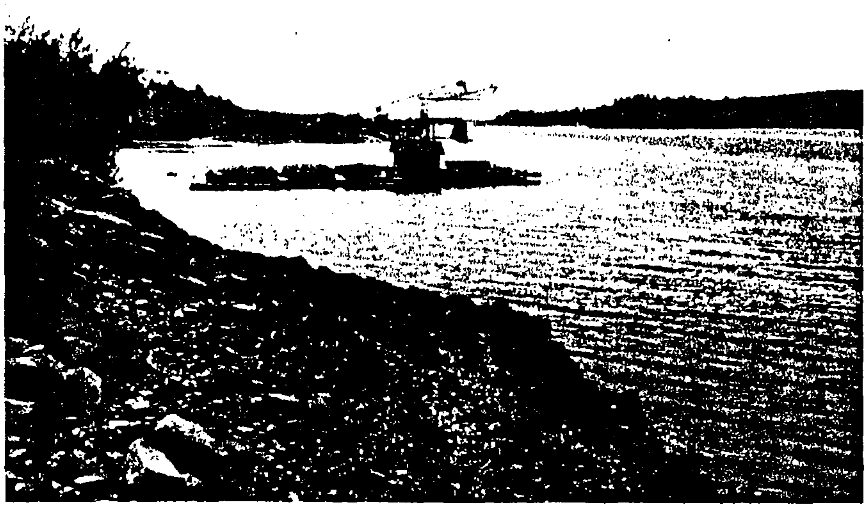

Plate 10 A view of the Sechelt Net Pen Facility.

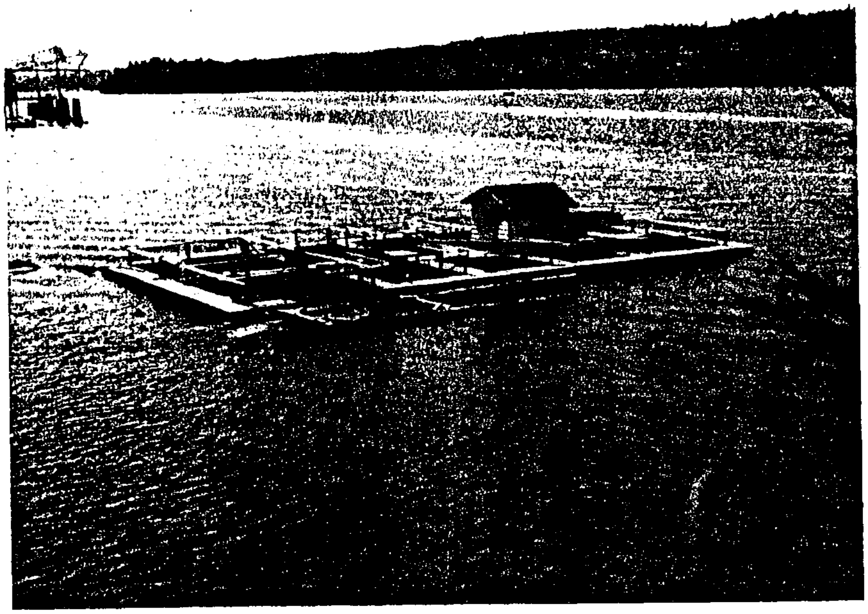

Plate 11 A closer look at the floats showing the configuration of the ten pens.

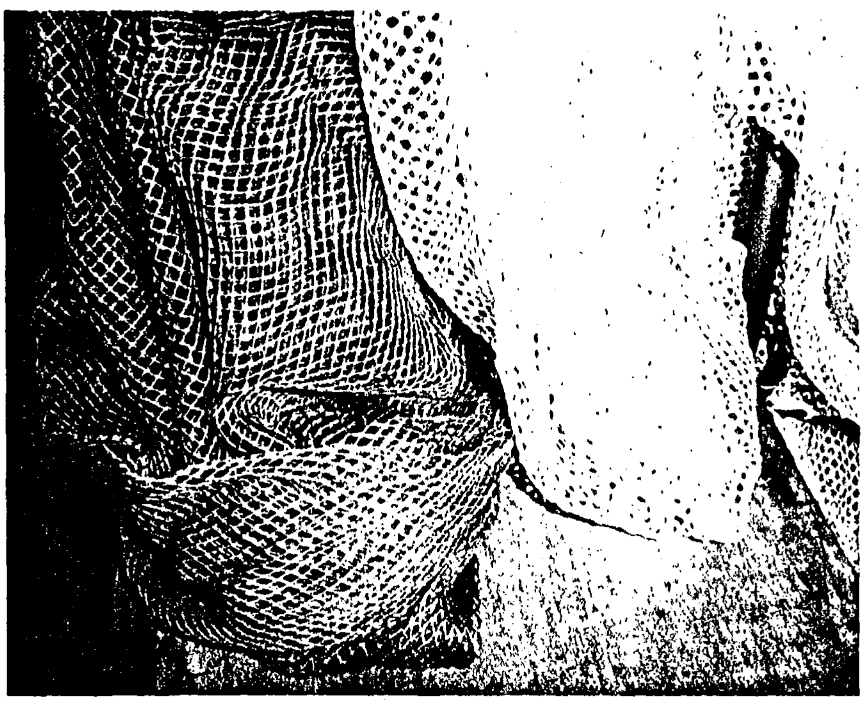

Plate 12 The facility has replaced the green nets with the more pliable white knotless nylon nets.

