AN ASSESSMENT OF THE BIOLOGICAL AND ECONOMIC FEASIBILITY OF EXTENSIVE AQUACULTURE IN NORTHERN MANITOBA

by
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Submitted in Partial Fulfillment of the
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A practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of Master of Natural Resources Management.

ABSTRACT

The biological and economic feasibility of extensive aquaculture in northern Manitoba was assessed in five lakes in the Lynn Lake region and two lakes at Grand Rapids.

The biological feasibility was assessed by investigating growth and survival rates of rainbow trout and arctic charr in lakes. Some lakes at Lynn Lake produced marketable size fish after two growing seasons in the lake. However, fish in other lakes took longer to reach this size. Size differences between lakes was related to lake basin shape, water temperature and food availability. The non-winterkill nature of these lakes is crucial to northern extensive aquaculture. This allows fish the longer growing period necessary to reach a marketable size, as well as a strategy of continuous cropping, where only marketable sized fish are removed. The extremely high fish mortality rate experienced in these lakes was the major biological drawback to this operation. Stress at stocking and food availablity were probably the largest contributing factors, rather than predation, disease or the physical environment of the lake.

Economic feasibility was assessed through economic analysis of the costs and benefits associated with harvest of arctic charr from one lake at Lynn Lake. The income statement of the production cycle showed that the aquaculture operation was not viable at low fish survival rates. However, if the operation was viewed as a hobby and certain

costs ignored, a small profit could be made. Break-even analysis showed that the operation would become viable beyond a 15% recovery rate, and profits would greatly increase with higher recovery rates. Large profits at higher recovery rates were a result of the high retail price of arctic charr, and the relatively low costs involved in the operation. Profits were shown to be highly sensitive to fish retail price, stocking rate, and size of fingerling stocked into the lake.

The overall conclusion was that extensive aquaculture in northern Manitoba was biologically feasible, but due to the extremely high mortality rates the operation was not economically feasible. However, other biological parameters in the lakes appeared favourable for fish culture, and once fish survival is improved the lakes would be suitable for fish culture. Two recommendations to improve survival rates were to stock fingerlings in cages for a few days after planting, and to decrease the stocking rate. The economic analysis showed that the operation would be feasible if a recovery rate of 15% was experienced, this is certainly not outside the realm of feasibility. If survival rates of fish in these lakes can be improved then this operation would be both biologically and economically feasible.

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Chapter I
INTRODUCTION

1.1 PROBLEM STATEMENT

Northern communities which rely on a single industry are vulnerable to economic disaster if such an industry comes to an end. It is therefore in their best interests to diversify their economic base into other industries that would help support the community in the event of such a collapse. Also, many northern native communities are searching for economic development schemes compatible with their culture and lifestyles. One potential industry is 'fish farming' or aquaculture. However, a feasibility study for this type of enterprise in northern communities has never been undertaken.

There are many northern boreal lakes that could be suitable for aquaculture enterprises, and there is a growing need for identification of these lakes to determine their suitability for raising fish, as well as determining the economic feasibility of undertaking an aquaculture enterprise. The qualification of a large number of lakes in this way was unfeasible in terms of time and funding for this study. However, it was feasible to qualify a few lakes, and then develop a biological and economic model that could be applied to other northern lakes to determine their suitability for aquaculture. The resultant model is an easy and inexpensive way of evaluating northern lakes for use in extensive aquaculture.

1.2 BACKGROUND

Extensive aquaculture is defined as "utilizing natural lakes and natural food sources". Fingerlings are stocked into natural lakes, left to feed on naturally available food, and then harvested once they have reached a marketable size. An opportunity to evaluate the feasibility of northern extensive aquaculture in Manitoba was made available at Lynn Lake and at Grand Rapids (Figure 1).

Lynn Lake is a single industry town with a population of 1800 people, located 800 kilometers north of Winnipeg. Until very recently, the economy of Lynn Lake was based on mining, as well as other secondary industries to serve the mine and it's employees. Following the announcement in 1981 of the mine closure scheduled for November 1985, there have been many plans for diversification of the economy. The Northwest Development Corporation was set up to look into alternative economic development projects. One of the diversification projects proposed was fish farming using local lakes. Experimentally, two local residents stocked several small lakes with rainbow trout, and succeeded in producing marketable size fish over a number of years. In May 1985 three lakes were stocked with rainbow trout (Salmo gairdneri Richardson) and two with arctic charr (Salvelinus alpinus) (Figure 2).

A local resident of Grand Rapids has been utilizing lakes in the vicinity for rainbow trout farming with some success. In June 1986 two lakes were stocked for the first time with arctic charr fingerlings. One lake contained a population of northern pike (Esox lucius), and an attempt was made to remove all these fish by trap nets be-

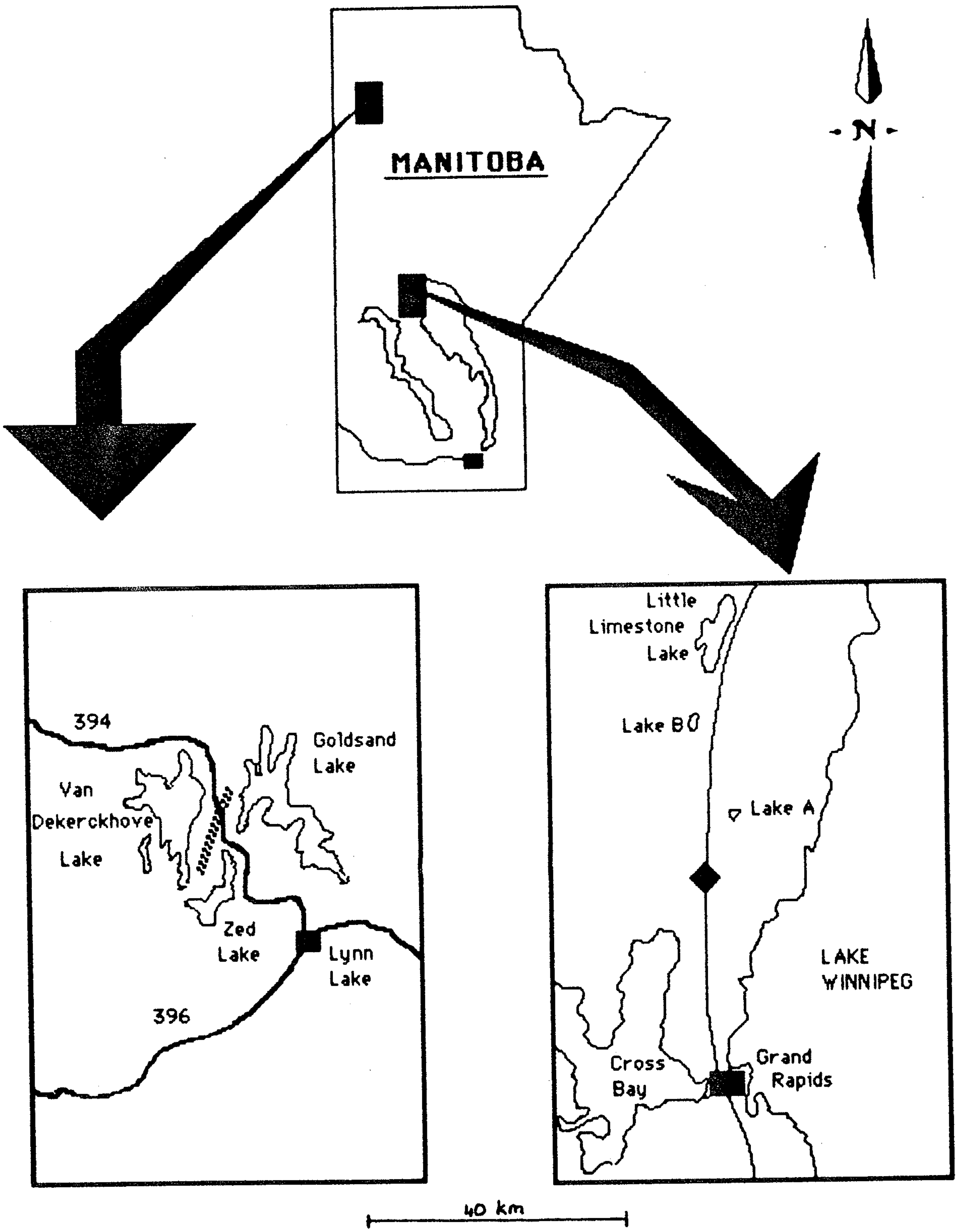


Figure 1: Location of study areas in Manitoba

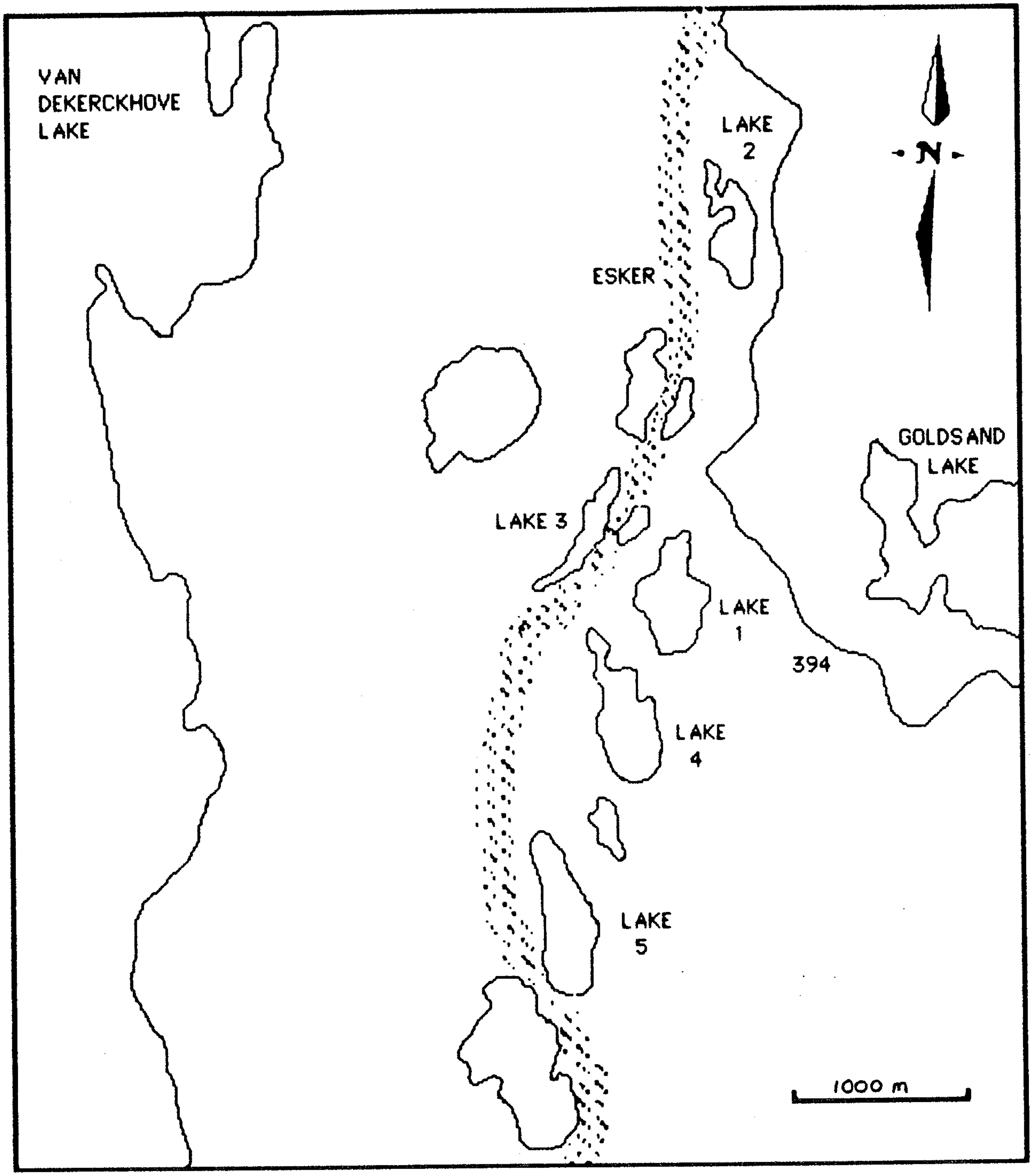


Figure 2: Lynn Lake Study Area

fore fingerlings were planted. Also, the other lake had been stocked with rainbow trout fingerlings a month earlier.

The growth and survival rates of fish over the growing period were used to determine the yield of fish in the lakes at Lynn Lake and Grand Rapids, and hence determine if the lakes were suitable for aquaculture. The feasibility of an aquaculture enterprise also depends on it's "profitability", the amount of net income generated by the operation. This depends on the various "costs" involved, as well as the "profits" made from fish sales. Subsequently, a market for the fish is needed, as well as a relatively inexpensive method of transporting fish to market. The distance of northern aquaculture operations from markets is a concern, especially as a consideration in economic analysis. Both the biological and economic feasibility of an aquaculture enterprise need to be examined in order to determine the operation's viability. However, viability is also dependant on other factors that are less easily quantified, and can be losely classified as social, political and policy factors. These will not be discussed in this study.

1.3 OBJECTIVES

The purpose of this study was to assess the biological and economic feasibility of extensive aquaculture in northern Manitoba. This involved two objectives:

1. To determine growth and survival rates and hence yield of arctic charr and rainbow trout in selected small northern lakes, and to identify factors effecting such a yield; and

2. To evaluate the economic feasibility of using selected northern lakes for extensive aquaculture.

1.4 JUSTIFICATION

A feasibility study concerning northern extensive aquaculture is justifiable in two ways. Firstly, aquaculture in these small northern lakes has never been attempted, and therefore this study will contribute to the scientific literature concerning growth and survival rates of rainbow trout and arctic charr in these lakes. Secondly, this study will determine if the raising of these species is economically viable for people living in northern communities. This is extremely important at a time when communities are searching for new economic development plans.

1.5 LIMITATIONS OF THE STUDY

1. Due to the small number of sampling periods, estimates of growth rates and survival rates were only an approximation.
2. Other biological data collected was also limited eg. temperature and oxygen profiles, due to time limitations.

Chapter II

REVIEW OF RELATED LITERATURE

2.1 SIGNIFICANCE OF AQUACULTURE

A definition of aquaculture in the most general sense is the "cultivation and harvesting of aquatic plants and animals" (Science Council of Canada, 1984). This can range from extensive aquaculture, which are simple hatchery reared introductions into natural environments, up to a combination of hatching, rearing and feeding under controlled conditions.

The world output of aquaculture has increased rapidly in recent years. In 1984 ten percent of total world harvest of fishery products was produced by aquaculture. In many countries commercial aquaculture is profitable, creating new wealth and employment opportunities. However, in Canada the industry is still in an early stage of development. Canada is the number one fish exporting nation in the world, and in attempting to conserve wild stocks, while at the same time maximizing yields, has established an extensive program of fisheries management. However, the common property nature of the resource leads to overcapitalization and overexploitation of wild stocks. Aquaculture eliminates the problem of nonattenuated property rights, and establishes sole ownership of the resource. At a time when the wild fisheries are experiencing difficulties, aquaculture is supplying a significantly increasing proportion of fish products.

The Science Council of Canada (1985) has identified aquaculture as being:

> "an emerging area of science and technology offering new opportunities to Canadians to maximize the social and economic benefits of the natural resource industry. Canada's resource base, both salt and freshwater is more than adequate to support an industry of major dimensions."

The Council has also listed several opportunities available for Canadians through aquaculture, including:

- employment opportunities;
- continual production and processing;
- competitive new markets;
- improved quality standards;
- import substitution; and
- special interest for native peoples.

The Council concluded that the application of science and technology to our natural resources can create new wealth and employment opportunities, especially in remote communities.

However, the Science Council of Canada has observed that the growth of aquaculture in Canada has been "disappointing" especially when compared to other countries such as Norway, Denmark and Britain. The Council identified several constraints to aquaculture development in Canada, some are:

- traditional dependence on conventional fisheries;
- lack of a positive public policy statement on aquaculture;
- inadequate application of existing knowledge;

- inadequate pilot scale testing;
- inadequacies of present government incentives; and
- lack of market and product development.

2.2 FRESHWATER AQUACULTURE IN CANADA

Canada has a large percentage of the world's freshwater, and has a traditional reputation as a producer of high quality commercial fish such as lake trout, whitefish and walleye. However, due to over-exploitation and pollution, the amount of fish being harvested from more southernly waters is decreasing rapidly (Freshwater Institute, Hull Workshop, 1972).

The origins of freshwater aquaculture date back to 1857 when Richard Neille, the first Superintendent of Fisheries for Lower Canada, incubated and hatched brown trout (MacCrimmon, 1973). Freshwater aquaculture has since developed along more conservative lines than salt water aquaculture (Ayles and Brett, 1978). Since then the traditional freshwater cultured species has been trout (salmonoids), and emphasis has been placed on refinement of trout farming technology rather than consideration of other species. Many new technologies are available to Canadian fish culturests from the well developed trout industry in the United States, such as egg and fingerling supplies, feeds, raceway technology and automatic feeders.

Freshwater aquaculture includes the following forms: government fish stocking programs; commercial fish farming for egg and fingerling production and grow out operations; commercial fish stocking for private recreational use; and prairie pothole fish farming. Today over 4000 farmers stock rainbow trout (Salmo gairdneri Richardson) in prairie pothole private lakes for recreational and commercial use (Ayles and Brett, 1978).

2.2.1 Prairie Pothole Trout Farming

In 1968 the Freshwater Institute initiated an "aquaculture research program" with the initial objective being to determine the feasibility of using small prairie pothole lakes for raising an annual crop of fish of commercial value. Secondary objectives where to attempt to define lake types which would be most suitable, and to determine conditions under which a successful crop of fish could be grown (Johnson et al, 1970).

Species selection for cultivation is limited by the following factors defined by Johnson et al. (1970):

- must be fast growing in order to reach marketable size in one summer;
- must be easy to culture in the young stages prior to planting;
- must be readily available in quantity at planting time;
- must be capable of withstanding high summer water temperatures; and
- must be acceptable on the market.

Rainbow trout, native to the western mountains of Canada and the United States, meets all these requirements. The species is also marketed in large quantities in North America, with a significant proportion of fish being imported from Denmark and Japan.

It was found that a pothole stocked in May with 3-4g trout fingerlings produced marketable fish of over 200 grams by fall, when feeding on only natural organisms (Johnson et al, 1970). As a result of the success of the initial experiments an 'infant' fish farming industry emerged. Bernard and Holmstrom (1978) found that trout growth in these natural water bodies, with no supplementary feeding, compared favorably with trout reared in intensive culture programs, where fish are grown under 'optimum' conditions. In 1978 the pothole lakes sustained a 'cottage' industry of approximately 4,000 farmers, providing 130 tonnes of rainbow trout and grossing $400,000 (Freshwater Institute, 1979).

One of the most important requirements for pothole lake selection was that the lake 'winterkills'. Nikum (1970) characterized 'winterkill' as a combination of circumstances during the period of ice cover which results in the consumption of dissolved oxygen at a higher rate than oxygen production. This lowers the oxygen levels to below the critical minimum values for fish. This ensures that unharvested fish cannot overwinter in the lake as a result of anaerobic conditions that develop under the ice. This prevents older trout from predating on newly planted fingerlings, as well as ensuring a good food supply of invertebrates which have been able to develop dense populations for the introduced trout (Fish Mangmt. Division Saskatchewan, 1980). There is an inverse relationship between oxygen depletion rate and mean depth (Mathias and Barica, 1980). Since most prairie potholes are less than five meters, this means that most are 'winterkill' lakes.

There are other requirements for a suitable lake. They must have no indigenous fish that would prey on young trout, they are enclosed with no inflow or outflow, they are not alkaline, they do not have large algal blooms, and they have good access and measure less than twenty hectares in area (Ayles, 1973). The natural food in these lakes consists of zooplankton and small insect larvae on which fingerlings feed in spring and early summer. Later, as the fish grow they start to feed on larger organisms such as the amphipod Gammarus lactistris, and small minnows if they are present.

While annual trout production has expanded, large scale industrial development has been hampered by both biological and non biological problems associated with the prairie pothole fish farming industry.

One of the major biological problems is size variability. Trout growth variability between lakes could be due to differences in food availability, partial 'summerkill', or water temperature (Bernard and Holmstrom, 1978). Ayles (1973) found that growth and survival rates of domestic strains of rainbow trout were higher than that of wild strains, and suggested that cross breeding of different strains could lead to a greater increase in growth and survival rates of trout in these lakes.

A second major biological problem is the variable survival rate of fish in prairie pothole lakes, ranging from 0-80%, with an average of 30-40%. Low survival rates have partially been due to a phenomena known as 'summerkill'. In some very eutrophic lakes large numbers of the blue-green algae, Aphanizomenon flos-aquae, start to grow in mid-summer, and then exceed the environmental carrying capacity of the lake and all die within a few days. The subsequent decomposition of algae uses up dissolved oxygen and the trout become stressed and die (Ayles, 1973).

A further problem associated with eutrophic prairie lakes is that some fish develop a muddy flavour which is caused by microorganisms present in the water. This undesirable flavour can be eliminated by holding the fish in cool clean water for several days or by smoking. Also, problems associated with holding and transporting small quantities of fish to a processing plant have lead to some unsatisfactory products reaching the market. However, recent advances in the technological and biological field have decreased the risks of these problems arising.

Ayles (1977) attributed the lack of further development of a major trout farming industry in prairie Canada to:

- lack of efficient means of harvesting large numbers of live fish;
- lack of a centralized quality controlled processing facilities; and
- lack of a coordinated marketing program.

The risk associated with annual yield is regarded as a critical factor and is considered to be a major deterrent in the immediate development of extensive aquaculture (Cauvin and Thompson, 1977). Despite the increase in individuals engaging in fish farming, the turnover rate of fish farmers entering and leaving trout farming is approximately sixty percent. It is possible that this is related to the financial failure of fish farming enterprises.

Cauvin and Thompson (1977) found that, based on a mean recovery of 36.2%, experienced on non algal collapse lakes, investment in rainbow trout farming as a commercial venture was not considered to be advisable. However, if the farmer wished to regard the venture as a hobby and ignore wages and the cost of investing in the enterprise, then it was possible to cover operating costs and generate a small surplus income. Ayles and Brett (1978) suggested that it is a lack of cooperative processing and quality control, rather than biological problems, that remain as deterrents to a thriving industry.

2.2.2 Trout Cage Culture

As a result of the problems facing the prairie pothole trout farming industry, other aquaculture schemes have been investigated, one being the intensive culture of trout in cages. Intensive culture relies on confinement of fish in a given area, and provision of the majority of food required from outside the area of confinement. The major advantage of intensive culture operations is that they provide a relatively guaranteed level of production of fish of consistent size and quality. This is important for the establishment of a viable industry (Fisheries Service, Hull Workshop). One suggestion is that the main thrust of the aquaculture industry should be focused on intensive culture operations.

In 1972 the concept of intensive cage culture of rainbow trout in precambrian lakes in Manitoba was investigated as a means of improving supply and quality of fish. Whitaker and Martin (1974) suggested that since summerkill is the main problem of extensive trout culture in agriculture areas of the southern prairies, cooler mid-summer temperatures of precambrian lakes would be more conducive for growth and health of trout. A study was conducted at Heming Lake Manitoba, 50 kilometers northeast of Flin Flon. The experiment involved stocking 1.7 gram fingerlings in May into cages suspended in the lake, and feeding every ten minutes from sunrise to sunset. Harvesting in October demonstrated a survival rate of 52%. Two outbreaks of gill disease were the major cause of mortality. The average final weight of the trout (95g) was too small to be marketable. In 1973 1.3g fingerlings were stocked into cages at the begining of June, and fed with automatic feeders at two minute intervals. 54% of the fish were harvested in October, of which half were of marketable size. Mortalities were again due to disease. The study demonstrated the biological feasibility of rainbow trout cage culture. Disease resulting from high water temperatures, lack of water circulation and crowding in the cages, was shown to be the major cause of mortality. The economic feasibility was shown to be less certain due to the high cost of fish food and fingerlings, and a relatively low return for the finished product.

A more recent study done by the Saskatchewan Research Council (Sawchyn, 1984) attempted intensive cage culture of rainbow trout in farm dugouts. Their objectives were to:

- maximize use of conveniently available water resources;
- realize maximum growth rates for the largest number of fish possible;
- maximize harvest recoveries of stocked fish;
- control fish quality and size to meet market demand; and

- identify risks associated with various pond culture strategies.

Fingerlings were stocked into two oval nylon netted cages, at a density that was estimated to be fifteen times that which the pond could support naturally. Both cages were equiped with demand feeders. The pond was also aerated with a spray aerator from dusk to dawn in order to maintain dissolved oxygen levels and suppress pond temperatures. In the first year mortality was 2% in the experimental cage and 0.1% in the control cage. Fingerlings stocked at 41.7g and 50.6g grew to 205g and 255.6g respectively in 145 days, well within marketable size.

The research program was extended a second year, where seven cages in two ponds were stocked with rainbow trout fingerlings. Mortalities were higher, as all fish in one pond died as a result of summerkill caused by high temperatures and low levels of dissolved oxygen. Fish mortality in two cages in the other pond was 4% and 5%. Sawchyn (1984) suggested that mortality through disease experienced in earlier studies was avoided from causing higher mortalities by the use of fingerlings from certified disease free stock, and the use of water bodies that did not contain a natural fish population that might serve to transmit disease.

In marine and large lake culture, the stocking density is generally not a limiting factor as water quality is maintained by a constant flushing action of waves and water currents. However, in smaller ponds and dugouts this does present a problem. The S.R.C. concluded that dissolved oxygen is the most critical limiting factor in intensive cage culture in closed ponds. The limiting dissolved oxygen resource must be carefully managed and should be maintained over 5mg per litre. Dissolved oxygen levels in the pond that experienced fish kill dropped to 4.2mg/l at the surface and 3.2mg/l at one meter.

The study concluded that intensive cage culture of trout could be successfully undertaken in farm ponds without the need for recirculating water. Advantages of this type of aquaculture are the insurance of 100% recovery at harvest time with minimum time and effort, and monitoring of fish growth and conditions offers flexibility for harvest with respect to timing market availability and market requirements. However, they concluded that dissolved oxygen depletion at night is the single most serious hazard to intensive pond culture systems. Aeration devices are required to sustain dissolved oxygen above critical lethal limits.

Drawbacks to intensive cage culture can be listed as follows:

- possible high mortality due to 'summerkill' resulting from lethally low dissolved oxygen levels;
- crowded conditions in cages invites the occurance of disease causing organisms that spread quickly;
- highly labour intensive requiring constant supervision;
- High costs of initial investment of cages, feeders and aerators as well as high cost of feed;
- demand feeders can result in size variability; and
- lack of natural food, such as the crustacean Gammarus, whose carotenoid pigments produce orange coloured flesh in fish.

2.2.3 Northern Extensive Aquaculture

Aquaculture in northern regions of Canada has rarely been attempted. The suggestion has been made that the area most suited to both intensive and extensive aquaculture is the southern prairies (Fisheries Service, Hull Workshop), as a result of:

- a more favourable climate with a longer growing season;
- inherently more productive soil and water than on the Canadian Shield; and
- the importance of a young and growing industry being located as close as possible to potential markets and supply routes.

The conclusion was made that there is little potential for aquaculture in more northerly regions. However, northern aquaculture has been attempted in the past, and it is entirely feasible that these problems can be overcome.

In 1972 a rainbow trout farming project was carried out by the Pilot Use Planning Project in The Pas Special Area (Harper, 1973). Various sized water bodies were stocked in May with trout fingerlings that were harvested in October. Some winter fishing was done, but the lakes winterkilled in March. The overall recovery success rate was 12.6%. In 1973, as a result of local interest, a further project was designed by the Pilot Land Use Planning group, to stock four lakes with rainbow trout. The fall and harvest recovery rate was extremely poor, with all lakes being less than 1%. They suggested that the prime factor for mortality could be attributed to the quality of the stock. This statement was based on reported low recovery from lakes stocked in southern Manitoba with stock supplied from the same source (6-7%). Another contributing factor for poor recovery was the unknown damage caused by a faulty oxygen regulator during transportation of the stock. Also several hundred common terns were observed feeding after the fingerlings had been released.

Conclusions from this study were that:

- primarily because of unhealthy stock, most of the fingerling did not survive;
- rainbow trout fingerlings can be raised to marketable size in one spring to fall season in these lakes; and
- the quality of harvested trout was excellent in flavour, shape, size and pinkness of flesh, and there appeared to be abundant natural food in the lakes and warm summer temperatures did not appear to raise water temperatures to critical levels.

The study recommended that the Freshwater Institute should expand their experimentation to pursue the possibility of establishing commercial trout farming in the north. They felt that economically successful trout farming could be carried out in northern waters.

A more recent study by Saskatchewan Parks and Renewable Resources (Laiw, 1984) demonstrated that rearing of walleye (Stizostedion vitreum vitreum) from fry to fingerling size in suitable waters, is feasible in both southern and northern Saskatchewan. Growth of fingerlings was rapid whereas survival and yield were low, but within the normal ranges expected for natural ponds. A similar study (Laiw, 1984) for whitefish (Coregonus clupeaformis) demonstrated the same results.

