Feasibility Of The Intensive Culture Of Arctic Char (salvelinus Alpinus) At Jackfish Lake, N.w.t.

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FEASIBILITY OF THE INTENSIVE CULTURE OF ARCTIC CHARR (*Salvelinus alpinus*) AT JACKFISH LAKE, N. W. T.

Section 4.4 - Addendum

4.4 ADDENDUM - ORGANOCHLORIDE SCAN OF FISH MUSCLE TISSUE FROM JACKFISH LAKE

Total concentrations of organochloride compounds present in muscle tissue from northern pike and whitefish collected from Jackfish Lake, N.W.T. were low (Table 1) and well within National Health and Welfare guidelines for commercial fish (D. Muir, Freshwater Institute, Winnipeg, personal communication) .

Arctic charr would be expected to have slightly higher organochloride levels than reported here however, due to the higher fat:protein ratio of muscle tissue of charr than either pike or whitefish, but are not expected to be a problem.

It can be concluded that due to the low levels of organochloride compounds present in resident fish of Jackfish Lake, this will not be a factor in the use of Jackfish Lake for aquiculture purposes.

Table 1. Analysis of total organochloride compounds present in whitefish and pike muscle tissue collected from Jackfish Lake, N.W.T. on 26 February, 1987. All units are in rig/g wet weight (parts per billion.)

Compound*		Pike	Whitefish
CBZ		0.18	0.29
HCH		0.38	0.96
CHLOR		0.26	0.30
DDT		36.36	24.34
PCB-T		17.22	12.52
ARO 1:1		13.63	9.00
TOXA		10.39	7.49
DIELDRIN		0.05	0.10
PCB's			
	TRI	1.70	1.41
	TETRA	4.84	4.05
	PENTA	3.62	2.52
	HEXA	4.14	2.75
	HEPTA	2.39	1.48
	OCTA	0.50	0.29
	NON/DEC	0.03	0.02

* (23Z = chlorobenzenes
HCH = hexachlorocyclohexanes
CHLOR = chlordane - related compounds
DDT - DDT related compounds
PCB-T = total polychlorobiphenyls
ARO = PCB's as Aroclor 1254-1260 equivalents
TOXA = toxaphene
TRI - trichloro - PCB
TETRA = tetrachloro - PCB
PENTA = pentachloro - PCB
HEXA = hexachloro - PCB
HEPTA = heptachloro - PCB
OCTA = octachloro - PCB
NON/DEC = nona, decachloro - PCB

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1.0 INTRODUCTION

Recently aquiculture, or the farming of finfish, shellfish and aquatic plants, has been identified by government and private industry as an area with significant potential for new growth and development. Integrating Canada's abundant natural resources with the developing science and technology of aquiculture can provide valuable opportunities for supplying the increasing Canadian export market demand for fresh fish, generating employment and creating new economic opportunities.

Worldwide, aquiculture is a rapidly expanding industry having experienced a growth rate of 67% during the past decade (MacDonald 1985). The development of aquiculture in Canada however, has been limited and slow. Our low level of aquiculture development relative to other countries, is due primarily to the abundance of our wild fish resources and our environmental conditions. Canada produced only 6,000 tonnes of fish and shellfish in 1984 versus a total production of 1.24 million tonnes of wild fish. Contrast this with the 2.5 million tonnes of aquiculture production in China the same year (MacDonald 1985).

Aquiculture development is typically a long term process, characterized by slow initial growth. There are numerous problems to be overcome such as nutrition, disease, genetics anda technology which has been developed for specific application to a southern, temperate climate. Additional problems specific to Canada and the north exist such as weather, transportation, high operational costs, cold water and competition from other fish (Ayles 1980, Table 1). Additional research is required to develop a technology specific to aquiculture in the Northwest Territories.

Interest in developing Arctic charr (Salvelinus alpinus) as an aquiculture species in Canada has been increasing due to its value, limited availability and its unique Canadian identity. Biological Arctic charr also may be better suited to aquaculture in Canada than more traditional species such as rainbow trout because charr are w-en adapted to cool water, of which we have an abundance.

Intensive aquiculture of Arctic charr has recently been examined by researchers in Norway (Gjedrem and Gunnes 1978, Wandsvik and Jobling 1982, Jobling 1983a, 1983b and others) and in Canada (Baker 1983, Papst and Hopky 1984). Initial results indicate that Arctic charr require cooler waters than other salmonids and a high quality of food to achieve maximum growth rates. In Canada, most of our water is too cold to provide for maximum growth year round and therefore must be heated to achieve optimum growth temperatures. As energy and food requirements are the major costs of an aquiculture operation, these must be reduced if intensive culture of Arctic charr is to be viable. Use of low grade or waste heat from liquified natural gas compressor stations, mining or smelting operations and electrical generating stations have been identified as potential energy sources (Ayles et al. 1980).

The purpose of this stud.. is to assess the biological and technological feasibility of intensive aquiculture of Arctic charr utilizing waste heat generated from a Northern Canada Power Commission (NCPC) electrical generating station on Jackfish Lake, near Yellowknife, N.W.T. (Fig. 1). This station operates at least nine months of the year providing up to 11,250 L/min of 400 C water, which could be used to supplement lake water for the culture of charr either in cages or in raceways.

This study also evaluates relative technological, economic and nutritional merits of providing a locally manufactured fish feed derived from coarse fish, available in large quantities from the Great Slave Lake commercial fishery, versus an imported, commercially manufactured feed. Although this report addresses the specific suitability of Jackfish Lake for Arctic charr aquiculture, these results have a broad applicability to the general feasibility of intensive aquiculture of Arctic charr, utilizing waste heat, in the Northwest Territories.

2.0 REVIEW OF TECHNICAL INFORMATION

Included in this section is a review of the technical information pertaining to the intensive aquiculture of Arctic charr. This information was gathered from all available published material, from unpublished material kindly provided by individuals who work or have worked with Arctic charr and from personal contact with individuals in Canada, Scotland, Denmark and Norway who are involved in aquiculture research.

Arctic charr have not been successfully raised in freshwater in Scotland or the Scandanavian countries. Ninety-five percent of all aquiculture in these countries involves sea cage culture, primarily of Atlantic salmon and rainbow trout. Arctic charr perform poorly in sea cages (Gjedrem 1975a, Gjedrem and Gunnes 1978) and attempts at their culture exclusively in freshwater has not yet been attempted on a commercial scale. Research on Arctic charr aquiculture in Scandinavia is still in its early stages but is developing rapidly.

The following section provides a synopsis of the technical information available on the intensive culture of Arctic charr. This begins with the procedures which initially must be followed to obtain and establish a source of Arctic charr, followed by a discussion of the biological and physical environmental factors which affect growth and development of arctic charr from early life stages to juvenile fish.

2.1 ARCTIC CHARR ACQUISITION

Acquiring up to 200,000 eggs annually, until a brood stock can be established, will be both costly and difficult. The first obstacle will be identifying populations which are known to be free of infectious diseases (see Section 2.3.7).

Selection of an Arctic charr population should be based upon previously known data in order that the risk of importing diseased eggs is minimized. The imported eggs must then be held in a quarantine facility until certified disease free in order to eliminate contact with non-diseased fish or eggs.

It is strongly recommended that Arctic charr eggs are obtained from at least two geographically distinct populations (strains) so that if a particular strain is infected with a disease, a source of eggs would still be available so that production could continue. In addition, it is desirable to evaluate the performance of different strains under commercial aquiculture conditions in order that the better strain can be utilized for production purposes. Further information on obtaining a certified disease free stock of fish is detailed in the Canadian Fish Health Protection Regulations.

The basic biology or life history of Arctic charr is discussed in Appendix 1. Arctic charr are fall spawners, reproducing primarily in lakes between September and October, depending upon latitude. It is during this time that weather conditions deteriorate and become unpredictable thus making the collection of eggs potentially difficult. It is therefore necessary to know exactly *when* and where the charr will spawn.

2.2 EARLY LIFE HISTORY

The facilities required in which to rear Arctic charr from egg to swim-up or feeding fry are the same as those required for other salmonids, however the conditions under which charr must be reared are slightly different.

Eggs are reared in standard Heath trays until shortly before yolk-sac absorption is completed. They are then transferred to raceways before they begin to "swim-up" to commence feeding.

It is important that early development of eggs (at least until the "eyed" stage) occur in cold (6°-8°C) water (Swift 1965) . Before the eyed stage the eggs should be maintained in a darkened area and should not be handled as they are quite fragile. Fungal growth on dead eggs during this period is generally a problem, but can be treated with a standard application of malachite green. Once the eggs become eyed (eyes become visible in the egg), they are more resilient and can be handled. It is very important that high water quality standards are maintained throughout all early life history stages (see Section 2.3.5). Water temperature has the greatest influence on development and survival of eggs and growth of juveniles, Swift (1965) reared Arctic charr eggs at temperatures ranging from 40 to 12°C. The relationship between temperature, hatching time and mortality is as follows:

Temperature (°C)	Days to Hatch	% Mortality
4	97	6
6	76	8
8	54	14
10	41	90
12	36	97

In order to gain the best compromise between the number of c&w required to hatch the eggs and the percent mortality of the eggs a temperature of 8°C is recommended. Accelerated yolk-sac absorption, earlier feeding and increased growth can be achieved by maintaining water temperatures at 10°C from hatch until swim-up and 12°C thereafter. It is estimated that approximately 6-8 weeks would be required to reach 1 g following this regime as compared to the 4 months normally required at a constant temperature of 6.5°C.

Baker (1981) exposed eyed Arctic charr eggs to temperatures of 6°, 80, 100 and 12°C. At 10°C survival of eggs and alevins remained high (89%), while at 12°C survival fell off to less than 50%.

The overall estimated mortality of wild eggs imported to the Fisheries and Oceans, Rockwood Experimental Hatchery from Labrador and Norway in 1980 was 10-15%, with an additional 10-15% mortality occurring between alevin and fry stages. Baker (1983) and M. Papst (Fisheries and Oceans, Winnipeg, personal communication) have both reported that loss of individuals due to cannibalism had occurred, although this was never directly observed.

In a first attempt at the development of a brood stock of Arctic charr, Papst and Hopky (1984) reported a mortality of 83% to the eyed egg stage and 92% to hatching. This high mortality was due primarily to a low rate of egg fertilization. Improvements in fish husbandry of charr, better timing and co-ordination of maturity within and between sexes, correct environmental manipulation and the use of hormones to induce maturity can be employed to significantly reduce egg mortality, Increases in survival of eggs at the Rockwood Hatchery have since been documented (M. Papst, personal communication).

2.3 FACTORS AFFECTING GROWTH

Many factors, both environmental and genetic affect growth rate and efficiency of food utilization of fish. The most important factors are temperature, food ration and fish size. No one factor operates independently, rather they combine to operate synergistically, affecting growth and food conversion efficiency. A rise in temperature may increase growth rate and food ration requirements, however these changes will be tempered simultaneously by changes in fish size. The process of growth is a complicated, interactive one dependent upon many factors.

Each of the major factors which influence growth rates; temperature, food ration, fish size and density, will be discussed separately. First, their general influence, followed by an evaluation of their specific effects on Arctic charr. In addition the parameters of water source and quality, fish health and genetics will be discussed as they relate to Arctic charr.

2.3.1 Effect of Temperature

Temperature is the most important environmental factor influencing the growth and activity of fish. Because fish are cold blooded, their rate of activity is directly determined by temperature.

At low temperatures all physiological activities including growth, will also be low. As temperatures increase growth will increase until such a point is reached where further increases in temperature will not produce a further increase in growth rate rather, rates of growth will decline. The point at which growth is highest is called the optimum growth temperature.