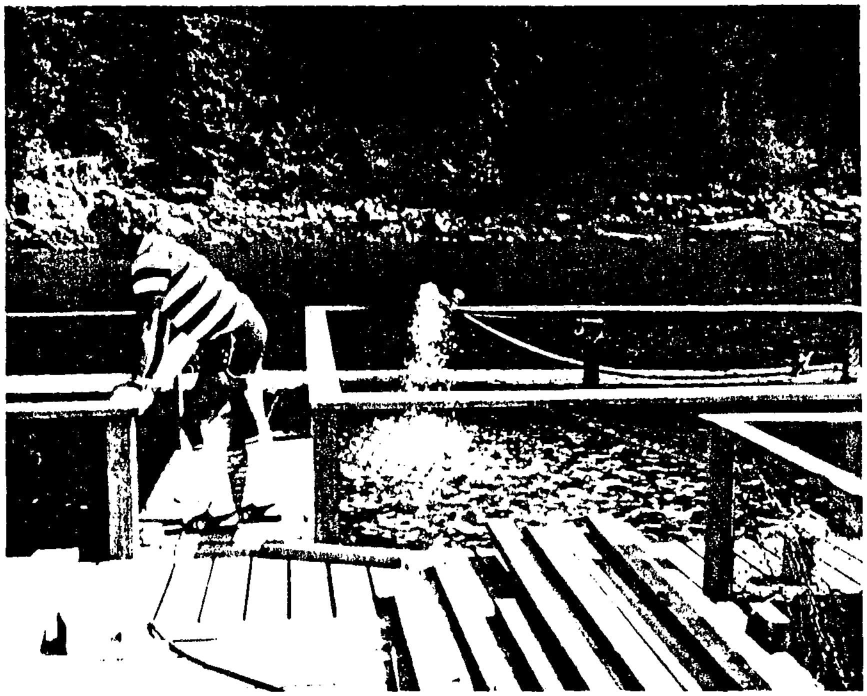

Plate 13 Fresh water from the shore is pumped to the pen through a long hose.

PBS EXPERIMENTAL FISH FARM

The net-pen facility in Departure Bay, Nanaimo, has been in operation since 1972. Its purpose was to provide the appropriate environment for PBS scientists to improve the tools and information required by commercial farmers in particular and users of net pens in general. In the first years, the research conducted had an emphasis on learning how to successfully rear coho and other species to market size in net pens. More recently, scientists are examining salmon brood stocks for a commercial farm setting. In the spring of 1982, the facilities also held prespawned herring to see whether the herring could survive in high density and restricted enclosures. Brett and Solmie (1982) discuss the details of the operation. Some illustrative photographs which may be of interest to the reader follow (Plates 14-23).

There have been several experimental releases (usually coho) by the Pacific Biological Station personnel at the Rosewall Hatchery in an attempt to establish a local fishery in the Georgia Strait similar to the one in Puget Sound. Dr. Brett will be presenting a paper on the results of this experiment in the summer of 1983 (R. Brett, pers. comm. 1982).

The staff at PBS were very helpful in providing useful information for this report. In particular, the author is grateful to A. Solmie and R. Brett for their assistance.

PHOTOGRAPHS TAKEN AT THE PACIFIC BIOLOGICAL STATION, NANAIMO, B.C.

Plate 14 The experimental farm located in Departure Bay, Nanaimo. The two large sheds in the foreground contain net pens also. The back shed is for storage of food and a protected work area.

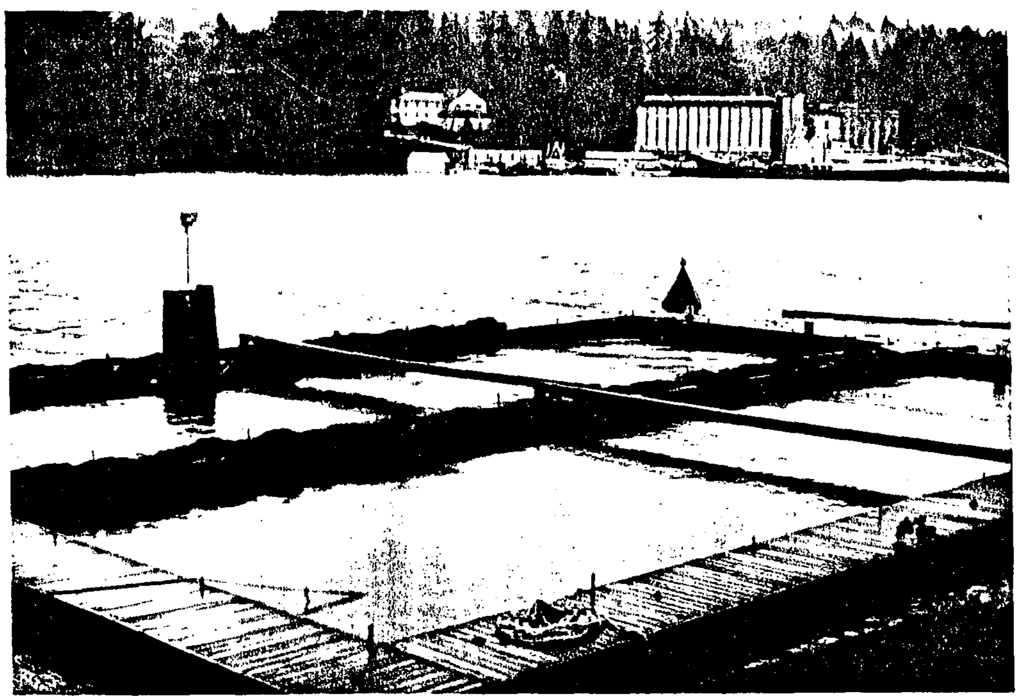

Plate 15 These two large pens were built for the herring containment project which began in the spring of 1982. The Pacific Biological Station can be seen in the background.