This study involved the stocking of rainbow trout (Salmo gairdneri) and arctic char (Salvelinus alpinus) fingerlings into lakes in May of the first year and harvesting in fall of the second year. The primary requirement for lake selection is that the lake does not winterkill. Precambrian shield oligotrophic lakes are less likely to develop winter anoxia than prairie pothole lakes as a result of the overall trophic status of the lake (Barica and Mathias, 1979). Also the sediments of eutrophic lakes consume oxygen about three times faster than those of oligotrophic lakes, but water column respiration is about the same (Mathias and Barica, 1980).

It is necessary to allow fish two growing seasons in cooler northern waters, to ensure that they have reached a marketable size by harvest. However, one drawback is that any fish left unharvested will be able to predate on newly planted fingerlings the following year. However, studies have shown that cannibalism is not as prevalent as previously thought. One method of protecting newly planted fingerlings from older trout and other predators, is to cage them for a few weeks in the lake before releasing them. This gives them time to adjust to their new environment.

Advantages to northern extensive aquaculture are seen to be:

- cooler summer water temperatures and trophic state reduce summer-kill resulting from large algal blooms, as well as reducing the likelihood of a muddy flavour in fish;
- no winterkill allows a longer growing period, over two or more seasons, this might be necessary to ensure that the fish reach harvestable size due to cooler water temperatures;
- natural food in the lakes gives fish flesh a pleasant taste as well as a pink colouration;
- low costs resulting from a small initial investment, no feed and low labour costs; and
- potential for winter harvesting under the ice.

Potential disadvantages to this type of aquaculture enterprise are envisaged to be:

- no winterkill means that unharvested fish remain to predate on newly planted fingerlings;
- the fish might not grow to marketable size in two seasonal due to lower water temperatures;
- low catches during harvesting; and
- the distance from markets might present problems in supply, quality of the fish and transport costs.

2.3 ECONOMIC ASPECTS OF AQUACULTURE

As has been documented there are numerous biological problems associated with freshwater aquaculture in Canada. However, with improved technology and scientific understanding these can be overcome. A major constraint on the development of freshwater aquaculture is the perception that aquaculture enterprises are uneconomical (Pillay, 1973). Where aquaculture has assumed the guise of an industry, factors not predominately biological determine it's success or failure. Dominant among these are the costs of the various inputs, financing and marketing (Bardach, 1976). Although in many cases it is biologically feasible to produce fish, an operation's viability will also in part depend on the economics of the operation.

While traditional fisheries economics relies heavily on bioeconomic modeling, aquaculture uses production economics. The principal advantage of aquaculture is that it has moved fish production from the realm of hunting to that of agricultural production. Thus the overexploitation problem of the common property resource disappears and is replaced by the benefits of sole ownership.

The following review of aquaculture economics is taken from Cunningham et al. (1985). Production economics uses the revenues and costs incurred by the aquaculture operation to determine profitability. Total profit (TP) received per area of water that is farmed is derived from the relationship between total revenue received from the sales of fish produced (TR), and the total cost of producing fish (TC), ie. $TP = TR - TC$.

The cost of producing fish may be divided into two main categories. Fixed costs which do not vary with the quantity of fish produced. The main element in fixed costs is usually that associated with paying interest on financial capital to construct and operate the farm. Also, because aquaculture enterprises are often seen as risky, interest rates may be high. Other fixed costs include land purchase or leases, capital depreciation and indirect operating costs. There are also variable costs, which vary with production volume. These include feedstuffs and fertilizers, fry supplies, labour, harvesting, marketing and other production costs which vary with different systems, ie. fuel costs for boats.

Total revenue is based on total physical production of the operation. This depends on two major factors, stocking rate and growth and survival rates. An area of water which is limited by space and natural food supply has an "environmental carrying capacity" in terms of the weight of fish that is sustainable. This can be increased by several methods, such as fertilization of the water to increase plankton production, supplementary feeding, aeration and polyculture. Growth and survival rates depend on many factors including stocking rates, water quality, disease, predators, parasites and natural events.

Total revenue may be defined as the total income to the farm, although more relevant parameters for optimum output decisions are average revenue and marginal revenue. Revenue and marketing are closely tied. The fish that are sold will be entering a market for fish where they will compete with other farmed fish, fish from traditional fisheries, and non fish products. Dependent upon the nature of competition the producer may have to accept the going market price or may be able to have some influence on price. Canadian fish farmers must compete with imported trout from the United States, Japan and Denmark. In a study done in Ontario, retailers prefered imported trout to locally produced trout because the imported trout were of a higher quality, more standardized size, better packaged and better produced (Robbins at al., 1980).

Fish farmers are interested in selling more fish, and at higher prices. Farmers can undertake a number of marketing activities to sell more, or improve the price they will receive for their fish. These are:

- by maintaining a high and reliable quality;
- by processing to change the form and appeal of the product;
- by gearing production to seasonal or regional demands and/or maintaining a steady and reliable supply to outlets; and
- by active product promotion.

All these activities should, other things being equal, increase the demand for their fish in the market. Marketing is a major concern for the fish farmer. In order for the operation to be commercialy viable, there has to a market for the fish produced. Also, development of an aquaculture industry in addition to the existing wild fisheries is only justified if a market exists for all the products produced. However, it is encouraging that the consumption of fish and fish products is increasing in all markets (Siddiqui, 1972). There appears to be a ready market for aquaculture products in Canada, if quality and price are competitive with foreign products. However, mention must be made of the possible problem for fish farmers in that increasing total production may drive down market prices, affecting both farmed and captured fish. The response to such problems lies in market development, cooperative marketing, and pursuit of new markets.

Chapter III
METHODS

3.1 INTRODUCTION

Methods used to assess the biological and economic feasibility of northern extensive aquaculture are described in this chapter. Biological and economic data were collected during two field trips to Lynn Lake, from the 17th to 25th of June and from 3rd to 10th of October 1986, and one field trip to Grand Rapids from 3rd to 5th of September 1986.

3.2 BIOLOGICAL DATA

3.2.1 Morphometric Data

The five study lakes at the Lynn Lake study site were depth sounded on the June field trip. Depth measurements were taken along two transects for each lake; one over the longest axis and the other at right angles to the first. Depths measured in feet were determined and later converted to meters, from a "fish spotter" depth sounder. Topographical maps and aerial photographs were used to find the maximum length and width of each lake. The depth sounding readings were then extrapolated onto enlarged maps of each lake using the distance covered in the transect and the exact time between each reading (Appendix 1). These maps were then used to find surface area, shoreline length, and volume of each lake, using a computer digitizer. Mean depth and shoreline development were also calculated.

3.2.2 Chemical Data

A continuous record of temperature was made in Lake 5 at 1 meter using a Ryan thermograph, from 10 June to 6 October 1986. Temperature profiles using a YSI tele thermometer at 0.5 meter intervals were taken at the deepest point in each of the 5 study lakes in June and October at Lynn Lake, and in Lake A at Grand Rapids. Secchi depths were also measured in each lake at this time. This is a measure of water transparency and is proportional to algal biomass.

Water samples were collected from the five study lakes at Lynn Lake in June and October, and from the two study lakes at Grand Rapids in September. The water samples were taken at the deepest point in each lake using a "Kemmerer" sampling bottle (manufactured by Wildco Instruments). At Lynn Lake, samples were taken at 2-4m depth intervals in each lake in June, while surface samples were taken in October. At Grand Rapids, water samples were taken at 2m intervals from Lake A, while surface samples were taken from Lake B.

Water samples were tested for dissolved oxygen by the "Winkler" method. Three hundred ml of water from each sample were placed in B.O.D. bottles, which were filled to overflowing. Immediately, 2 ml of manganous sulphate and 2 ml of potassium iodide were added, and the mixture shaken. Within 24 hours, 2 ml of sulphuric acid were added and the mixture shaken. Two hundred ml of this mixture was titrated against 0.025 N thiosulphate solution, and the end-point was determined with a few drops of starch solution. The amount of thiosulphate used to reach the end-point was equivalent to the amount of dissolved oxygen (ug/l) in each sample.

The water samples were also used to test for nutrients. Five hundred ml of each sample were placed in translucent polyethylene bottles. Within 24 hours, 100 ml of this water was filtered using Whatman 42.5 mm GF/C glass filter paper, and 30 ml of this was placed in a glass vial with a few drops of sulphuric acid, and later tested at the Freshwater Institute Analytical laboratory for total dissolved nitrogen and phosphorus (TDN/TDP). Two sets of 100 ml's of this water was then filtered through ignited Whatman GF/C filter paper. The filters were then placed in separate plastic petri dishes and frozen. These were later tested at the Freshwater Institute laboratory for suspended carbon, nitrogen and phosphorus. Hence, dissolved and particulate phases are defined by what passes through or is retained by the preignited filter paper. Finally, 100 ml of water was filtered with unignited Whatman GF/C glass filter paper. These filters were then placed in individual petri dishes and frozen. These were later tested for chlorophyll-a using a Turner Fluorometer at the Freshwater Institute.

Surface water samples were collected from each lake in translucent polyethylene bottles, and stored at 5 C until delivered to the Freshwater Institute's Analytical laboratory, where they were analyzed for major ions (sodium, potassium, calcium, magnesium, manganeses, chloride, and sulphate ions), conductivity, alkalinity, organic acids and pH.

3.2.3 Fish Data

At Lynn Lake on 12 June 1985, 7,500 arctic charr (anadromous strain cross anadromous strain) were stocked into Lake 4, and 7,500 (anadromous strain cross landlocked strain) were stocked into Lake 5. These strains of arctic charr were bred at the Rockwood Experimental Fish Hatchery from original anadromous or landlocked stock taken from the wild. The fry in Lake 4 had a mean weight of 1.34g, and those in Lake 5 a mean weight of 0.84g. The fish were transported to Lynn Lake from the Rockwood hatchery near Winnipeg in a transport tank on the back of a pick-up. The fish were in the tank approximately 17 hours and oxygen was supplied at 1.0 - 1.5 l/min. The only losses were due to injuries from water sloshing in the tank. Once planted in the lakes, the fry swam away immediately. Lakes 1, 2 and 3 were stocked with rainbow trout in late May or early June 1985, with 0.15 gram fry. They were transported to Lynn Lake by air in plastic bags. 3,000 rainbow trout were stocked into Lake 3, 6,000 into Lake 2 and 3,000 into Lake 1. This was the first stocking for Lakes 1, 3, 4 and 5, whereas Lake 2 had been previously stocked with rainbow trout in 1981.

At Grand Rapids the two lakes were stocked in mid June 1986 with artic charr. Lake A was stocked with 5,000 actic charr with a mean weight of approximately 12 grams and Lake B was stocked with 3,500 arctic charr with a similar mean weight. Lake A had also been stocked earlier in the season with 11,500 rainbow trout. Lake B had never previously been stocked although there were northern pike in the lake at the time of stocking. However, these fish were small enough to slip through a 1 inch net.

At Lynn Lake in June 1986 standard gangs of nets (4 nets of 2, 2 1/2, 2 3/4, and 3 inch mesh sewed together), and small nets of 2 inch mesh were placed in all of the five study lakes. Generally, one standard gang and two 2 inch nets were left in the lake overnight. The next morning the netted fish were counted, their fork length measured and weighed. Either the whole fish or stomaches were placed in jars and preserved in formalin.

At Grand Rapids in September, four nets of 2 1/2 and 3 inch mesh were set in Lake A for four hours in the evening. The caught fish were counted, measured and weighed, and some stomaches were removed and preserved for later analysis.

At Lynn Lake, in October, Lake 3 and Lake 4 were harvested. Lake 4 was harvested over three days using twenty nets with mesh sizes of 2, 2 1/2, 2 3/4, 3 and 3 1/2 inches. The nets were laid each evening and picked up the following morning. The lake was fished until there was less than 2 fish per net. The smaller mesh nets were generally laid along the shore and the larger mesh nets were laid in the middle of the lake. Harvested fish were all weighed and measured, and fifty fish were weighed both before and after gutting. Some stomaches were also collected. Lake 3 was harvested over one night, with ten nets of 2 3/4, 3 and 3 1/2 inch mesh which were laid all over the lake. The netted fish were all weighed and measured, and their stomaches taken and preserved in formalin.

Harvested fish were processed before marketing. Gills and viscera were removed from each fish, and fish were then washed and carefully packed in ice in cardboard boxes lined with plastic.

3.2.4 Analysis

Data analysis proceeded as follows: depth profiles were drawn for temperature and oxygen readings in each lake; nutrients and ions were compared in and among lakes; size frequency charts were drawn for netted fish in Lake 4. Also, mortality and recovery rates of fish in Lake 3 and 4 were determined. These rates were easy to calculate as the original number of fish planted in each lake was known (n0), and after harvest, the number of fish caught was determined (n1):

$$\text{Total Relative Mortality} = A = n0 - n1 / n0$$

$$\text{Total Relative Survival} = S = 1 - A$$

Specific growth rates (Gw) for the fish populations in each lake were also determined. These were calculated for the periods between sampling. The natural logs of the two different weights were subtracted and then divided by the growth period, and then multiplied by a 100 to give a percentage increase in weight per day:

$$Gw = \ln W1 - \ln W2 / \text{days} \times 100$$

Productivity of Lake 3 and 4 was determined by the known mass of fish produced by the lakes, and the mass of fish at stocking. Production is the amount of fish biomass that the lake has produced over the growing season. Also, by knowing the volume of each lake, production per unit area was determined.

Stomach contents of the fish were examined and the food organisms were keyed into order and class.

3.3 ECONOMIC DATA

An economic analysis of the financial returns of the Lynn Lake enterprise was done from harvest data of Lake 4. The analysis was based on fixed and variable costs involved in stocking and harvesting the lake, as well as revenues generated from fish sales. Two types of economic analysis were done: generation of an income statement, and a break-even analysis of annual production (Cauvin and Thompson, 1977)

3.3.1 Analysis of Annual Income and Expenditures

An income statement was generated for Lake 4 for the operating season. The information collected allowed an evaluation of financial performance of the lake. This included assessment of net profit, cash flow and cash balance.

3.3.2 Break-Even Analysis of Production

Break-even analysis was used to determine the level of yield at which income would just cover expenses. Based on information collected in the income statement, it was possible to estimate fixed costs, variable costs and sales for different levels of production. This information provided the basis for analyzing the percentage recovery of stocked fingerlings needed to cover costs.

The break-even analysis was also be used to:

- compare the effect of different stocking rates on profit;
- compare the effect of stocking different size fingerlings on profit; and
- compare the effect of different fish prices on profit.

Chapter IV
BIOLOGICAL RESULTS

4.1 MORPHOMETRIC RESULTS

The study lakes at Lynn Lake are closely associated with an esker running in a N/S direction, which is approximately 10 meters high. Eskers are glaciofluvial sediments formed by deposition in meltwater tunnels during glacial retreat. Esker deposits commonly grade into fine grained sediments of sand and gravel. Small lake basins are created by melting of stagnant ice which causes slumping and faulting, and hence the creation of small lake basins (Miall, 1983). Morphometric parameters were measured for the study lakes (Table 1). Shoreline development measures the proportion of the lake's area to the amount of shoreline, hence a perfect sphere would have a shoreline development of one.

At Lynn Lake, Lake 5 is the largest and deepest, has the smallest value for shoreline development, has a smaller littoral area as a result of a steep sided basin, and less shoreline per unit than the other lakes. Lake 4 and Lake 1 have approximately the same area, although Lake 4 has a shallower mean and maximum depth, and a higher value for shoreline development. Lake 2 is the second smallest lake in area, but the second deepest for both maximum and mean depth. However, due to this lake's peculiar shape it has the highest value for shore-

TABLE 1

Morphometric Parameters of Study Lakes

Lake	Maximum Length (m)	Maximum Width (m)	Surface Area (ha)	Shoreline Length (m)	Shoreline Development	Maximim Depth (m)	Mean Depth (m)
1	600	384	13.17	2037.1	1.58	8.2	3.3
2	648	216	9.90	2134.8	1.91	10.4	4.6
3	480	104	2.52	1047.9	1.86	6.7	3.6
4	752	272	13.09	2253.3	1.76	6.1	2.6
5	800	264	14.10	1488.6	1.12	19.2	10.5

line development. Lake 3 is the smallest and the second shallowest, and has the second highest value for shoreline development.

4.2 TEMPERATURE AND OXYGEN DATA

4.2.1 Temperature

A continuous recording of temperature was made for 116 days in Lake 5 at 1 meter (Figure 3). The maximum temperature reached during the summer was 17 C. Studies have shown that optimum temperature for growth of arctic charr is 14 C and rainbow trout is 17 C (Jobling, 1982). The temperature recording showed that the lake reached 14 C on 22 June and remained mostly above this point until 29 August. Hence, the arctic charr in the lake experienced optimum growing conditions

JUNE 10 TO OCTOBER 6 1986

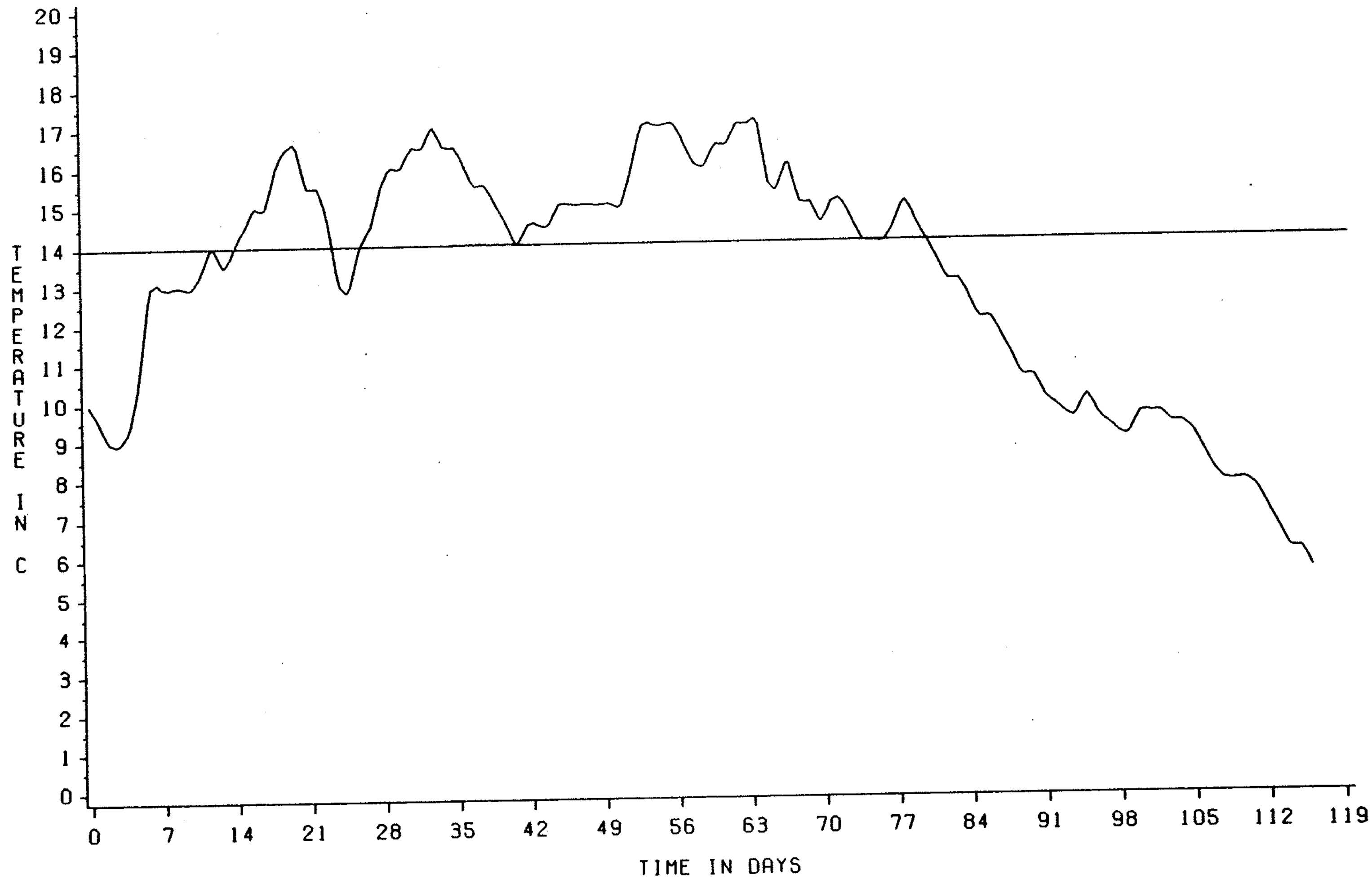
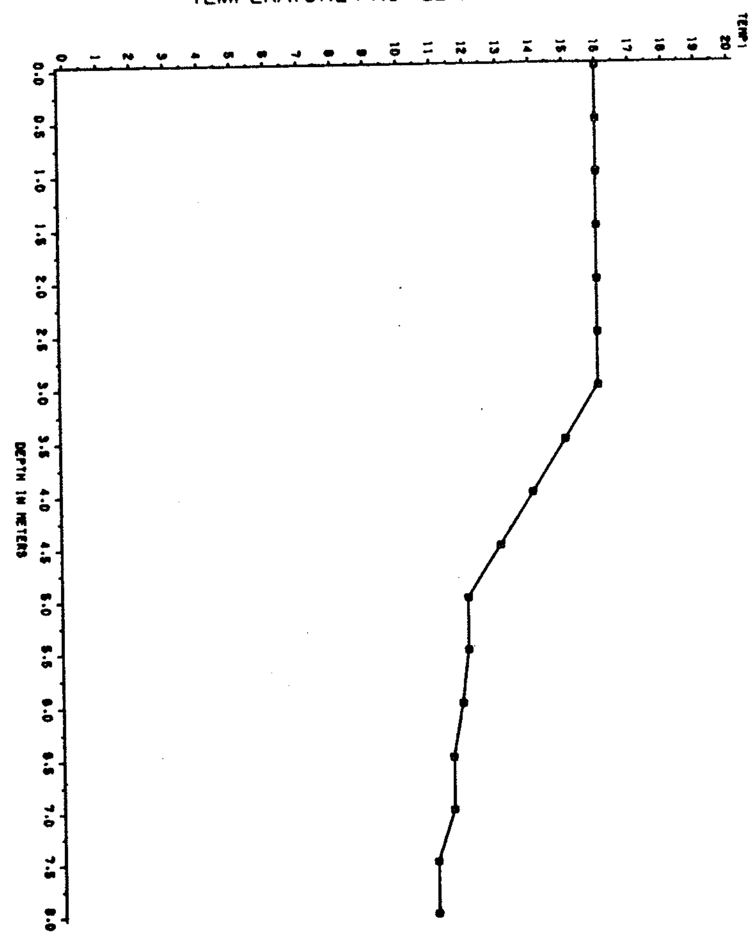


FIGURE 3: SURFACE WATER TEMPERTURE OF LAKE 5

tions for a period of 68 days, provided they remained at this depth. After the end of August the temperature dropped to 5 C on 6 October when the recording was terminated.

Depth profiles for the study lakes were drawn (Figure 4, Figure 5, and Figure 6). Lakes 1 and 2 at Lynn Lake were only sampled once, and only Lake A at Grand Rapids was sampled. In mid June Lake 1 was not thermally stratified as, apart from a slightly higher surface water temperature, the water column remained at 16 C. Lake 2 was thermally stratified in mid June with the epilimnion at 16 C, the thermocline being formed between 3-5 meters, and the hypolimnion decreasing to 10 C on the bottom at 8 meters. Lake 3 did not have a thermocline in mid June, with the temperature profile remaining at approximately 16 C. In October the temperature profile in this lake was constant at 2 C to the bottom at 5 meters. Lake 4 was thermally stratified in mid June, with the epilimnion at 16 C, the thermocline between 1.5 to 2.5 meters, and the hypolimnion decreasing to 10 C at the bottom of 6 meters. The temperature profile in October was constant throughout the water column at 2 C. Lake 5 was also thermally stratified in June with the surface temperature being 14 C and decreasing to 9 C at the thermocline which was formed between 7 to 9 meters, and the hypolimnion decreasing from 6 C to 4 C at the bottom of 16 meters. The temperature profile when measured in October was fairly constant at 4 C for the whole water column. Lake A at Grand Rapids had a relatively constant temperature of 15.5 C throughout the water column when measured in September.

TEMPERATURE PROFILE OF LAKE 2



TEMPERATURE PROFILE OF LAKE 1

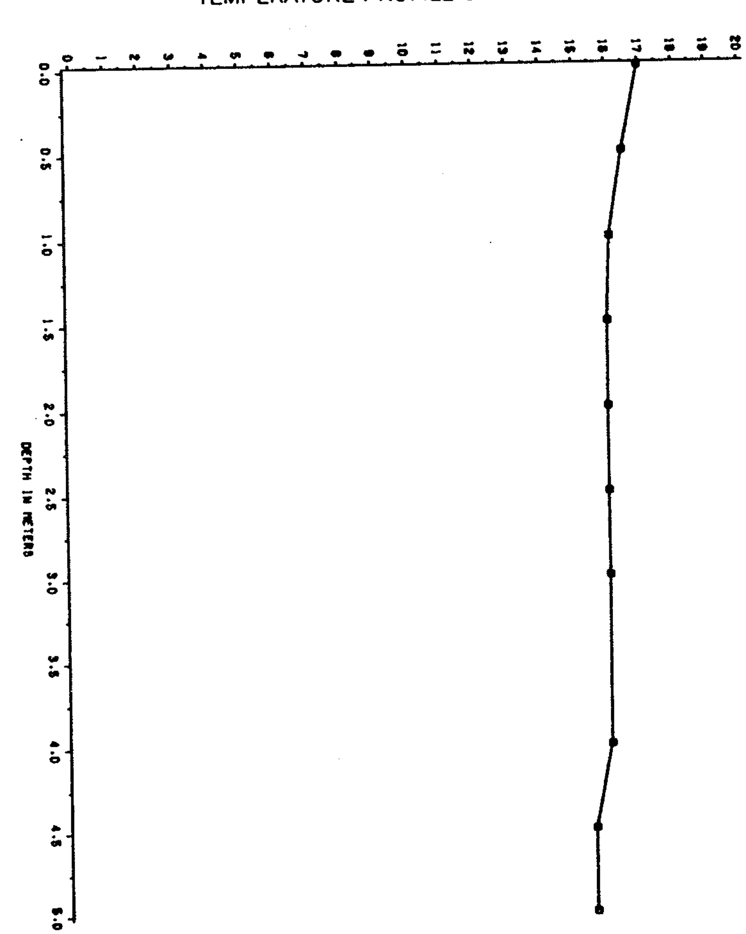


Figure 4: Temperature Profiles of Lakes 1 and 2

Key: ___ June
___ **October**

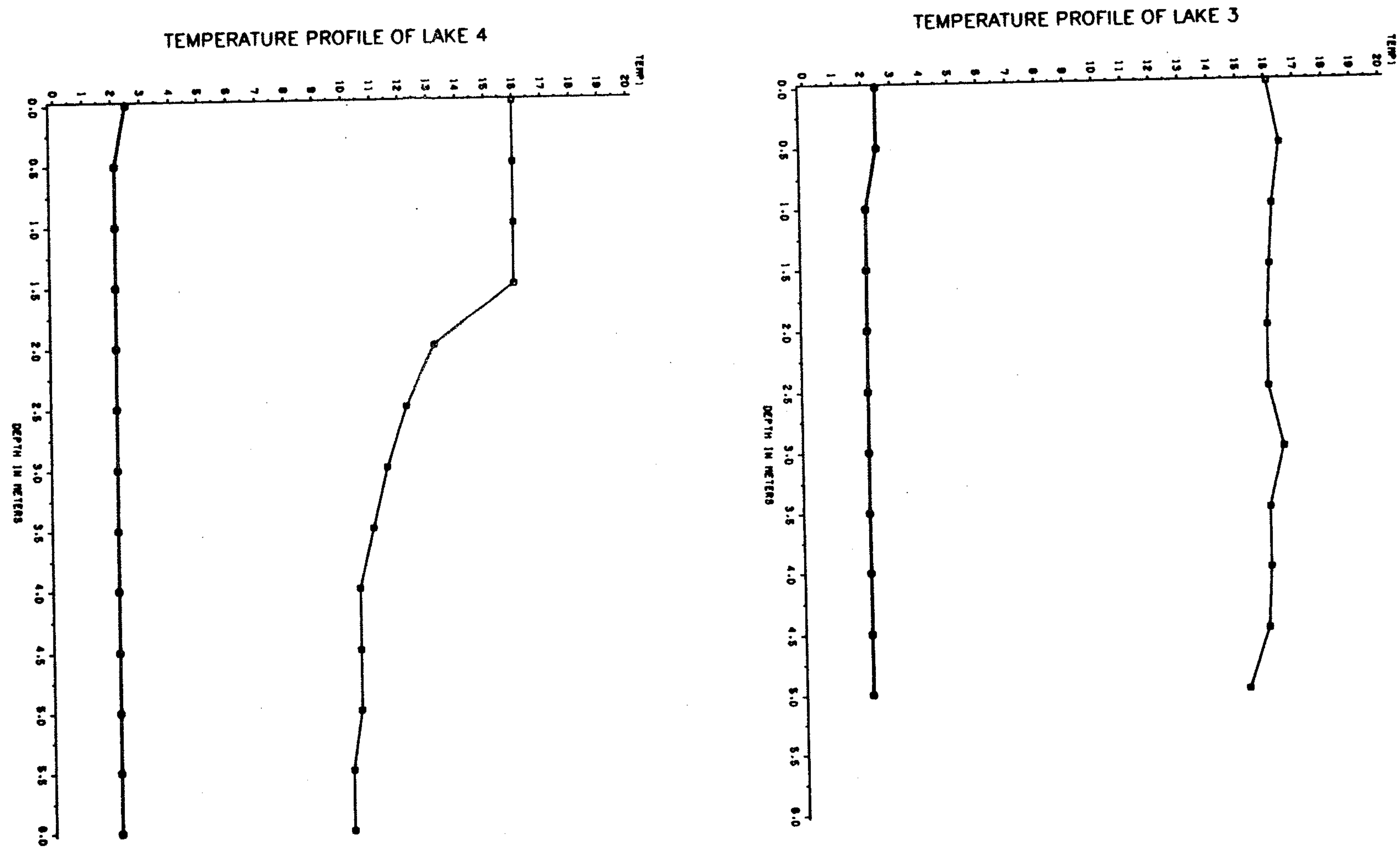
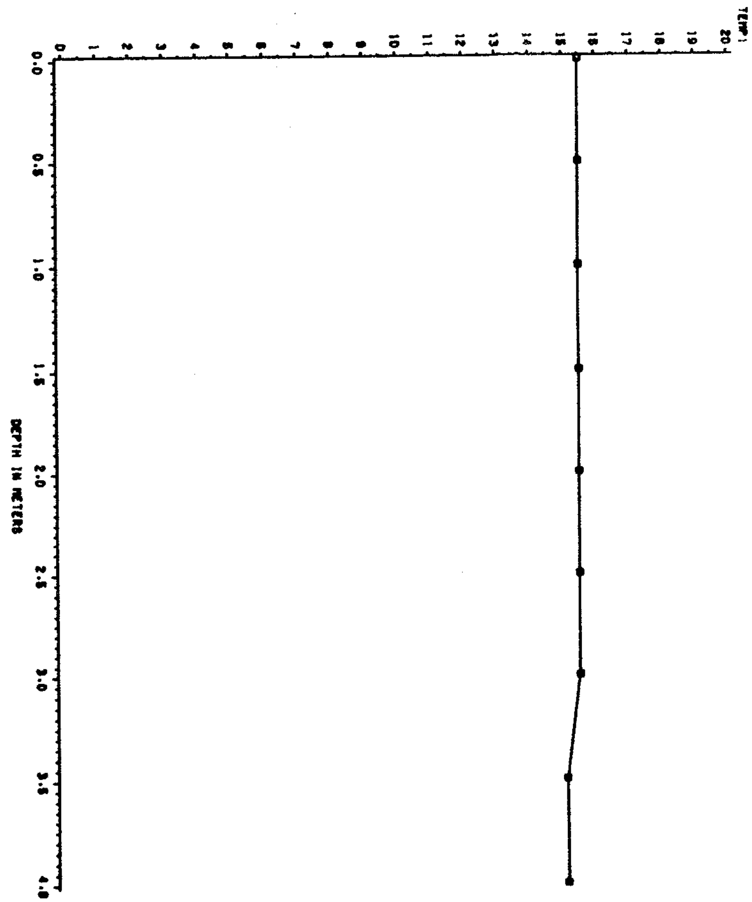