The optimum growth temperature, as well as the temperature range over which high rates of growth are achieved, differ widely among salmonid species.

The optimum temperature for growth of Arctic charr is between 12° and 13°C (Swift 1964, Wandsvik and Jobling 1982, Uraiwan 1982 and Baker

1983), relatively lower than for most other salmonids. Optimum growth temperatures range from 15-16°C for the Pacific salmon to 170 - 18°C for rainbow trout (Brett 1979, Hokanson et al. 1977). Swift (1964) was the first to culture charr over a wide range of temperatures (4°-18°C) and found that growth was highest between 120 and 14°C and poor at 40 and 18°C. Wandsvik and Jobling (1982) rearing charr in freshwater in Norway at 3°, 8.5° and 13°C observed that growth and feed intake was highest at 13°C. Uraiwan (1982) compared the growth rates of Arctic charr, brook trout and rainbow trout at 4 temperatures (10, 13, 16, 19°C) and found that growth of the Arctic charr was highest (2.0% body weight/day) at 10° C, exceeding that of both the brook and rainbow trout (1.8%/day).

In an extensive study Baker (1983) grew two different strains of Arctic charr and one strain of rainbow trout simultaneously over a wide range of temperatures and fish sizes. He found that at low temperatures, growth rates of all strains were low and similar. Between 100 and 14°C specific growth rates of the Arctic charr strains were at their highest level, up to 2.0% body weight/day (Fig. 2). Growth rates of the rainbow trout however exceeded those of the charr at 14°C and remained high at 19°C.

At 14°C near the optimum growth temperature, the mean weight of the charr increased from 10.2g to 115g in approximately 140 days (Table 2, Fig. 3). To estimate the number of days required to produce a 250g fish it was necessary to extrapolate the data using a simple growth model given in Baker (1983). To produce a charr of mean weight 250g an additional 55 days growth under similar conditions would be required.

Although charr have a lower optimum temperature for growth than other salmonid species, they normally do not have a higher rate of growth than other salmonids at this or lower temperatures. Arctic charr do not appear to be better adapted or suited to intensive culture at lower temperatures than other salmonids. To achieve the highest rate of growth possible, culture temperatures should be maintained as close to the optimum growth temperature for charr as possible.

Papst and Hopky (1983) were the first workers to have attempted to raise Arctic charr in a commercial production system utilizing waste heat and water recirculation. Charr were stocked in 1500 litre tanks at an initial size of 2.2g and raised at a mean temperature of 13.3°C for 209 days. Mean weights and specific growth rates for the charr during each growth interval are given in Table 2 and illustrated in Fig. 3. At day 209 the mean weight of the peculation had increased to 158g. Using the data provided and a projected average specific growth rate of 1.0%/day, it is estimated that an additional 45 days would have been required for the population to achieve a mean weight of 250g. Thus, to raise a charr from 2g to market size at the optimum growth temperature, approximately 254 days would have been required (Fig. 3).

At the end of day 209 however, only 28% of the population exceeded 200g in weight, with a weight range of 20g to 530g. This considerable variation in growth rate has also been observed by Jobling and Wandsvik (1983a), Baker (1983), Jobling (1983a and 1983b) and Jobling and Reinsnes (1986).

At lower temperatures, the time required to achieve market size increases greatly. Based upon data provided by Wandsvik and Jobling (1982) and Baker (1983) it is estimated that at a mean temperature of 9°C, it would take approximately 510 days to grow a fish from 2g to 250g. Thus roughly 40-50 additional days of growth are required to achieve market size for every degree that average culture temperatures are below the optimum range.

As the study by Papst and Hopkey (1983) was a first attempt at commercial production, I feel that this estimate is somewhat exaggerated. Reduced handling stress, better temperature control, extended feeding times, experience and other factors will reduce the time required to produce a market sized product.

Considerable differences in growth rate, as well as the temperature range over which high growth is maintained also exists between strains of Arctic charr. Baker (1983) found that charr from Labrador maintained significantly higher growth rates and food conversion efficiencies over a wider temperature range than did charr which originated from Norway.

In Summary, the optimum temperature for growth of Arctic charr appears to be between 12° and 13°C, however the rate of growth can vary considerably depending upon genetic differences (the origin of the particular strain) and environmental differences such as the type of culture system employed, culture density, water quality, type of food and other factors.

2.3.2 Food Ration

Food ration requirements of fish depend primarily upon temperature and fish size. At low temperatures, metabolism and growth are lowand less food is required by the fish to satisfy these demands. As temperatures increase, metabolic processes become more efficient and more energy becomes available for growth, however nutritional demands also increase, Above the optimum growth temperature, food ration requirements remain high but growth is reduced due to the decreased efficiency of food utilization. Thus food conversion efficiency or the efficiency with which the fish converts food into flesh is greatest nearest the optimum growth temperature.

2.3.2.1 Food Conversion Efficiency

Food conversion efficiency, commonly represented as the feed to gain ratio, is calculated by dividing the total weight of food fed by the gain in wet weight of fish produced. The smaller. the ratio, the more efficient the conversion of food to flesh. .4 fish with a feed:gain ratio of 1.4 will gain 1 g of weight for every 1.4 g– of food fed. Considerable differences in feed:gain ratios exist between different strains of Arctic charr fed the same diet (Table 3). Growth and food conversion efficiency depends not only upon quantity of food, but also on the composition of the diet. Baker (1983) found that the charr from the Fraser River in Labrador were much more efficient (1.4:1) and had higher growth rates than charr from Sunndalsora, Norway (2.1:1). Tabachek (1984) has found similar, considerable differences between strains as well as substantial differences in conversion efficiency of charr fed different diets. Feed:gain ratios varied between 1.4:1 up to 2.4:1 for Sunndalsora charr, depending upon the diet (Table 3).

2.3.2.2 Nutritional Requirement

In a limited stud.., Jobling and Wandsvik (1983c) concluded that the protein requirements of charr were similar to those of trout, and that a commercial trout food would satisfy the nutritional demands of charr. Tabachek (1984) however suggests that differences in nutritional requirements, nutritional tolerance to dietary ingredients or digestibility exists between trout and charr and possibly between strains of charr. Interstrain differences in carbohydrate and protein requirements have been previously demonstrated for rainbow trout (Austreng and Refstie 1979, Refstie and Austreng 1981).

Tabachek (1986) presented Arctic charr with nine different diets of varying protein: lipid ratio's. She found that charr utilized protein more efficiently with an increase in dietary lipid, and that maximum weight gain and food conversion efficiency occurred at the highest protein:lipid ratio (54%:20%) tested. Economically, food with a ratio of 44%:20% was less expensive, producing the lowest feed cost per unit weight gain, however growth rates were 6,8% lower. The protein:lipid ratio required by rainbow trout is 35% protein to 15-20% lipid (Takeuchi et al., 1978), thus it appears that contrary to Jobling and Wandsvik (1983), nutritional requirements of charr may not be optimally satisfied by commercial trout food. A higher protein:lipid ratio may be required.

Selection of a strain of Arctic charr which has demonstrated a high feed:gain ration and employment of a diet formulated to the specific nutritional requirements of charr is essential to the commercial success of any aquiculture operation.

2.3.2.3 Size Effects

The nutritional demands of fish also change with size. Young, smaller fish require a relatively greater amount of food as a proportion of their body weight, than do larger fish.

Standard feeding tables have been developed to satisfy the specific demands of salmonids which dictate the amount of food required to be fed to the fish, based on water temperature and mean weight of fish (Table 4 after Hilton and Slinger 1981). For example, at 120C a fish having a mean weight 5g should be fed 4.3% of their body weight/day. If the tank contains 10,000 fish, 2.15 kg of food should be given (10,000 x .005g x .043% - 2.15 kg).

Feeding tables have been developed primarily to satisfy the nutritional demands of rainbow trout and salmon. Baker (1983) has found that the quality of focal demanded by different strains of Arctic charr can vary, thus current feeding tables for rainbow trout, although useful, will initially only serve as a rough guide. Existing tables should be modified to suit the specific demands of Arctic charr as more experience in their culture is gained and adjustments according to genetic (strain) and environmental differences are incorporated. A feeding table developed for charr will improve food conversion efficiency and reduce cost.

2.3.2.4 Feeding Frequency

The frequency with which fish are fed also affects growth rate. Young, swim-up fish should be fedup to 20 times per daY. This rate is reduced to 8-10 times per day for fingerlings (<5g), 4-5 times per day for fish between 5 and 50g and 2-3 times for fish exceeding 50g (Brett 1971). Frequent feeding of fish for shorter durations will decrease wastage and increase growth. Hilton and Slinger (1981) recommend that fish not be overfed so that they maintain a keen appetite at each feeding, the result being higher growth rates. Feeding charr over a 12 to 16 hour period rather than 8 hours each day may also increase growth rates (Baker 1983). The method of feeding will be discussed in Section 3,3.

2.3.3 Effect of Fish Size on Growth

Generally, a fishes growth rate declines with a progressive increase in size. The specific growth rate (gain as a% of its body weight/day: Bertlanffy 1957) of small fish (1g) can be as high as 5-6%/day at the optimum growth temperature, but decline to less than 1%/day over 200g.

There is a fairly well established $\log_e$ linear relationship between declining growth rate with increasing $\log_e$ size. This relationship seems to be consistent for a wide variety of salmonids. Brett and Shelbourn (1975) have suggested that a slope of -0.41 (+/- .04) is characteristic of the family. The form of the equation is as follows:

$$\log_e \text{(specific growth rate)} = a - 0.4 (\log_e \text{weight})$$

Thus the decline in $\log_e$ (growth) varies directly according to increases in $\log_e$ (weight). The greater the increase in weight, the more reduced the growth rate. The intercept 'a' will vary according to environmental differences (i.e. temperature, ration) and genetic (strain) differences. The reduction in the amount of food required with increased size is incorporated in feeding tables (Table 4).

Several studies have been performed which examine the relationship between size and growth rate on Arctic charr. Jobling (1983a) reared charr from 18 to 135g over 6 months at 100C and found that the rate of decline in the specific growth rate of charr with size was -0.325, slightly lower than the rate of -0.41 described by Brett and Shelbourn (1975). Similarly, Baker (1983) also found that growth rates of charr did not decline as rapidly with size as for other salmonids. This may be significant in that charr may be able to maintain relatively higher growth rates at larger sizes than other salmonids and thus may be better suited for culture to larger sizes.

2.3,4 Variation in Size and Growth

During experimental growth trials it has been found that a tremendous variation in growth rate and size develops (Jobling 1983a, 1983b, Baker 1983, Papst and Hopky 1984, Jobling 1985, Jobling and Reinsnes 1986). These size distributions are remarkably similar despite differences in strains and conditions. They are characterize by having a number of large, fast growing individuals, a wide range of intermediate sized fish and a group of very small fish, often no larger than the initial weight. In parallel growth trials with charr, rainbow trout have been much more uniform in size (Baker 1983, Papst and Hopky 1983).

This great size variation represents a serious obstacle to the commercial success of Arctic charr culture. Multiple harvesting periods to harvest fish as proportions of the population achieve market size will increase labour costs and the increased handling stress will reduce overall growth rates. In addition, if 20-30% of the population does not achieve market size in a reasonable amount of time, a considerable amount of potential, tank space, food, time and money are lost.