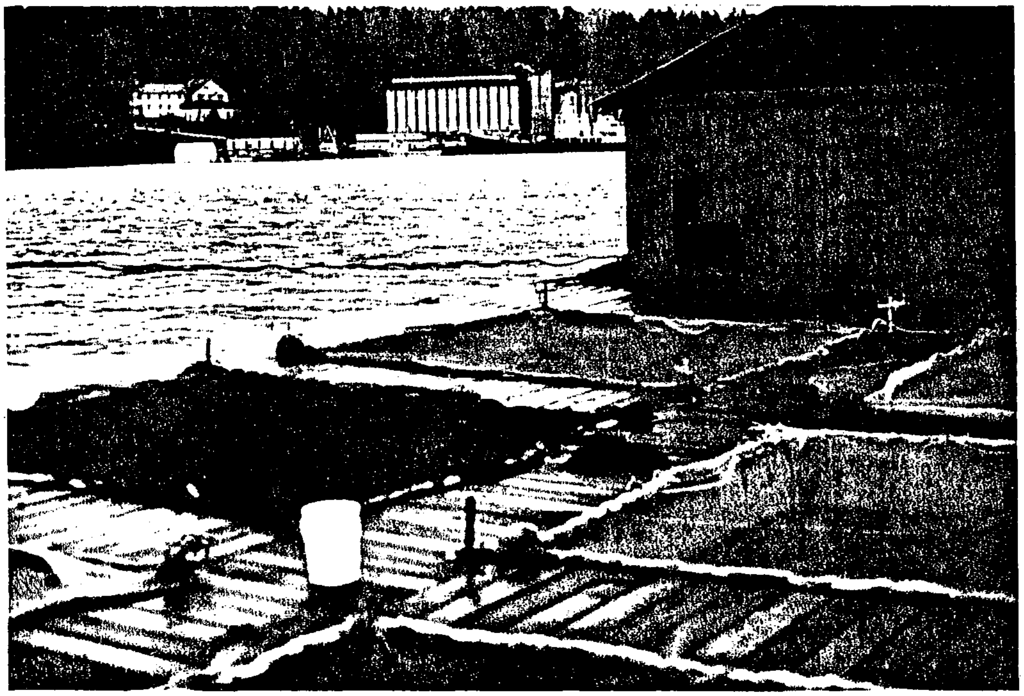

Plate 16 These small pens are located between the storage shed and the buildings containing more net pens. Each pen has a tightly laced cover. The tops of the pens are raised at least one foot above the water level.

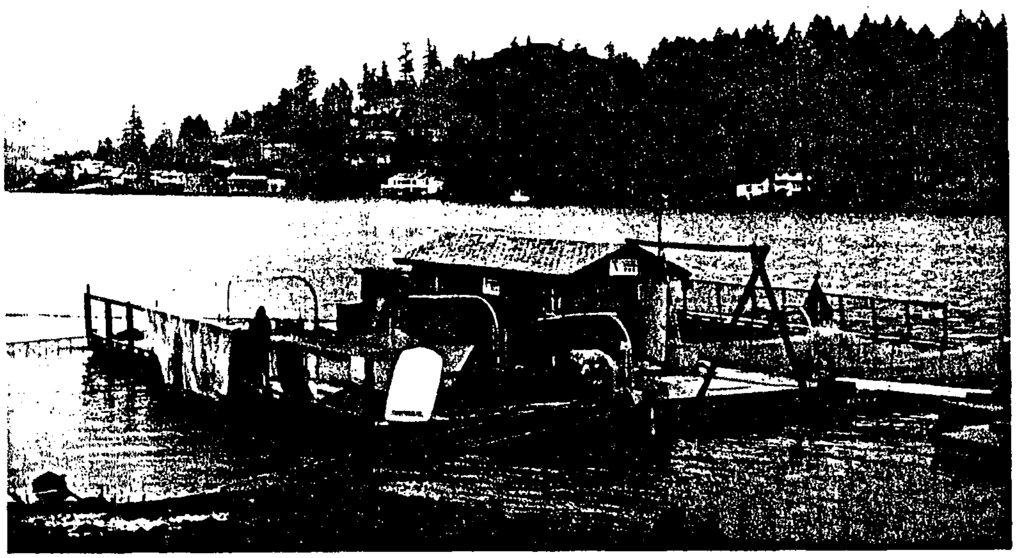

Plate 17 There are more net pens on either side of the storage shed. The stiff-leg which keeps the float in position off a small island can be seen.