Figure 5: Temperature Profiles of Lakes 3 and 4

Key: ___ June
___ October

TEMPERATURE PROFILE OF LAKE A
ON SEPT 4 1986



TEMPERATURE PROFILE OF LAKE 5 IN C

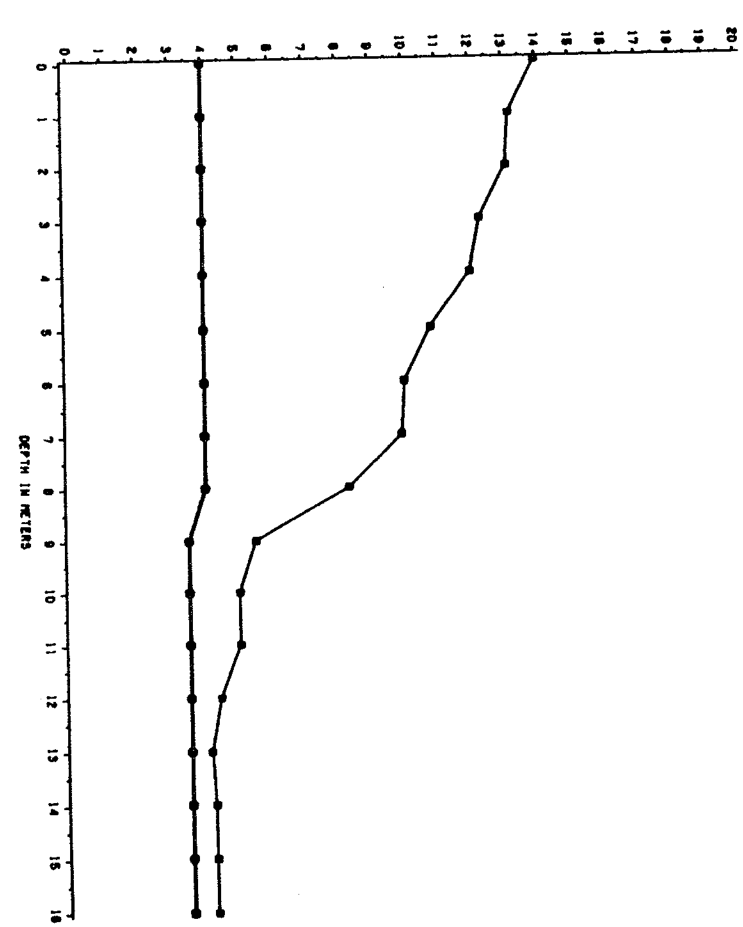


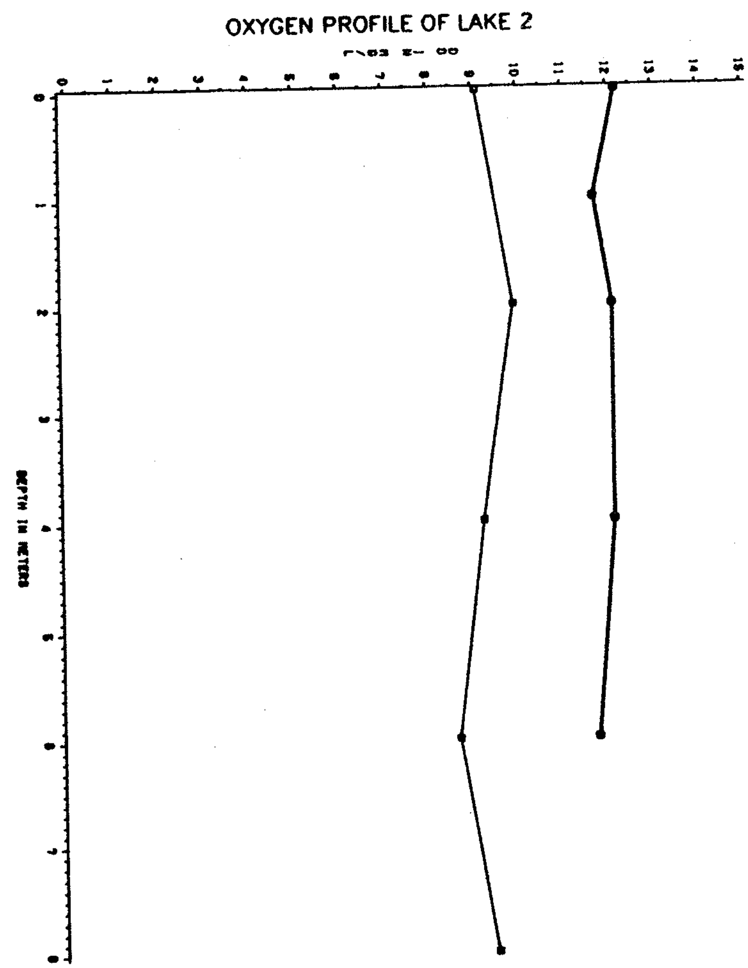
Figure 6: Temperature Profiles of Lakes 5 and A

Key: ___ June
___ **October**

4.2.2 Oxygen

Dissolved oxygen profiles for the lakes were drawn (Figure 7, Figure 8 and Figure 9). Profiles were recorded both in June and October in all the lakes except Lake 1 at Lynn Lake, and Lake B at Grand Rapids was not sampled. Generally, dissolved oxygen concentrations in all the lakes at Lynn Lake in June were constant throughout the water columns and ranged from 8.4 to 10.7 mg/l. However, Lake 5 had a decrease in dissolved oxygen at 12 meters to 6.5 mg/l. Measurements taken in October were higher than those of the summer, ranging from 11 to 12.2 mg/l and also remaining constant with depth. The dissolved oxygen profile for Lake A at Grand Rapids was slightly lower than those of the Lynn Lake lakes, being between 7.5 to 8 mg/l when measured in September. The relative saturation of these dissolved oxygen concentrations was also determined (Table 2).

Solubility of oxygen in water is affected nonlinearly by temperature and increases considerably in colder water. Also, an increase in altitude decreases solubility because of the pressure reduction. Relative saturation is the relation of existing solubility (amount of gas present) to the equilibrium content expected at the same temperature and partial pressure, and is expressed as a percentage (Cole, 1983). The table therefore determines that summer saturation levels for the Lynn Lake lakes ranged from 98.8 to 116.3 % saturation, and October saturation levels ranged from 88.1 to 104.0 % saturation. The saturation levels of Lake A at Grand Rapids were lower, ranging from 79.3 to 89.7 % saturation.



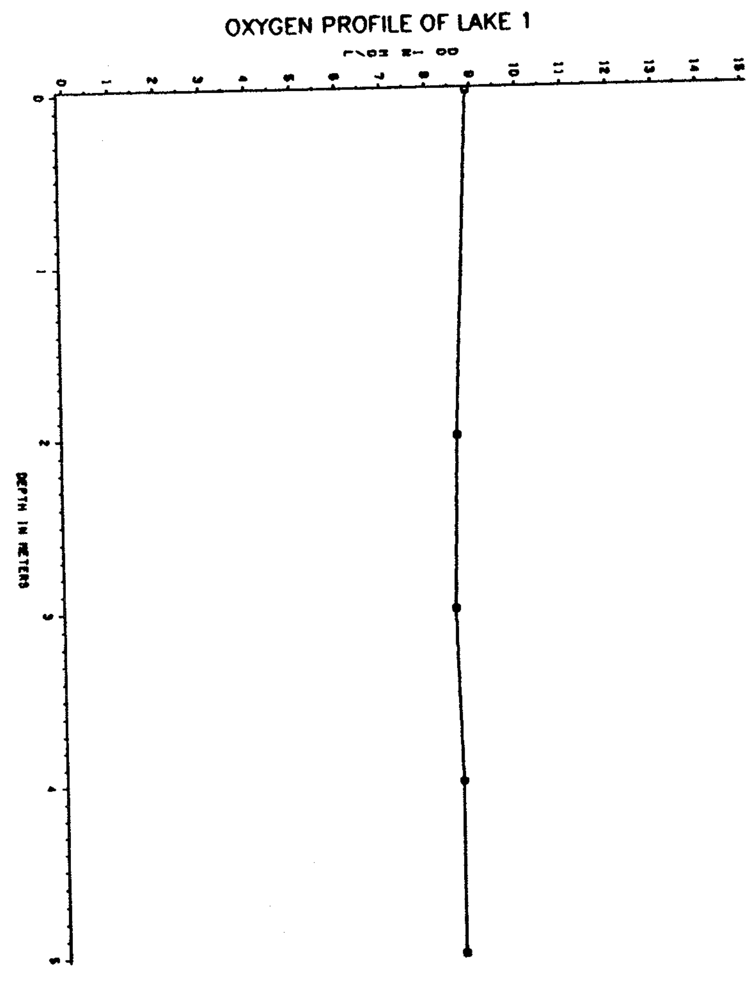
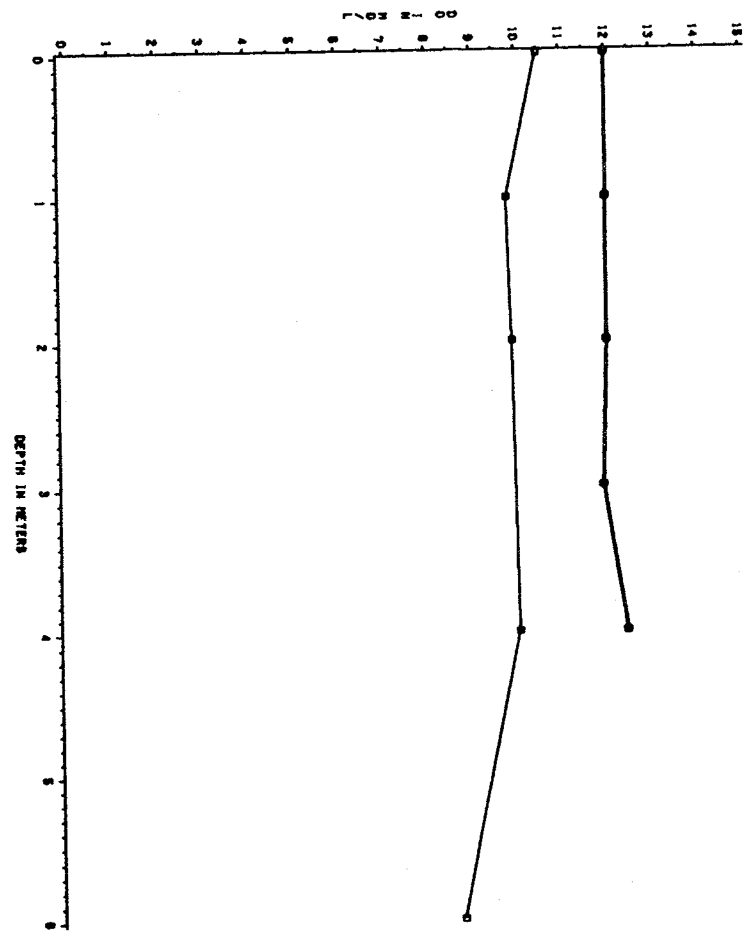


Figure 7: DO Profiles of Lakes 1 and 2

Key: ___ June
___ October

OXYGEN PROFILE OF LAKE 4



OXYGEN PROFILE OF LAKE 3

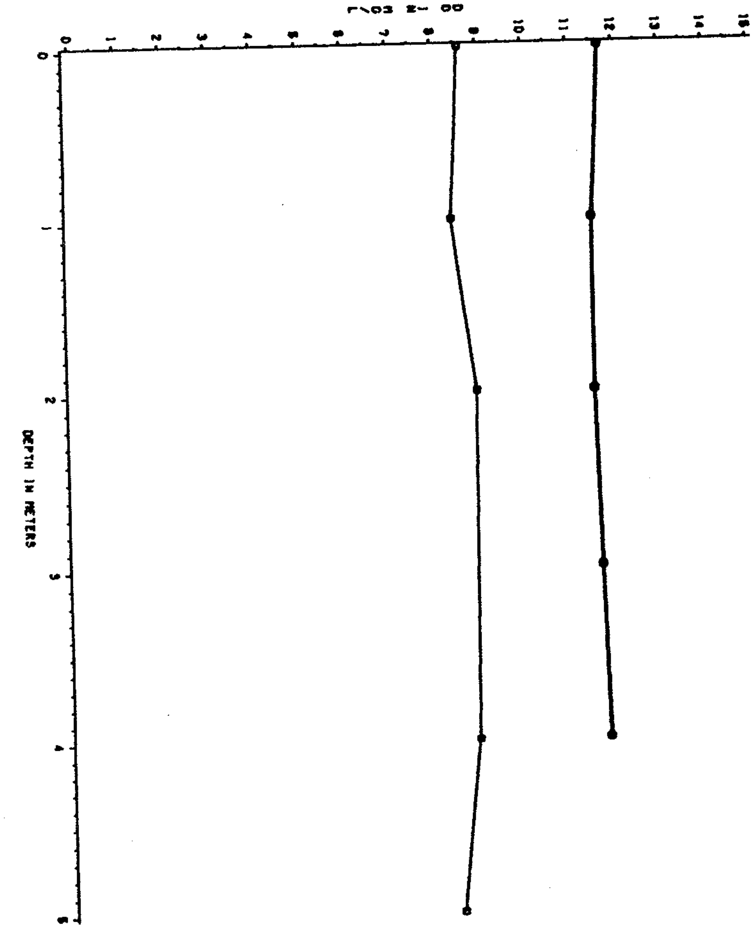


Figure 8: DO Profiles of Lakes 3 and 4

Key: ___ June
___ October

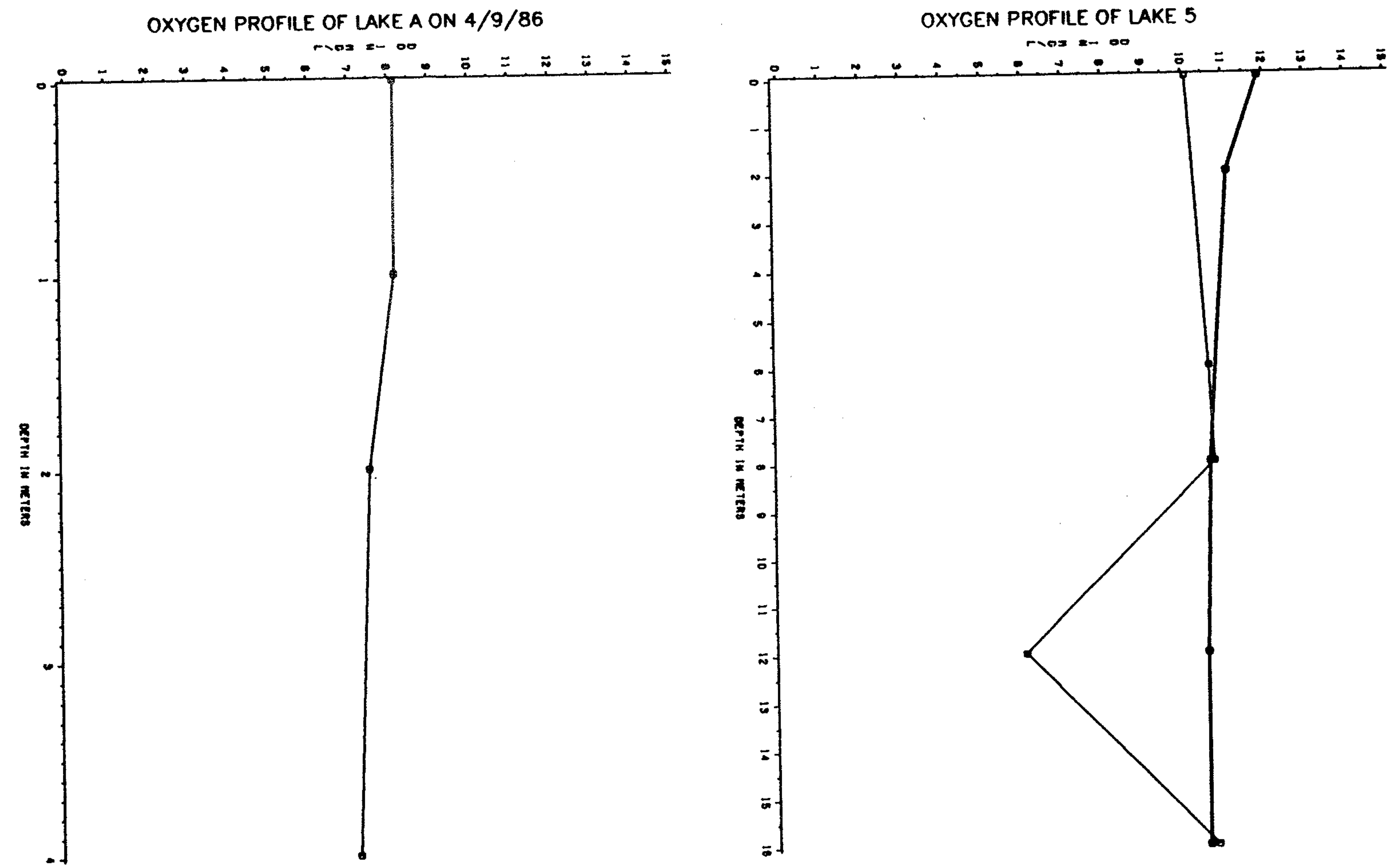


Figure 9: DO Profiles of Lakes 5 and A

Key: ___ June
___ October

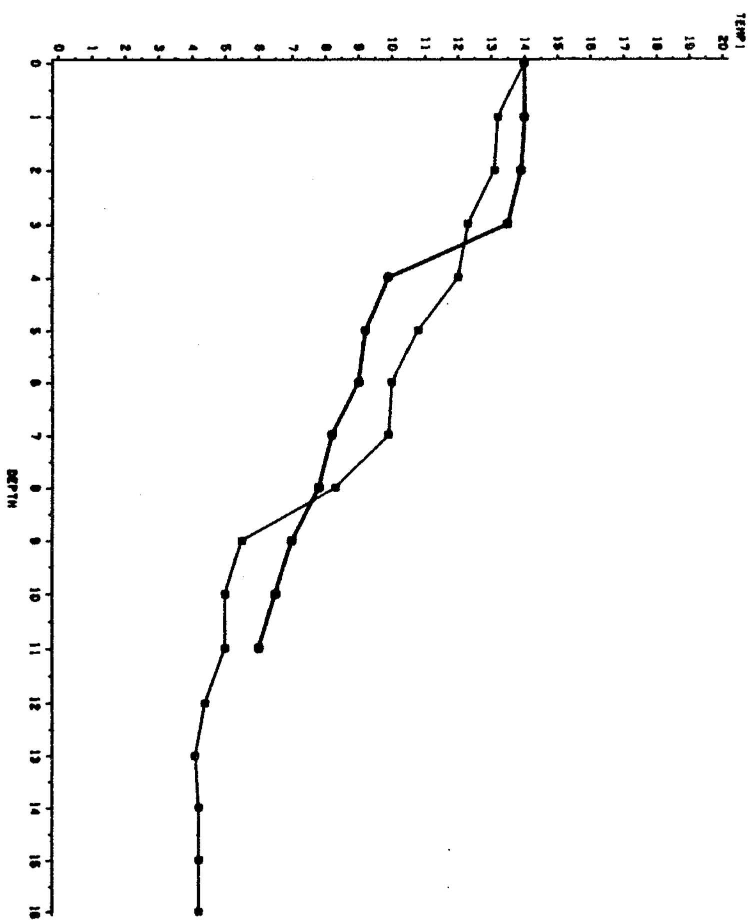
TABLE 2

Oxygen Saturation Ranges of the Study Lakes

Temp	Solubility at 1 atmo	Recording adjusted for altitude	% Relative Saturation
LYNN LAKE:			
17 C	9.66	10.32	106.8%
16 C	9.87	8.6 - 9.9	101.0 - 116.3
11 C	11.03	9.4 - 10.7	98.8 - 112.5
10 C	11.29	11.6 - 12.41	102.7 - 112.5
8 C	11.84	12.41	104.8
4 C	13.11	12.41	94.6
2 C	13.83	12.18 - 14.38	88.1 - 104.0
GRAND RAPIDS:			
15 C	10.08	7.99 - 9.05	79.3 - 89.7

Finally, temperature and dissolved oxygen profiles of lakes 4 and 5 over 2 years were compared (Figure 10 and Figure 11). Recordings were made when the fry were stocked into the lakes on 12 June 1985, and these results are compared to the ones recorded in June 1986. The temperature profiles of the 2 lakes were very similar, as well as the oxygen profile of Lake 4. However, Lake 5 had much higher dissolved oxygen levels in June 1985, ranging from 16 to 17 mg/l compared to 6 to 10 mg/l in June 1986.

TEMPERATURE PROFILE OF LAKE 5



TEMPERATURE PROFILE OF LAKE 4

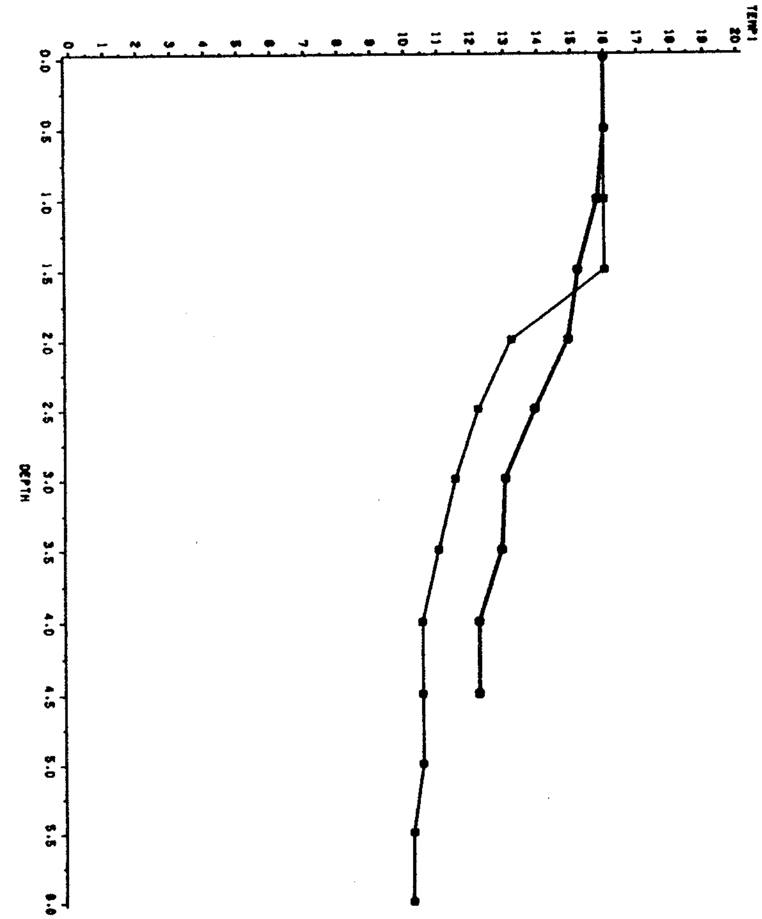


Figure 10: Temperature Profiles of Lakes in 1985 and 1986

Key: ___ 1986
___ 1985

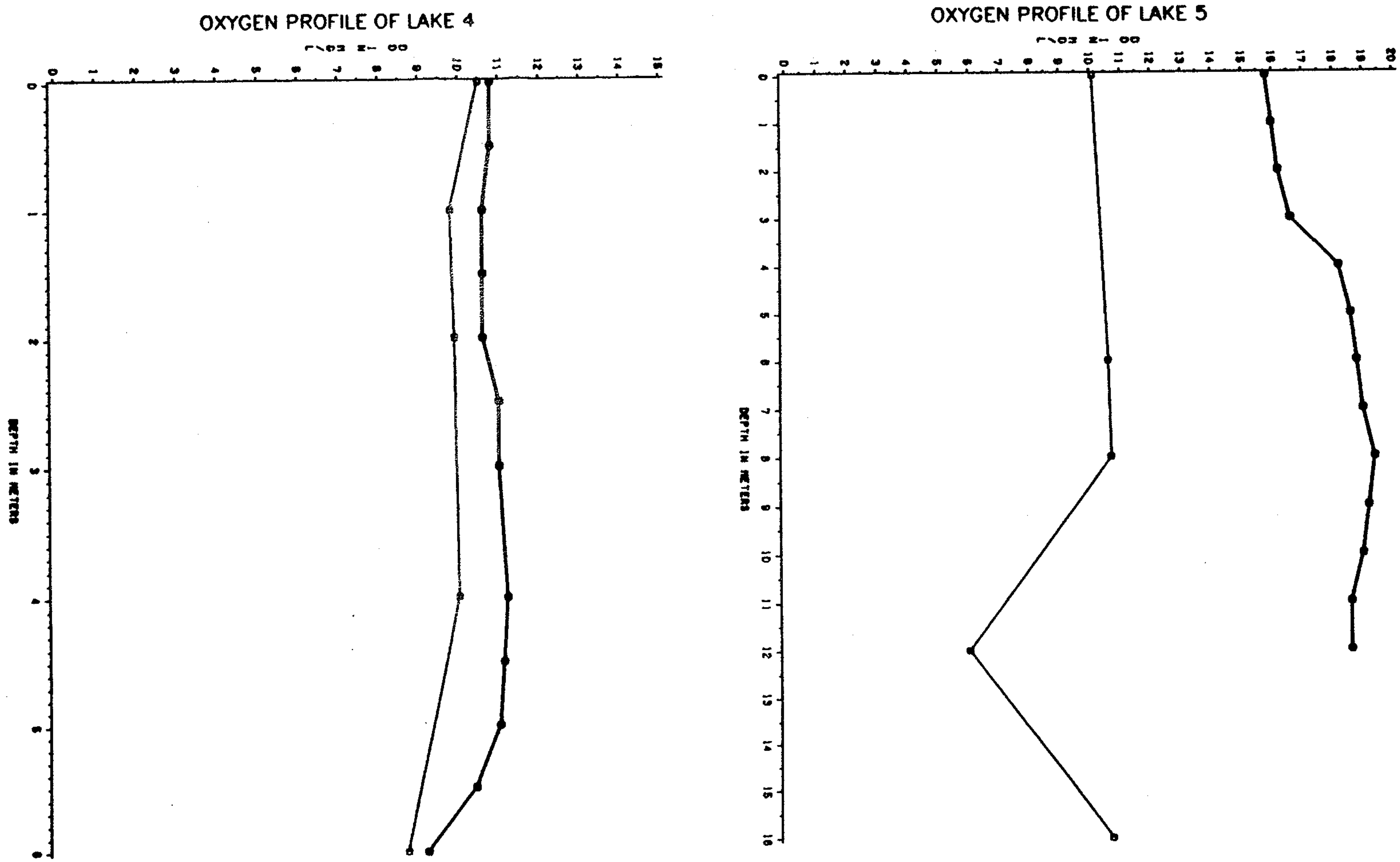


Figure 11: DO Profiles of Lakes in 1985 and 1986

Key: ___ 1986
___ 1985

4.3 NUTRIENTS AND IONS

4.3.1 Nutrients

Total nitrogen, total phosphorous and chlorophyll-a concentrations in ug/l were recorded at various depths in each lake (Table 3). Nitrogen and phosphorous concentrations are direct measures of these nutrients in a lake. Chlorophyll-a is a measure of algal biomass in a lake and therefore is an indirect measure of nutrient status. Recordings were made in June 1986 at Lynn Lake and in September at Grand Rapids. Total dissolved nitrogen was added to suspended nitrogen to give total nitrogen, and the same was done for phosphorous. In Lake 1 nutrient concentrations were well distributed in the water column, perhaps because no thermal stratification occured in this lake. Both lakes 2 and 3 deepest samples had higher concentrations of nutrients than the rest of the water column. Lake 4 and 5 nutrient concentrations appeared to be well distributed in the water column even though thermal stratification occured in these lakes. Nutrients in Lake A at Grand Rapids also were well distributed, except for a higher value for chlorophyll-a in the bottom sample. Between lakes, Lake A at Grand Rapids and Lake 4 at Lynn Lake had the highest nutrient concentrations, with Lake 1, 2 and 3 next all being very similar, and Lake 5 the lowest. Total dissolved nitrogen and phosphorous, suspended nitrogen, phosphorous and carbon, chlorophyll-a concentrations and secchi disk depths were measured in all the study lakes (Table 4). Secchi disk depth is another indirect method of measuring nutrient status in a lake, as it measures algal biomass which is determined by nutrient concentration in the lake.