Reasons as to why this occurs are complicated. Jobling and Wandsvik (1983a) and Jobling (1985) have observed aggressive behavior of larger fish towards smaller fish, thus increasing stress, reducing feeding efficiency and growth rate. However, in studies by Papst and Hopky (1983) and Jobling and Reinsnes (1986) where 'small' and 'large' fish have been separated and allowed to grow, no differences in growth occurred. Larger fish maintained unusually high growth rates while the small fish continued to perform poorly. Thus it appears that social or hierarchal factors are not the sole basis for the wide variability in size and growth, but a great deal of the variability can be attributed to genetic factors.

In the wild a similar variability in growth rate occurs (Johnson 1980). The mature, spawning proportion of the Arctic charr population is represented by individuals from many year classes. Large, young fish represent 'fast' growers and small, old fish represent 'slow' growers. In this way a single year class can contribute gametes to the population over a period of many years. Thus, the situation observed in a hatchery environment can largely be attributed to the large, natural variation in size and growth rate which is inherent to wild populations.

To overcome or at least minimize this factor, a genetic selection program must be establish with the aim of reducing the large variation in growth. Rainbow trout for example, which have been reared in a hatchery over several generations and are considered to have become "domesticated", no longer demonstrate a great diversity in size or growth, have a high survival rate and have become adapted to the hatchery environment. This is however, a long term solution to the problem.

Over the short term there are several measures which can be taken. Refstie and Kittelsen (1976) have shown that territoriality and aggressive behavior of salmonids is reduced at higher densities. Culturing charr at high densities may reduce the social hierarchal factors which contribute to the manifestation of a group of small fish exhibiting low growth rates. Because charr are a gregarious species by nature, they maybe better suited to culture at higher densities than other salmonids. Recently, Baker and Ayles (198'7) have demonstrated that in fact charr do perform well at high densities, exhibiting higher growth and food conversion efficiency rates than other salmonids at similar densities. The benefits of exploiting this ability maybe twofold in that not only will growth rates and yield be increased, but that variation in size may be reduced. Culling of "small" fish in the population will also reduce size variation, the amount of food fed and the time required for the population to reach harvest size.

It must be kept in mind that the intensive culture of Arctic charr is a relatively new technology, Standard rearing methods will have to be adapted and refined to meet the different and often unique requirements of Arctic charr.

2.3.5 Density

The density at which fish are cultured is usually measured as kg of fish per cubic metre of water volume (kg/m^3)The optimum density at which a species should be cultured is not necessarily at a low density, where growth rates are highest. Rather, culture densities which are "acceptable" depend upon predetermined production goals such as rapid growth, production of as much weight as possible, or high fish quality. The optimum culture density will generally be the density which provides for a very high yield while maintaining good growth without compromising fish health and water quality.

As densities increase from low (5-10 kg/ins) to high (>60 kg/ins) levels, most salmonids suffer a progressive decline in growth rate and food conversion efficiency (Burrows 1964, Fenderson and Carpenter 1971, Brauhn et al. 1976, Refstie and Kittelsen 1976, Refstie 1977). The increased density of fish per unit volume causes an increase in the level of interaction between individuals which increases stress, reduces food conversion efficiency (due to greater competition) and lowers water quality. Each of these factors contribute to a decrease in production.

Unlike other salmonids, Arctic charr respond differently to high densities as growth rates increase from low to moderately high densities. Recently, Kolbeinshavn and Wallace (1985) reported that high stocking density of charr was not a significant factor affecting growth and that survival of charr was actually highest at the highest density. They also reported unpublished findings by Wallace et al. (1986, unpublished) that young charr were not stressed by high densities in their growth experiments. Baker and Ayles (1987) grew rainbow trout and Arctic charr in parallel growth trials at initial densities ranging from 10 kg to 85 kg fish/m^3. They found that characteristically, growth rates of rainbow trout declined linearly as density increased and that the growth of Arctic charr was curvilinear, increasing with density to an optimum between 40 kg and 60 kg/m^3, suffering only a slight decline at the highest density tested. This response was consistent for two strains of charr over a wide size and temperature range. Only Arctic charr have shown a positive correlation between growth and increased density.

Reasons for this response are not clear. In the wild, Frost (1977) and Johnson (1980) have observed that Arctic charr will tend to school at high densities. Charr may therefore be naturally more suited to high densities. In addition, Baker and Ayles (1987) did not observe any aggressive behavior or attempts to defend territories at high densities. Erosion of the pelvic, pectoral and caudal fins in the rainbow trout was severe, particularly at densities exceeding 25 kg/m^3. The Arctic charr suffered no fin erosion whatsoever, even at the highest densities. Thus fish quality and presentability of charr are high and can be maintained despite high densities.

The decline in growth of the charr at the highest density tested (85 kg/m^3) in the study by Baker and Ayles (1987) presumably occurs for the same reasons as for the rainbow trout. Increased crowding, compounded with the effects of low oxygen and increased ammonia levels will eventually cause a decline in growth and food conversion.

Growth rates of Arctic charr were 30% higher at the optimum density than at low densities and hada yield almost five times as great (Baker and Ayles 1987). Higher initial and fiml stocking densities of charr resulted in at least a 20% higher yield than rainbow trout cultured at a similar density. In fact charr have been maintained at densities of up to 150 kg/ins with no apparent ill effects (M. Papst, Freshwater Institute, personal communication). Growth at high densities can only be achieved if high water quality standards are maintained.

The ability of charr to perform well at densities higher than traditional levels (>4C kg/ma) represents a tremendous advantage to fish culturists as higher stocking levels result in a more efficient use of available tank space and increased yield.

2.3.6 Loading Rate

Another aspect of production, related to density (kg/m^3) is called "loading" and is expressed in terms of weight of fish (kg) per litre per minute inflow (kg/litre/min). Optimum loading rates vary according to water quality and culture system (flow through or recirculation), but range between 0.5 to 1.5 kg/litre/min (Brauhn et al. 1976). Fish reared in single use systems can withstand greater loading levels. At high loading levels (>2 kg/litre/min.) water quality will be reduced resulting in increased stress and poor growth. At low levels (<0.5 kg/litre/min.), flow rates (turnover) may be too high, forcing the fish to expend more energy swimming which will reduce the amount of energy available for growth.

Westers and Pratt (1983) suggest that a turnover rate of up to four times per hour is ideal. A greater turnover rate will not allow for the settling of solids while lower turnover will result in low-density rearing. The relationship between flow rate, loading and density (Table 5) given different levels of water quality has been illustrated by h-esters (1983). High water quality allows for greater loading and density levels, a lower turnover rate and ultimately, a greater yield.

2.3.7 Water Quality

Water quality standards for aquiculture purposes are very high and very few natural water supplies meet all the requirements for artificial culture (Burrows & Combs, 1968). There are many aspects to water quality ranging from pH, to oxygen, metabolites, minerals and heavy metals. Judicious selection of a clean, well buffered, disease free water source will provide an environment which will maximize fish health and production. Ideally, water temperatures should be close to the optimum growth temperature of the species and should not be subject to wide fluctuation. It is easier to monitor and control water quality and temperature in a land based aquiculture facility than a cage rearing facility. In either case, water quality standards will remain the same, although how they are controlled will differ. Daily and Economon (1983) present a table of water quality standards for fish culture as compiled by the U.S. Environmental Protection Agency which has been reproduced in Table 6 to serve as a general guide. Any one of a number of parameters below optimum level or the presence of pollutants or undesirable organisms will adversely affect growth, food conversion and survival of fish, thus reducing the economic viability of the enterprise.

Frequently, the only water source available is less than ideal and it is often necessary to pre-treat the water to improve its chemical and physical characteristics (Westers 1983). This may involve increasing oxygen concentrations, degassing (nitrogen, hydrogen sulfide and carbon dioxide), removal of suspended solids and buffering (PH control) .

Water must be present in sufficient quantity to supply the necessary amount of oxygen to the fish and to remove waste products, as well as for domestic purposes, cleaning and fire protection (Daily and Economon, 1983). In addition, sufficient water should be available in the event that expansion of the existing facilities is desired.

Each of the major water quality parameters will be discussed separately in the following subsections. A discussion and comparison of water quality data for Jackfish Lake to accepted standards will be provided in Section 4.2.

2.3.7.1 **Oxygen**

Oxygen concentration is one of the most important water quality parameters in the culture of fish. Oxygen levels will naturally vary depending upon the source of the water, temperature, altitude and biochemical processes occurring in the water. The oxygen demand of fish also varies and is regulated by metabolic rate. The higher the rate, the greater the demand. Metabolic rate is influenced by water velocity, temperature, growth rate and age (Klontz et al. 1979).

The amount of dissolved oxygen in the water (ppm) should be maintained at as high a level as possible (at least 90% saturation) and should never fall below 75% saturation (Daily and Economon 1983). Oxygen levels below 5.0 mg/l will result in a considerable loss of growth and increased mortality (Wedemeyer snd Wood 1974, Westers and Pratt 1977).

Current information suggests that Arctic charr may be more resistant to lower oxygen levels than other salmonids. Swift (1964) exposed Arctic charr to water which was only 50% saturated with oxygen and found that growth rate was not significantly lower from fish raised in 100% saturated water. In growth experiments conducted on charr by Baker and Ayles (1987), oxygen concentrations at the highest densities tested were only 5.2 ppm, yet growth rates of the charr still remained high.

High oxygen levels can be maintained through the use of mechanical aeration devices, providing supplemental oxygen and through proper management of tank conditions (density, flow rate).

2.3.7.2 **Ammonia**

Ammonia is one of the major metabolic waste products of many aquatic organisms, including fish. This nitrogenous waste is produced as a consequence of protein deamination and will vary in quantity depending upon metabolic rates (Burrows 1964, Smith and Williams 1974, Thurston et al. 1981). Ammonia occurs in two forms. A nontoxic, ionized form (NH_4^+) and a very toxic un-ionized (NH_3-N) form. The ratio of NH_4^+ to NH_3-N is both temperature and pH dependent (Trussell 1971). Generally, the percentage of un-ionized ammonia present in the water increases with temperature and pH.

Un-ionized ammonia levels in excess of 0.012 mg/l causes a thickening of gill lamellae which decreases oxygen uptake, resulting in depressed growth. Ammonia can be removed from the system by converting it to nitrate which is non-toxic (NO_3-N). This is accomplished in recirculating systems by vitrifying bacteria, which offers the most practical and economical means of ammonia removal (Burrows and Combs 1968). During vitrification, ammonia (NH_3-N) is first converted to nitrite (NO_2-N) by Nitrosococcus and Nitrosomonus bacteria and subsequently by Nitrobacter, to nitrate (NO_3-N) which is completely- harmless to the fish. The intermediate nitrite is also toxic to fish at concentrations of 0.1 - 0.2 mg/l and will retard growth and food conversion, causing death at 0.5 mg/l. However, biological filter units containing these bacteria are very efficient at converting ammonia to nitrate in recirculated water.

2.3.7.3 Nitrogen

The concentration of nitrogen gas (N_2) in water depends solely upon temperature and pressure. Under normal circumstances it is harmless, however if the gas becomes supersaturated as a result of air being forced into the water due to faulty pump lines or seals, it can be very harmful to fish (Daily and Economon 1983). A review of gas supersaturation problems has been provided by Weitkamp and Katz (1980). In nitrogen supersaturated water, gas emboli develop in the fishes' blood vascular system which can cause a reduction in growth and food conversion or even death.

2.3.7.4 pH

The optimum pH level for rearing salmonids is between 7.5 and 8.0 (Klontz *et al.* 1979). Water with a pH below 6.5 is too acidic and will increase the susceptibility of fish to both infectious and noninfectious diseases. Slightly acidic waters also have increased dissolved carbon dioxide, mineral and organic acids which will reduce the buffering capacity of the water (Klontz *et al*. 1979).