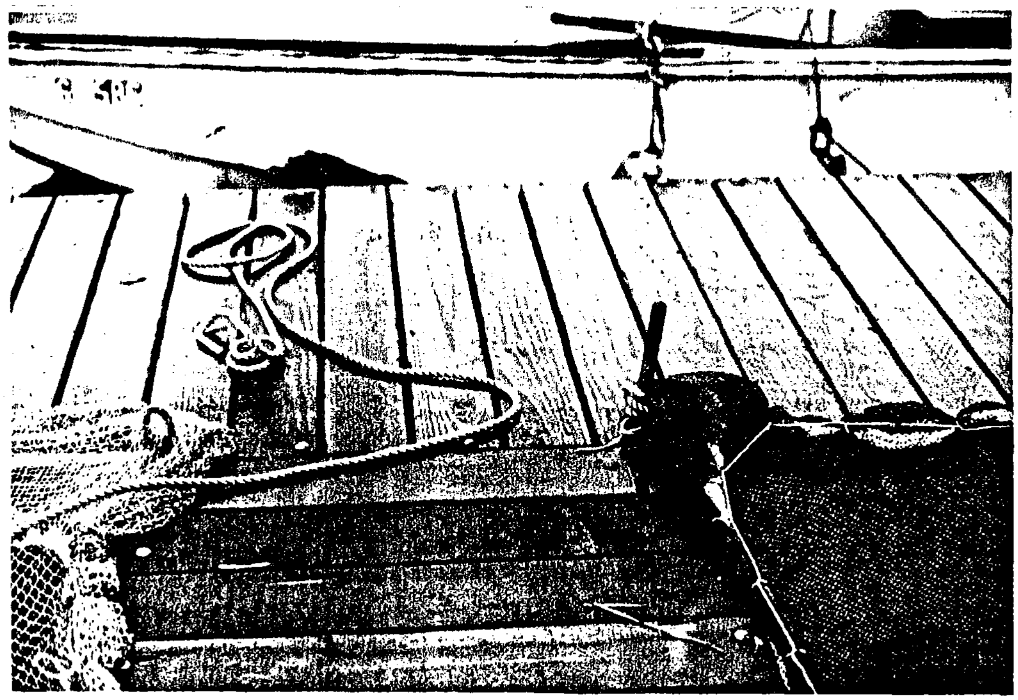

Plate 18 A closer look at how the net pens are tied.

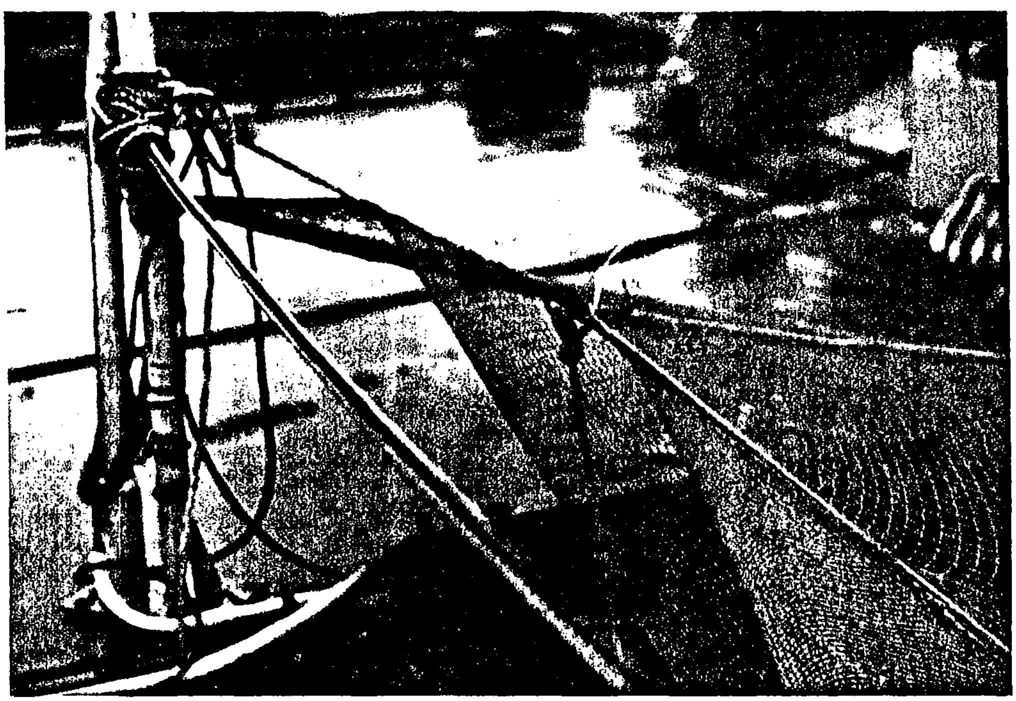

Plate 19 A different method of rigging the nets.