Table 3: LAKE NUTRIENTS

DEPTH m	LAKE 1 TN	LAKE 1 TP	LAKE 1 CHL	LAKE 2 TN	LAKE 2 TP	LAKE 2 CHL	LAKE 3 TN	LAKE 3 TP	LAKE 3 CHL	LAKE 4 TN	LAKE 4 TP	LAKE 4 CHL	LAKE 5 TN	LAKE 5 TP	LAKE 5 CHL	LAKE A TN	LAKE A TP	LAKE A CHL
0	367	27	1.57	338	25	1.59	417	19	1.06	636	41	4.9	250	22	0.52	613	19	1.66
1	-	-	-	-	-	-	340	20	-	591	29	-	-	-	-	596	20	1.45
2	-	-	-	387	13	-	360	20	-	557	34	3.14	220	19	-	600	20	1.48
3	360	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	1.58	360	17	-	608	27	-	200	21	-	629	21	4.83
5	390	31	-	-	-	-	460	18	-	-	-	-	-	-	-	-	-	-
6	-	-	-	366	14	-	-	-	-	582	41	6.08	196	17	-	-	-	-
8	-	-	-	491	30	4.86	-	-	-	-	-	-	197	19	0.28	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	195	21	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	176	22	0.55	-	-	-

(Note: all measurements in ug/l. TN= total nitrogen, TP= total phosphorous, CHL= chlorophlly-a)

TABLE 4

Lake Nutrients at 0 Meters

LAKE	TDN ug/l	TDP ug/l	SUSP ug/l	SUSN ug/l	SUSC ug/l	CHLOR ug/l	SECCHI m
1 June	290	21	6	77	700	1.57	2.00
2 June	250	16	9	88	890	1.59	3.25
Oct	340	22	6	81	860	2.34	3.50
3 June	300	19	-	87	800	1.06	4.75
Oct	200	13	3	55	780	0.96	5.00
4 June	470	30	11	166	1860	4.90	1.70
Oct	440	18	5	46	540	1.98	2.75
5 June	190	16	6	60	500	0.52	5.00
Oct	260	13	4	48	550	1.24	5.00
A Sept	530	14	5	83	1150	1.66	3.00
B Sept	800	16	17	90	1380	1.04	-

(Note: TDN=total dissolved nitrogen, TDP=total dissolved phoshorous, SUSP=suspended posphorous, SUSN=suspended nitrogen, SUSC=suspended carbon, CHLOR=chlorophyll-a)

Generally, the parameters measured are relatively similar between June and October in the Lynn Lake lakes, except Lake 4 which has lower nutrient concentrations in October. In June, Lake 4 had the highest concentrations of nitrogen, phosphorous and chlorophyll a, as well as the lowest water transparency, this is all indicative of a higher "eutrophic" state compared to the other lakes. The two study lakes at Grand Rapids had higher dissolved nitrogen and suspended carbon concentrations than the Lynn Lake lakes, but similar phosphorous and chlorophyll-a concentrations.

4.3.2 Ions

Ion concentrations in the study lakes were measured (Table 5). The sum of all cations and anions was used to calculate specific conductivity, and this value was then compared to the measured value. The difference between values was either due to one or more major ions being ignored in analysis, and hence the calculated value being incorrect. The measured value could also be incorrect if the samples were left too long before conductivity was measured. Specific conductivity is a measure of the water's reciprocal of resistance to an electrical flow, and is closely proportional to the concentration of major ions (Wetzel, 1983).

Generally, potable water has a conductivity range of 50 to 1500 umhos/cm, and distilled water a range of 2 to 4 umhos/cm. Lake 4 had the lowest concentration of anions and cations and consequently the lowest conductivity measurement, while Lake 3 the highest in June. In October the conductivity measurements for all the Lynn Lake lakes were very low and similar. The Grand Rapid study lakes had considerably higher concentrations of calcium, magnesium and dissolved inorganic carbon, as well as higher conductivity readings in comparison with the Lynn Lake lakes.

TABLE 5: MAJOR IONS

Lake		Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Mn (mg/l)	Cations ueq/l	Cl (mg/l)	SO4 (mg/l)	DIC (umol/l)	DOC (umol/l)	Anions ueq/l	Cal.Con (us/cm)	Con (us/cm)	pH	Alk. (ueq/l)	Org.Ac. (ueq/l)
1	J	0.88	0.44	4.58	0.42	0.04	0.01	313	0.2	1.0	210	-	384	28	41	7.72	203	155
2	J	0.93	0.50	1.72	0.32	0.04	0.01	165	0.4	0.5	80	-	185	14	18	7.21	71	93
	O	0.97	0.47	1.14	0.33	0.04	0.01		0.4	0.6					14	6.73		10
3	J	0.47	0.31	6.11	0.38	0.68	0.04	365	0.4	0.6	190	-	401	29	44	7.94	187	199
	O	0.83	0.51	1.19	0.31	0.04	0.01		0.2	1.0					13	6.72		9
4	J	0.42	0.39	0.89	0.27	0.76	0.03	95	0.1	1.2	40	-	73	9	9	6.30	19	26
	O	0.52	0.36	1.76	0.34	0.20	0.04		0.2	1.0					16	6.69		22
5	J	0.93	0.48	1.77	0.39	0.04	0.01	173	0.1	1.2	120	-	193	16	14	6.37	97	68
	O	1.05	0.53	1.86	0.46	0.04	0.01		0.2	1.2					19	6.88		12
A	S	0.73	0.83	26.8	26.8	0.04	0.01	-	0.4	3.7	2460	720	-	-	301	8.62	21	21
B	S	1.06	1.17	24.9	37.2	0.04	0.01	-	0.6	1.7	3820	890	-	-	350	8.64	44	44

(Note: J=June, O=October, S=September, DIC=disolved inorganic carbon, DOC=disolved organic carbon, Cal.Con= calculated conductivity, Con=measured conductivity, Alk=total alkalinity, Org.Ac.=organic acids)

4.4 FISH DATA

4.4.1 Fish Production

Production statistics for the Lynn Lake lakes were calculated (Table 6).

TABLE 6

Production Statistics

LAKE	Number Planted	Number Harvested	Relative Mortality	Relative Survival	Production (kg)	Production/Area (kg/ha)
1	3,000	0	100%	0%	N/A	N/A
2	6,000	N/A	N/A	N/A	N/A	N/A
3	3,000	10	99%	1%	11.093	4.40
4	7,500	426	94.3%	5.68%	64.128	4.89
5	7,500	N/A	N/A	N/A	N/A	N/A

Only lakes 3 and 4 were harvested. Fish survival rates were 1% and 5.68%, and hence the mortality rates were 99% and 94.3% respectively. Lake 1 was fished a few times over the summer and no fish were found, hence the mortality rate is estimated at 100%. Lakes 2 and 5 were only sampled over the study period and hence survival and mortality rates for these lakes are unknown. Production of Lakes 3 and 4 was determined from the amount of fish harvested minus the amount stocked into the lakes. Production was 11.09 kg and 64.13 kg respectively. Production per hectare was similar for the two lakes at 4.4 kg/ha for Lake 3 and 4.89 kg/ha for Lake 4. Production statistics for the study lakes at Grand Rapids were not calculated. Of the 11,500 rainbow trout stocked into Lake A in June, approximately 20% were harvested in late October, with fish weighing up to 1 lb (350 grams). Of the 5,000 arctic charr stocked into the same lake only one was harvested weighing approximately 1/2 lb. Lake B was not harvested (McKay pers. comm.).

Growth statistics for fish in the Lynn Lake study lakes were calculated (Table 7). The size variability of rainbow trout in Lake 2 was great, ranging from 5 to 355 grams. However, the majority of fish caught were in the 5 gram range, and only 1 fish of 355 grams was caught. As this lake had been previously stocked in 1981 this large fish might have been a remnant of this stocking. The rainbow trout caught in Lake 3 were much larger than fish in any of the other lakes, and the size variability of fish in this lake was relatively small. The specific growth rate for these fish between June and October 1986 was 0.97 %/day.

Arctic charr caught in Lake 4 had a wide size variability. The size distribution of arctic charr on stocking and at harvest was determined (Figure 12). At stocking fry sizes exhibited a 'normal distribution', whereas on harvesting fish exhibited a distribution 'skewed' to the right. In other words there were more smaller fish than larger fish. Specific growth in the first year, from June 1985 to June 1986 was 1.19 %/day, and from June to October 1986 was 0.5 %/day. The size variability of actic charr in Lake 5 was small when measured in June and October, and the specific growth rate of the fish for their first year in the lake was 0.33 %/day, and from June to October 1986 was 1.02 %/day.

TABLE 7

Growth Statistics

Lake	Date Sampled	Sample Size	Mean (g)	St.E.	90% Confidence Interval	Range (g)	Sp. Growth (%/day)
1	June 86 Aug 86	0 0	- -	- -	- -	- -	- -
2	June 86 Oct 86	15 0	30.87 -	23.22 -	+/- 40.88 -	5 - 355 -	- -
3	June 86 Oct 86	3 7	386.66 1147.60	43.04 98.23	+/- 125.66 +/- 190.88	306 - 453 711 - 1454	- 0.97
4	June 85 June 86 Oct 86	100 11 208	1.34 103.36 181.46	0.26 33.27 78.98	+/- 0.043 +/- 18.18 +/- 9.008	.82 - 2.01 48 - 168 42 - 380	- 1.19 0.50
5	June 85 June 86 Oct 86	100 25 4	0.84 10.33 116.75	0.18 1.58 14.96	+/- 0.030 +/- 0.966 +/- 17.60	0.4 - 1.37 9.3 - 11.7 101 - 135	- 0.33 1.02

(Note: St.E. = standard error of the mean ,Sp. growth = specific growth)

The size variability between lakes is very large. The two rainbow lakes, 2 and 3, exhibit a difference in mean size of 5 grams and 386 grams respectively in June 1986. There is also a large size difference between the two charr lakes, with fish in Lake 4 having a mean weight of 103 grams in June and those in Lake 5 having a mean weight of 10.3 grams.

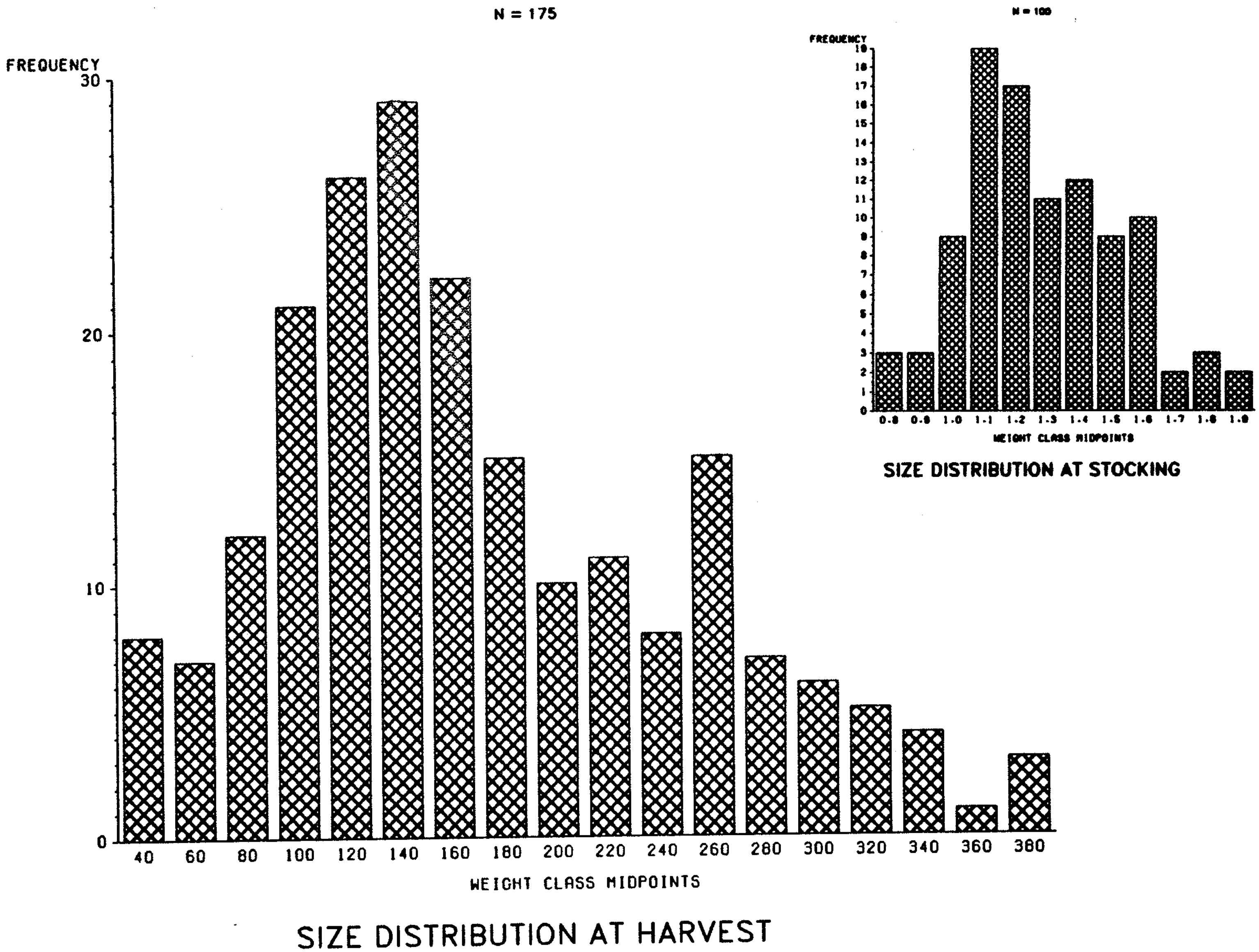


Figure 12: Size Distribution of Arctic Charr in Lake 4

4.4.2 Harvest Data from Lake 4

Over 3 days, 368 arctic charr were harvested from Lake 4. Previously, 60 fish had been caught from the lake by the owners, bringing the total number of fish harvested to 426. The size distribution of charr caught over the three days was determined (Figure 13). Larger fish were caught in the first day, with smaller fish being caught in the following two days. The total weight of fish caught over the three days was also determined (Figure 14), and it can be seen that the total weight of fish caught decreases sharply over this period.

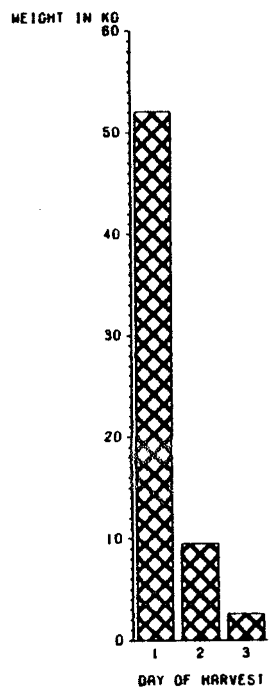


Figure 14: Total Weight of Arctic Charr Caught Over 3 Days

Fifty fish were also weighed before and after eviceration, and an average of 8.47% of body weight was lost through eviceration with a range of 2.24% to 16.6%.

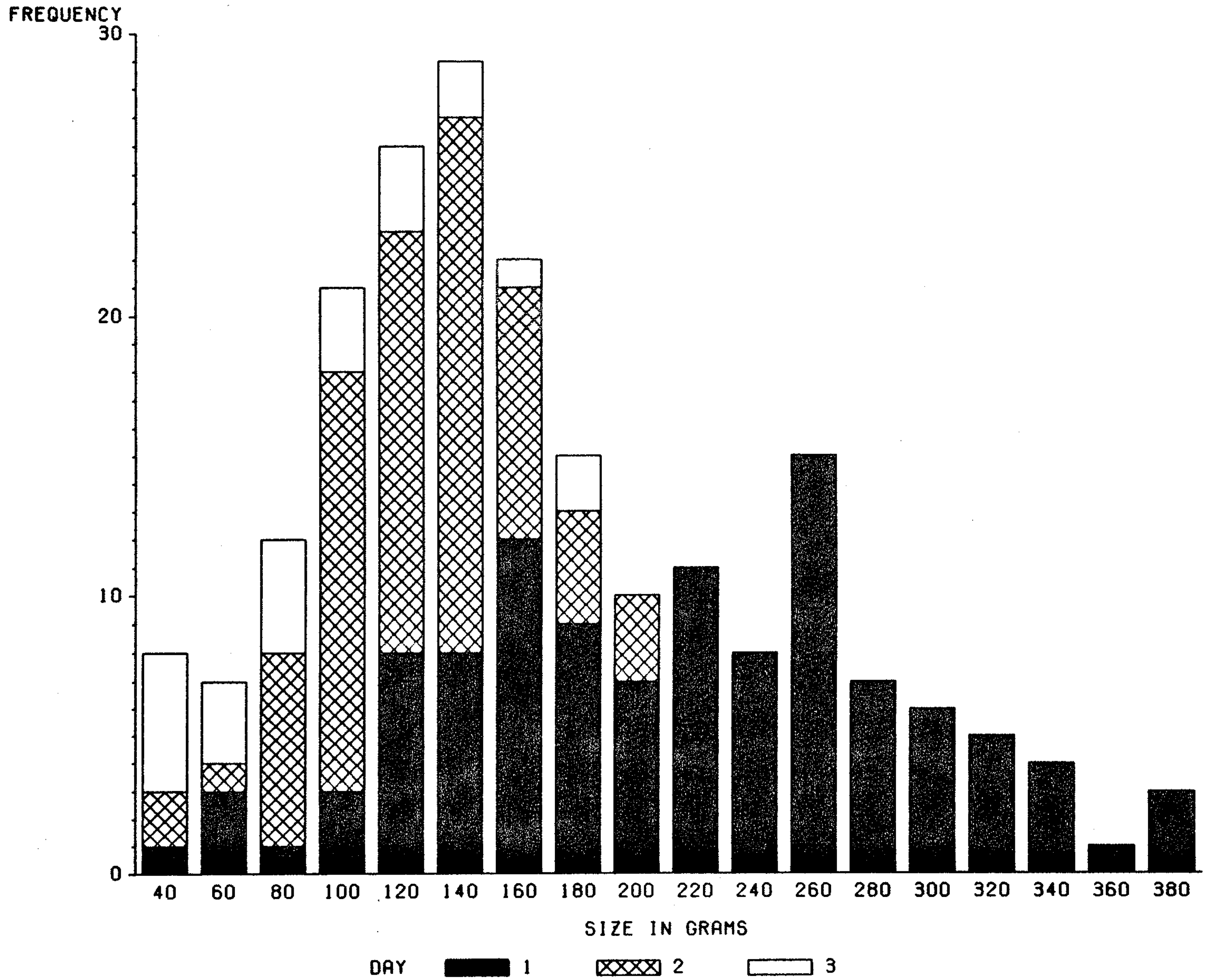


Figure 13: Size Distribution of Charr in Lake 4 Caught Over 3 Days

4.4.3 Growth Model

Using temperature data collected from the thermograph in Lake 5, a model of arctic charr growth in Lake 4 was determined using the growth model devised by Papst et al. (1982). The model expresses specific growth as a function of temperature and weight. Knowing the starting size of fry and the temperature of the lake over the whole growth period, specific growth can be calculated. A scaling factor a6 has to be known, and is used to adjust the growth equation to different culture conditions. The scaling factor was determined to be 0.25 by experimenting with different scaling factors to obtain growth closed to that of observed growth.

Growth of fish was simulated at Lynn Lake conditions and at conditions found in prairie potholes (Figure 15). The pothole fish achieve 200 grams before 150 days, whereas the Lynn Lake fish only achieve this size after 400 days. The effect on growth of stocking fingerlings of variable size was also simulated (Figure 16), using 5 gram (3 inch), 12 gram (4 inch) and 40 gram (6 inch) fingerlings. The 40 gram fingerlings achieve market size (200 grams) after 200 days, whereas the 12 gram and 5 gram fingerlings only achieve this size after 350 days.

MODEL BY PAPST ET AL. (1982)

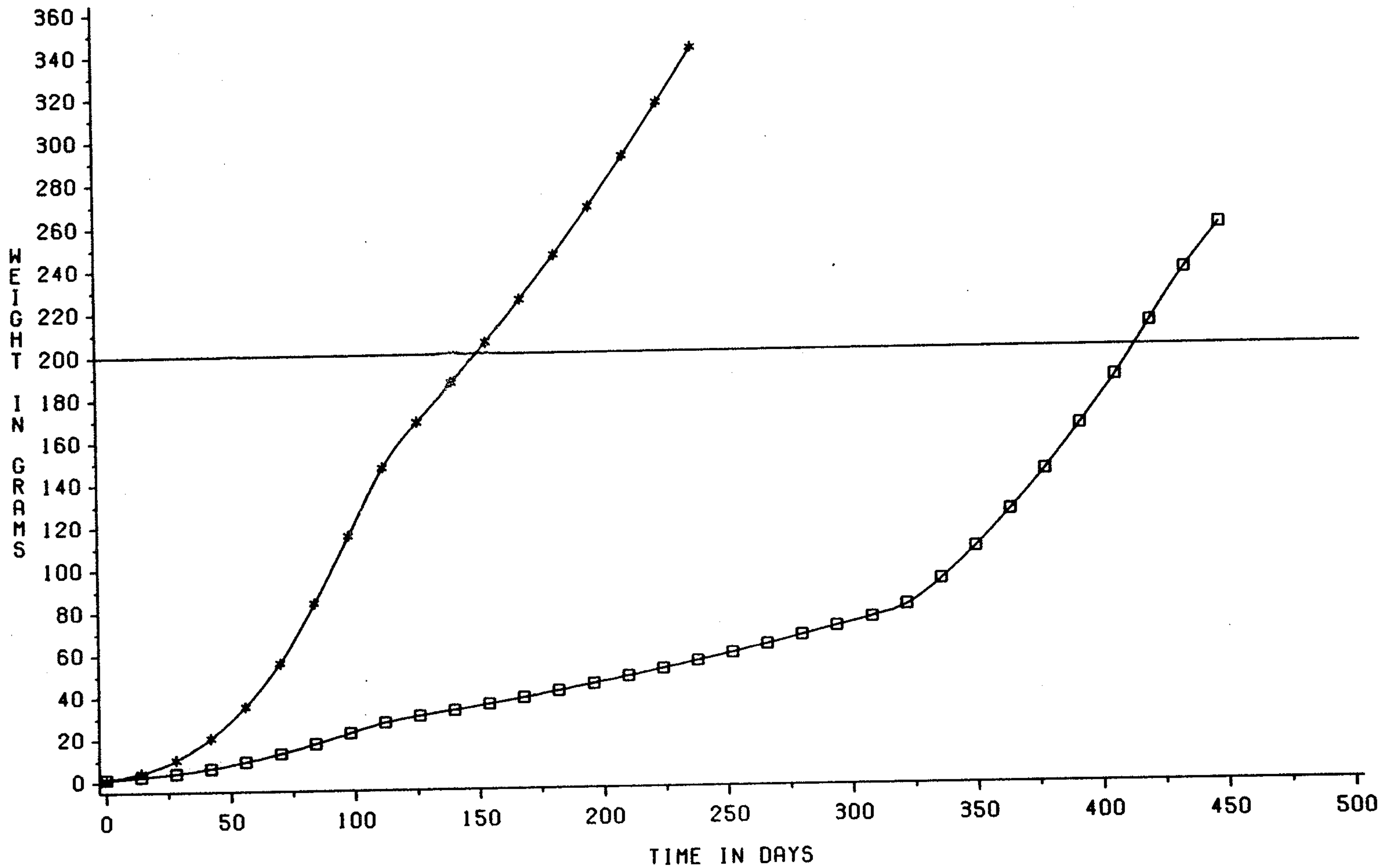


FIGURE 15: GROWTH OF ARCTIC CHARR AT LYNN LAKE TEMPERATURES
KEY: STAR = POTHOLE LAKE, SQUARE = LYNN LAKE

MODEL BY PAPST ET AL (1982)

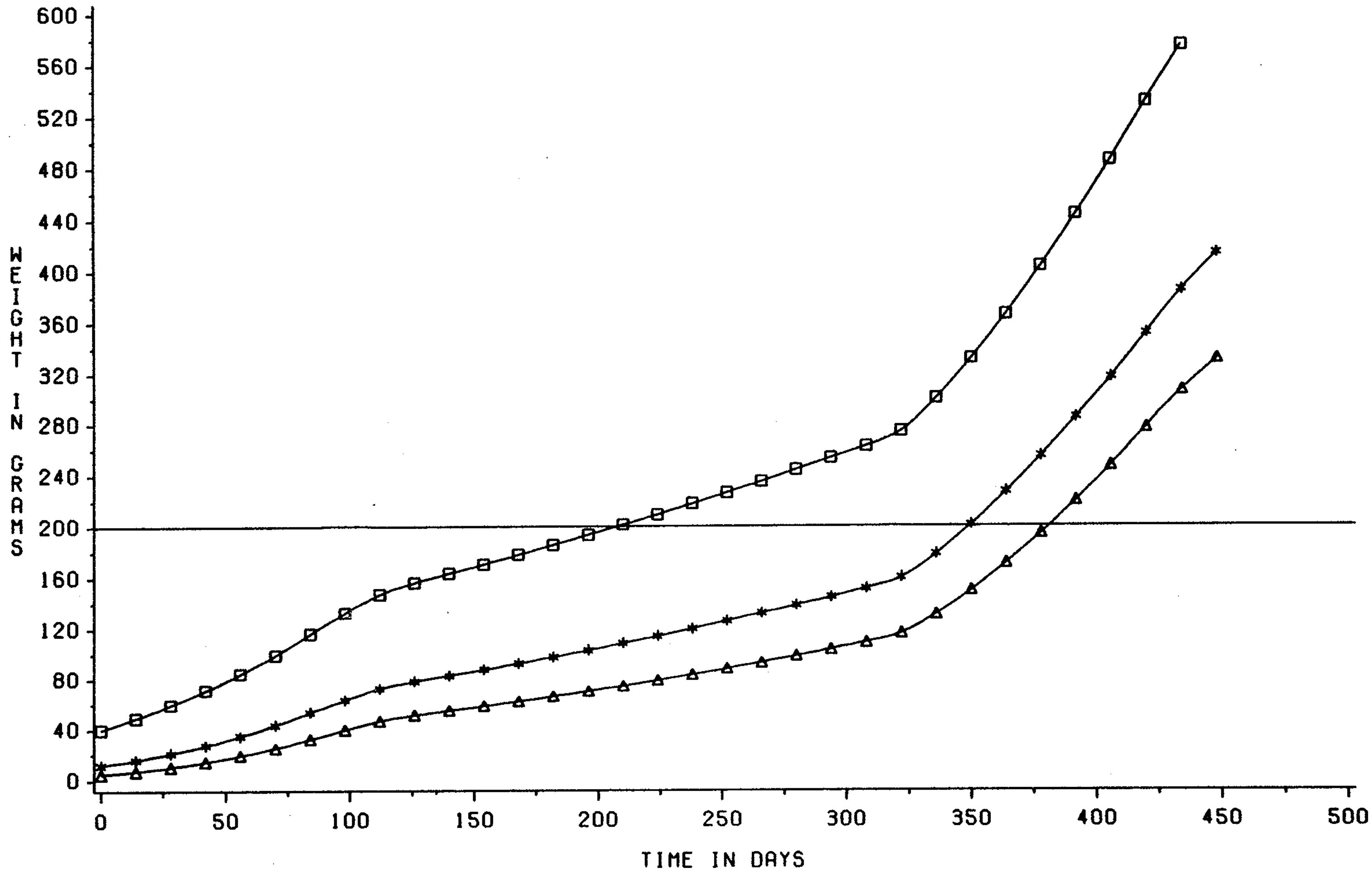


FIGURE 16: EFFECT OF STARTING SIZE ON GROWTH
KEY: TRIANGLE = 5g, STAR = 12g, SQUARE = 40g

4.4.4 Stomach Analysis

The stomach contents of about 5 to 10 fish from each lake were examined and classified under general taxa headings (Table 8).