2.3.7.5 Alkalinity or Hardness

The minimum acceptable alkalinity (as $CaCO_3$) is 20 mg/l with a maximum of 200 mg/l (Daily and Economon 1983, Klontz et al. 1979). Calcium is required for metabolism, which is mostly satisfied by the diet, but in addition must be present in the water to aid in respiratory and osmoregulatory activities. $CaCO_3$ is also effective in buffering the effects of contaminating substances. Hard water is more productive, which would benefit a cage culture operation in that natural food sources may be more abundant.

2.3.7.6 Heavy Metals

There are many heavy metals which can have deleterious effects on fish health and condition, growth and feed conversion even at very low levels. The concentration at which different heavy metals adversely affect fish also vary (Table 6). Cadmium, arsenic, copper, iron and manganese are all particularly detrimental to fish culture.

2.3.7.7 Organic and Chemical Contaminants

The potential contamination of the water supply as a result of industrial, agricultural or municipal activities is a genuine threat. This can occur as a result of an accidental spill, long-term, low-level input into the drainage system or, as has recently been discovered, via long range transport in the atmosphere. Most contaminants such as pesticides, PCE's and organochlorides are slow to break down and can remain in the environment for a very long time. These compounds may be almost undetectable in the water, but over time become deposited and concentrated in the tissues of the fish.

The proximity of' the municipal dump and a large gold mining operation to Jackfish Lake represent a potential inter quality hazard. Leeching of chemicals, PCB's and heavy metals such as arsenic through the ground water would introduce these compounds to the lake water, and ultimately to the resident fish population. In addition, the presence of the NCPC electrical generating station on the north-east shore of the lake also represents a potential threat to water quality. The continuous low level input of hydro carbons and petroleum by-products and the risk of a large spill does exist. These factors must be considered when determining the location and type of aquaculture facility to be constructed. A program to evaluate and monitor the resident fish population for the presence of organic or chemical toxicants was instituted in February 1987 and shouldbe continued for at least one year.

Preliminary results of heavy metal analysis of water samples from Jackfish Lake and a scan for organic contaminants from muscle tissue of fish captured on February 26 will be presented in Sections 4,2.2 and 4.5 respectively.

2.3.8 Water Source

The availability of a sufficiently large volume of high quality water is the most important factor determining the potential and viability of an aquiculture operation (Castledine 1986). The design of an aquiculture facility will depend strongly upon the source and quality of the available water supply. The facility should incorporate those elements designed to minimize the limitations or constraints imposed by the water source as well as optimize the qualities available.

Surface water sources, such as from Jackfish Lake, are usually undesirable as a primary hater source. Water temperature, dissolved oxygen, suspended solids, pH, minerals and other parameters can fluctuate dramatically both vertically and seasonally. Being exposed, surface water is also vulnerable to pollution or contamination. Ideally, the water source for a fish culture operation should also be free of resident fish which would eliminate the possibility of disease transmission.

2.3.9 **Fish Health**

Arctic charr **are susceptible to a variety of diseases** which **commonly affect both wild and hatchery reared** salmonids. Common **diseases include bacterial kidney disease** (BKD), **infectious pancreatic necrosis virus** (IPNV), **furun**culosis, **abacterial disease of the skin and whirling disease, caused** by **a** parasitic **protozoan.**

The effects of disease are more easily observed and more strongly felt in a hatchery environment than in the wild. The high density and great stress imposed upon hatchery fish *increases* both **susceptibility todisease andtheease of transmission. Fish which become infected** with a disease such as IPNV and survive, become life long carriers of the disease able to pass it on to other groups of fish or through the egg to subsequent generations (Hill 1977, Hnath 1983).

The most effective and only sure means of control of IPNV and other diseases is avoidance. This requires the incubation of disease free eggs and the propagation of disease free stock in an uncontaminated water supply. Very few wild stocks of Arctic charr from which fertilized eggs can be obtained are known to be disease free.

Arctic charr from six sites in four river draimges in the Mackenzie River basin were collected and assayed for IPNV by Souter et al. (1986). They found that the virus was present in fish from all locations with a frequency of infection of' at least 44%. Thus it appears that the Mackenzie River drainage and Yukon and Alaska north slope rivers are not a suitable source of Arctic charr. IPNV has also subsequently been identified in charr from several other areas in the western Arct c as well as BKD in charr from the eastern Arctic (B. Souter, Fisheries and Oceans, Western Region, personal communication).

The Department of Fisheries and Oceans, Western Region, Rockwood Experimental Fish Hatchery is the only North American facility maintaining several stocks of Arctic charr. In 1978 charr from Nauyuk Lake on Kent Peninsula, N.W.T. and in 1980 and 1981 charr from the Fraser River in Labrador were imported to the hatchery. Arctic charr eggs were also received from Norway in 1980. Each of the stocks were certified as being disease free, however their export from the hatchery is prohibited because BKD has been identified in the rainbow trout present in the hatchery.

Strategies for preventing or controlling the outbreak of a disease must be developed. Several important elements of disease prevention include the reliable detection of disease carriers, knowledge of how pathogens are transmitted, development of effective methods to limit the entry of pathogens or carriers into clean fish cultural facilities and to avoid environmental conditions which might allow a disease to become established (Griffiths and Warren 1983).

The most important facet of disease prevention is to restrict impartation of fish stocks into the hatchery which have not been certified "disease free". Strict adherence to this regulation will ensure that the introduction of pathogens is virtually eliminated.

Maintaining a high level of fish health such that fish are not stressed by poor environmental conditions kill also significantly reduce susceptibility to disease.

It is not known to which diseases Arctic charr are particularly resistant or susceptible to, or if they differ from other salmonids in this regard. Immunization, water treatment techniques and attempts to 'breed in' genetic resistance to disease in salmonids are new areas of technology and are still in the developmental stage (Warren 1983). Their specific application to Arctic charr is unknown.

2.3.10 Genetics

Arctic charr are genetically, still considered to be in their wild or undomesticated state. Virtually no selective breeding of charr to improve commercially important traits has been performed to date, Most experimental work with Arctic charr has been performed on wild stocks which have been brought into a hatchery either as eggs or fry (Swift 1964, Wandsvik and Jobling 1982, Papst and Hopky 1983, Jobling and Reinsnes 1986). The exploitation of genetic differences between populations or strains, selective breeding, crossbreeding and inbreeding are all important techniques as means of improving commercially important traits.

Large and rapid gains in production traits can be made through selective breeding! as large phenotypic variation, high fertility and moderately short generation interval allow for very intense selection (Gjedrem 1975b). The degree to which such characteristics as survival, fecundity, egg size and growth rate are heritable, are also very high. Through selective breeding one can expect substantial, rapid improvements in growth, food conversion efficiency, fecundity, flesh quality, disease resistance, and maternal or egg related qualities.

Hybridization within and between salmonid genera has also been employed in order to attempt to improve production characters. Chevassus (19'79) gives an extensive review of the success achieved thus far with interspecific hybridization. Refstie and Gjedrem (1975) also crossed several species of salmonids and found that in most cases the hybrids involving Arctic charr had higher growth rates but lower hatching success than the other hybrids or pure strains.

One of the most important factors when initiating a commercial aquiculture operation is the selection of a suitable strain of fish. The judicious selection of a strain which may possess certain desirable characteristics, or is best suited for a particular environment will offer immediate benefits to the fish culturist without generations of selective breeding. Large variations in growth rates, food conversion efficiencies, survival and other parameters have been shown to exist between strains of fish (Ayles and Baker 1983) and Baker (1983) has shown that the variation in specific growth rate, food conversion efficiency and ration requirement was at least as great between two Arctic charr strains as between Arctic charr and rainbow trout.

The opportunities for selection of a certified stock may be quite limited. This factor however remains of the highest importance and every effort should be made to evaluate at least two geographically distinct strains.

3.0 FEED TYPE EVALUATION

Fish have specific protein, lipid (fat), and vitamin and mineral requirements which must be satisfied by the diet in order to maintain good health. When basic maintenance nutritional demands are satisfied, the extra energy consumed becomes available for growth.

Different diets vary both in composition and in quality and quantity of ingredients. The specific nutritional requirements of each salmonid species have not been determined and many different diets have been manufactured to satisfy the general requirements of salmon or trout. It is therefore important to choose a diet which will provide for the maximum feed conversion efficiency and growth rate possible.

Several of the commercially manufactured diets which are available have been evaluated using Arctic charr. Tabachek (1984) found that not all trout or salmon diets were suitable, depending upon the strain of charr being tested. (See Section 2.3.2) For example, Martin Feed Mills trout feed proved to be an excellent food source for Arctic charr from Labrador, but was inadequate for charr from Norway. Therefore it is recommended that initially, at least two different diets be evaluated. Nutritional deficiencies become manifest as increased feed:gain ratio, poor growth, increased mortality and other symptoms. A list of the symptoms displayed by salmonids, which occur as a result of nutritional deficiencies are presented in Table 7 (after Hilton and Slinger 1981),

The cost of feed accounts for between 30% and 50% of total production cost. It is therefore important to provide a feed that not only satisfies nutritional requirements, but is also economical. The following sections will briefly discuss the general nutritional requirements of Arctic charr and feed types available, followed by an evaluation of the economic benefits and technical feasibility of providing a food source manufactured locally, versus a commercially manufactured trout food.

3.1 GENERAL NUTRITIONAL REQUIREMENTS

The four major nutritional groups which are represented in all manufactured diets are protein, lipid, carbohydrate and vitamin and mineral supplements. The proportion of each item in the diet varies according to the manufacturer, but also according to the size of the fish for which the feed is designed. Older fish which grow relatively slower, have a lower protein and lipid requirement than do small, fast growing fish. Requirements of each of the major nutritional groups will be discussed separately.

3.1.1 Protein

Protein comprises the majority of the diet (40 - 50%) and is the single most expensive ingredient (Hilton and Slinger 1981). Fish require at least twelve essential amino acids, the building blocks of proteins. Unfortunately, vegetable proteins which are most economical source, do not provide all of these amino acids so it is necessary to include animal protein, particularly fish meal, in the diet. Alternative protein sources include animal by-products such as poultry by-product meal, blood and meat meal, including various vegetable meals such as soybean or corn gluten.

Diets which are relatively higher in animal protein sources are generally more palatable to the fish and contain less carbohydrate, for which salmonids have a relatively low tolerance. The availability of an inexpensive protein source, such as rough fish from the Great Slave Lake fishery has the potential to provide a large proportion of the protein requirement in a manufactured diet. However, rough fish and fish silage must still be supplemented with a high quality fish meal (herring or capelin) to provide additional protein and lipid.

3.1.2 Lipid

Lipid or fat provides twice the energy per unit weight than protein. It is also important in cell membrane function and formation (Hilton and Slinger 1981). There are a variety of different types of fatty acids which are required by fish. They differ from one another depending upon their degree of saturation and position of double bonds between carbon atoms.

Salmonid diets normally contain between 15 - 20% fat, which is supplied in the form of animal and vegetable fats. Marine fish oils provide high levels of essential fatty acids and seem to provide for improved growth rates than fish fed vegetable oils.

The ratio between protein and lipid also seems to be important for Arctic charr. In a study by Tabachek (1986) Arctic charr performed better at higher protein:lipid ratios (44-54%:15-20%) than normally employed in salmonid diets (35% protein:10% lipid). It is believed that the higher amount of fat present is utilized as an energy source before protein is, leaving more protein available for growth (Reinitz and Hitzel 1980, Clarke et al. 1982).