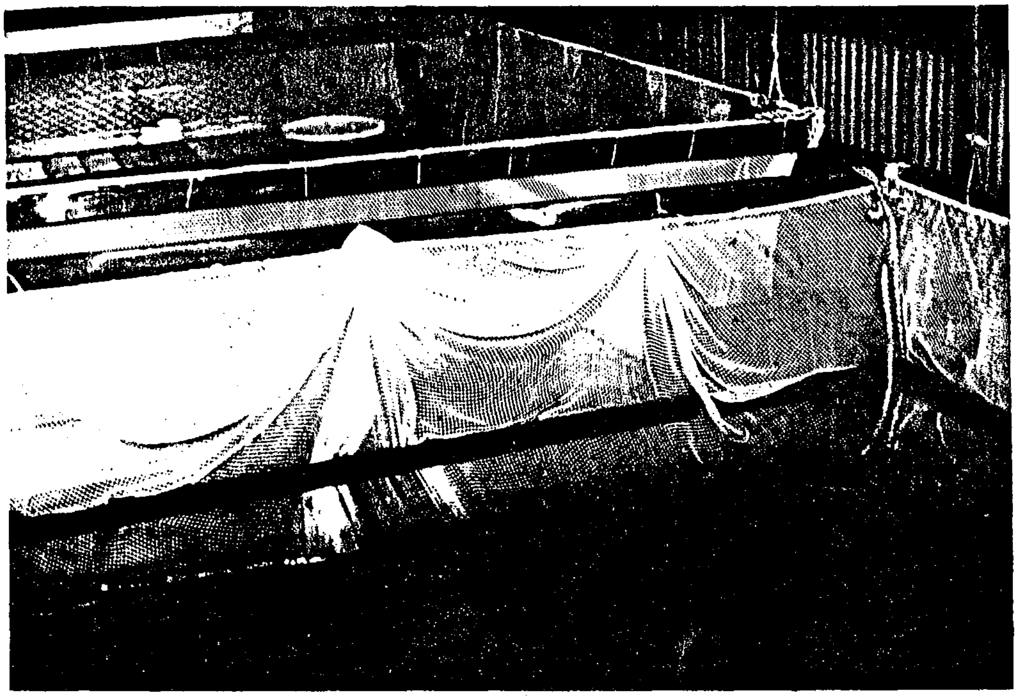

Plate 20 The pens inside the large buildings usually contain the larger and unique or experimental stocks. The net in the foreground is an example of a poorly made net.

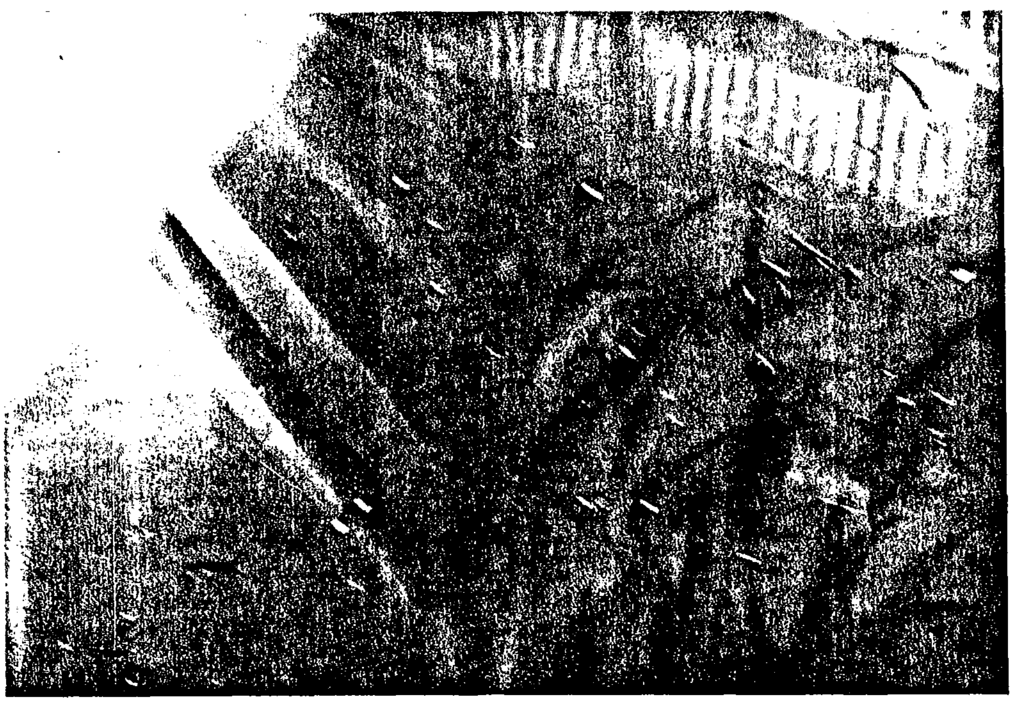

Plate 21 The same poorly-made net under water. Al Solmie stressed that keeping the nets taut is a major factor in preventing predation from dogfish.

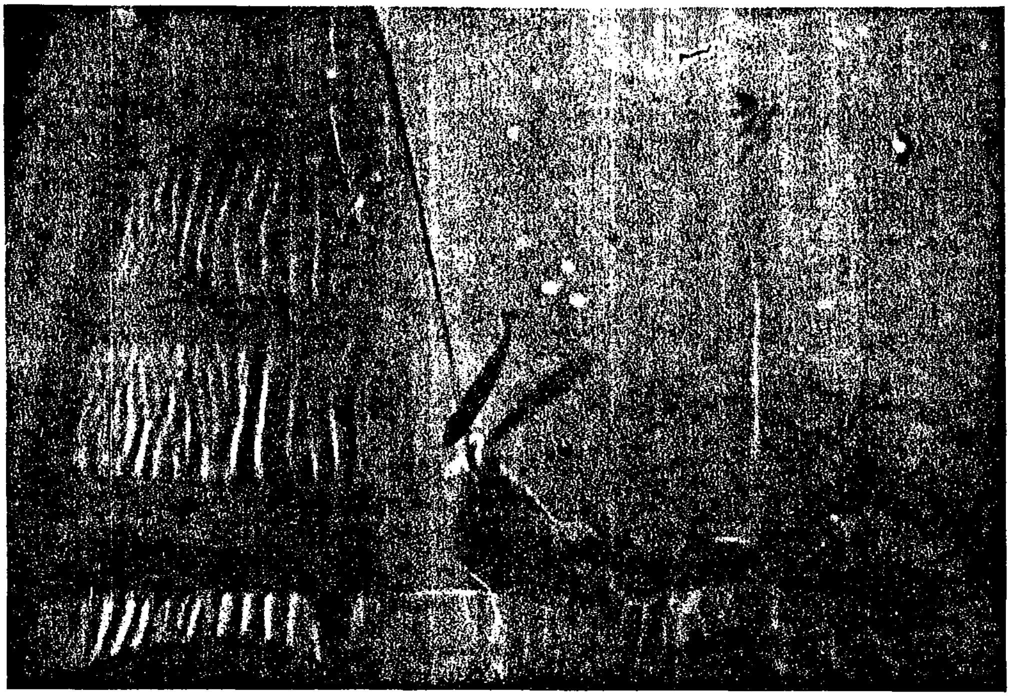

Plate 22 By looking closely, a line with a heavy weight on the end can be seen in a corner of the net, helping it keep its shape.