TABLE 8

Stomach Contents

TYPE	LAKE A	LAKE 2	LAKE 3	LAKE 4	LAKE 5
Ampipoda	++	-	-	-	-
Aquatic insects and larvae	+	+	+	++	++
Chaoborus	-	-	++	-	-
Hirudinea	-	+	+	+	-
Cladocera	-	-	-	+	-
Sticklebachs	-	+	-	-	+

(Note: ++ = numerous, + = present, - = not present)

Aquatic insects, their nymphs and larvae were found in fish stomachs from all the lakes; and insects included Ephemeroptera (mayflies), Diptera (flies and mosquitoes), Odonata (damselflies), and Coleoptera (beetles). In lakes 4 and 5, aquatic insects were numerous in stomach samples. The stomach contents of fish from Lake A at Grand Rapids predominantly contained the amphipod Gammarus lacustris. Stomach contents of fish in Lake 3 also contained amphipods but in much smaller quantities and possibly the amphipod Hyalella (they were much smaller and the first antennae were shorter than the second). The predominant organism in stomachs from fish in Lake 3 was the phantom midge larvae Chaoborus americanus, and were found in both samples from fish in June and October. These larvae were not found in stomachs of fish from any other lakes. Leeches (Hirudinea) were found in stomachs of fish from Lakes 2, 3 and 4. Cladocera were found only in stomach contents of fish from Lake 4. Finally, stickleback minnows (Gasterosteiformes) were found exclusively in stomachs of fish in Lakes 2 and 5, also, these are the only lakes in which sticklebacks were observed.

Chapter V

BIOLOGICAL DISCUSSION

5.1 INTRODUCTION

The first objective of this study was to determine the biological feasibility of using selected northern lakes for extensive aquaculture. The determination of factors essential to the production of fish of appropriate size and quantity is therefore imperative. Once these "critical factors" have been determined and identified, they can be extrapolated to other northern lakes to assess their capability for producing fish. Of the five lakes at Lynn Lake, four have been shown to produce fish, although at very low survival rates. There is also a great size variability of fish in and between lakes. What factors produced such a wide size variability between lakes, and what was the major cause of the high mortality rates? These and other questions will have to be answered to determine the feasibility of extensive aquaculture in northern Manitoba.

Many researchers have explored the potential for using abiotic and biotic factors as predictors of fish yield or biomass, and various "morphoedaphic indexes" to predict fish yield have been developed. Such factors include ionic concentrations (Ryder, 1965), phosphorous and nitrogen (Hrbacek, 1969 and Carlson, 1977), gross photosynthesis (Melack, 1976 and McConnell et al., 1965), chlorophyll-a (Ogelsby,1977) and partical size (Sheldon et al.,1972). Some of these parameters will be assessed for their utility in explaining productivity in the study lakes. Also, the questions of growth rate, mortality, size variability, feeding habits and production will be discussed.

5.2 GEOLOGY AND MORPHOLOGY

Lake basin morphology is a major consideration in determination of nutrient dynamics, oxygen regime, heat budget and general productivity in a lake. Ultimately, morphology is a major factor in determining fish yields (Ryder, 1982). Standard morphometric dimensions of major importance are area, volume and mean depth. Secondary dimensions are littoral zone, flushing rate and shoreline development.

The study lakes at Lynn Lake are ideal for aquaculture since they are enclosed (having no inflows or outflows), and have no indigenous fish populations excepting sticklebacks in some lakes. The water columns of all the lakes are well mixed and well aerated. However, the small size of the lake basins probably constrain nutrient loading, and the esker's sands contribute to low ionic concentrations in the lakes.

At Lynn Lake, Lake 5 has the lowest value for shoreline development, the highest mean depth and, hence, the smallest littoral area. These factors all act together to decrease productivity in the lake. On the other hand, Lake 4 has a shallow mean depth, a large littoral area and a high value for shoreline development, and consequently is a more productive lake.

Which, therefore, is the critical factor that controls lake productivity? Or is it a combination of all these morphometric parameters? One of the earliest attempts to predict fish yield for proposed reservoirs was by Roundsefell (1946), who used a single predictor variable, area. Ryder (1965, 1974, 1982) acclaimed mean depth as the best single indicator of morphometric conditions within a lake basin. Within a homogenous climatic zone, mean depth determines, to a large extent, the temperature regime of lakes during the growing season, with deep lakes generally being colder than shallower lakes. Therefore, theoretically, shallower lakes are more productive. Hence Lake 5, the deepest lake, would be less productive than the shallower lakes and this could account for smaller sized fish in this lake.

However, there is a minimum depth that has to be maintained in order to avoid "winterkill", a condition where all oxygen is used up in a lake over the period of ice-cover, resulting in fish mortality. The deeper the lake, the higher the oxygen content of the lake and the less the likelihood of winterkill. Nevertheless, Precambrian Shield oligotrophic lakes are not known to develop winter anoxia even at shallow depths, suggesting that there is an effect of overall trophic state (Barica and Mathias, 1979). The shallowest study lake is Lake 4, which has a mean depth of 2.1 meters and a maximum depth of 6.1 meter. Therefore, the "critical depth" for northern lakes is less than a mean depth of 2 meters.

5.3 TEMPERATURE AND OXYGEN

Water temperature plays a significant role in fish growth. The relationship between specific growth and temperature is best described by a dome shaped curve (Stauffer, 1973). Increasing water temperature leads to an increase in growth rate until optimum temperature is reached, above which optimum growth rate gradually decreases.

The continuous temperature recording from Lake 5 showed that the lake reached 12 C in mid June and remained above this temperature untill mid September.This temperature recording is compared to a surface water temperature recording taken from a prairie pothole lake (Bernard and Holmstrom, 1978) (Figure 17). The pothole lake has consistently higher temperatures than lakes at Lynn Lake, and the temperature remained over 18 C for approximately 3 months during the summer, and reached up to 23.5 C on occasions. While these conditions are suitable for rainbow trout, they are not suitable for arctic charr who dislike temperatures over 18 C. Therefore, while the pothole lakes would be suitable for the optimum growth of rainbow trout, they are not suitable for arctic charr.

Swift (1964) showed that the optimum temperature for growth of landlocked Windermere charr was 12 to 16 C. He was unable to find any difference in growth rate when charr were maintained in water with 50% and 200% oxygen saturation. Jobling (1982) reported that the optimum temperature for growth of arctic charr is 14 C, with the upper lethal temperature being 22 C. Hokanson et al. (1977) reported that the optimum growth range for rainbow trout to be 17.2 to 18.6 C and the upper

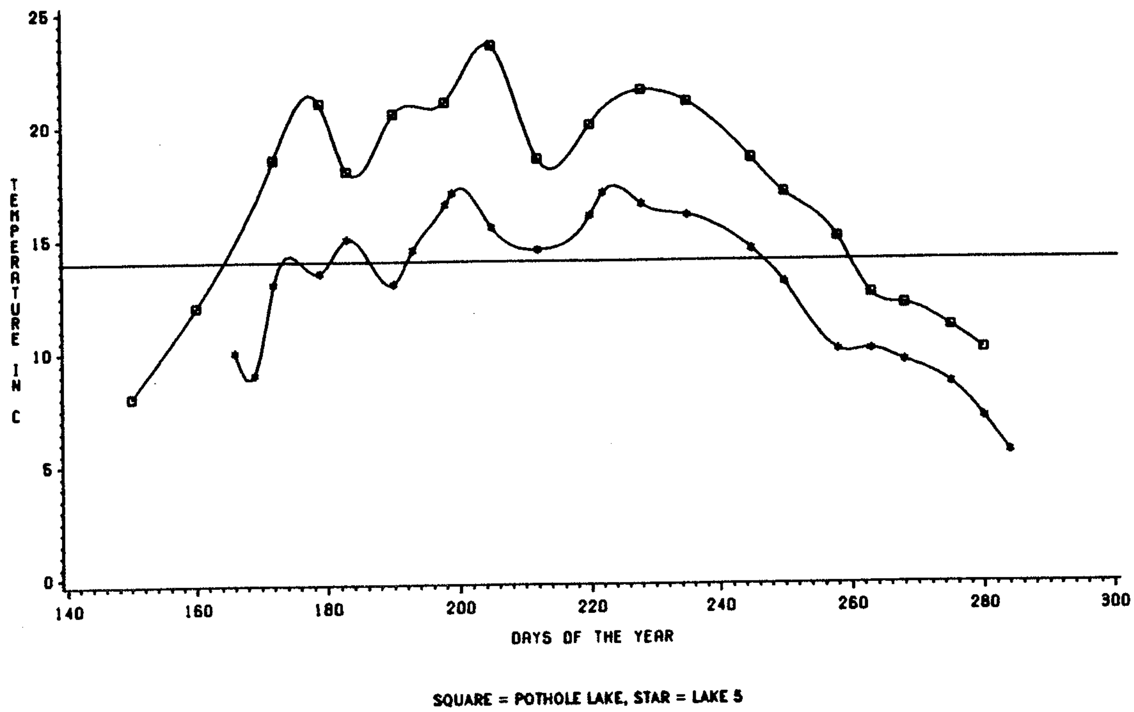


Figure 17: Surface Water Temperatures of Lake 5 and Prairie Lake

incipient lethal temperature was 25.6 C for trout acclimated at 16 C. Papst (pers. comm.) states that the optimum growing temperature for rainbow trout is 15.5 C.

To conclude, the Lynn Lake lakes provide optimal growing conditions for arctic charr over the summer months, with surface water temperatures remaining over 12 C for 77 days, and not exceeding 17 C, providing that fish remain in the upper epilimnion of the lake. Lake 5 was found to be the coolest of the Lynn Lake lakes when recordings were taken in June, with the hypolimnion considerably colder than the epilimnion. This could account for the slower growth rates of fish in this lake. Lake 4, on the other hand, had higher water temperatures and therefore better growing conditions for arctic charr.

On the prairies aquaculture of rainbow trout in potholes has been limited by "summerkill", where catastrophic drops in summertime dissolved oxygen levels in lakes are brought about by the concurance of hot weather and decomposition of algal blooms, resulting in high rates of fish mortality. This is not a problem for northern lakes since oxygen saturations remain high and algal biomasses remain low, even over the summer.

Another phenomena of prairie potholes is "winterkill", which has already been mentioned in relation to mean depth. Estimation of winterkill risk introduces the concept of "dissolved oxygen storage" in a lake. This is the total oxygen mass in a lake just after freeze-up, and the depletion rate of oxygen after this time depends on the lake's mean depth and trophic state. Barica and Mathias (1979) devised a model whereby the time taken to reach complete oxygen depletion could be determined. Using this model, the oxygen mass per square meter was estimated for Lake 4 to be 31.2 g/m2, and the number of days under ice cover was calculated to be 200 days, from mid October to mid May. Hence the critical mean depth could be determined. However, since the the model was devised for prairie lakes, the model does not extend beyond 180 days. Precambrian shield oligotrophic lakes are not known to develop winter anoxia even at shallow depths due to their oligotrophic state (Schindler, 1971). Lake 4 is the shallowest lake with a mean depth of 2 meters, and has not winterkilled. Therefore, it can be assumed that the critical depth for winterkill for northern lakes is less than a mean depth of 2 meters.

To summarize, summerkill caused by low oxygen levels is not experienced in these northern lakes, and is not a problem for fish farmers. Winterkill is not found in northern lakes which are more than two meters in mean depth, this is a prerequisite for aquaculture, as it allows fish to overwinter in the lake.

5.4 IONS

Major ions and conductivity values for the study lakes are compared to the same variables from other lakes in north-west Manitoba which were subject to extensive sampling for the development of a 'pulse' fishing project (Lysack, 1982), as well as similar variables from prairie pothole lakes (Barica, 1975) (Table 9).

The Pulse fishing lakes in north-west Manitoba and the Lynn Lake study lakes share similar latitude, altitude and climate. However, in all parameters except iron, the Lynn Lakes lakes have lower ionic concentrations and hence, lower conductivity measurements than the Pulse lakes. Factors that could account for this are: local geology of the lake basin, local topography and biotic activity. The local geology of the esker's sands would account for the lower ionic concentrations in the Lynn Lake study lakes, and also the small basin sizes would inhibit ion loading into these lakes. Conductivity measurements, as well as calcium and magnesium ion concentrations, in the Grand Rapids study lakes fall between the northern Shield lakes and Prairie eutrophic lakes.

TABLE 9

Comparison of Ions Between Lake Types

Parameter		Lynn Lake Study Lakes	Grand Rapids Study Lakes	N/W Manitoba Pulse Lakes	S/W Manitoba Prairie Lakes
Conductivity (us/cm)	R: M:	9 - 44 25.2	301 - 350 325.5	35.4 - 117 79.3	305 - 7837 -
Calcium (ug/l)	R: M:	0.89 - 6.1 3.01	26.8 - 24.9 25.85	5.0 - 22.0 13.6	28 - 336 -
Magnesium (ug/l	R: M:	0.27 - 0.42 0.36	26.8 - 37.2 32.0	5.0 - 10.0 5.0	9 - 1236 -
Iron (ug/l)	R: M:	0.04 - 0.68 0.31	0.04 0.04	0.02 - 0.26 0.11	0.0 - 0.18 -
Pottassium (ug/l)	R: M:	0.31 - 0.50 0.42	0.83 - 1.17 1.0	2.0 2.0	11.2 - 248 -
Sodium (ug/l)	R: M:	0.42 - 0.93 0.58	0.73 - 1.06 0.89	10.0 10.0	1.6 - 980 -
Chloride (ug/l)	R: M:	0.1 - 0.4 0.18	0.4 - 0.6 0.5	2.0 2.0	1.0 - 191 -

(Note: R=Range and M=mean)

Ryder (1965, 1974) proposed the morphoedaphic index (MEI) of total dissolved solids (TDS) divided by mean depth (Z) to predict lake productivity. Since conception this model has been widely used. The fundamental concept of the MEI "embraces standard thermodynamic theory, that of matter (nutrients) transported as energy within an open system, with fish yield as the biotic output of the system" (Ryder,1982). Constraints on the level of fish yield are determined by lake basin morphometry and nutrient and energy availability. The MEI's success lies with its simplicity as a result of the inclusion of only two abiotic factors out of an array of hundreds that could potentially predict productivity. Ryder's MEI is useful for a number of practical purposes where monetary and manpower constraints preclude detailed studies of lakes.

The MEI was calculated for other lakes in north-west Manitoba (Lysack,1982) by the following equation:

$$Y = 5.616\ X1\ 0.2877\ X2\ -0.5089$$

Where: Y = predicted yield (kg/ha/year)

X1 = mean depth (m)

X2 = total dissolved solids (mg/l)

For 13 lakes in N/W Manitoba the mean MEI was 18.7 (range of 5.1 to 50.8), and the mean predicted yield was 5.18 kg/ha (range of 2.9 to 8.9). These fish yields are similar to those determined for the Lynn Lake study lakes (4.4 and 4.9 kg/ha). However, the yields at Lynn lake could be low because of high mortality rates, not low growth rates. Higher survival rates of fish in these lakes would be required before Ryder's MEI could be applied to the Lynn Lake study lakes.

There is a relationship between specific conductivity (K) and total dissolved solids. TDS data from a given lake district through the seasons can be compared with concurrent conductivities to reveal a relationship, and hence the conversion coefficient (c) can be determined for the equation 'Kc = TDS' (Cole, 1983). The conversion coefficient that relates conductivity to TDS for northern lakes has not been determined, hence the TDS for the study lakes has not been calculated. However, since there is a strong relationship between TDS and specific conductivity, the low ionic concentrations found in the Lynn Lake study lakes would indicate a low TDS and hence a low productivity. However, growth rates were relatively good in the lakes, and productivity levels were low due to a low survival rate. Since conductivity measurements were similar between lakes at Lynn Lake, this would not account for the large size variability of fish between lakes. Ionic factors are not seen to be good predictors of lake productivity in the study lakes.

5.5 NUTRIENTS

Nutrient levels in a lake, total nitrogen and total phosphorous or other parameters that indicate nutrient levels, such as water transparency or chlorophyll-a, are used to generally classify a lake's trophic state. Wetzel (1983) uses these parameters in his general lake trophic classification (Table 10).

The Lynn Lake lakes fall into the mesotrophic classification with regard to total phosphorous concentrations and secchi disk depths, and into the oligotrophic classification in regards to total nitrogen and chlorophyll-a concentrations. The Grand Rapids study lakes fall into the mesotrophic classification for all the measured parameters. However, as can be seen by the wide ranges and overlap between categories, the distinction between trophic states is arbitrary, but they are helpful in generally classifying lakes.

Nutrient levels between lake types are compared (Table 11), and the study lakes are compared to other lakes in N/W Manitoba (Lysack, 1982) and prairie pothole lakes (Barica, 1975).

TABLE 10

General Trophic Classification

Parameter		Oligotrophic	Mesotrophic	Eutrophic
Total P (ug/l)	M: R:	8.0 3 - 17.7	26.7 10.9 - 95.6	84.4 16 - 386
Total N (ug/l)	M: R:	661 307 - 1630	753 351 - 1378	1875 393 - 6100
Chlor-a (ug/l)	M: R:	1.7 0.3 - 4.5	4.7 3 - 11	14.3 3 - 78
Secchi (m)	M: R:	9.9 5.4 - 28.3	4.2 1.5 - 8.1	2.45 0.8 - 7.0

(Note: M=mean, R=range, Total N= total nitrogen,
Total P= total phosphorous)

TABLE 11

Comparison of Nutrient Status

Parameter		Lynn Lake (n=5)	Grand Rapids (n=2)	N/W Man. (n=22)	Prairie (n=51)
Total P (ug/l)	R: M:	19 - 41 26.8	19 - 33 26.0	20 - 40 25.5	54 - 889 -
Secchi (m)	R: M:	1.7 - 5.0 3.34	3.0 3.0	0.75 - 2.5 1.65	0.2 - 3.0 -

(Note: Total P=total phosphorous, R=range and M=mean
n=number of lakes sampled)

The Lynn lake study lakes, other lakes in N/W Manitoba and the Grand Rapid study lakes have similar total phosphorous concentrations.

However, the prairie pothole lakes have considerably higher total phosphorous concentrations which reflect their eutrophic state. The Lynn Lake study lakes have higher water transparencies than other lakes in N/W Manitoba, but similar to the lakes at Grand Rapids. The prairie lakes have minimum transparencies of 0.2 meters in algal bloom lakes, and maximum transparencies of 2.3 meters in non bloom lakes, these values are still lower than the mean values for the study lakes.

In the original MEI, TDS and mean depth were used effectively as fish yield indicators (Ryder, 1965). However, in most fresh water lakes, where phosphorous is considered the major limiting ion, phosphorous concentrations might more appropriatly replace TDS as the numerator in the MEI expression (Ryder, 1982). In fact any parameter that is the major limiting factor in the system could be exchanged for TDS in the MEI. Factors include: ions, alkalinity, phosphorous, nitrogen, chlorophyll-a or quantitative measures of algae, zooplankton or benthos (Ryder, 1982).

Ogelsby (1977) proposed that models based upon fish yield as a function of phytoplankton production or standing crop are inherently more accurate, and subject to fewer exceptions than those related to morphoedaphic factors. Jones and Hoyer (1982) proposed chlorophyll-a as an index of lake trophic state as it is correlated with nutrient concentration, phosphorous production and zooplankton biomass. They proposed that this relationship implies that lake trophic state is a major factor controlling fish production in a broad range of lakes of similar depth.

Carlson (1977) provided a relative trophic classification as opposed to the more discrete oligo-meso-eutrophic classes. He developed a numerical trophic state index (TSI) for lakes that incorporated most lakes on a scale of 1 to 100, where each major division (10, 20 etc.) represents a doubling of algal biomass. The index can be calculated from any of several parameters, including secchi depth and total phosphorous from the following equations:

$$TSI\ (Secchi) = 10\ (6 - \log e\ Secchi\ /\ \log e\ 2)$$

$$TSI\ (TP) = 10\ (6 - 48\ /\ \log e\ TP\ /\ \log e\ 2)$$

These values were calculated for the Lynn Lake study lakes using secchi depth and total phosphorous (Table 12).

TABLE 12

Trophic State Indexes for Lynn Lake Lakes

Lake	TSI (Secchi)	TSI (TP)
1	60.0	51.7
2	43.0	50.6
3	37.5	46.6
4	52.3	57.7
5	36.7	48.7

As expected lake 4 has the highest value for both calculations of the TSI, and Lakes 3 and 5 the lowest. These values are compared to the same calculated TSI's for other lakes in N/W manitoba (Lysack, 1982), (Table 13).

TABLE 13

Comparison of TSI's Between Lakes

TSI		Lynn Lake Study lakes	N/W Manitoba Lakes
Secchi	M:	47.9	53.4
	R:	36.7 - 60.0	47.2 - 64.2
TP	M:	51.7	50.3
	R:	46.6 - 57.7	46.9 - 62.3

(Note: M=mean, R=range)

The means and ranges for both trophic state indexes are very similar. Hence, the Lynn lake study lakes have similar trophic states to other lakes in the area, with both sets of lakes being in the mesotrophic range.

To summarize, total phosphorous, total nitrogen, chlorophyll-a and secchi depths in the Lynn Lakes and Grand Rapids study lakes were all in the olig-mesotrophic range. Lake 4 at Lynn Lake and Lake A and B at Grand Rapids being the most mesotrophic and Lake 5 at Lynn Lake the most oligotrophic. A trophic state index (TSI) calculated from these parameters indicated Lake 4 to be the most productive lake, and Lake 3 and 5 to be the least productive. This would then account for the large size difference in arctic charr between Lakes 4 and 5, however, this would not account for the large size of rainbow trout in Lake 3. Generally, overall low nutrient concentrations would account for lower growth rates in these lakes compared to fish in prairie lakes, and in some lakes nutrient concentrations could be used to predict fish growth. Finally, TSI's calculated for other lakes in N/W Manitoba are similar to those calculated for the Lynn lake study lakes showing that they are indicative of lakes in the area.

5.6 MORTALITY AND SURVIVAL

The yield of an aquaculture operation unquestionably determines it's success, and mortalities are the largest single biological risk for the operation. In this study mortality rates of 100%, 99% and 94% were observed in Lakes 1, 3 and 4 respectively. In order for northern extensive aquaculture to be successful the cause of these high mortality rates must be determined and overcome.

Extensive aquaculture in small eutrophic lakes on the prairies has been plagued with varying survival rates which range from 0% to 85%, with an average of 25% to 30%. This variability of survival between different lakes and different years has precluded the determination of optimum long term productivity, or the analysis of any relationship between such production and limnological parameters (Ayles et al., 1976). This is exactly what has been encountered in this study, high mortality rates, and therefore low production values have precluded any attempt to predict yield and link it to some parameter(s) in each lake.

Ayles et al.(1976) demonstrated that mortalities in prairie pothole lakes occured in two distinct periods. Between 60% to 90% of fish die in the first period, which occured in all lakes and lasted from stocking in spring to early summer. The second mortality period occured only in conjunction with collapse of a bloom of Aphanizomenon flos-aquae, and 60% to 94% of fish present in the lake just prior to the collapse were killed. These summerkill mortalities were primarily caused by low dissolved oxygen levels following an algal collapse. However, the majority of mortalities in all lakes occured in the first period shortly after planting and were a result of unknown causes rather than algal summerkills. Ayles et al. (1976) kept a few fish in cages as well as those in the lake, and the lack of mortalities of caged fish except during summerkill, meant that the physical environment of the lake was suitable for trout survival. Bird predation was suggested as the major cause of early season mortality.

At Grand Rapids seagulls, cormorants and pelicans were observed on the two study lakes. This could account for the low recovery rate of arctic charr and rainbow trout in Lake A. However, at Lynn Lake no fish eating birds were observed on or near the lakes. Otters could be causing some mortalities as they occur in this area. Predation can probably be ruled out as the major cause of mortality. This could be tested by stocking a few fish in cages suspended in the lakes and observing their survival over the growing season. This would show if the physical environment of the lake was suitable for fish survival. As has already been shown, dissolved oxygen levels are high, summer temperatures do not reach lethal limits for trout or charr, and other parameters such as pH do not exceed the upper lethal levels. Food could be the limiting factor in these lakes as oligotrophic lakes are inherently less productive than eutrophic lakes. Food is not a limiting factor in prairie pothole lakes which are highly eutrophic and have an abundance of invertebrate food sources. However, northern Shield lakes contain less ions and nutrients, and hence less algae, macrophages, benthic invertebrates and zooplankton. However, if food was limiting this would rather result in low growth rates of fish, not high mortality rates, unless fish starved to death.

Disease can also be ruled out as the major cause of these high mortality rates. Both arctic charr and rainbow trout fingerlings came from a certifyed "disease free" hatchery and disease free stocks. Also, there were no indigenous fish populations in the lakes, besides sticklebacks, and stocked fish could not have become diseased through transferance.

Stress is an important consideration when stocking hatchery-reared fingerlings into a wild environment. In a typical stocking operation fingerling fish are captured in the hatchery, loaded into tank trucks, transported, and then planted directly into a lake. When stressed fish plasma cortisol levels are elevated. Barton et al. (1980) found that during capture in the hatchery fish cortisol levels increased dramatically, and were still high after they were loaded into the truck but decreased after 2.5 hours in transit. However, during stocking cortisol plasma levels increased and remained high for one day after stocking, and reached significantly lower levels only after eight days.

When stocked into lakes, trout are subject to a variety of secondary stressors such as adverse water chemistry, sudden temperature changes, and predators. The study by Barton et al. (1980) indicated that fish arrive at a lake in an already stressed condition, and such secondary stressors might produce a stress response that can take up to eight days to return to normal. The poststocking stress recovery period may be important to initial fingerling survival rates. Fingerlings stocked into pothole lakes have shown signs of severe stress, spinning and jumping erratically on the surface which have attracted the attention of predators (Ayles et al., 1976).

The long journey for fingerlings from a hatchery in southern Manitoba to northern lakes induces a considerable amount of stress for fingerlings. Also, the natural lake in which the fingerlings are stocked is a foreign environment with different ionic concentrations, nutrient levels and temperatures regimes, and it would take fingerlings several days to acclimatize to their new environment. The first few days are a critical threshold of survival which fish have to overcome. Stocking fingerlings into large cages suspended in the lake for several days would give them time to acclimatize to their new environment and escape predators, and would also allow the fish farmer to monitor their survival over this critical period. Mortality in Lake 1 at Lynn Lake was observed to be 100%. This lake has no apparent physical differences from the other study lakes which would account for its inability to sustain fish. It is therefore possible that the rainbow trout fingerlings stocked into this lake were highly stressed and all died in the first few days.

At Grand Rapids, arctic charr were stocked into Lake A in mid June when summer water temperatures were high. It is likely that they were very stressed, and it is possible that their low survival rate is as a result of this stressfull situation. Also, the arctic charr were stocked into a lake that was already stocked with rainbow trout. Arctic charr are known to be out competed by rainbow trout for food, hence, this could also account for their low survival rate.