3.1.3 Carbohydrate

Carbohydrates do not naturally occur in the diet of wild Arctic charr and the requirement for carbohydrates are subsequently low. Economically, it would be desirable to use cereal grains as an energy (carbohydrate) source, but due to the low tolerance salmonids have to carbohydrates, it normally does not comprise more than 0% to 10% of the diet.

3.1.4 Vitamins and Minerals

There is a wide range of vitamins and minerals which fish require to maintain good health and condition (Table 7), however the exact quantities of each are not known for fish. Essential vitamins and minerals are mixed (premixes) and combined with the remaining dietary ingredients represent between one and two percent of the diet.

Vitamin and mineral premixes are essential ingredients in both commercially manufactured diets as well as diets manufactured primarily from fish or fish by-products. These premixes can be manufactured in bulk quantities by commercial feed companies according to supplied specifications.

3.2 FEED TYPES

There are three basic feed types. Wet, moist and dry feeds. The essential difference between the different types of feed is their moisture content. The uses, advantages and disadvantages of utilizing wet, moist or dry feeds will be discussed in the following sections.

3.2.1 Wet Feed

Wet feed consists simply of ground whole fish, fish parts or other **ground** meat. Vitamin and mineral supplements may be added, as well as binding agents (i.e. wheat middlings) to make the food "stick" together. Wet food contains approximately 80% moisture, 8 - 10% protein and 5 - 7% fat, depending upon ingredients. Wet feed is converted very inefficiently because of its high water content. Feed gain ratios of fish fed wet feed range from 5:1 to 7:1. Wet feed is commonly used in Norway to feed salmon held in sea cages (Edwards 1978) but is only used in areas where large, consistent supplies of fresh, trash fish are available.

Wet feed is very palatable and can be economical, however it has many disadvantages. Preparation of wet feed requires special machinery and is very labor intensive as four times the amount of wet feed must be fedas dry feed. The ingredients are also highly perishable and must be received fresh every day or frozen. Wet feed also breaks down very quickly and tends to pollute the water and is therefore not recommended for use in tanks or raceways.

3.2.2 Moist Feed

Moist feeds are manufactured with a combination of wet fish or fish by-products and dry ingredients. Dry ingredients include fish meal and oil, vegetable meals, binders, minerals and vitamins. Raw fish are minced and combined with the dry ingredients, mixed and extruded to form moist pellets.

Moist feed has a water content of only 20 - 25% and is converted much more efficiently than wet food with a feed:gain ratio of 2:1. It is \-cry palatable and can be easily manufactured on site on a daily or weekly basis as required. Refrigeration or freezing of moist feed and wet ingredients is necessary.

Capital costs of equipment required to manufacture a moist feed will be discussed in Section 3.5.

3.2.3 Dry Feed

Dry feed is manufactured from a mixture of fish meal, fish oil, poultry and blood meal, vegetable meals (soybean, corn), wheat middlings, choline chloride and mineral and vitamin premixes. Manufacture of dry feeds require large, expensive equipment such as an industrial blender, a hammer mill for grinding, a roller mill for crumbling, an extruder, pelletizer and drier. Total cost for this equipment is estimated to be $220,000 to s250,000 (Dr. C. Frantsi, Connors Bros. Ltd., Blacks Harbour, N.B., personal communication). It is not economical for most aquiculture operations to manufacture their own dry feeds.

There are many commercially manufactured dry feeds available. The major suppliers of trout and salmon feeds are listed below:

1. Martin Feed Mills Trout Feed, Elmira, Ontario
2. Abernathy Salmon Diet, Buhl, Idaho
3. Ranger Foods Inc., Buhl, Idaho
4. Zeigler Bros. Inc., Gardners, P.A.
5. Purina Trout Chow, St. Louis, Miss.
6. Sterling Silver Cup Trout Feed, Murray, Utah.

More feeds manufactured in Canada should become available with the increase in the number of salmon farms on the east and west coasts.

Composition of the diet varies according to both the manufacturer and type of pellet (for starter, production or brood fish). A list of ingredients which are typically present in dry feds is provided in Table 8. Feeds containing synthetic ingredients such as canthaxanthin can be purchased which will give a red color to the flesh to make it more presentable. While fish fed synthetic carotenoids can be marketed in Canada, their export to the U.S. is forbidden. Choice of a dry feed should be based upon performance of your fish on that feed. Arctic charr have a higher protein to fat ratio requirement, therefore choice of a dry feed for initial evaluation should be based upon the percentage of protein and fat contained in the diet.

Feed conversion efficiencies of fish fed dry feeds are very high. Dry feeds contain only 10% moisture so the food ingested contains much higher levels of essential nutrients by weight than any other food type. Feed:gain ratios of 1:1 or less have been attained under certain conditions, however a feed:gain ratio of 1.4 to 1.5 could be expected for Arctic charr fed a commercially manufactured dry feed.

3.3 TYPES OF FEEDERS

Fish can be fed either by hand, by mechanical, automatic feeders or by demand feeders. Feeding fish by hand allows close monitoring of the fish so that over or underfeeding is avoided. Charges in fish feeding behaviour, often indicative of a problem (disease or low water quality), are also easily recognized by hatchery personnel. Feeding large quantities of fish by hand however requires a great deal of time and effort and may not be economical. Fish fed wet feeds must be fed by hand due to the volume and condition of the feed.

Automatic feeders dispense a prescribed proportion of the daily food ration at set intervals. There are a variety of types of automatic feeders available. Food can be broadcast from trays suspended over raceways, from "cannon like" feeders using compressed air to disperse feed or from hoppers suspended over a spinning disk. If the automatic feeder broadcasts food uniformly over the tank it can be very effective in delivering the daily quota of food with a minimum of labour and cost. Automatic feeders are commonly employed in raceway or cage culture facilities.

Demand feeders, as is implied, allow the fish to feed upon demand. By stimulating a pendulum suspended within the tank a small volume of food is released. The more the fish stimulate the pendulum, the more food is delivered. Demand feeders require no power, can reduce labour and maintenance costs and ensure that fish receive food only when they are hungry which subsequently increases feed gain:ratios

3.4 EVALUATION OF COMMERCIALLY MANUFACTURED FEEDS

3.4.1 Source

There are numerous sources of commercially manufactured fish feeds and an abbreviated list is provided in Section 3.2.3. One of the major Canadian producers of high quality fish feed is Martin Feed Mills, Elmira, Ontario. Martin Feeds has been chosen tobe evaluated because it is a reputable Canadian company which produces a satisfactory feed for Arctic charr (Tabachek 1984, 1986).

3.4.2 Cost and Volume

As discussed in Section 3,2.3, there are several types of feed available. Prices vary according to pellet size and formulation, whether for starter, grower or brood stock (Table 9).

The total estimated amount of dry feed required annually to raise 32,500 kg of fish is 48,750 kg, based on a feed:gain ratio of 1.5:1 (Appendix 2). Following is a breakdown of estimated **annual** cost and volume requirements of starter and grower feeds during full production, again assuming a feed:gain ratio of 1.5.

Proportion	Mean Cost per 25 kg	Estimated Total Volume (kg)	Estimated Total Cost
15% Starter	$19.73	7,313	$5,777.00
85% Grower	$15.35	41,438	s25,443.00
Total		48,751	s31,220.00

At lower or higher feed: gain ratios, annual feed costs will be reduced or increased accordingly as illustrated below.

Feed:Gain Ratio	Total Annual Feed Cost
1.3	$27,057
1.4	$29,139
1.5	$31,220
1.6	$33,301

For delivery of the feed to Yellowknife, Martin Feed Mills has quoteda price of $32.80 per 100 kg of feed for orders in excess of 9,000 kg. For 18 tonnes of feed, the total annual transportation cost to Yellowknife would be approximately $15,745.

Arnold Bros. Ltd., Winnipeg, was also contacted to provide an estimate for the cost of shipping a years supply of feed to Yellowknife. Prices quoted are as follows:

Guelph to Edmonton	$7,200
Edmonton to Yellowknife –	$5,100
Total Cost	$12,300

Therefore, the minimum total cost, including transportation for one year's supply of commercially- manufactured dry feed delivered to Yellowknife is $43,601 (assuming a feed:gain ratio of 1.5:1).

3.4.3 Availability

Commercially manufactured dry feeds are readily available in large quantities year round, Maintaining sound records and allowing sufficient time for manufacture and shipping will ensure that shortages of a particular feed or feed size do not occur.

3.4.4 Handling and Storage Requirements

Dry feeds do not require refrigeration or freezing. They are treated with an antioxidant and hermetically sealed in plastic bags to prevent breakdown of the fish oil and loss of vitamins. It is important that dry feeds do not become damp or wet which would result in loss of nutrients and mouldy feed.

It is recommended that dry feeds be used within six months to ensure maximum quality. Their shelf life can be extended with refrigeration or freezing.

3.5 EVALUATION OF LOCALLY MANUFACTURED FEED

Manufacturing a moist or wet feed from raw ingredients requires specialized equipment such as grinders, mixers and extruders, large refrigeration or freezer capability, and experienced personnel, high quality supplemental ingredients and above all, a reliable source of fresh or frozen fish on a year round basis.

A moist feed for swim-up and small (<12 g) fish cannot be economically manufactured on site. Specialized, expensive equipment is required to manufacture the small, high quality, discrete granule's required for young fish. A commercially manufactured starter feed would still have to be imported for fish of < 12 g.

The following sections evaluate the technical and economic aspects of each of the above requirements, followed by an overall evaluation of the feasibility of manufacturing a moist feed locally.

3.5.1 Diet Formulation

To manufacture a moist feed requires fresh fish and a variety of supplemental ingredients which must be included to give the proper nutritional balance and consistency to the feed. As discussed in Section 3.2.2 a moist feed is recommended over a wet feed because of its high palatability, its nutritional quality and low moisture content.

The specific diet formulation of a moist feed will vary according to the type of fish and other ingredients available as well as the species for which it is being manufactured. A general formulation as provided by Dr. C. Frantisi (Connor's Bros. Ltd., Black's Harbour, N. B.) who has experience in manufacturing moist feed for Atlantic salmon and more recently Arctic charr, is as follows:

45%	raw fresh or frozen fish (whole or parts)
35%	fish meal (herring or capelin)
6%	fish oil (herring)
0.4%	choline chloride
12-13%	binder (wheat middlings)
1-2%	vitamin and mineral premix

The fresh or frozen fish recommended for use is lake cisco or tulibee, which is an abundant trash fish of the Great Slave Lake fishery. The remaining ingredients are available in bulk from most commercial animal feed manufacturers. If specific quantities of all ingredients, other than the fish are provided to the feed company, it can be mixed and bagged in Winnipeg or Edmonton and shipped to Yellowknife. This mixture (55% of the total weight) can then be combined with the raw fish as required to obtain the correct dietary formulation.

3.5.2 Equipment Requirements and Cost

The equipment required for manufacturing a moist feed can be satisfactorily supplied by manufacturers of industrial food processing equipment such as the Hobart Manufacturing Co. Ltd. in Don Mills, Ontario. The manufacturing process requires that the raw fish be ground into small pieces, mixed with the supplementary ingredients and extruded through dies of varying diameter to produce different sized feeds of a hamburger like consistency.

Approximately 165 kg of feed would be required per day based upon the proposed design (Appendix 2). This could be manufactured on a daily or weekly basis and frozen until required. A freezer facility of at least 50 m^3 volume is recommended for feed storage.

Additionally, the fish must also be pasteurized before mixing with the dry ingredients. This is done for two reasons. Using raw, unpasteurized fish greatly increases the risk of introducing a disease into the resident fish population and secondly, the viscera of raw fish contains an enzyme called thiaminase. Thiaminase breaks down the vitamin thiamine in the feed which causes a thiamine deficiency in the fish resulting in convulsions and neuritis.