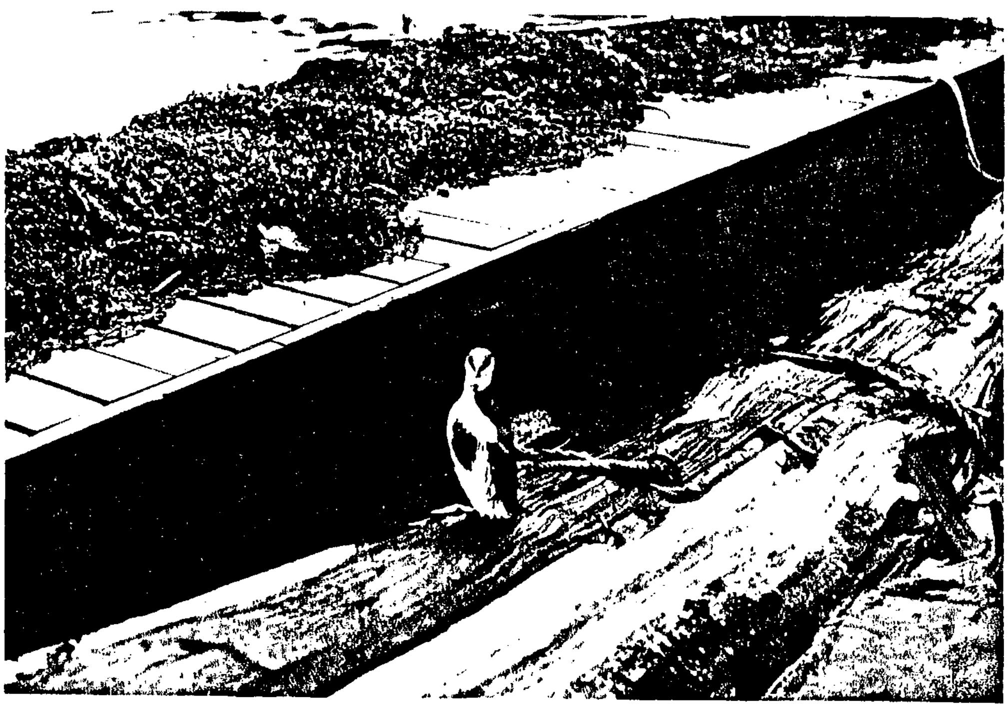

Plate 23 A bird who found a safe spot to try and remove the oil from its front feathers.

VI AN EVALUATION METHODOLOGY

One objective of this report is to produce a list of considerations for evaluating a net-pen-rearing opportunity. This methodology applies strictly to the enhancement facility where juveniles will be released after a certain length of time in the pens. The points raised are mainly for the ocean facilities but in most cases will apply to freshwater facilities as well. The evaluation is divided into three steps:

1) examine the objectives of the proposed project;
2) perform a preliminary site assessment;
3) prepare a detailed plan.

The evaluation proceeds through each step only if the conditions of the preceding step are satisfied. It is strongly recommended that the first year of implementation be, in fact, a pilot study, and may even be concurrent with the detailed site survey. Al Solmie, from PBS, observed that the greatest difficulties in net-pen rearing arise from inexperience and so it is best to start with a few thousand (less than 10,000) fish in a new area unless the project is managed by experienced personnel. The trade-offs between costs of training staff and employing experienced staff, setting up a pilot study and performing a site survey in the absence of a pilot project, should be recognized.

1) The Objectives

Examining the objectives entails reviewing D.F.O. policies and in particular the Five Account Methodology used by SEP, and the transplant policy.

- Does the project address a real problem?
- Is the species to be enhanced appropriate for the area?
- Is there a source of juveniles? If eggs are to be taken from a local stream, is there a sufficient resident population? If not, what are the proposed alternatives?
- How is the project going to be funded and what is the budget? Is it adequate for the proposed size of the stated objectives? (Unfortunately, costs of net-pen rearing have not been included in this report. Technical staff involved in present net pen operations would probably be able to supply estimates. The Department of Fish and Wildlife offer information to fish farmers in B.C. which also may be useful.)
- What are the possible side effects, i.e. straying and interference with the rest of the fishery?
- How are the returns going to be harvested?

2) Preliminary Site Assessment

- Is the physical environment suitable with respect to temperature, salinity, winds, competing users, water quality etc?

- Is a fresh water lens necessary and, if so, is there a natural lens or is there a nearby stream of good water quality to provide one? Conversely is a fresh water lens present that is not necessary?

- The necessary information can be gathered from talks with locals and fishermen, marine charts etc.

3) A Detailed Plan

If the answers to the above questions indicate that a net-pen facility is feasible, then more detailed plans can be drawn up. These should include:

- a detailed site survey
- exact location of pens
- float construction
- staff
- timing of transfer and release
- cost analysis including maintaining the facility, fish food etc.

A time schedule for the preparation, implementation and possible expansion could be outlined. Also, certain goals can be set so that if the project does not reach these goals, the project can be abandoned.