Finally, it must be recognized that there are differences in growth and survival performances between wild and domestic stocks (Ayles, 1973). Generally, in a hatchery the character most selected for is high growth rate, not growth and survival in a wild environment. Therefore these hatchery reared fingerlings of arctic charr and rainbow trout might inherently have low survival performances in natural lakes.

5.7 GROWTH

The yield of an aquaculture enterprise not only depends on fish survival, but on fish size, which is determined by the growth rate. The harvestable size of trout and charr is 200 grams (pansize), and it is therefore important that fish reach this size in a sufficient time period.

Arctic charr in Lake 4 at Lynn Lake obtained harvestable size after two growing seasons (470 days) with a mean weight of 181.5 grams. However, arctic charr in Lake 5 did not achieve harvestable size and it was necessary to leave them for another growing season. The difference in fish size between these two lakes has already been discussed in relation to basin morphology, water temperature and nutrient availability, with Lake 5 being deeper, colder and having a smaller littoral area and nutrient concentration. Lake 3 at Lynn Lake also produced rainbow trout of harvestable size with a mean weight of 1147.6 grams. These fish are very much larger than rainbow trout in Lake 2 which only averaged 30.9 grams in June compared to fish in Lake 3 which had a mean weight of 386.8 grams. There are no obvious differences between the two lakes to explain these size differences.

Temperature, ration and fish weight are the primary factors controlling fish growth, with the former considered a "controlling factor" and the latter two "limiting factors" (Brett, 1979). The difference in growth of arctic charr between Lakes 4 and 5 can therefore be attributed to temperature and food availability, as fingerlings stocked into each lake were of similar sizes. The difference in growth of rainbow trout in Lakes 2 and 3 cannot be attributed to fish weight or temperature as fingerlings were of the same size, and the temperature regimes of the two lakes were similar. Therefore food availability would have to have been the limiting factor in Lake 2.

On the prairies fingerlings of different strains of rainbow trout stocked into winterkill lakes can gain 200 grams in approximately 160 days, from May to October (Bernard Holmstrom, 1978). It is important for trout to attain harvestable size in one summer in prairie pothole lakes as these lakes winterkill. Ayles (1975) found significant effects of the environment (lakes), and genotype-environment interactions on growth, and he concluded that environmental differences, as yet unidentified, were mostly responsible for variation in growth and survival between lakes. Variability of growth in trout between prairie pothole lakes is a recognized problem. Bernard and Holmstrom

(1978) concluded that there are many factors such as availability of food organisms as discussed by Larkin et al. (1957), and other physical factors and/or the interaction of several factors which are responsible for variability in growth. Wandsvik and Jobling (1982) reported a significant degree of variation in growth rates of arctic charr in sea-pens and concluded that this variation was detrimental to their future commercial culture.

Genetic differences between strains could be used as an explanation for differences in growth performances of arctic charr in Lakes 4 and 5. Lake 4 was stocked with an anadromous cross landlocked stock, and Lake 5 was stocked with an anadromous cross anadromous stock. However, growth trails between these two stocks under hatchery conditions have not shown any significant differences (Papst, pers. comm.). Also, the rainbow trout stocked into Lakes 2 and 3 were of the same stock. Hence, growth variability between lakes can not be attributed to genetic differences.

The specific growth rate of rainbow trout in Lake 3 was calculated to be 0.97 %/day for the summer period. This is lower than mean specific growth rates recorded in the literature. The optimum temperature range for growth of rainbow trout is 17.2 to 18.6 C, and the maximum specific growth rate is 5.12 %/day under intensive culture conditions (Hokanson et al., 1977). Rainbow trout growth in natural water bodies with no supplemental feeding was shown to compare favourably with trout reared in intensive culture situations (Bernard and Holmstrom, 1978). However, specific growth rates of trout showed marked seasonal variation (Figure 18). There was a general decrease in specific

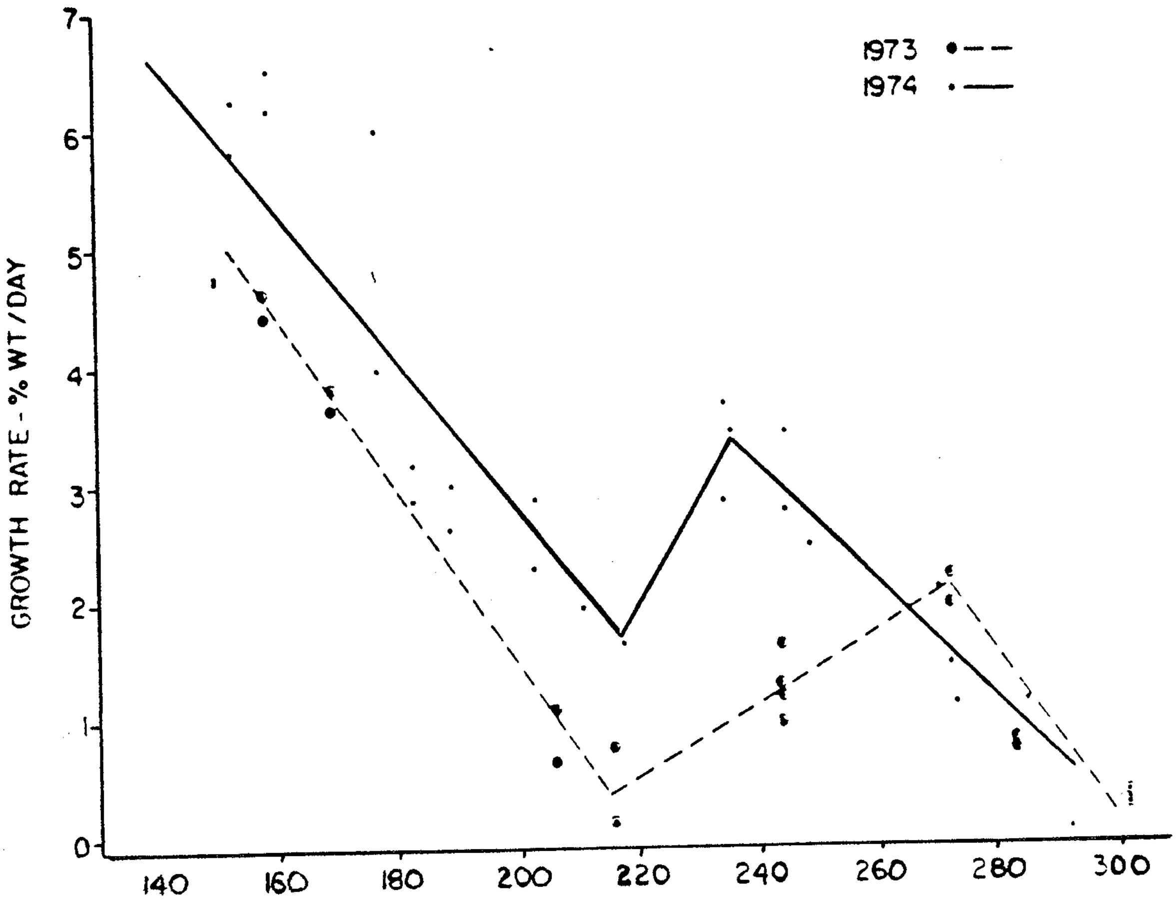


Figure 18: Growth Rates of Rainbow Trout in Prairie Lakes

growth rate with growing days (or aging). Differences between years was probably due to differences in water temperature. High water temperatures in July and August appeared to effect growth of trout with a minimum of 1.6 %/day recorded. Rainbow trout reared in an intensive commercial rearing system obtained an overall mean specific growth rate of 1.6 %/day (Mt. Lassen strain) and 1.7 %/day (Sunndalsora strain) (Papst and Hopky, 1982). Specific growth rates declined with increasing fish weight, and the overall mean growth rates were slightly less than the 1.9 %/day reported by Brett and Sutherland (1970) for sockeye salmon reared at 14 C.

In Lake 4 specific growth rates of arctic charr of 1.19 %/day (size 1.3-103.3g) and 0.5 %/day (size 103.3-181.5g) were recored, and in Lake 5 growth rates of 0.33 %/day (size 0.8-10.3g) and 1.02 %/day (10.3-116.7g) were recored. Arctic charr have not before been raised in extensive culture systems as have rainbow trout, therefore there is no comparable growth data for charr in the Lynn Lake study lakes. Under intensive culture conditions the optimum temperature for growth of arctic charr has been reported by Jobling (1982) to be 14 C resulting in a maximum specific growth rate of 7.5 %/day. He reports the growth rates of arctic charr to be amongst the highest reported for any salmonid species. Swift (1964) reported the optimum temperature for growth of landlocked Windermere charr to be between 12 C to 16 C, with a maximum specific growth rate of 5.3 %/day. Wandsvik and Jobling (1982) reported that arctic charr (size range 25-78g) reared at 13 C in freshwater had a mean specific growth rate of 1.4 %/day. Uraiwan (1982) observed that arctic charr (size 10-30g) reared at 13 C in freshwater had a specific growth rate of 2.0 %/day. Papst and Hopky (1983) raised arctic charr in a pilot commercial rearing system and reported mean specific growth rates of 2.6 %/day (size 2.2-14g), 2.2 %/day (size 15.3-46.9g) and 1.8 %/day (size 47-84.7g).

Mathisen and Berg (1968) studied growth of marked arctic charr in the Vardnes River in Norway, and found a rapid increase of growth in the summer period with maximum growth rates of 2.05 %/day (44 days), and minimum growth rates of 1.23 %/day recorded. For the winter freshwater period they found negative growth rates ranging from -0.11 %/day (293 days) to -0.01 %/day (230 days). Johnson (1980) found growth patterns of arctic charr at Nauyuk Lake (NWT) followed a similar pattern, with high rates of growth in the summer followed by weight loss in the winter.

To summarize, the growth rates of arctic charr at Lynn Lake are lower than those recorded for arctic charr reared under intensive culture conditions, as well as those reported for wild arctic charr in the summer period. However, growth rates for arctic charr in the Lynn Lake lakes are summed over long periods of time, and hence include periods of high and low growth (winter and summer). Therefore, considering the short growing season (4 months) where water temperatures are in the optimum growing conditions, these growth rates are reasonable.

Growth data for the Lynn Lake study lakes is sketchy due to long periods between sampling, and specific growth rate determinations are summed over a long period of time. However, it was possible to use a growth model to draw the relationship between weight increase and time (Figure 15). Although the model was devised for estimating growth of cultured rainbow trout, this model has also been shown to closely resemble arctic charr growth (Papst, pers. comm.).

It was found that arctic charr required 400 growing days in order to reach 200 grams at Lynn Lake, as compared to 150 growing days under prairie pothole conditions. This presents no problem to northern fish farmers as Shield lakes are less likely to winterkill, and fish can remain in the lake overwinter. Also, by starting with different size fingerlings, the time required to reach harvestable size has been determined using this growth model (Figure 16). Fingerlings stocked into Lynn lake in late May have approximately 140 days before ice-over in mid October. All sizes of fingerlings (40g, 12g and 5g) do not obtain harvestable size in this time. By the following spring (360 days), the 40g and 12g fingerlings would be of harvestable size, and the 5g fingerlings would reach 200g by late summer. Consequently, whatever the starting size of fish, more than one growing season is required by arctic charr in these lakes to reach 200 grams. Therefore economically the smallest fingerlings would be the best size to stock.

5.8 SIZE VARIABILITY

A large variation in size of arctic charr was observed in Lake 4 at Lynn Lake (Figure 12). This is a recognized problem in fish culture operations that results in a percentage of fish reaching and passing harvestable size, and a percentage remaining below this size. In Lake 4 only 57.3% of arctic charr reached harvestable size. With a survival rate of 6%, this decreases the percentage of harvestable fish to 3.4%

When fish are reared together their size range increases with age. This phenomena is due to natural variation, as well as size hierarchy effects in which competition between fish suppresses growth of certain individuals, where smaller fish were inhibited from feeding in the presence of larger more aggressive individuals (Jobling, 1981). Papst and Hopky (1982) use the term "growth depensation" in regard to an increase in the variance of size frequency distributions with time. Typically, the larger fish grow larger while the small fish lag further behind (Brett, 1979). Papst and Hopky (1982) suggest genetic variation and/or size hierarchy differences may contribute to growth depensation. Size hierarchy differences result from some fish begining to feed earlier than others acquiring an initial size advantage, and maintaining the advantage through establishment of the size hierarchy.

The coefficient of variation (CV) is important in the detection of growth depensation. If a given weight distribution's CV does not change over time then there is no growth depensation. The coefficient of variation for arctic charr in Lake 4 at Lynn Lake was determined, where CV = SD/mean x 100 (Table 14). The CV increased over time and therefore there is a growth dispensation.

TABLE 14

Coefficient of Variation for Arctic Charr in Lake 4

Date	n	Mean Weight	CV
June 85	100	1.34 g	19.4%
June 86	11	103.36 g	32.2%
Oct 86	208	181.46 g	43.5%

Papst and Hopky (1982) found that rainbow trout reared in a pilot commercial rearing system showed no change in CV. They suggested that the pilot production system, where feed is not limiting, does not facilitate the establishment of size hierarchys. However, arctic charr reared in a commercial pilot rearing system did show growth depensation and the CV for the final weight distribution was 59% (Papst and

Hopky, 1983). The extent of variation in bodyweights of arctic charr was consistent with that reported by Wandsvik and Jobling (1982). Papst and Hopky (1982) suggested that variability in growth of arctic charr precluded a single harvest of commercially sized arctic charr at the end of a production cycle, as some individuals would never grow to harvest size. Rather, a strategy of continuous cropping would be better where market size fish are removed, thus allowing for additional growth in premarket size fish.

This is a drawback to raising arctic charr in northern lakes. However, this phenomena is common to arctic charr reared under hatchery conditions and consequently the "wild" environment is <u>not</u> seen to be the major cause of this size variation. Rather, size hierarchys and genetic variation are probably the cause. Size variability in prairie pothole lakes is a major problem as all fish have to be harvested before ice-over because of winterkill. However, fish in northern lakes that do not reach harvestable size at the end of the second growing season could be left in the lake untill the following season. Size selective harvesting could be done using larger mesh gill nets, the harvestable sized fish could be removed and the pre-harvest fish left until the following season.

5.9 <u>FEEDING HABITS</u>

Growth is closely related to ration, and hence feeding habits of fish and their relation to growth must be explored. Fish diets between lakes varies widely, with rainbow trout in Lake A at Grand Rapids mainly consuming amphipods, Lynn Lake rainbow trout in Lake 3 mainly consuming Chaoborus, and arctic charr in Lake 4 and 5 mainly consuming aquatic insects and their larvae. Food consumption by rainbow trout in prairie pothole lakes also varies greatly between lakes and between years, with comparisons between time and lakes having a percentage similarity of less than 50%. Trout in these lakes mainly consumed amphipods, but at different times fed off choronomid larvae, cladocera and stickleback minnows (Bernard and Holmstrom, 1978).

Differences in food consumption of rainbow trout and arctic charr demonstrate that they are versatile, opportunistic feeders capable of exploiting a variety of food sources. Bernard and Holmstrom (1978) suggest that this response is most likely dependent on food availability and/or a size dependent response where smaller trout consume smaller food organisms. They also found that changes in food habits were not related to any changes in the growth pattern of trout as Scott and Crossman (1973) stated that, "the availability of other fish as food is often considered necessary for the attainment of large size of rainbow trout". This is not true in this study, where rainbow trout in Lake 3 grew to a large size with no fish in their diet, compared to rainbow trout in Lake 2 which only reached a small size and had stickleback minnows in the lake.

Competition with other fish for food could account for the size differences between fish in the Lynn Lake study lakes. Stickleback minnows were observed only in Lakes 2 and 5, and fish in these lakes were significantly smaller than their counterparts in other lakes. Larkin et al. (1957) found that when species other than rainbow trout were present in lakes growth rates were not linearly related. For example, trout grew slowly because of competition with shiners for food, but once trout attained a certain size they preyed on shiners for food and embarked on a new growth relationship. This is probably what is occuring in lakes 2 and 5, where small rainbow trout (Lake 2) and arctic charr (Lake 5) are competing with stickleback minnows for a limited amount of food and, as a result, exhibit slow growth rates. However, once fish have obtained a certain size they can begin to utilize sticklebacks as a food source and begin to grow faster. In fact, sticklebacks were found in stomach samples from arctic charr in Lake 5 in October, but not in June. Therefore by October charr had grown enough to prey on sticklebacks and, by the following year should attain harvestable size. Again, the fact that these lakes do not winterkill allows these fish the extra time needed to overcome this growth "hump" and attain harvestable size in three growing seasons.

Food is not a limiting factor on fish growth in prairie pothole lakes. Although sticklebacks in some lakes competed with young trout for the same food, trout from all lakes obtained the same size (Bernard and Holmstrom, 1978). Food is probably limiting in the Lynn Lake lakes due to their oligotrophic nature (low nutrient concentrations), and this plus cool water temperatures for 8 months of the year is the major factor limiting faster growth. A decrease in stocking rate of fish in these lakes might improve fish growth. Lake 4 at Lynn Lake was stocked at a rate of approximately 500 fish per hectare (200 fish per acre). This is very similar to the stocking rate for prairie eutrophic lakes. As these northern lakes are considerably less nutrient rich, and hence lower in food, it might be better to decrease the stocking rate so there would be less competition for food resources.

5.10 PRODUCTION

High yield from an aquaculture operation is the ultimate goal. The production values (harvest) for Lake 3 (4.4 kg/ha) and Lake 4 (4.9 kg/ka), are similar to those predicted by Lysack (1980) for wild fish in northern Manitoban lakes (5.18 kg/ha). At first glance it appears that the Lynn lake lakes produced up to their capacity. Hunter (1970) estimated the yield of arctic artic charr in Keyhole Lake (NWT) to be 4.35 kg/ha/yr from a standing crop of 43.5 kg/ha. Rigler (1975) estimated the standing crop of arctic charr in Char Lake, Cornwallis Island, to be 104 kg/ha which could sustain a yield of 1.99 kg/ha/yr. In the Sylvia Grinnell system, Hunter (1976) estimated the optimum yield to be about 10% of the standing crop, equivalent to 1.72 kg/ha/yr.

Yield from wild fish populations is estimated on a sustained basis. This is the quantity of fish that can be removed from the population each year, without decreasing the overall amount available for the following year. This is also termed the "maximum sustained yield", and is defined to be "the largest average catch or yield that can continuously be taken from a stock under existing environmental conditions" (Ricker, 1975). The estimations of yield quoted above are therefore the amount of arctic charr that the lakes can produce on a sustained basis. An extensive aquaculture operation, on the other hand, views yield as the amount of fish that a lake can produce over the production period. This yield is equivalent to "standing crop", or the total amount of fish in the lake. This is because all fish can be harvested from the lake, as the lake will be restocked the following year.

Yields (harvests) from the Lynn Lake lakes, although comparable to yields from other northern Manitoban and artic lakes, are very different to standing crops of these lakes, which are the same as 'yield' from an aquaculture lake. Hence, the Lynn Lake lakes are not producing the quantity of fish that they are capable of producing. This is a result of the very high mortality rates experienced in these lakes. An estimation of yield from the Lynn Lake lakes is not possible as a result of the high mortality rates experienced in these lakes.

5.11 SUMMARY

Factors controlling lake productivity were discussed in regard to the study lakes. Lake basin morphology was shown to be important to lake productivity, with deeper lakes being less productive than shallower lakes. Littoral area and shoreline development are other important factors, with lakes having a higher value for shoreline development and a larger littoral area being more productive. The phenomena of "winterkill" not seen to be a problem for northern lakes, and it was estimated that a mean depth of less than 2 meters would be necessary in order for winterkill to occur. Summer water temperatures were shown to be suitable for optimum growth of arctic charr, and cooler water temperatures in Lake 5 may be responsible for slower growth of arctic charr. Dissolved oxygen concentrations were high in all the lakes, and lake productivity was not hindered by either summerkill or winterkill.

Ion concentrations in the Lynn Lake study lakes were low as a result of local geology of the esker. Ionic loading into the lakes is limited by the small size of lake basins. However, ionic concentrations were not seen to be the major cause of differences in fish growth between lakes. Nutrient concentrations for the Lynn Lake study lakes were similar to other lakes in the area, and were in the oligotrophic range. The conclusion was made that nutrient concentrations could not be used to predict fish growth in these lakes. However, overall low nutrient concentrations could account for lower growth rates of fish in these lakes compared to fish in prairie eutrophic lakes.

The possible causes of high mortality rates of fish in the lakes were discussed. Summerkill was ruled out as a cause of mortality as a result of high dissolved oxygen levels and low algal biomass. Predation by fish eating birds was probably a major cause of mortality of fish in the Grand Rapids study lakes, but not at Lynn Lake. The physical environment of lakes was not seen to be harmful for fish survival, and hence stress was probably an important factor in fish mortality.

Growth rate differences of rainbow trout and arctic charr were discussed in relation to temperature and food availability. It was concluded that both factors were important in accounting for size differences of arctic charr between lakes, and food availability was probably the most important factor in accounting for size differences of rainbow trout between lakes. Specific growth rates of rainbow trout and arctic charr at Lynn Lake were shown to be lower than those recorded by other authors, but were still reasonable considering the short growing season. Results from a growth model which was used to estimate growth rates of arctic charr in these lakes, showed that fish took more than one growing season to reach harvestable size. However, this presents no logistic problem as fish can overwinter in the lakes, and reach harvestable size by the following fall. The model also showed that larger sized fingerlings took more than one season to reach harvest size.

Size variability of arctic charr in Lake 4 was discussed, and it was shown that this phenomena is common to arctic charr reared under intensive culture conditions. The coefficient of variation of arctic charr in this lake was shown to increase over time, and hence indicated a growth depensation. However, this was shown not to be a problem as because fish can overwinter in the lake, a strategy of continuous cropping could be adopted.

Feeding habits of fish in the study lakes were discussed in regard to fish growth. Food consumption was found to vary greatly between lakes. The conclusion was made that both rainbow trout and arctic charr were versatile opportunistic feeders, with food consumption being dependent on food availability and size of food organism. Competition with stickleback minnows for food in lakes could have accounted for the smaller size of fish in lakes in which minnows occured. However, the suggestion was made that once fish reached a certain size they could then begin to utilize minnows as a food source, and hence embark on a new growth relationship. It was concluded that food is probably limiting in these lakes, and this plus cooler water temperatures for 8 months of the year, is the major factor limiting faster growth.

Finally, yield of the Lynn lake lakes was discussed, and compared to those of other northern lakes. Although, yields appeared similar, it was argued that the "yield" from an aquaculture lake would be equivalent to "standing crop" from a natural lake, and on this basis, yields from Lynn Lake were very low. Hence, it was concluded that because of the high fish mortality rates experienced in these lakes, an accurate estimation of yield from these lakes could not be made.

Chapter VI

ECONOMIC RESULTS AND DISCUSSION

6.1 ANALYSIS OF INCOME AND EXPENDITURES

An income statement for Lake 4 at Lynn Lake was compiled following the method of Cauvin and Thompson (1977). Presented in the income statement are the financial results of an operation for a specified period of time, usually a fiscal year. For Lake 4, the income statement covers 16 months, the period from planting to harvesting (see Table 15). Costs have been separated into variable and fixed costs according to their relation to production:

- Harvest costs are considered variable costs directly related to the level of production in the harvesting operation.
- Pre-harvest costs are regarded as semi-variable costs as they are indirectly related to the level of production.
- Fixed costs are considered to be direct, overhead costs which are incurred regardless of the level of production, and do not vary in relation to production.

The income analysis is done for three different scenarios:

- Scenario (1) refers to the "observed" income statement, which is the actual costs incurred by the fish farmers. All the arctic charr were sold locally due to the small harvest, and this avoided marketing expenses. A higher price was received for the charr through local marketing, and also the cost of labour and depreciation expenses were ignored.

- Scenario (2) is the "real" income statement which includes all costs had the fish farmers incurred all expenses, hence labour and depreciation costs were added. However, due to the small harvest (46 kg) all the fish were sold locally at a higher price and there were no marketing expenses.
- Scenario (3) presents a hypothetical income statement where a "30% harvest" of 450 kg of fish would be harvested. This requires that fish be transported to Winnipeg for retail, and a lower price received for fish.

6.1.1 Revenue and Cost Components

6.1.1.1 Arctic Charr Sales

Production from Lake 4 for the 1985/86 season was 64.15 kg (361 fish). The charr were divided up into a "marketable" category size of 200 grams or more, and a "unmarketable" size category of less than 200 grams. There were 207 marketable sized fish (45.9 kg), and 154 non marketable size fish (18.25 kg). The marketable sized charr were all sold locally in Lynn Lake for $22 per kg for fresh fish ($10/lb), and $16.53 per kg for frozen fish ($7.50/lb). The exact quantity of each type was unknown, therefore 50% of each (fresh and frozen) is used to calculate the price received. Originally, the charr were to be sent to Winnipeg where a retail agent would buy the fish for $11 per kg ($5/lb). However because the harvest was so small all the fish were sold locally. Hence, under scenario (1) and (2), charr sales were determined using the Lynn Lake price of $19.26/kg. Under scenario (3) where 450 kg of fish were harvested the assumption was made that 10% of the charr could be marketed locally and sold at $22/kg, and the other 90% sold in Winnipeg at $11/kg.

6.1.1.2 Harvest Costs

Labour Costs: Harvesting labour consists of setting and lifting nets, removing charr from the nets, and dressing and packing the charr. It was estimated that a two man crew would be required. It took three 8 hour days to harvest the lake, for a total of 48 man-hours, and labour costs were based on the wage rate of $7.50/hour. Under scenario (1) no labour costs were included as the enterprise was viewed as a "hobby" rather than business, and the fish farmers did not include their own wage. However, under scenario (2) the real labour costs were included. For scenario (3) it was estimated that 7 days would be required to harvest the lake if a 30% recovery was realized, hence, a total of 112 man hours would be required and at a wage rate of $7.50/hour the total labour costs would be $840.

Harvest Transportation Costs: Variable costs associated with harvest transportation include the owning and operating costs of a truck and the operating cost of an outboard engine. A 4 wheel drive half ton truck was required for harvesting. The lakes are approximately 40 km from Lynn Lake, hence 80 km a day for three days equals 240 km driven for the harvesting operation. The operating cost for the truck over the harvesting period was calculated on the basis of $0.22 per km to total $52.8. The operating cost for an outboard engine has been estimated on the basis of hourly fuel consumption. Total running hours for the period of harvesting is approximately 2 hours per day, hence for three days the total operating time was 6 hours. Operating cost for an outboard motor has been estimated at $1.00 per hour. For scenario (1) and (2) where harvesting took 3 days the total harvest transportation costs have been estimated to be $58.80, and under scenario (3) where harvesting took 7 days the total harvesting costs are $137.20.

Ice Costs: It is estimated that 1 kg of ice is required for 1 kg of fish. The price of ice is $2 per 10 kg, hence the price is $0.20 per kg. Under scenario (1) ice was purchased before fish were harvested, and 30 kg were purchased for a total of $60. Under scenario (2) where 46 kg of fish was harvested, the cost of ice was $9.20. Under scenario (3) where 450 kg of fish would be harvested the total cost of ice would be $90.

Marketing Costs: The transport of fish to market entails transportation and labour expenses. However, under scenario (1) and (2), because of the small harvest all the fish were sold locally at no expense. Under scenario (3) charr would have to be transported to Winnipeg for marketing. A "back haul" rate of $500 is the cheapest method of transporting fish, and this is a fixed rate for up to 20,000 kg. Hence whatever the quantity of fish transported the cost would be $500.

6.1.1.3 Pre-Harvest Costs

Fingerlings: Seven and a half thousand 2 inch arctic charr fingerlings were stocked into Lake 4. They were supplied free of charge from the Department of Fisheries and Ocean's Rockwood experimental hatchery, as part of their policy to promote commercial aquaculture. Therefore under scenario (1) there is no cost associated with the purchase of fingerlings. As there are no commercial suppliers of arctic charr fingerlings, equivalent prices for rainbow trout fingerlings were used to assess the true cost of purchasing these fish. The smallest locally available rainbow trout fingerlings in Manitoba are 3 1/2 inch fingerlings, which retail at $0.19 each. However, 2 inch rainbow trout fingerlings can be purchased from the U.S. for $0.10 per fish. This price was used to calculate the true value of the charr fingerlings. Arctic charr fingerlings take longer to grow than rainbow trout fingerlings, therefore the price of arctic charr raised commercially would be $0.12 per fingerling. Under scenario (2) and (3) fingerling prices reflect commercial prices of $0.12 each to total $900 for 7,500 fish

Pre-Harvest Transportation: This includes the transport of fingerlings from a hatchery near Winnipeg to Lynn Lake. The fingerlings were flown up to Lynn Lake on a commercial airline at a cost of $150. Fish were transported in plastic bags in boxes each weighed approximately 18 kg, and the cost of freight was $1.97 per kg. The total weight of 7,500 arctic charr fingerlings was approximately 7.5 kg. Approximately 1.8 kg of fish are transported per box, therefore 4 boxes were required whose weight totaled 72 kg. Hence, the total cost is $150. Under all three scenarios this cost is included.