Total costs for the required equipment as supplied by Hobart is as follows:

5 hp 4146 Meat Grinder	$5,223
V-1401 Mixer (including bowl and beater)	s21,496
424(WI) Extruder	S9,105
TOTAL	s35,824

The total cost of $35,824 does not include the cost of a freezer or pasteurizing oven, both of which are required.

3.5.3 Availability of Feed Ingredients

Supplementaral dry ingredients are available in bulk year round and their supply is guaranteed. As the supply of trash fish is expected to be sporatic it is recommended that large volumes of fish be purchased when available and frozen to ensure that a shortage does not occur.

3.5.4 Annual Cost of Manufacturing Feed

Based upon an annual production of 32,500 kg of Arctic charr and assuming a feed:gain ratio of 2:1, 65,000 kg of moist feed would have to be manufactured. Approximately 7,313 kg of this total requirement would have to be fulfilled by a commercially manufactured starter feed. At a mean cost of s0.79/kg, this represents a cost of S5,777, plus transport. Of the remaining volume (57,700 kg), 45% of this (25,965 kg) is comprised of raw fish and 55% (31,735 kg) of supplementary ingredients.

Feed - Rite Mills. Winnipeg was contacted to provide a cost estimate of supplying the required supplementary ingredients in bulk quantities, premixed and bagged. Following is a cost breakdown by ingredient as quoted by Feed - Rite Mills.

	$/kg	Total Volume (kg)	cost
35% Herring Meal	0.84	20,195	$16,934
6% Fish Oil	1.68	3,462	$5,816
12% Wheat Middlings	0.27	6,924	$1,869
2% Choline, Vitamin and Mineral Premix	0.93	1,154	$1,073
TOTAL		31,735	$25,692

To supplement the dry ingredients raw, trash fish must be purchased regularly. According to Mr. D. Stewart, President of the Fishermen's Federation in Hay River, N.K.T., fish and fish offal would be available at a cost of approximately, $0.25/kg on a sporadic, noncontractual basis. On a contract basis this cost would be considerably higher, For a required estimated volume of 25,965 kg fish per annum, the total cost of the raw, trash fish is $6,491.

Therefore, the total estimated cost of manufacturing a moist feed in Yellowknife is $43,060 and is broken down as follows:

Cost of Raw Fish	$6,491
Cost of Supplementary Ingredients	$25,692
Cost of Commercial Starter Feed	$5,777
Transportation Cost of Dry Ingredients from Edmonton	$5,100
TOTAL COST	$43,060

3.5.5 Storage and Handling Requirements

The dry supplementary ingredients are treated with an antioxidant and do not require freezing. The raw fish silage must either be used immediately or frozen. The final manufactured pellet can be refrigerated for several days or covered and frozen for subsequent use. A minimum of one to two weeks supply of feed should be kept on hand in the event of a shortage of raw fish.

3.6 COST COMPARISON BETWEEN MANUFACTURED AND COMMERCIAL FEEDS

The total cost of importing a commercially manufactured feed, including transportation is s43,601. per year. Total cost including purchase and transport of all ingredients of a locally manufactured feed is approximately $43,060. Note that capital costs for equipment purchase and labour are not included.

Based on the absence of a cost difference (other than capitol and labour) between the feed types, combined with the higher palatability and performance of fish on a moist feed, it is recommended that a locally manufactured feed be used. If a reduction in the raw fish:dry ingredient ratio does not affect performance, this will further reduce feed costs and supply the Great Slave Lake fishermen with a limited market for their trash fish.

4.0 PHYSICAL SUITABILITY OF JACKFISH LAKE

Jackfish Lake is located 1 km northwest from the city of Yellowknife in an area of low rocky hills which are sparsely covered with black spruce, poplar and birch (Roberge and Gillman 1986). The lake has a surface area of approximately 60 ha with a mean depth of 6m. Like most precambrian shield lakes it is relatively unproductive.

The following sections will assess the limnological and biological suitability of Jackfish Lake to support an intensive culture facility for Arctic charr.

4.1 LIMNOLOGICAL ASSESSMENT

4.1.1 Seasonal Temperature Regime

The following evaluation is based upon information collected from Jackfish Lake during 1980-1981 by Roberge and Gillman (1986),

Jackfish Lake is a dimictic lake which circulates freely from top to bottom during the spring and fall and is directly stratified in the summer and inversely during the winter.

In the spring of 1980, shortly after break-up the lake circulated freely and water temperatures rose uniformly throughout the lake (Fig. 4a). By mid-May the lake began to stratify with surface waters (11°C) becoming warmer than bottom waters (9°C). This warming continued rapidly through the spring and early summer until surface waters were up to 6° - 7°C warmer than bottom waters.

During the summer, surface water temperature reached a maximum of 19°C and the lake became stratified to a depth of 6m. Bottom water temperatures ranged between 10°C and 160c on 13 May and 22 August respectively.

By the end of August water temperatures had begun t. decline and wind action had mixed the lake to a uniform temperature of 16°C to within 1 m of the bottom. Rapid cooling and complete mixing continued to occur and by the end of September the lake was a uniform 8°C (Fig. 4a). This uniform cooling continued until the mid to end of October when freeze up occurred. During the winter, water temperatures ranged from OOC to 3.0°C at the bottom (Fig. 4b).

During the present winter survey (February 1987) water temperature ranged from 0°C at the ice . water interface to 2.0°C at the bottom (Fig. 4c). Differences in temperatures between stations on Jackfish Lake did not differ according to depth. The ice thickness below 0.6 m of snow was 1.0 to 1.2 m in depth.

4.1.1.1 Effects of Water Temperature on Cage Culture

Fish cultured in cages in Jackfish Lake would occupy space in approximately the upper 5 m of water. Between the end of May and early September (Fig. 4a), the upper 5m of water exceeded 15°C and was generally in excess of the optimum growth temperature for Arctic charr. At 18°C growth rates would be reduced by 50% from what could be achieved at 13°C and the feed:gain ratio would double. The problem during most of the summer therefore lies not in heating the water, but in cooling it, Cooler water from the bottom 1-2 m would have to be brought to the surface through the use of mechanical aeration devices. Rising air will "drag" water with it to the surface, reoxygenating it at the same time. However, the bottom water is virtually depleted of oxygen (Fig. 4a) and contains a high concentration of hydrogen sulfide (H_2S) which is toxic to fish. It is not known if' mixing with an aeration system would overcome these problems.

In winter the water in the vicinity of the cage culture operation would have to receive the maximum degree of heat output from the NCPC electrical generating station and be circulated continuously with an aeration system to prevent freezing. If freezing can be avoided, water temperature would remain \-cry low (1°-4°C) because recirculation will keep the water in continuous contact with very cold air. At these temperatures, Arctic charr will not feed and will suffer a net loss of 'weight.

4.1.1.2 Effect of Water Temperature on Tank Culture

Arctic charr raised in tanks or raceways in a hatchery exist in a more controlled environment and are not subject to the seasonal and vertical fluctuations in temperature to which cage reared fish are exposed.

During the winter, tanks can be supplied with the proper mix of warm water effluent from the generating station and cold lake water, such that growth and food conversion rates can be maintained at their highest levels.

In the summer, water from Jackfish lake is warm enough so that waste heat from the generating station is not required. To control temperatures, the hatchery's water intake valve should be adjusted vertically in the water column in order that water nearest the optimum growth temperature can be obtained. In this way lake water temperatures which fluctuate dramatically both vertically and seasonally are buffered and their effect on growth ameliorated.
However, because summer water temperatures in the lake are high, a similar problem is faced here as during cage culture in the summer. Methods t. reduce temperatures and sulphur dioxide levels would have to be investigated.

4.1.2 Seasonal Oxygen Regime

The annual fluctuation in the distribution and abundance of oxygen in the water column follows that of temperature quite closely. During the spring and fall, the entire water column is circulated and comes in contact with the surface and is oxygenated to near saturation.

During the summer as the lake stratifies, the epilimnion (the warm, surface water) becomes cut off from the hypolimnion (the cooler, bottom water), Oxygen concentrations in the circulating epilimnion remain relatively high while the hypolimnion becomes anoxic with an oxygen concentration near zero mg/l (Fig. la). Because the volubility of oxygen in the water also depends upon temperature, less oxygen is dissolved in the warm epilimnion, only 6-8 mg/l. This approaches the lower limit of 5 mg/l whichis required to prevent respiratory stress and to maintain fish health, Duringthe winter after ice formation, the only generation of oxygen in the lake occurs as a result of a very low level of photosynthesis. The continued respiration of aquatic animals and decomposition of organic material depletes much of the available oxygen, particularly in the bottom 1-2m (Fig. 4b). Should oxygen levels bocome low enough, mortality of fish can result.

4.1.2.1 Effects of Oxygen on Cage Culture

During the spring, summer and fall, oxygen concentrations in the epilimnion ranged between 7 and 9 mg/l which is marginal for cage culture purposes. Given the increased oxygen demand by fish stocked at relatively high densities in a small area and metabolizing at a high rate, there is a risk of reducing oxygen concentrations to the threshold limit. To prevent oxygen depletion of the water, especially during the summer, an aeration system would be required to oxygenate the entire water column.

During the winter, oxygen concentrations under the ice ranged from 2 to 14 mg/l with a mean concentration of 10 mg/l. If an area of open water could be maintained and circulated, sufficient oxygen might be present, however the presence of hydrogen sulfide may pose a hazard.

Cages cannot be maintained intact in the ice through the winter as they would be easily destroyed.

4.1.2.2 Effects of Oxygen on Tank Culture

Incoming warm water gained from the electrical generating station will be very low in oxygen content due to the low volubility of oxygen in water at high temperatures (a maximum of 7.0 mg/l at 35°C). Therefore all incoming water derived from the NCPC station and from the lake must be oxygenated in order to satisfy the high oxygen demand of fish reared under intensive aquiculture conditions. This should be performed regardless of season as the process of oxygenation will also release gases which are harmful to fish, such as nitrogen (N_2) and hydrogen sulfide (H_2S), into the air, Tnis procedure is very simple, efficient and inexpensive.

A greater degree of control can therefore be achieved in maintaining high oxygen concentrations in a land based operation than a cage culture facility.

4.2 WATER CHEMISTRY

Lake water samples were collected from the surface and from within 1 m of the bottom at each of the five sampling locations on Jackfish Lake during February 26, 1987 (Fig. 1). These were analyzed for essential ions, dissolved solids, pH and ammonia levels (Table 10). In addition, the water was analyzed for the presence of dissolved heavy metals (Table 11). These are compared with data collected from Jackfish Lake by the Department of Fisheries and Oceans during 1977-78 (Table 12) and compared to acceptable maximum limits of water as established by the U.S. Environmental Protection Agency (1979-80) (Table 6).

4.2.1 Evaluation of Dissolved Minerals and pH

All essential ions and dissolved minerals examined from water collected from Jackfish Lake in 1977-78 (Table 11) and in 1987 (Table 9) fell within U.S. EPA (1978-79) water quality standards with the exception of calcium levels which were slightly lower than recommended (Table 6).

Equilibrated pH levels however were extremely high. Before the samples had equilibrated in the lab (by allowing CO_2 to escape), pH levels averaged 7.5, normal for most lakes (Wetzel 1975). During equillibration, levels rose and stabilized at a PH of 10.2-10.3. At these very high levels, the concentration of unionized ammonia (NH_4-N) exceeds lethal limits to fish. Reasons for the high equilibrated pH levels are not known and no explanation can be offerred for these results (Mr. M.Stainton,Department of Fisheries and Oceans, Winnipeg, Water Chemistry Section). It is strongly recommended that further water chemistry analysis, particularly on pH and ion balance be performed.