It is during this stage, that the information and details may be accumulated from a pilot project, given that the department is willing to spend the money. After the pilot study, some re-evaluation of steps (1) and (2) would need to be made.

It probably does not need to be said that good planning increases chances for success but the reader might question why it is included in the evaluation methodology. Certainly, at this stage, there should be no major obstacles and smaller problems are worked out; but even at this level of detail, the project evaluation may come across problems which render the opportunity infeasible. For example, a Community Education and Development Project proposed somewhere on Vancouver Island was to be maintained primarily with volunteers. Unfortunately the site is located two hours away by boat and because volunteers could not be expected to make the trip everyday, the project had to be cancelled.

VII CONCLUSIONS

It has been difficult to fully assess the net-pen rearing technique. There is just too little data available on returning adults to make such an analysis.

This study has shown however, that net-pen rearing, when performed in properly-chosen sites with well-designed facilities that are carefully managed, can have very high survivals during the rearing stage. As a means for raising salmonids to increase growth, imprinting or simply holding hatchery excesses, net pens are effective and probably less expensive than land-based facilities. Delaying the transfer of coho to saltwater will reduce survival and growth rates. If delayed releases are used to alter migration patterns, then sea pens are the most economical method for holding fish.

Although evidence is not conclusive, net-pen rearing does not appear to be a superior technique for improving survival rates and increasing production. However, it can be applied in many areas along the coast and the scale of production can range from one net up to 20 nets (depending on the location and design). It also has the advantage that it can be piloted, thus, avoiding very expensive mistakes.

In the future, the data on the returning adult population of present net pen facilities should be analyzed for straying and survival. Also, the transplant policies should be re-examined in light of experiments which show that straying is less when the distance transferred is greatest.

APPENDIX A

Locations of Net Pen Facilities

To give the reader some idea of the broad range of applications of net pen rearing, a comprehensive list is presented in this section. Two facilities are described in more detail in Section V.

British Columbia

1. The Small Projects Unit of SEP have contemplated the use of net-pen rearing on Sachs Creek and Vancouver River to enhance natural runs there. Since net pens are a larger, more expensive undertaking than the usual Small Project, no steps have been taken thus far to implement the technique (Logan, 1982).

2. CEDP (Community Economic Development Program) projects presently applying to net-pen rearing are:

   (i) False Creek Net Pen Rearing Project (see Section V for a detailed account);
   (ii) Sechelt Net Pen Rearing Project (See Section V);
   (iii) Marie Lake (near Masset) has fresh water net pens for raising chinook to smolt stage and coho about 1.5 years;

(iv) There are sea pens at the mouth of McLoughlin Creek (Bella Bella) which hold chum for one month for feeding before release to the sea.

(v) The Nanaimo hatchery occasionally holds excess juveniles in fresh water pens on the Nanaimo River

(McQuarrie, 1982)

3. Hatcheries such as Pallant Creek are now raising some of their juveniles before releasing them to the sea (see Section V for a more detailed account) (Shepherd, 1982).

4. Commercial farms in B.C. for raising salmon and some trout use net pens. There were ten fish farms licensed for growing salmon in November, 1980, by the Fish and Wildlife Branch of the Ministry of the Environment.

5. An Experimental fish farm using sea water net pens was built in 1974 off-shore from the Pacific Biological Station in Nanaimo. A great deal of research and information has been generated at this farm. A detailed description of the PBS fish farm will not be provided since its design and operations have been well documented elsewhere (Kennedy, 1978 and Brett and Solmie, 1981). However, it should be mentioned that at some time, the facility has handled the five species of Pacific salmon (coho, chinook, chum, pink and sockeye), steelhead, and herring.

6. The Fish and Wildlife Program has initiated several net-pen rearing projects such as:

   (i) A freshwater facility located in Cowichan Lake for steelhead and cutthroat;

   (ii) Several projects on Black Creek and Saanich Creek for cutthroat only (Sparrow, 1981);

   (iii) Lake-pen rearing at O'Connor Lake of steelhead smolts for transplant (Slaney and Harrower, 1981).

Eastern Canada

1. A project was conducted in Scotts Pond, Trinity Bay, (Nfld) in 1978, to raise rainbow trout in brackish water to test the viability of a commercial operation (Jamieson, 1980).

Alaska

1. Due to the difficult topographic conditions in Alaska, constructing and operating floating sea pens is more practical for growing juvenile salmon than providing hatchery facilities. Thus, private and public attempts to rehabilitate salmon fisheries through ranching are inclined to use the net pen method. In Alaska, private hatcheries must be non-profit but can qualify for state subsidies.

2. Experimental net-pen facilities supported by the National Marine Fisheries Service, NOAA, are located at Little Port Walter, Baranof Island. Coho have been raised to smolt stage for release and transplant studies (Heard and Cone, 1976).

Washington State

1. The National Marine Service began culturing salmon in freshwater floating net pens in 1967 on the Columbia River (Novotny, 1975).

2. In 1969, a net-pen facility was established at Clam Bay, Puget Sound for research into raising the five species of Pacific Salmon for two reasons:

   (i) To commercially produce pan-sized salmon.

   (ii) To extend rearing of hatchery-produced salmon for release to the local sport fishery.

   Studies have focused largely on coho (Novotny, 1975).

3. Floating net pens in Lake Quinault are used by the Quinault Indians to rear coho, chum, sockeye and steelhead smolts for release (Donaldson, 1980).