6.1.1.4 Fixed Costs

Commercial Fish Farming Licence: A licence is required by the fish farming enterprise for the use of lakes and commercial sale of fish. In Manitoba the cost of the licence is $15 for two lakes, hence $7.50 for one lake. This cost is included for all three scenarios. This fish farming licence conveys sole use of the lake to the fish farmer. Other people are prohibited by law from fishing from that lake, although the licence does not prohibit people from being near the lake if it is on Crown land. The lakes at Lynn Lake are all on Crown land, therefore other people can be near the lake, but cannot fish from the lake. Recently people were caught fishing from one of the fish farmer's lakes, and they were prosecuted and fined.

Unemployment Insurance, Pension Plan and Worker's Compensation: UIC contributions are $0.03 per hour x 1.4, CPP contributions are $0.03 per hour and worker's compensation is $0.01 per hour. The total for 60 man hours is $4.20. This cost was not included under scenario (1) as no labour costs were included, however, these costs are included under scenario (2) and (3).

Depreciation Expenses: Depreciation is a system of accounting that distributes the cost of an asset over its estimated useful life. The following calculations are based on rates consistent with the Federal Income Tax Act.

- Boat: a 14 foot aluminum boat retails in Winnipeg for approximately $1,500. A boat is categorized as a class 7 asset and is depreciated at 15%/year. Hence the depreciation value per year is $238.5 including tax.

- Outboard engine: a 9 hp outboard engine retails at approximately $1,495 in Winnipeg. An engine is classified as a class 10 asset and is depreciated at 30%/year. Hence the depreciated value per year is $475 including tax.
- Nets: ten 100 yard nylon twine nets were required for harvesting fish. These nets with floats and lead line retail for approximately $100 each. Nets are classified as Class 8 asset and are depreciated at 20%/year. Hence the depreciated value per year is $200.
- Fish tubs: approximately 10 plastic fish tubs are required to carry fish, ice and nets. Tubs retail at approximately $20 each and hence the total outlay was $200. Nets are regarded as a class 8 asset and depreciated at 20%/year. Hence the depreciated value per year is $40.

Consequently, the total capital outlay for the operation would be $4,285. Depreciation expenses were not included under Scenario (1), as the fish farmers view their operation as a hobby rather than a business. Depreciation expenses were included under Scenario (2) and (3).

TABLE 15

Fish Farming Income Statement

SCENARIO	(1)	(2)	(3)
CHARR SALES	884.03	884.03	5,445.00
HARVEST COSTS:			
labour	-	360.00	840.00
transportation	58.80	58.80	137.20
ice	60.00	9.20	90.00
marketing	-	-	500.00
GROSS PROFIT	**766.26**	**456.83**	**3,877.80**
PRE HARVEST COSTS			
fingerlings	-	900.00	900.00
transportation	150.00	150.00	150.00
GROSS OPERATING PROFIT	**616.26**	**- 593.97**	**2,827.80**
INDIRECT COSTS			
fish farming licence	7.50	7.50	7.50
UIC, CPP	-	4.20	8.40
NET OPERATING PROFIT	**608.76**	**- 605.67**	**2,811.90**
DEPRECIATION EXPENSES boat, outboard engine gill nets, ice	-	940.00	940.00
NET PROFIT	**608.76**	**-1,545.67**	**1,871.90**
income tax	36.00	-	254.10
NET INCOME	**572.76**	**-1,545.67**	**1,617.80**
CASH FLOW			
net income	572.76	-1,545.67	1,617.80
depreciations	-	940.00	940.00
TOTAL CASH FLOW	**572.76**	**- 605.67**	**2,557.80**
CASH BALANCE			
net income	572.76	-1,545.67	1,617.80
depreciation	-	940.00	940.00
labour	-	360.00	840.00
TOTAL CASH BALANCE	**572.76**	**- 245.67**	**3,397.80**

6.1.2 Analysis of Income Statement

The income statement evaluates the financial position and the profitability of the operation.

6.1.2.1 Net Profit

For the three scenarios presented, a net profit of $572.76 was realized for scenario (1), a net loss of -$1,545.67 was made under scenario (2), and a net profit of $1,618.80 was made under scenario (3). The situation which actually occured (1) made a small profit. However, this is because many costs were not included, such as the operator's wages, cost of fingerlings and depreciation expenses. When these costs were included the operation made a net loss. Alternatively, when a 30% harvest rate was used the operation made a profit, even after all the costs were included.

Cauvin and Thompson (1977) calculated two ratios in connection with net income. While a fish farming enterprise may appear profitable from the accounting view, the "sales margin" and "productivity of assets" ratios allow more insight into the operation. The sales margin ratio relates net income to sales, and is calculated by dividing net profit after tax by sales. For scenario (1) this is 0.45, and for scenario (3) this is 0.34. These ratios of net income to net sales are greater than those of other businesses, for example grocery stores (1.0), wholesale diary products (1.32), meat products (0.67) and poultry products (1.29). This indicates that the operations sales price is high, or else that costs are low. The high price now paid for arctic charr reflects a large potential market, but as production increases over time this price will fall.

The productivity of assets ratio measures the rate of return on the assets of the firm, and is calculated by dividing net income after tax by tangible net worth. For the fish farming enterprise tangible net worth is estimated by the total depreciated fixed assets. Hence for scenario (3), the ratio is 40%. Generally a relationship of at least 10% is required as a desirable objective for providing dividends plus funds for future growth. Net profit on tangible net growth for other enterprises are: grocery stores (11.5%), wholesale diary products (13.3%0, and meat products (11.6%). Hence the productivity of assets is greater for this fish farming operation than other commodity producers.

6.1.2.2 Cash Flow

This is calculated by adding depreciation to net income after tax. Depreciation distributes the cost of an investment over time at 0% interest rate. The cash flow provides a measure of the amount of money generated, after all other costs have been deducted to repay the cost of total investment. The cash flow provides an important method of assessing the profitability of an enterprise over an investment period. The cash flow was $2,557.80 under scenario (3).

6.1.2.3 Cash Balance

In the short run cash balance is probably more relevant than cash flow. The cash balance is calculated by adding depreciation and salary to net income after tax. The cash balance reflects the actual amount of cash a fish farmer receives annually from the enterprise to pay for his investment and his labour. The cash balance under scenario (3) was $3,397.80

6.1.3 Discussion

Over the production period and under scenario (1), where 45 kg of fish are harvested (6% survival rate), the fish farming enterprise breaks even and makes a small profit. However, this was an unrealistic situation as labour costs, fingerling costs and depreciation expenses were not included. When these costs were included under scenario (2) the enterprise suffered a large loss, and net profit, cash flow and cash balance were all negative. However, when the catch was increased to 30% (450 kg), and marketing transportation costs as well as all other costs were included the operation made a large profit. Hence at a 30% recovery rate the operation is viable and net profit, cash flow and cash balance are all positive. Also, the profitability indices were greater than alternative food industries. However, profitability is very sensitive to changes in price, costs and level of production.

6.2 BREAK-EVEN ANALYSIS OF PRODUCTION

Break-even analysis is used to determine the level of harvest at which revenue from sales of arctic charr will just cover fixed and variable costs of production.

- Variable costs are those costs which are incured in the actual harvesting operations.
- Fixed costs include: pre-harvest costs, indirect costs and depreciation expenses.

The precise break-even level of production can be determined by the following formula:

$$Q = \frac{F}{P - V}$$

Where: Q = quantity produced (kg)

P = sales price per unit ($/kg)

V = variable cost per unit ($/kg)

F = fixed cost ($)

These variables are calculated for the three scenarios (Table 16).

The break-even level of production is calculated for 7,500 arctic charr and for fish weighing 200 grams. The price used for scenario (1) and (2) has been calculated from the assumption that all fish are sold at Lynn Lake, and 50% of fish are sold at $22/kg (fresh) and 50% sold at $16.53/kg (frozen). Under scenario (3), 10% of arctic charr are sold at the Lynn lake price of $22/kg, and 90% are sold at the Winnipeg retail price of $11/kg. The percentage survival rate, or production rate, required is very low for scenario (1), less than 1%. However, this is an unrealistic situation and therefore scenario (2),

TABLE 16

Break-Even Level of Production

Variable	Scenario (1)	Scenario (2)	Scenario (3)
Fixed Costs Variable Costs Price	\$157.50 \$2.58/kg \$19.26/kg	\$2,001.70 \$9.32/kg \$19.26/kg	\$2,005.90 \$3.48/kg \$12.10/kg
Q Fish (200 g) S (7500 fish)	9.44 kg 48 > 1%	201.38 kg 1,007 13.4%	232.70 kg 1,164 15.5%

(Where: Q = break-even production, S = Survival Rate)

where all costs are included, gives a much better indication of the level of production required, which is a 13.4% survival. Finally, under scenario (3), where most of the fish are sold in Winnipeg and all the costs are included, the break-even level of production is 15.5%. This is a very similar result to scenario (2). However, it is unrealistic to expect all fish in Scenario (3) to be sold locally in Lynn Lake (1000 fish), as the market would be quickly saturated. Therefore, scenario (3) is the most realistic situation where 10% of the harvest is sold locally and the rest sold in Winnipeg. Consequently scenario (3) will be used in the following analysis. Income, variable and fixed costs, total cost and net profit or loss were calculated for scenario (3) (Table 17 and Figure 19).

Income from fish sales increase rapidly with increased % survival, however, initially fixed costs are so high that there is a net loss up to 15% survival rate. After this point net profit increases rapidly,

TABLE 17

Break-Even Table

Rec %	Prod kg	Income $	Var C $	Fix C $	Total C $	Net P/L $
1	15	181.5	52.2	2005.9	2058.1	-1876.6
5	75	907.5	261.0	2005.9	2266.9	-1359.4
10	150	1815.0	522.0	2005.9	2527.9	-712.9
20	300	3630.0	1044.0	2005.9	3049.9	580.1
30	450	5445.0	1566.0	2005.9	3571.9	1873.1
40	600	7260.0	2088.0	2005.9	4093.9	3166.1
50	750	9075.0	2610.0	2005.9	4615.9	4459.1
60	900	10890.0	3132.0	2005.9	5137.9	5752.1
70	1050	12705.0	3654.0	2005.9	5659.9	7045.1
80	1200	14520.0	4176.0	2005.9	6168.9	8338.1
90	1350	16335.0	4698.0	2005.9	6703.9	9631.1
100	1500	18150.0	5220.0	2005.9	7225.9	10924.1

with a profit of over $10,000 realized if a 100% survival rate was experienced. Although costs are high, net income is increasingly larger over the % recovery range, this is as a result of the high price paid for charr.

The effect of stocking rate, fish price and size of stocked fingerlings will be analyzed using this type of analysis. Finally, the fact that this analysis uses the assumption that only 200 gram fish are caught must be pointed out. Fish size is wide ranging, as has already been mentioned in the biological analysis. Approximately 57% of the fish were of marketable size, therefore in order for the break-even level of production to be realized, a survival rate of 24% would now be necessary.

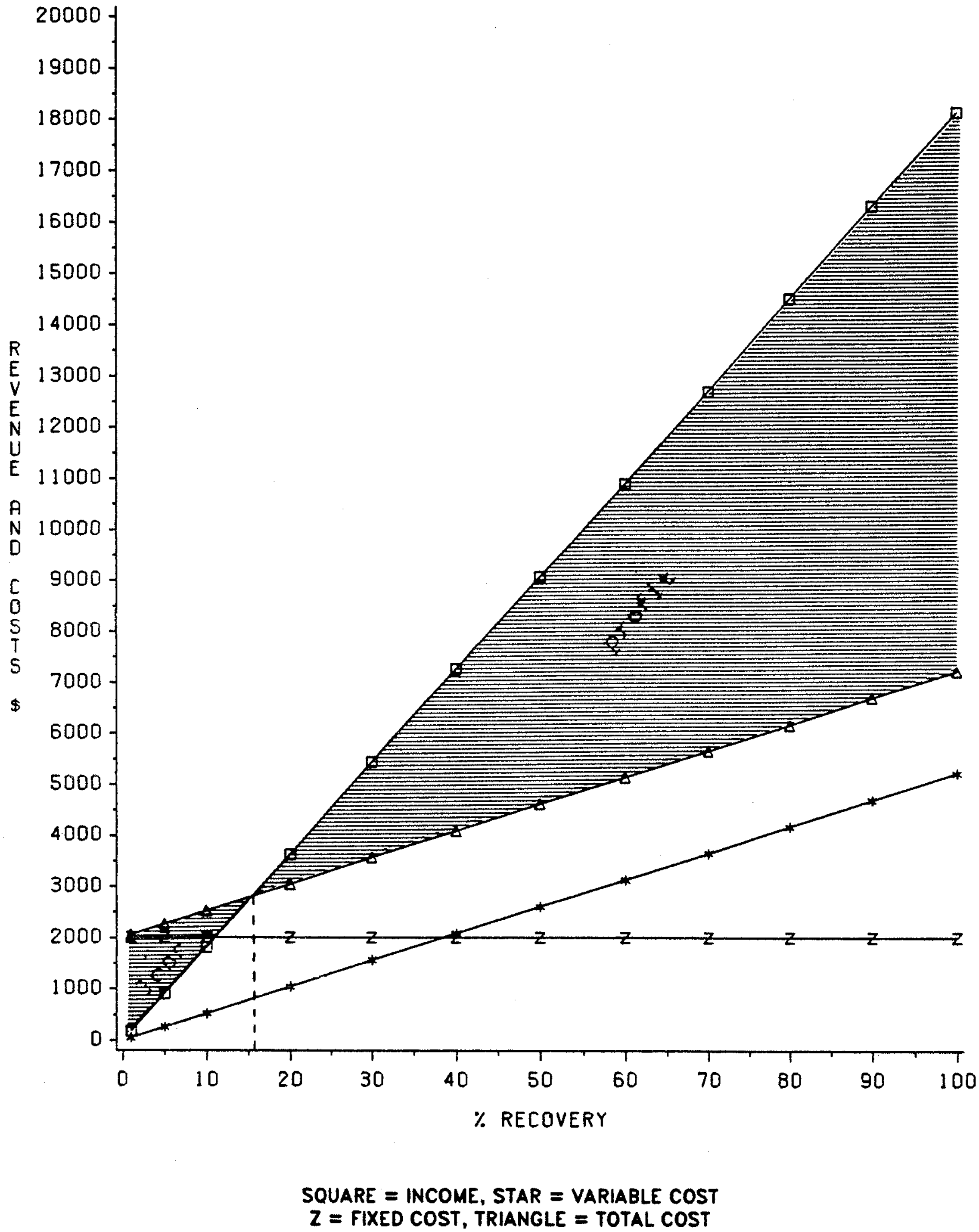


Figure 19: Break-Even Analysis Showing Net Profit or Loss

6.2.1 Effect of Stocking Rate on Profit

As a result of the low survival rate experienced in these lakes, it might be better to stock fewer fingerlings into the lakes since most of them die anyway. Alternatively, it can be argued because the survival is so low it might be better to stock more fingerlings in order to increase the survival rate. These hypothesis' could only be determined biologically, by either increasing or deceasing the stocking rate and observing the effect on survival. However, it is possible to vary the stocking rate empirically through this analysis and determine the financial effect.

On the prairies, pothole lakes are generally stocked at a rate of 200 fish per acre or 500 fish per hectare. Lake 4 at Lynn lake was stocked at a rate of 573 fish per hectare which is very similar to the prairie stocking rate. The effect of doubling (14,000 fish) and halving (3,750 fish) the stocking rate on break-even point was determined (Table 18).

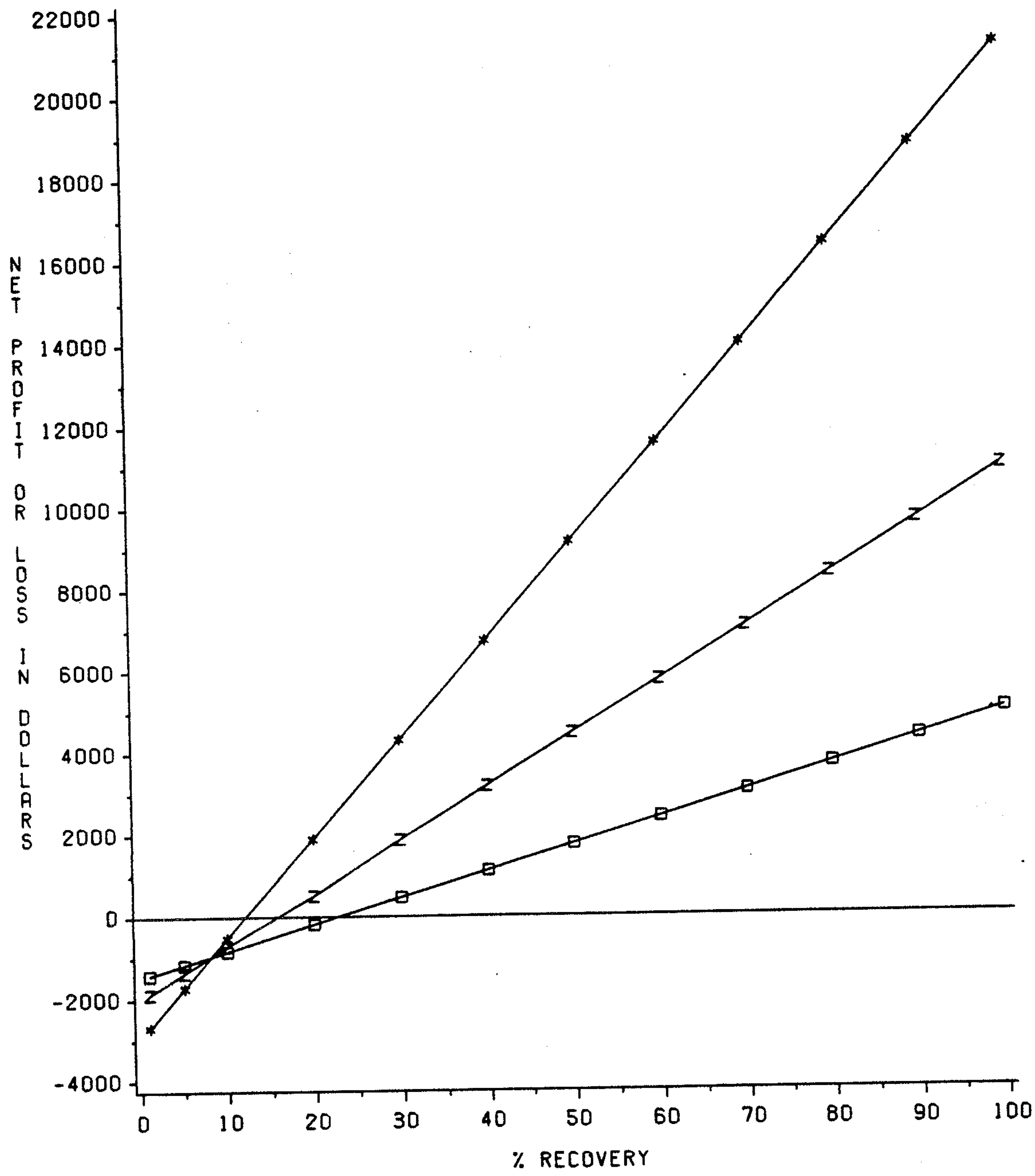
TABLE 18

Effect of Stocking Rate on Break-Even Point

Variable	7,500 fish	14,000 fish	3,750 fish
Fixed Cost	$2,005.90	$2,931.70	$1,480.90
Price	$12.10/kg	$12.10/kg	$12.10/kg
Variable Cost	$3.48/kg	$3.48 /kg	$3.48/kg
Break-even Point	232.7 kg	340.1 kg	171.8 kg
Fish (200g)	1,164	1,700	859
Survival	15.5 %	12.1 %	22.9 %

The only change was in fixed costs which increase to $2,931.70 when the stocking rate is doubled, and decrease to $1,480.90 when the stocking rate is halved. For a doubled stocking rate, 14,000 fingerlings would have to be purchased at $0.12 each to total $1,680, and transportation costs would be doubled to $300. For a halved stocking rate, 3,750 fingerlings would have to be purchased at $0.12 each to total $450, and transportation costs halved to $75. The break-even level of production is 340 kg or a 12% survival for the double stocking rate, and 172 kg or a 23% survival for the halved stocking rate.

Net profit of loss for each stocking rate was graphed (Figure 20). The double stocking rate, although exhibiting larger net losses to begin with, increased net profits sharply and realized over $20,000 if a 100% recovery was experienced. On the other hand, the halved stocking rate showed much lower profits and only realized a profit of $4,000 if a 100% recovery rate is experienced. Profits and losses were purely hypothetical, and survival rates under different stocking rates can only be determined biologically. Even though the double stocking rate appears more attractive financially, a 12% survival of 1,700 fish in the lake may not be biologically feasible due to limited food resources. Hence, it can not be concluded that a higher stocking rate will increase profits. However, if a higher stocking rate exhibited high survival rates, a large profit could be made.



KEY: SQUARE = 3,750 FISH,
Z=7,500 FISH, STAR = 14,000 FISH

Figure 20: Effect of Stocking Rate on Profit

6.2.2 Effect of Price on Profit

The profits realized in the previous analysis' have been high, this has been as a result of the high price received for arctic charr ($12.1/kg). The following prices have been used to determine the effect of price on break-even level of production (Table 19).

- $11 per kg ($5/lb), if all charr are sold to a retailer in Winnipeg this is the price that would be received;
- $4.6 per kg ($2.10/lb), if all the charr were sold at the lowest price received for rainbow trout;
- $5.5 per kg ($2.5/lb);
- $6.6 per kg ($3.0/lb);
- $8.8 per kg ($4.0/lb).

TABLE 19

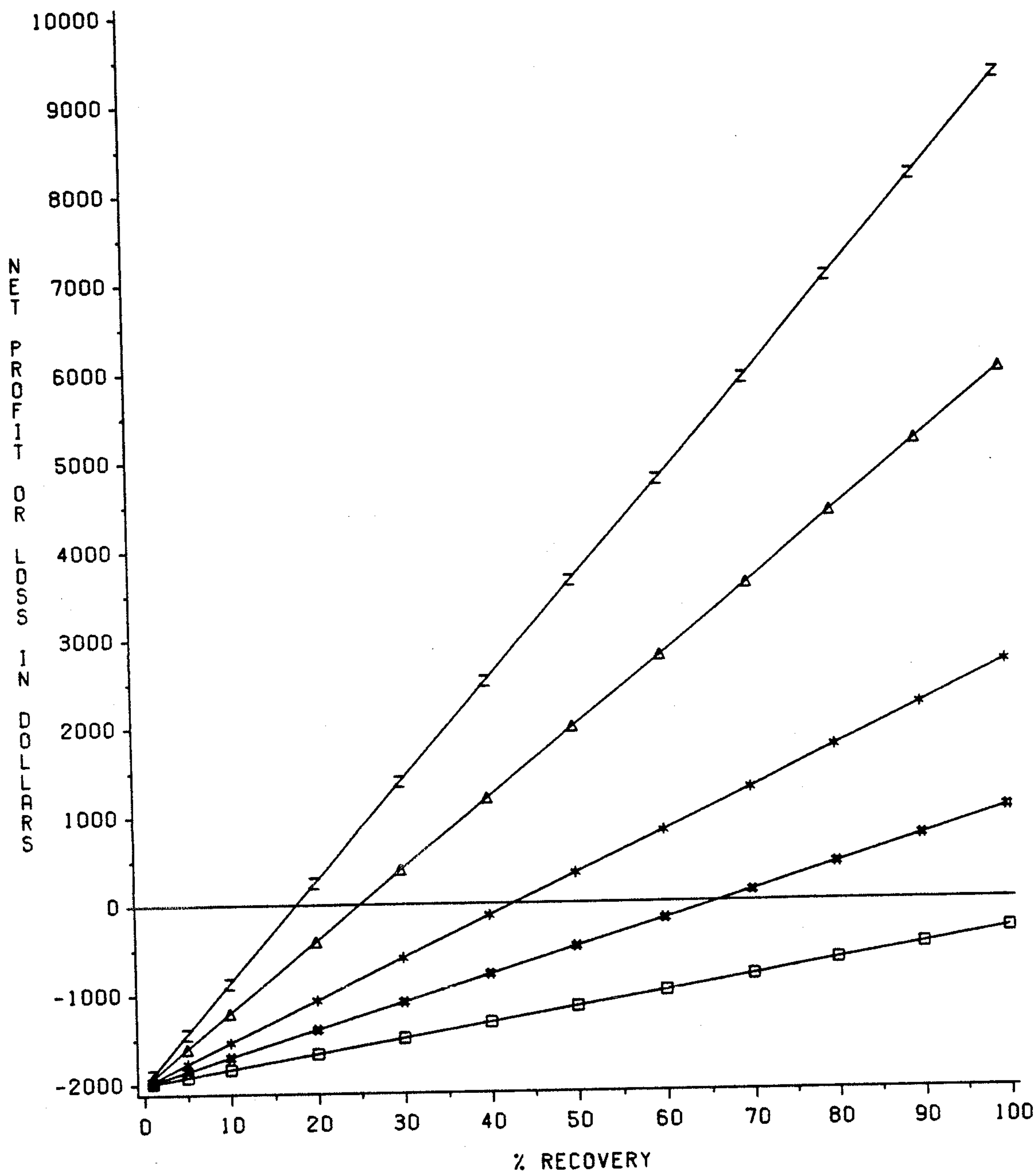
Effect of Price on Break-Even Point

Variable	$4.6/kg	$5.5/kg	$6.6/kg	$8.8/kg	$11/kg
Fixed Cost	$2005.9	$2005.9	$2005.9	$2005.9	$2005.9
Variable Cost	$3.48/kg	$3.48/kg	$3.48/kg	$3.48/kg	$3.48/kg
Price	$4.6/kg	$5.5/kg	$6.6/kg	$8.8/kg	$11/kg
Break-even Point	1790.9kg	993 kg	642.9 kg	377 kg	266.7 kg
Fish (200g)	8,955	4,962	3,216	1,885	1,334
Survival	119 %	66.2 %	42.9 %	25.1 %	17.8 %

The break-even point of production is effected greatly by price. Using the lowest price received for rainbow trout, the break-even level of production is beyond the number of stocked fingerlings (119%).

Hence, the operation would never exhibit a profit even at a 100% recovery rate. As the price received for charr gradually increases the break-even level of production decreases concurrently. The effect of price on net profit or loss has been determined using break-even tables and the results graphed (Figure 21).

This analysis shows that net profits are highly sensitive to price, with a small decrease in price sharply reducing profits. If the minimum price for rainbow trout is used the operation will never break-even, and even higher prices of \$2.50/lb (\$5.5/kg) and \$3.0/lb (\$6.6/kg) are not viable as the recovery rates necessary are too high. This analysis also shows that if all arctic charr are sold at the Winnipeg retail price of \$11/kg (\$5/lb) the break-even level of production would be 18%. However, because the survival rate of fish in Lake 4 was so low (6%), the highest price possible would be necessary in order to break-even or else limit losses.



KEY: SQUARE=$4.6/KG, HASH=$5.5/KG,
STAR=$6.6/KG, TRIANGLE=$8.8/KG, Z=$11/KG

Figure 21: Effect of Price on Profit

6.2.3 Effect of Fingerling Size on Profit

Size of stocked fingerlings can also be varied to determine the effect on profit. Two inch (1 gram) fingerlings were stocked into Lake 4 at Lynn Lake, and hence the previous analysis' have been calculated using this size. This is generally the smallest size available commercially and arctic charr fingerlings of this size would retail for $0.12 each. However, many fish farming operations prefer to stock larger sized fingerlings in order to give fish a "head start" in growth. It is estimated that 4 inch (12 gram) fingerlings have a 2 month head start in growth over 2 inch fingerlings. However, larger size fingerlings are more expensive, with 4 inch rainbow trout fingerlings costing $0.22 each, and 6 inch (40 gram) rainbow trout fingerlings costing $0.75 each. Fish farmers therefore have to make a trade-off between higher cost of fingerlings and increased number of harvestable sized fish at the end of the growing season. However, northern fish farmers do not have to worry about harvesting fish after one growing season as northern lakes are less likely to winterkill, therefore they can purchase smaller sized fingerlings. The effect of starting size of fish on growth was demonstrated in the biological analysis, and it was shown that all 2 inch, 4 inch and 6 inch fingerlings required more than one growing season in order to obtain harvestable size. Now the financial effect of stocking different size fingerlings can be analyzed.

The increased cost of stocking larger size fingerlings can be divided up into two parts:

- The increased purchasing cost: 4 inch arctic charr fingerlings would cost $0.24 each to purchase ($0.02 premium on rainbow trout fingerlings), and 6 inch arctic charr fingerlings would cost $0.80 each to purchase ($0.05 premium on rainbow trout fingerlings).
- The increased cost of transport: fish are transported to Lynn Lake by commercial airline in plastic bags in boxes weighing 18 kg, and the cost of transport is $1.97 per kg.