4.2.2 Heavy Metals Analysis

Generally, levels of the heavy metals iron, lead, copper and magnesium from water collected in February 1987 (Table 11) fell within acceptable standards (Table 6). Zinc levels were slightly in excess of maximum acceptable limits both during the present survey and during the 1977-78 survey as were levels of nickel, copper and magnesium (Tables 11 and 12). The levels observed are not significantly in excess of recommended limits and would not be expected to represent a threat to fish health. Concentrations of heavy metals from water samples taken from near the bottom are generally higher than from surface water samples which indicate that the sediments act as a trap for heavy metals. Sediment samples would be expected to have considerably higher concentrations of heavy metals (Wagemann et al. 1978).

High levels of arsenic in lakes from the Yellowknife area have been previously documented (Wallace and Hardin 19'75, Wagemann et al. 1978).

Arsenic is a gange mineral, generated as a by-product from gold mining operations of which there are several in the vicinity of Yellowknife. Arsenic is very soluble in water, and becomes abundant in the local atmosphere as a gas, in rainwater and associated with dust particles, During 1975 arsenic levels were measured in aquatic invertebrates, sediments, macrophytes and– water from lakes near Yellowknife by Wagemann et al. (1978). Aquatic arsenic concentrations as high as 5.5 mg/l were found in Kam Lake while levels up to 2.4 g/kg dry weight (2400 ppm) of zooplankton were observed. There was however, considerable variation in arsenic concentrations with time, location and species.

Levels as high as these were not observed from water samples collected during the present study (0.1 mg/l) or during the 1977-78 survey (0.14 mg/l), however they still significantly exceed U.S. EPA acceptable limits (0.05 mg/l) (Tables 11 and 12). Very little is known about the sub-lethal toxicity limit of arsenic to aquatic organisms. It is also not known if exposure to chronic levels of arsenic such as those presently found in Jackfish Lake are harmful to fish, nor is the relationship between arsenic and the age and size of fish known.

Despite very high levels of arsenic in the water and in the herbivores, arsenic does not seem to become concentrated in carnivorous organisms. Unlike other trace metals such as mercury, there is no evidence of bioaccumulation through the food chain to higher trophic levels, for example by invertebrates and fish. However, as intensively cultured fish would not be consuming a natural food source, this might limit the amount of arsenic incorporated in the tissue.

Wallace and Hardin (1975) examined whitefish and northern pike from Kam Lake and found a maximum level of 3.2 ppm (mg/kg) in pike muscle tissue. According to the Canadian Focal and Drug act and Regulations (1S79), the maximum acceptable level of arsenic in fish protein is 3.5 ppm. These fish would therefore still be acceptable for commercial sale, although just barely. Further study on the relationship between dissolved aquatic arsenic levels and the size and age of fish is strongly recommended.

4.3 Fish Health

Six lake whitefish and two northern pike collected on 26 February 1987 from Jackfish Lake were examined for the presence of protozoan, bacterial and viral diseases by the Department of Fisheries and Oceans, Winnipeg, Fish Health Section. No pathogens were detected from these fish and they were judged to be "disease free". A larger number of fish should be examined before a definitive statement as to the health of the resident fish population can be made.

4.4 Tissue Analysis of Hydrocarbon and Organochloride Contamination

Muscle tissue samples of the northern pike and whitefish species captured were examined for the presence of hydrocarbon and organochloride cent.amlnation, These would result from chronic, low level input due to chemicals or toxicants leeching into the lake through groundwater or via airborne transport. At the time of publication, results from the organochloride scan were not available and will be included as an addendum when received and interpreted.

No unusually high levels of hydrocarbons were found in the pike or whitefish muscle tissue. Trace levels of ethylbenzyne, orthobenzene and xylene were found in both species which are believed to have become introduced as a result of long range atmospheric transport of industrial pollution. The levels of hydrocarbons found in fish from Jackfish Lake are no higher than for fish found elsewhere in isolated lakes in North America (Dr. D. Murray, Fisheries and Oceans, Winnipeg, personal communication) .

5.0 EVALUATION OF THE NCPC JACKFISH LAKE ELECTRICAL GENERATING STATION

Discussions were held with NCPC staff at the Jackfish Lake electrical generating station on February 24, 1987. The Jackfish Lake station has two diesel fueled generators, each with a maximum electrical generating capacity of 5 megawatts. The majority of Yellowknife's power demand is supplied by the 30 MW Snare River hydroelectric station. The diesel generators at Jackfish Lake therefore only supply supplementary power during peak periods and normally do not operate between June and August. In addition, an expansion of the Snare River generating station is planned which may reduce the demand for power from the Jackfish Lake facility. However, staff of the Jackfish Lake facility expect power output to increase during the next several years. In 1986-87, 3,300,000 litres of diesel fuel were burnt but is expected to increase to 5 million litres in 1987-88 and 8 million litres in 1988-89.

During normal operation, the station produces 11,250 l/rein of 360 to 50° C water between September and May. However, the pump which circulates water through the station functions continually on an annual basis, regardless of operational status. The fluctuating and intermittent generation of waste heat by the Jackfish Lake station must be considered in the design of an aquiculture facility.

6.0 EVALUATION OF CULTURE SYSTEMS

The following sections will examine the relative advantages and disadvantages of cage culture and tank culture as they apply t. Jackfish Lake. A brief summary and evaluation is detailed in Table 13,

6.1 Cage Culture

Cage culture can be defined as the intensive rearing of fish in a freshwater or marine environment where fish are contained h'ithina large net which is suspended in the inter by a floating frame.

6.1.1 Capital Investment

The capital investment for a cage culture facility is low. Land requirement is minimal and cost of materials (nets, flotation, dock, anchors) are low. However, feed storage and refrigeration facilities, cleaning equipment, vehicles, sampling gear and processing facilities will be comparable to a tank culture operation. In addition, the cost of a heat exchanger (to gain heat from the effluent), piping, flow regulators and control mechanisms will have to be provided for both facilities.

6.1.2 Operational Cost

Operational costs of a cage culture facility are slightly lower than in a hatchery. Less electricity is required to operate pumps and lights, less heat is required to heat buildings, and the cost of maintenance is reduced. Reduced maintenance costs will also reduce the cost of labour slightly.

A significant reduction in relative labour costs can only be achieved through the economy of scale. An aquiculture facility operates 24 hours per day, seven days a week. Staff must normally be present 10-12 hours per day with some provision for additional costs incurred during harvest or for emergencies during off-hours.

A high degree of security must also be present during off-hours to prevent theft or vandalism.

6.1.3 Maintenance and Monitoring

The effort involved in the maintenance and care of a cage culture facility is fairly low. Regular attention must be paid to the physical condition of the cages so that rips or tears do not go unnoticed which would allow fish to escape. Nets must be cleaned by divers at regular intervals so that algae does not build up on the mesh, thereby reducing circulation.

Monitoring the health of the fish is easy and comparable to that of a tank culture system. Changes in swimming or feeding habits, a reduction in growth or feed conversion and increased mortality are easily observed and may indicate a potential environmental or biological problem. Removal of mortalities is however, slightly inore difficult.

6.1.4 Water Quality

The water quality of lakes are generally of higher quality than is found in tanks. Provided there is adequate circulation or movement of water through the cage, oxygen levels are higher and concentrations of metabolic wastes are lower because they are carried away. As no pumping of water is required, the risk of a supply failure does not exist.

Water depth must be at least 6m over a substantial area with a steep increase in depth near shore. Jackfish Lake barely provides this in several areas (Fig. 1), being 7'-8 m deep relatively near shore. However, according to NCPC station staff at Jackfish Lake, the lake is subject to fluctuations in depth, with water levels dropping from 1-2 m in dry years. This factor combined with the anoxic conditions which exist in the bottom 1-3 m (Fig. 4a) of the lake during mid-summer and winter could possibly reduce the effective, reliable depth to 4-5 m, which is insufficient depth for cage culture purposes.

The combination of an elevated nutrient load surrounding the cages and insufficient circulation (which is a strong possibility given the small size of the lake and lack of inflow or outflow) increases the risk of eutrophication and developing an algal bloom. Should this occur, the possibility of a "summerkill" situation exists, whereby the algae suddenly dies off and its decomposition depletes the available oxygen. This would result in a high loss of fish due to oxygen starvation. To minimize this risk, an emergency air supply would have to be available to circulate and re-oxygenate the water.

6.1.5 Growth and Yield

Growth rates of fish raised in cages are generally higher than growth rates of fish raised in tanks. This is primarily due to the lower density of fish and higher water quality found in cages. Densities in cages rarely exceed 30-40 kg/m³, compared to densities in excess of 80-100 kg/m³ in tanks. Consequently, yield on a m³ basis is lower in cages than from tanks. This is compensated for by maintaining large volume cages.

As it would be very difficult, if not impossible to hold fish in cages over the winter, fish would have to be harvested before freeze-Up. The combination of low, fluctuating summer water temperatures and short growing season would not guarantee the fish will achieve market size in one season. If the fish did achieve market size, they would coincide with the harvest of wild charr and the market price would be lower.

6.1.6 Environment

Environmental conditions present at Jackfish Lake make the feasibility of developing a cage culture operation extremely low. Ice thickness on Jackfish Lake varies between 1 and 2 m in depth with anoxic conditions existing within 1-3 m of the bottom during much of the winter. Water temperatures would below, no more than 2°-4° , and any growth would be extremely low. Faeces, excess food and nitrogenous wastes would accumulate in the water and sediment in the vicinity of the cages, causing a significant loss of water quality due to the lack of circulation.

The area of open water surrounding the effluent outlet of the NCPC electrical generating station during February, 1986 Las small, less than 800 m². The area of open water required for a small operation of six 10 m cages would be approximately 2275 m². Temperature data from station 5, within 100 m directly offshore of the ice edge, was not significantly different from water temperatures elsewhere in the lake (Fig. 4c).

Handling of fish during the winter for censusing, inspection, transfer or disease treatment would be very difficult. Water coating the delicate gill filaments would quickly freeze extensively damaging gill tissue, impairing respiration and causing death.

During spring break-up shifting ice driven by high winds could cause extensive damage to nets and the supporting frame resulting in the possible escape of all fish.

6.1.7 Disease

There is a moderate risk of d.isease occurring amongst fish reared in cages in freshwater, particularly in an environment containing resident fish. The existance of a parasite, protozoan, bacterial or viral disease in the resident population increases the risk of its spread through the cage reared fish. Proper fish husbandry practices can reduce the risk of infection, however this is fully dependent upon the type and severity of the disease.

6.1.8 Predation, Theft and Vandalism

Loss of fish due to predation, from birds and small mammals such as mink and muskrat is a common problem. Predation from birds can be prevented by placing string or a removable mesh over the cages but the loss of all fish as a result of a hole from a muskrat is difficult to prevent.

Poaching of fish from cages can also represent a significant loss of potential yield, which, combined with the vulnerability of cages and fish to vandalism, demands that a security system be instituted to prevent unnecessary loss.

6.2 Tank Culture

Tank culture is the general term applied to any of a variety of fish holding Facilities such as raceways, circular or rectangular tanks and silos of varying size and construction, usually concrete, plastic. or fiberglass. These systems are all land. based and occasionally enclosed. Where only a cold water source is available, it is recirculated to elevate temperatures and maintain a high degree of control. The amount of fish which can be grown is limited by the volume of water available. Recirculation will increase the amount of water available, but also increases the risk of high mortality due to a mechanical breakdown of the system.