4. A large-scale saltwater pen rearing facility began in 1974 at Fox Island for raising coho and chinook (Mills, 1977).

5. Several private fish farms such as the one owned by Domsea Farms, rear pan-sized coho in floating net pens in Puget Sound. The growth of the commercially-raised coho is accelerated by early rearing in warm water (Donaldson, 1980)

Oregon State

1. Private salmon ranching has been legal since 1973 in Oregon. The largest interest is held by Weyerhaeuser Corp. who operate a hatchery near Eugene. They have a permit to release 40 million chum, 20 million coho and 20 million chinook (1982 figures). Coho growth is accelerated with warm water in the first seven months. The catch-release facility in Newport's Yaquina Bay is a system of ponds through which seawater from the bay is circulated. Net pens are not used in this commercial operation.

2. The literature search did not locate any reference on the use of net pens in Oregon. According to Geoff Meggs (1982), the public program has decreased output of smolts and eliminated releases of fry from off-hatchery sites compared to the early 1970's so that the amount of private salmon production permitted in Oregon in 1979 was over twice that produced by the public hatcheries.

Norway

1. Commercial operations raise rainbow trout in sea cages using a density of 9-10 kg/m3 (Sutterlin and Merrill, 1978), and raise Atantic salmon in sea

pens using densities up to 16 kg/m^3 (Kennedy, 1978).

Sweden

1. In an attempt to increase survival by reducing predation of newly-released smolts into the river system and at the same time imprint the river migration, some experiments of towing smolts down the river in net pens have been conducted. The success of the strategy has not yet been determined. (Larson, 1980)

United Kingdom

1. In Scotland, decagonal floating cages, 25 feet across, have been used to raise rainbow trout (Brett, 1974).

2. According to Kerr and Kingwell (1977) of the White Fish Authority in Edinburgh, it is possible to raise plaice in floating cages with a good tidal flow at densities up to 87 kg/m^3. They also found reasonable success raising turbot, salmon and rainbow trout in floating cages.

Japan

1. Native Japanese salmon stocks are chum, pink and masu salmon all of which can be transferred to seawater shortly after emergence. The technique of feeding for two months in sea pens to improve fry survival was first tried

in 1967. The program was not initially successful, but problems concerning transfer methods and timing, release methods and timing, and net pen rearing fish husbandry are being worked out at several net pen sites located in Iwate and Mijagi prefectures (Kobayshi, 1980 and Ioka, 1979).

2. Japanese fishfarmers have found that raising yellowtail in coastal floating net pens has been much more successful than raising them in embanked ponds and enclosed lagoons (Brett, 1974). They use submerged cages for protection from typhoons and have produced up to 500 tons annually (FAO, 1976).

USSR

1. According to Konovalov (1980):

Floating fishpen rearing of Pacific salmon will not be developed; it is much more expensive than hatchery rearing and requires a number of deep, sheltered bays.

Philippines

1. Large scale cage culture of milkfish has developed in recent years (Food and Agriculture Organization, 1976).

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APPENDIX B

Pallant Creek Hatchery Returns

In 1978, 152,214 chum fry were marked and released. In 1981 8. marks were counted of 4,616 brood stock. Of total escapement of 30,882, the possible no. of marks is 563.

The 1978 age composition of Pallant Creek chum was:

Age 3	2.5%
4	88.8%
5	8.7%

Let X = return-to-esc. rate and Y = the number of age 4 and 5-year-old returns. Then:

$$X \times 152{,}214 = 53 + Y$$

and $$Y = 9.75 \times X \times 152{,}214$$

Solving for X:

$$X = 1.39\%$$

APPENDIX C - ENVIRONMENTAL DATA FOR FALSE CREEK NET PEN FACILITY

During February 1979 to February 1980, data such as weather, temperatures, salinity, oxygen levels, and clarity were monitored on a daily basis. The ranges of the observations are:

Ave. Water Temp. (°C)		Average Salinities (ppt)		Ave. Oxygen (PPM)	
0 Meters	2 Meters	0 Meters	2 Meters	0 Meters	2 Meters
5.5 - 19.1	4.8 - 15.7	13.1 - 26.0	15.7 - 26.4	7.5 - 11.7	8.4 - 12.9

Ave. Water Clarity by Sechi Disk (M)
1.2 - 3.7

Samples were taken on five occasions for heavy metal analysis of water and substrate sediment in the Granville Island/Granville Dolphins region. The maximum levels found for each element in the water sample are as follows:

Element	Concentration (ppm)	Element	Concentration (ppm)	Element	Concentration (ppm)
Ba	.002	Sr	.0191	Na	34.2
Cd	.002	Ti	.047		
Cr	.004	V	.016		
Cu	1.14	Zn	1.11		
Hg	.002	Al	.29		
Mn	.0235	Fe	9.57		
Ni	.03	Si	.77		
P	.37	Ca	1.25		
Pb	.08	Mg	3.51		

Records were kept in the first year involving large traffic and waterfowl. Because these factors were not believed to affect the success of the rearing facility data, collection of this data ceased.

APPENDIX D - ENVIRONMENTAL DATA FOR SECHELT BAND NET PEN FACILITY

From December 1979 to July 1980, some environmental data were collected. A summary of the observations is given below.

	Range
Average Monthly Salinity	15 - 26 ppt
Average Monthy Water Temperature	6 - 20 °C

Data was also collected from January 1980 to June 1981 for the average monthly water flows of the following creeks: Grey Creek, Angus Creek, Wilson Tributary Wilson Creek, Snake Creek, Carlson Creek, Chapman Creek and Burnett Creek. This data is available in the Sechelt SEP Annual Reports.