The cost of purchasing 7,500 4 inch fingerlings would be $1,800. The cost of transporting fingerlings to Lynn Lake was calculated from knowing: the total weight of fingerlings (90 kg), that there would be 1.8 kg of fish per box, 50 boxes (18 kg each) would be required, and the total cost of transportation would therefore be $1,773. The cost of purchasing 7,500 6 inch fingerlings would be $6,000. The cost of transporting fingerlings was calculated from knowing: the total weight of fingerlings (300 kg), that there would be 1.8 kg of fish per box, 166 boxes (18 kg each) would be required, and the total cost of transportation would therefore be $5,910. These fixed costs were added to the other fixed costs, and effect of fingerling size on break-even level of production was determined (Table 20).

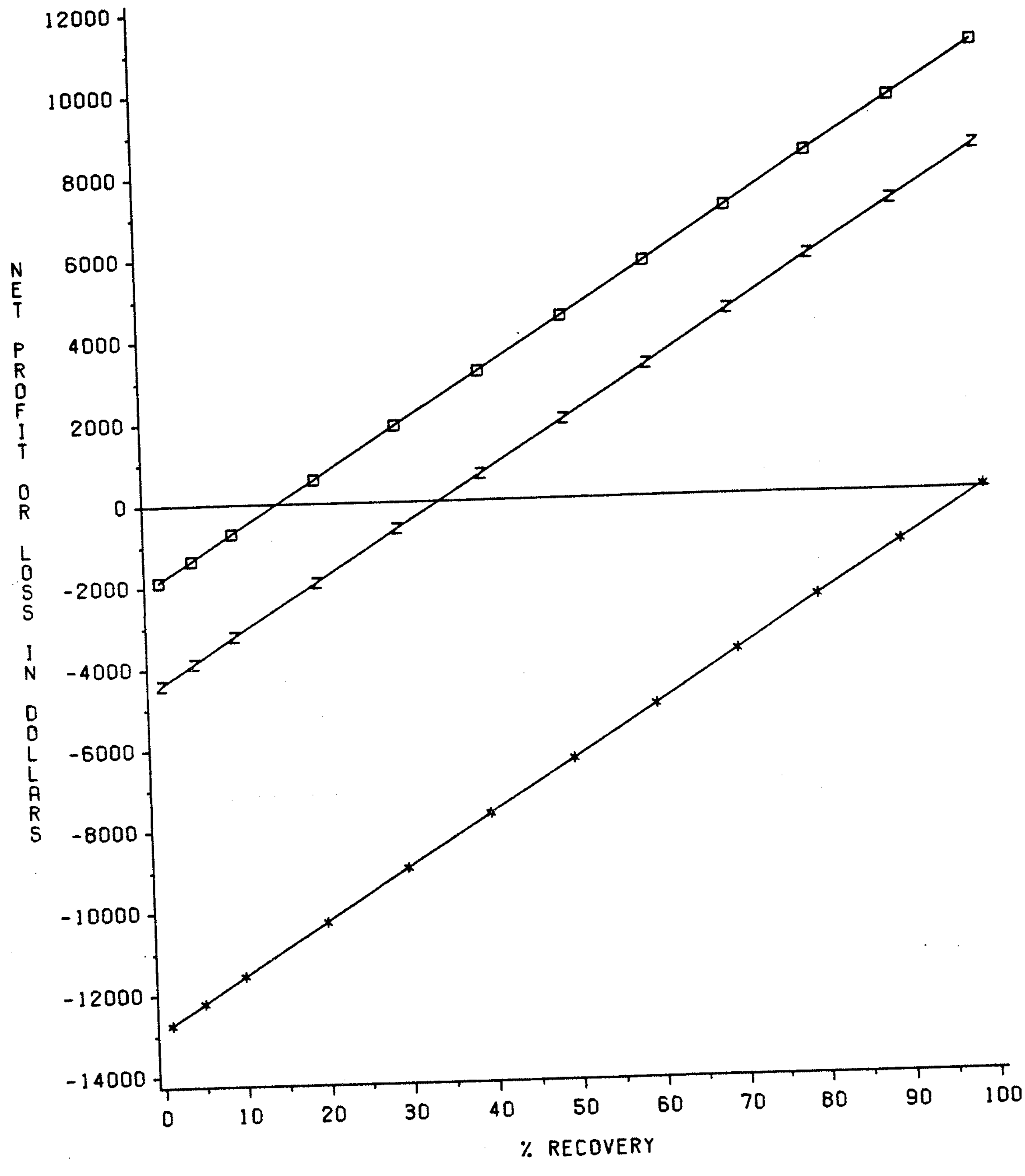
If 4 inch fingerlings were stocked into the lake, the break-even level of production would be 525.4 kg of fish (35% survival), and if 6 inch fingerlings were stocked the break-even level of production would be 1,493 kg of fish (99.5% survival). The effect of fingerling size on profit has been determined using break-even tables and net profits or losses graphed (Figure 22).

TABLE 20

Effect of Fingerling Size on Break-Even Point

Variable	2 Inch	4 Inch	6 Inch
Fixed Cost	$2,005.90	$4,528.90	$12,866.0
Price	$12.10/kg	$12.10/kg	$12.10/kg
Variable Cost	$3.48/kg	$3.48 /kg	$3.48/kg
Break-even Point	232.7 kg	525.4 kg	1492.6 kg
Fish (200g)	1,164	2,627	7,463
Survival	15.5 %	35 %	99.5 %

If 6 inch fingerlings are stocked into the lake, the operation would never realize a profit, this is due to the very high fixed costs. If 4 inch fingerlings were stocked into the lake, the operation would only realize a profit after a 35% recovery rate. Hence, two inch fingerlings are the most profitable size for this operation. However, the fact that larger size fingerlings produce larger size fish has not being taken into account in this analysis. Therefore, if 4 inch fingerlings were stocked into the lake, the percentage of harvestable size fish might increase, there would be more weight of fish to sell, and hence a higher income would be obtained. This factor has not being taken into account because it is impossible to estimate the increased weight of fish at harvest. Hence, although it appears that 2 inch fingerlings are the most profitable size to stock, this can only be determined biologically by stocking different size fingerlings.



KEY: SQUARE = 2 INCH, Z = 4 INCH, STAR = 6 INCH

Figure 22: Effect of Fingerling Size on Profit

Biological analysis has already shown that all size fingerlings take more than one growing season to reach harvestable size, hence the only real advantage of stocking larger size fingerlings would be that they reach harvestable size earlier. Since all sizes take more than one season to reach harvestable size, this factor is not crucial to this type of operation where costs do not increase with time. It does not cost the fish farmer any more to leave the fish longer in the lake, as there are no feed and labour costs. Consequently since the smallest, and cheapest, fish reach harvestable size by the end of the second growing season, they would be the best size to stock.

6.3 SUMMARY

The fish farming operation on Lake 4 at Lynn Lake made a small profit. This is because many of the real costs, such as cost of fingerlings, operator's wages and depreciation expenses were not included. If all these expenses were included the operation made a net loss. This was due to the extremely low survival rate (6%), and hence, low harvest of fish from the lake of which 57% were of harvestable size. When a hypothetical situation of a 30% survival rate was simulated, the operation made a profit, even when all costs were added, including the increased marketing costs.

Break-even level of production was shown to be 1,164 fish or a 15.5% survival rate. Income from fish sales increased rapidly with increased survival rate, due to the high retail price for charr. However, fixed costs were so high that there was a net loss up to a 15.5% survival rate. Doubling the stocking rate of the lake was shown to increase profits, and halving the stocking rate was shown to decrease profits. However, even though higher stocking rates appear more financially attractive, the lake might not be able to biologically support the number of fish necessary to break-even. The break-even level of production was shown to be greatly effected by price, and hence it was concluded that net profits were highly sensitive to price changes. Also, because the survival rate in the lake was so low, the highest price possible would be necessary to break-even or else limit losses. Finally, the effect of size of stocked fingerlings on profit was examined. It was shown that net profits were lower, or losses higher, the larger the fingerling size stocked. Also, because it takes all size fingerlings more than one growing season to reach marketable size, the smallest fingerling would be the best size to stock.

Chapter VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 BIOLOGICAL CONCLUSIONS

Conclusions from the biological analysis can be summarized under the following points:

- Non winterkill, small oligotrophic lakes in northern Manitoba were able to produce marketable size rainbow trout and arctic charr after two growing seasons in the lake.
- Growth rates of fish are significantly different between lakes, and can be related to lake basin morphology, water temperature, food availability and the presence of competing stickleback minnows for food.
- Size variablity of arctic charr in these lakes poses a marketing problem, but is not unique to northern lakes since this phenomena is experienced in other culture systems.
- The "non winterkill" nature of these lakes is crucial for northern extensive aquaculture, as this enables fish to over-winter in lakes and hence allows them the necessary time to reach harvestable size after 2 or more growing seasons. Also, this allows a "continuous cropping" harvest strategy where only marketable size fish are removed, and hence compensate for size variation in fish.

- Mortality rates of both rainbow trout and arctic charr in these lakes is very high, and this precluded an attempt to estimate yield. The high mortality rates were probably not due to predation, or the physical environment of the lake. Rather, stress at time of stocking and limited food availability are more likely the cause. More care at stocking and a lower stocking rate might increase fish survival rates.

The major drawback to this operation were the high mortality rates of fish in these lakes. Although some fish reached marketable size by the end of the second growing season, the high mortality rates precluded any attempt to make a reliable estimate of yield. From the literature it appeared that the harvest from the lakes were well below the predicted yield of northern lakes. In order for this operation to be biologically feasible the cause of these high mortality rates has to be determined and overcome. Stress at stocking was pinpointed as probably the largest contributing factor. Also, the stocking rate of 500 fish per hectare is probably too high for these oligotrophic lakes, which have a limited amount of nutrients, food supply and hence carrying capacity.

However, once mortality rates are reduced in these lakes, other biological factors make these lakes suitable for fish culture. These lakes do not experience summerkill, which is the largest biological drawback to fish culture in prairie eutrophic lakes. Nor do these lakes winterkill, which provides two advantages. Fish can overwinter in the lakes and reach a harvestable size after two to three seasons. Also, a strategy of continuous cropping could be implemented, where only harvestable size fish are removed, and smaller fish left for later harvest. Fish from these lakes are of excellent quality with no muddy flavours. Therefore once survival of fish in these lakes has improved, these lakes would be excellent for fish culture.

7.2 ECONOMIC CONCLUSIONS

Conclusions from the economic analysis can be summerized under the following points:

- The Lynn Lake aquaculture operation was not profitable at such a low survival rate of fish, when all costs were included. However, if the operation was viewed as a "hobby" and the operator's wages, fingerling costs and depreciation expenses were not included, a small profit could be made.
- As a result of relatively low costs (no feed and labour costs), and high prices paid for arctic charr, the operation would become profitable for survival rates above 15%. Profits increase exponentially with higher survival rates, even when the cost of market transportation of fish to Winnipeg was included. Hence, the distance of the operation from major markets was not a problem.
- Profits were shown to be very sensitive to price, stocking rate and fingerling size. In order to realize a profit, or limit losses, the operation must obtain the highest price possible for arctic charr. Hence, it can be concluded that the culture of arctic charr is preferable to that of rainbow trout which retail at a lower price. Also, due to disproportionate expenses in stocking larger fingerlings, it was found that the smallest fingerlings were the best size to stock.

Overall, extensive aquaculture in northern lakes is not economically feasible at survival rates below 15%. However, if the operation is viewed as a hobby and several costs ignored, small profits can be made. The operation does become extremely profitable at higher than 15% survival rates, and large profits can be made due to the high retail price paid for arctic charr and relatively low costs involved. The risk associated with recovery rate could be a major deterrent in the immediate development of extensive aquaculture in this region. However, a survival rate of 15% is not unrealistic, and if appropriate measures are taken to improve survival rates, a 'profitable' enterprise is possible.

7.3 PERSPECTIVES

Aquaculture is a relatively young industry in Canada, and there are specific problems and drawbacks to each type of aquaculture, intensive and extensive, that have to be overcome before we can expect a thriving industry. Extensive aquaculture on the prairies has its own particular biological and economic problems, and therefore it is unreasonable to expect northern extensive aquaculture to be 'problem free'. However, apart from the high mortality rates, it is biologically feasible to produce good quality marketable size trout and charr after two or three growing seasons in a lake. Also, it is economically feasible to to undertake this kind of operation with a survival rate of only 15% marketable size fish. This is because the costs are so low, and the price received for charr so high. A survival rate of 15% is not unreasonably high, and once the problem of mortality has been overcome extensive aquaculture in these lakes would be both biologically and economically feasible.

Like any new industry, fish farming must be approached slowly and cautiously. Investing a large amount in a large operation would be unwise. However, this type of aquaculture lends itself to a low cost and low investment type enterprise. Also, aquaculture is particularly suitable to northern native community's lifestyles and culture. Many northern communities are searching for economic development projects and aquaculture would be a prospective enterprise. Demand for fish is increasing in Canada and there is a ready demand for both rainbow trout and arctic charr in Manitoba.

7.4 RECOMMENDATIONS

High mortality rate are the major drawback to extensive aquaculture in Northern Manitoba. The following recommendations are designed to increase fish survival in these lakes:

- Further study is needed in order to verify and expand on these conclusions. The data used to draw these conclusions is only from two lakes over one production cycle, and therefore in order to quantify growth and survival of rainbow trout and arctic charr in northern lakes more data is needed.
- Stress at stocking has been shown to be a significant factor in causing high mortalities, therefore in order to increase survival of fish in these lakes, fingerlings should be stocked in cages suspended in the lakes for a few weeks before they are released.

This would allow fingerlings time to adjust to their new environment, and also allow the fish farmer to monitor their survival over this critical period.

- A few fingerlings should be stocked in permanent cages in the lakes in order to see if they survive the first growing season. This would verify that the physical environment of the lake is suitable for their survival, and also show if predation or disease is a cause of mortality.
- Different stocking rates should be attempted in these lakes, to determine their effect on fish survival and growth rates. A lower stocking rate might increase fish survival as there would be less competition for food resources.

LITERATURE CITED

Ayles, G.B. 1973. Comparative growth and survival of matched plantings of wild and domestic rainbow trout in prairie potholes. Fisheries Research Board of Canada Technical Report 382: 13 p.

______ 1975. Influence of genotype and environment on growth and survival of rainbow trout (Salmo gairdneri) in central Canadian aquaculture lakes. Aquaculture 6: 181-189.

______ 1977. Trout farming. Freshwater Institute reprint 492: 4p.

Ayles, G.B. and J.R. Brett. 1978. Workshop on aquaculture research and development in Canada. Canadian Fisheries and Marine Service Technical Report 750: 26 p.

Ayles, G.B., J.G.I. Lark, J. Barica and H.Kling. 1976. Seasonal mortality of rainbow trout (Salmo gairdneri) planted in small eutrophic lakes in central Canada. Journal of the Fisheries Research Board of Canada 33 (4): 647-655.

Bardack, J.E. 1976. Aquaculture revisited. Journal of the Fisheries Research Board of Canada 33: 880-887.

Barica, J. 1975. Geochemistry and nutrient regime of saline eutrophic lakes in the Erikson-Elphinstone district in southwest Manitoba. Canadian Fisheries and Marine Service Technical Report 511: 82 p.

Barica, J. and J.A. Mathias. 1979. Oxygen depletion and winterkill risk in small prairie lakes under extended ice cover. Journal of the Fisheries Research Board of Canada 36 (8): 980-986.

Barton, B.A., R.E Peter and C.R. Paulencu. 1980. Plasma cortisol levels of fingerling rainbow trout (Salmo gairdneri) at rest, and subject to handling, confinement, transport and stocking. Canadian Journal of Fisheries and Aquatic Sciences 37: 805-811.

Bernard D, and C. Holmstrom. 1978. Growth and food habits of strains of rainbow trout (Salmo gairdneri Richardson) in winterkill lakes in western Manitoba. Fisheries and Marine Service Manuscript Report 1477: 19 p.

Brett, J.R. 1979. Environmental factors and growth, p. 599-677. In W.S. Hoar, D.J. Randall and J.R. Brett (eds.) Fish physiology Volume 8. Academic Press, New York.

Brett, J.R. and J.E. Shelbourne. 1975. Growth rate of young sockeye salmon (Oncorhynchus nerka) in relation to fish size and ration level. Journal of the Fisheries Research Board of Canada 32: 2103-2110.

Brett, J.R. and D.H. Sutherland. 1970. Improvement of the artificial rearing of sockeye salmon by environmental control. Fisheries Research Board of Canada, Naniamo Biological station Circular 89: 14 p.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography 22 (2): 361-369.

Cauvin, D.M. and P.C. Thompson. 1977. Rainbow trout farming: an economic perspective. Fisheries and Marine Service Industry Report 93. Department of Fisheries and Oceans, Winnipeg. 24 p.

Cole, G.A. 1983. Textbook of Limnology. C.V. Mosby Company. 401 p.

Cunningham, S., M.R. Dunn and D. Whitmarsh. 1985. Fisheries Economics. Mansell Publishing Limited, London. 371 p.

Fish Management Division of Fisheries and Wildlife Branch. 1980. Aquaculture in Saskatchewan. Saskatchewan Tourism and Renewable Resources. 15 p.

Fisheries Service. 1972. Aquaculture in central region and its potential - a viewpoint. In Freshwater Institute. Background Documents Prepared for Fisheries Service Aquaculture Workshop in Hull, Quebec. 10 p.

Freshwater Institute. 1972. Aquaculture in central Canada. In Freshwater Institute. Background Documents Prepared for Fisheries Service Aquaculture Workshop in Hull, Quebec. 13 p.

Freshwater Institute. 1979. Freshwater aquaculture information: marketing and production costs of pothole trout farming. Department of Fisheries and Oceans, Winnipeg. 3 p.

Harper, W.K. 1973. Rainbow trout farming project, The Pas Special Area. Pilot Land Use Planning (P.L.U.P.) Project. The Pas Special Area, Manitoba. 45 p.

Hokanson, K.E, C.F. Kleiner and T.W. Thorslund. 1977. Effect of constant and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout (Salmo gairdneri). Journal of the Fisheries Research Board of Canada 34: 639-648.

Hrbacek, J. 1969. Relations of biological productivity to fish production and the maintenance of water quality, p. 176-185. In L. Obeng (ed.) Man-made lakes. The Accra Symposium. Ghana University Press, Accra, Ghana.

Hunter, J.G. 1970. Production of arctic charr (Salvelinus alpinus Linnaeus) in a small arctic lake. Fisheries Research Board of Canada Technical Report 321: 190 p.

______ 1976. Arctic charr and hydroelectric power in the Sylvia Grinnell River. Fisheries Research Board of Canada Manuscript Report Series 1376: 21p.

Jobling, H. 1982. Influence of body weight and temperature on growth rates of actic charr (Salvelinus alpinus L.) Journal of Fish Biology 22: 471-475.

Johnson, L. 1980. The arctic charr Salvelinus alpinus, p. 15-92. In E.K. Balon (ed.) Charrs: salmonid fishes of the genus Salvelinus. Dr. W. Junk Publishers, The Hague.

Johnson, L., G.H. Lawler and L.A. Sunde. 1970. Rainbow trout farming in central Canada. Fisheries Research Board of Canada Technical Report 165: 13p.

Jones, G.A. and M.V. Hoyer. 1982. Sportfish harvest predicted by summer chlorophyll-a concentrations in midwestern lakes and reservoirs. Transactions of the American Fisheries Society 111: 176-179.

Laiw, W.K. 1984. Pond rearing of walleye (Stizostedion vitrium vitrium) fingerlings in Saskatchewan. Saskatchewan Fisheries Laboratory Technical Report 84-1.

______ 1984. Pond rearing of whitefish (Coregonus clupeaformis) fingerlings on Saskatchewan. Saskatchewan Fisheries Laboratory Technical Report 84-2.

Larkin, P.A., J.G.Terpenning and R.R.Parker. 1957. Size as a determinant of growth rate in rainbow trout (Salmo gairdneri). Transactions of American Fisheries Society 86: 84-96.

Lysack, J.M. 1982. Fish stock assessment of lakes in the pulse fishing project. Manitoba Department of Natural Resources M.S. Report 82-5: 307 p.

MacCrimmon, H.R. 1973. Freshwater aquaculture in Canada. Prepared for the Fisheries Service, Canada Department of the Environment. 69 p.

Malack, J.M. 1976. Primary productivity and fish yields in tropical lakes. Transactions of the American Fisheries Society 105: 575-580.

Mathias, J.M. and J.Barica. 1980. Factors controlling oxygen depletion in ice-covered lakes. Canadian Journal of Fisheries and Aquatic Sciences 37 (2): 185 -194.

Mathisen, O.A. and M. Berg. 1968. Growth rates of the charr (Salvelinus alpinus L.) in the Vardnes River, Troms, Norway. Institute of Freshwater Research Drottingholm Report 48: 177-186.

McConnell, W.J., S.Lewis and J.E.Olsen. 1977. Gross photosynthesis as an estimater of potential fish production. Transactions of the American Fisheries Society 106: 417-423.

Miall, A.D. 1983. Glaciofluvial transport and deposition. In N.Eyeles (ed.) Glacial Geology. Pergamon Press.

Nikum, J.G. 1970. Limnology of winterkill lakes in South Dakota, p. 19-25. In E.Schneberger (ed.) A symposium on the management of midwestern winterkill lakes. Special Publication of the North Central Division of the American Fisheries Society.

Oglesby, R.T. 1977. Relationships of yield to lake phytoplankton standing crop, production and morphoedaphic factors. Journal of the Fisheries Research Board of Canada 34: 2271-2279.

Papst, M.H., G.B.Ayles and S.Uraiwan. 1982. A model for estimating the growth of cultured trout (Salmo gairdneri Richardson). Canadian Technical Report of Fisheries and Aquatic Sciences 1088: 10 p.

Papst, M.H. and G.E.Hopky. 1982. Growth of rainbow trout (Salmo gairdneri Richardson) in a pilot commercial rearing system. Canadian Technical Report of Fisheries and Aquatic Sciences 1112: 18 p.

______ 1983. Growth of arctic charr (Salvelinus alpinus) in a pilot commercial rearing system. Canadian Technical Report of Fisheries and Aquatic Sciences 1182: 16 p.

Pillay, T.V.R. 1973. The role of aquaculture in fishery development and management. Journal of the Fisheries Research Board of Canada 30: 2202-2217.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Department of the Environment, Fisheries and Marine Service, Ottawa. 382 p.

Rigler, F.H. 1975. The Char Lake project, an introduction to limnology in the Canadian Arctic. In T.W. Cameron and L.W. Billingsley (eds.) Energy flow and its biological dimensions. Canadian Committee IBP, Ottawa.

Robbins, N.J. et al. 1980. A preliminary marketing study of the Ontario trout industry Part 1 and 2. In Ontario Trout volume 3 (5): 10 p. and (6): 6 p.

Rounsefell, G.A. 1946. Fish production in lakes as a guide for estimating production in proposed reservoirs. Copeia 1946: 29-40.

Ryder, R.A. 1965. A method for estimating the potential fish production of north temperate lakes. Transactions of the American Fisheries Society 94: 214 -218.

______ 1974. The morphoedaphic index, a fish yield estimater - review and evaluation. Journal of the Fisheries Research Board of Canada 31: 663-668.

______ 1982. The MEI - use, abuse and fundamental concepts. Transactions of the American Fisheries Society 111: 154-164.

Schindler, D.W. 1971. Light, temperature and oxygen regimes of selected lakes in the Experimental Lakes Area, N.W. Ontario. Journal of the Fisheries Research Board of Canada 28: 157-169.

Science Council of Canada. 1984. Aquaculture: a development plan for Canada. A Working Paper Prepared for Discussion Purposes by the Industry Task Force on Aquaculture. 22 p.

Science Council of Canada. 1985. Aquaculture: an opportunity for Canadians. Council Statement. 28 p.

Scott, W.B. and E.J.Crossman. 1973. Freshwater fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184: 966 p.

Sheldon, R.W. et al. 1972. The size distribution of particals in the ocean. Limnology and Oceanography 17: 327-340.

Siddiqui, R.M. 1972. Notes for a presentation on "marketing considerations with respect to aquculture". In Background Documents Prepared for the Fisheries Service Aquaculture Workshop in Hull, Quebec. 8 p.

Stauffer, G.D. 1973. A growth model for salmonids reared in hatchery environments. Ph.D. Thesis, University of Washington. Seattle, Washington.

Swift, D.R. 1964. The effect of temperature and oxygen on the growth rate of Windermere charr (Salvelinus alpinus willughbii). Comparative Biochemistry and Physiology 12: 179-183.

Sawchyn, W.W. 1984. Intensive cage culture of rainbow trout in farm dugouts. Saskatchewan Research Council Technical Report 161: 161p.

Uraiwan, S. 1980. Effect of genotype nd environment on growth of rainbow trout. M.Sc. Thesis, University of Manitoba. 177 p.

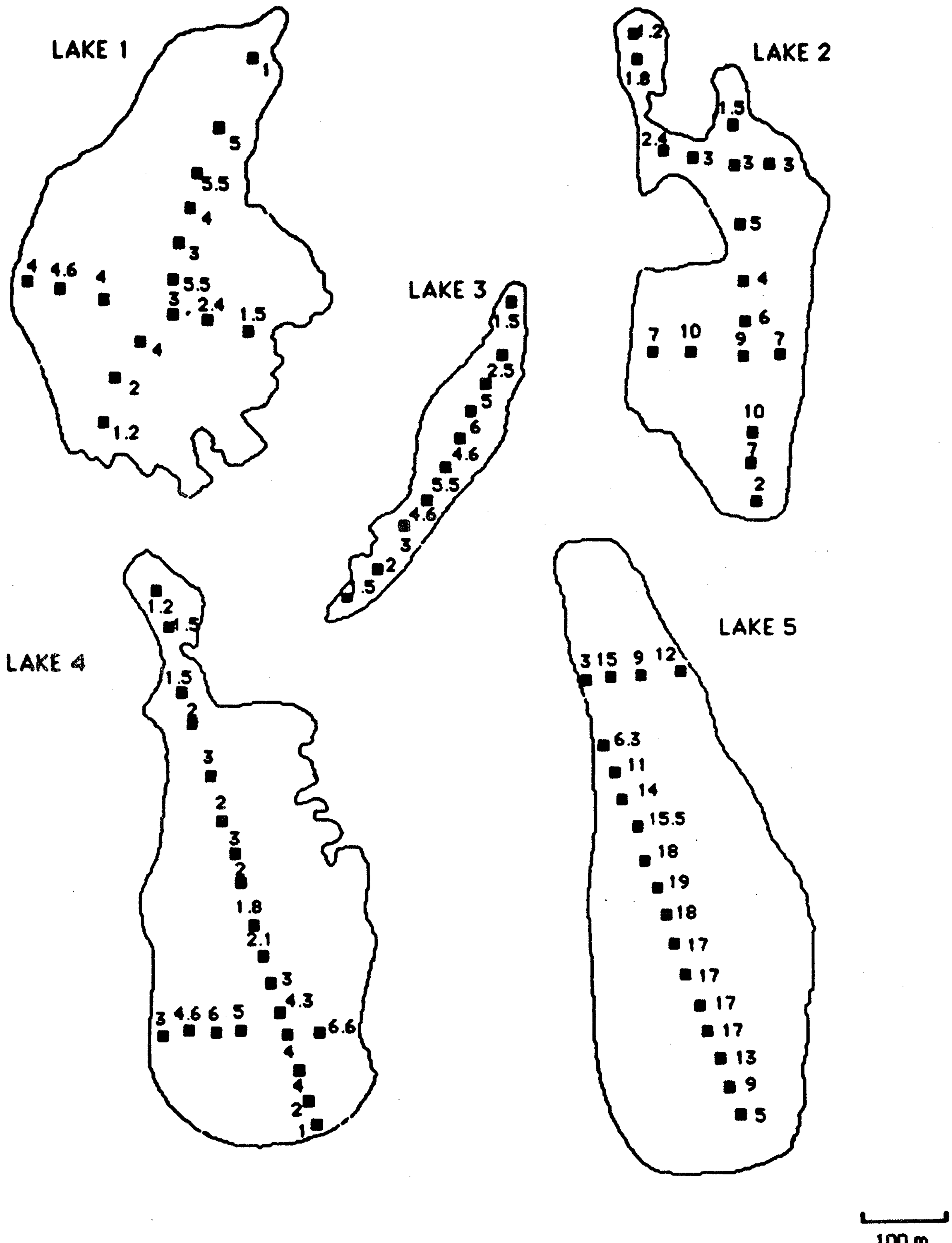
Wandsvik, A. and M.Jobling. 1982. Observations on growth rates of arctic charr (Salvelinus alpinus L.) reared at low temperature. Journal of Fish Biology 20 (6): 689-699.

Wetzel, R.G. 1983. Limnology. 2nd Edition. Saunders, Philadelphia. 767 p.

Whitaker, J. and J.Martin. 1974. The cage rearing of rainbow trout in Precambrian lakes. Fisheries Research Board of Canada Technical Report 446: 13 p.

Appendix A

BATHYMETRIC MAPS OF STUDY LAKES



DEPTH IN METERS