6.2.1 Capital Investment

Capital investment in a land based tank or raceway system is very high (Table 13). Land costs, buildings, rearing systems, construction costs, plumbing and wiring, backup generators, vehicles, pumps, aerators and other miscellaneous items were estimated to cost approximately S110,000 in 1985 in Ontario for a modest aquiculture facility producing 22,700 kg of fish annually (Castledine 1986). In the N.W.T. in 1988 or 1989, capital investment might run between S200,000 to $250,000.

The major expenditures would be property, 'building construction and purchase of rearing facilities. A significant reduction in capitol costs can be achieved through the use of low cost rearing units (such as culverts) within simple, inexpensive enclosures. These can be constructed of a heavy fabric material stretched over a metal frame and partially insulated (M.Papst, personal communication).

Pumps and plumbing required to recirculate water, temperate control mechanisms, aerators and a backup generator are unavoidable costs. This facility however imparts considerable environmental control capabilities, a particularly desirable characteristic given the severity of the northern climate.

Capital costs for vehicles, feed manufacturing equipment, a feed storage facility, a freezer facility, cleaning and processing equipment will be similar for both cage and tank culture operations,

In addition a security system would be required to alert staff in the event of an electrical or water supply failure which would result in significant losses of fish.

The high capital costs associated with this type of operation must be held to a minimum if it is to be economically viable.

6.2.2 Operational Costs

Operational costs of a tank system are slightly higher than for a cage culture facility. The amount of electricity required to pump water, and provide lighting is considerable, Building maintenance, tank cleaning and other factors will also increase labour costs.

6.2.3 Maintenance and Monitoring

The degree of maintenance and monitoring of a recirculating culture system is relatively high. Maintenance of equipment (pumps, generators, aerators, etc.) and monitoring of temperature, oxygen ammonia levels and flow rates are required. However, the greater level of control and security provided compensates for the increased complexity and expense.

6.2.4 Water Quality

Water quality parameters in tanks or raceways can be maintained at an acceptable level by the effective removal of suspended solids and metabolic wastes and reoxygenation of the water.

In single pass systems, water is circulated only once, so that the fish receive fresh water exclusively thereby maintaining high water quality. This is only practiced where there are very large volumes of water available of a suitable temperature for rapid growth. In Canada as most of our ground water is cold (6°-8°C) all year round a significant proportion (20-30%) of the annual operating budget would be consumed by heating costs (Ayles et al. 1980, McNown and Seireg 1983). Recirculating 90-95% of the water minimizes fresh water demand while providing large savings in heating costs. The increased cost and maintenance of a recirculating system is justified in most cases because recirculating water imparts a high degree of environmental control, stock management, and disease control (Muir 1981, McNown and Seireg 1983) .

The output of the NCPC Jackfish Lake electrical generating station could potentially satisfy the total thermal demand of a facility located there. However, a non-scheduled shutdown of the waste heat source would result in a complete exchange of cold water in the tanks within a matter of minutes causing a severe thermal shock and possible heavy losses of fish Ayles et al. 1980).

The construction of recirculation and a water storage or mixing tank would act as a buffer to ameliorate the effects of a shutdown over several hours. The effects of variable thermal output by the station as well as seasonal differences in lake water temperature would also be minimized. In addition, management and control of the water supply and treatment of diseased fish would be facilitated as residency time of treated water would be increased twenty fold.

6.2.5 Growth and Yield

Despite slightly lower growth rates of fish in tanks than in cages, the densities at which fish can be raised in tanks are at least double that of cages. Yield on a cubic metre basis is therefore considerably higher. Based upon the proposed 40 tank system (Appendix 2), between 5 and 6 harvest periods per year are possible. This rotational system has the ability to provide a constant, consistent supply of fresh charr which is not possible in cages. The ability to provide fresh fish to brokers, restaurants and retail outlets reliably, is an important facet to a successful commercial operation.

6.2.6 Environment

The environment in a tank or raceway is under strict control by the aquaculturist. Water temperature, flow rate, water quality, light and other environmental factors are easily manipulated. The fish are not exposed to the environmental or seasonal extremes in heat and cold, ice conditions, fluctuating water temperatures and light, to which they would be exposed to in cages. Should the water source become polluted (due to an oil spill or chemical dump) the inlet source could be relocated and intake volumes reduced in order to filter or at least minimize the effects of such an occurrence.

6.2.7 Disease

The risk of fish reared in a tank or raceway contracting a disease can be less than fish reared in cages, if a high level of water quality is maintained. The opportunity of filtering or treating incoming water exists in a tank facility where it does not in a cage facility. Treatment of infected fish in a tank is also easier and more effective. Again, it should be stressed that the most important facet of disease prevention is avoidance through the importation of only "certified disease free" fish.

Tank culture also allows different groups of fish to be isolated, not only from resident fish but from each other. In this way if one group of fish becomes infected with a disease, the risk of transmission between fish or through the water supply is negated,

6.2.8 Predation, Theft and Vandalism

Although predation is not a factor in tank culture, theft and vandalism remain a consideration, Because hatcheries support large numbers of fish in an extremely small area the?- are very vulnerable and a security system would have to be established.

7.0 CONCLUSIONS

1. The intensive aquiculture of Arctic charr in the Northwest Territories is considered to be biologically and technologically feasible. Jackfish Lake appears tobe a suitable location based upon the availability of an abundant supply of waste heat, convenient access to transportation and the presence of an abundant source of trash fish from which to manufacture feed.

2. Based upon available water quality information, a definitive conclusion as to the suitability of the water of Jackfish Lake to support an aquiculture facility cannot be made. Arsenic levels which exceed U.S. EPA (1978-79) accepted standards and a suspected pH imbalance may pose a threat to fish health and jeopardize aquiculture opportunities. Further study on both of these aspects is strongly recommended.

3. Cage culture of Arctic charr in Jackfish Lake, N.W.T. is not recommended. The traditional risks associated with cages such as disease and water quality combined with cold water temperatures, a short growing season and the unpredictability and extremes in environmental conditions found in the north create an unacceptable level of risk. The potential for failure exceeds the likelihood of success.

4. A tank or raceway system is recommended as being the most practical facility in which to raise Arctic charr. Such a facility will provide the high degree of environmental control required for aquiculture in the Arctic, reduce risk to an acceptable level and greater enhance economic return. It is the opinion of the author that these benefits exceed the deterrent of a high capital investment.

5. Despite the apparent biological and technological feasibility of aquiculture in the Northwest Territories, ultimately the success. ful culture of Arctic charr depends upon economic considerations. These include high transportation costs, high capital and operational costs in the Northwest Territories, high risk, an insecure market, competition from other wild and aquiculture fish and relatively low product value.

6. The economics of a tank or raceway culture system can only be improved by keeping capital investment to a minimum. Inexpensive rearing and housing units for the fish should be located before proceeding further.

7. To ensure that maximum growth rates are achieved, water temperatures should be maintained as near as possible to the optimum growth temperature of charr (12°-13° C).

8. Arctic charr should be raised to pan size (250 g) for introduction to the market, Pan size charr kill not compete with the wild product and because growth rates of larger fish are reduced, a higher turnover is maintained resulting in a greater return,

9. With the exception of capitol and labour costs, there is no difference in the cost of importing a commercially manufactured feed versus the local manufacture of a moist feed using trash fish from the Great SlaveLake fishery.

A moist feed should therefore be manufactured due to the greater palatability and performance of fish fed a moist feed. In addition, a portion of the money spent for the purchase and manufacturing of the feed would stay within the community.

10. Identification of further suitable sites for intensive aquiculture in the Northwest Territories should be based upon the following preliminary investigations being carried out. These include:
    - i) Performance of a complete water quality analysis to include essential ions, dissolved solids and heavy metals.
    - ii) Analysis of tissues from resident fish species to determine the levels of heavy metals and other contaminants such as pesticides, ~’s and other organic toxicants.
    - iii) Analysis of tissues of resident fish for the presence of pathogenic bacteria and viral organisms.
    - iv) Access to a sufficiently large, reliable source of trash fish from which to manufacture a moist diet.
    - v) Presence of a reliable waste or low grade heat source able to satisfy the total annual thermal requirements of a hatchery facility.
    - vi) Ready access to convenient land and air transport.
    - vii) Knowledge of the seasonal changes in limnological parameters such as depth, oxygen, temperature, salinity and hydrodynamics.
    - viii) Identification of potential hazards such as mines, pipelines, toxic waste disposal sites, or facilities which might pose a threat to water quality.

11. Construction and implementation of such a facility, even if ‘uneconomical at this time, may become economical in the near future. Development of the necessary technology will have been accomplished and the facility could serve as a pilot - commercial feasibility- operation which could be utilized and receive limited funding from interested industry and government agencies.

8.0 RECOMMENDATIONS FOR FUTURE STUDIES

1. It is recommended that before an aquiculture operation is initiated, the actual relationship between arsenic in the water from Jackfish Lake, N.W.T. and arsenic concentrations in the zooplankton, and tissues of resident whitefish and northern pike be determined. The effect of the arsenic level in the water on the growth and health of fish being fed a manufacture diet should be fully researched.

   Presence of the suspected pH imbalance and reasons for its occurance should be elucidated. Whether this condition actually exists or whether these values represent an anomally is not known and additional water quality data should be collected as soon as possible.

2. The collection of general water quality and chemistry data from Jackfish Lake should be continued for a one year period.

3. It is recommended that an economic evaluation and marketing study of artificially reared Arctic charr be performed. The local demand for fresh charr during periods when they are not competing with wild fish should be stressed in the study.

4. The temporal availability, exact costs and logistics associated with purchasing fresh trash fish from the Great Slave Lake fishmen should be further investigated.

5. A minimum of two distinct, disease free populations of Arctic charr should be identified, These stocks should each be evaluated to determine which strain demonstrates the highest growth rate and the lowest feed:gain ratio and mortality rate.

6. The design for a completely functioning hatchery/tank culture system, capable of producing a minimum of 32,000 kg of fish per year, with room for espansion, should be completed. All construction and equipment costs, and labour and operational costs should be detailed for inclusion in an economic feasibility study.

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Table 1. Summary of possibilities for new production of fish in the north by various methods including enhancement and aquaculture (after Ayles 1980).*

	Biological and technological complexity	Time frame for possible implementation	Areas where applicable	Who would participate	What species of fish	Environmental control
New areas	very simple	now	many in NWT, few in provinces	resource managers, commercial, domestic and sport fishermen	traditional species + some new species	none
New management	simple	now	many lakes in NWT and provinces	resource managers, commercial, domestic and sport fishermen	traditional species	very little
Enhancement and rehabilitation	intermediate	1-5 yrs.	large lakes in provinces and streams in many areas	resource managers, local communities, commercial, domestic and sport fishermen	traditional species	some
Lake culture	intermediate	now	few restricted areas in NWT and provinces	private operators, sport fishermen	trout	some
Cage culture	complex	1-5 yrs.	few restricted areas	cooperatives, private operators, Indian bands	trout	moderate
Ecological aquaculture	complex	5-10 yrs.	almost anywhere	individual households	many species including tropical	high degree
Waste heat aquaculture	complex	5-10 yrs.	very few areas, defined by industrial sources of waste heat	industries	many species including tropical	high degree

* Although published in 1980, time frames for possible implementation still apply.

C5

FEASIBILITY OF THE INTENSIVE CULTURE OF ARCTIC CHARR (*Salvelinus alpinus*) AT JACKFISH LAKE, N.W.T.

By

R. F. Baker

North/South Consultants Inc.
661 Pembim Highway
Winnipeg, Manitoba
R3M 2L5

NSC