Evaluation of Controlled Fertilization of Acidified Wetlands For Enhancement of Waterfowl Production

Year One Final Report
March 31, 1991

Prepared by

M. Brylinsky
Acadia Centre for Estuarine Research
Acadia University
Wolfville, Nova Scotia
B0P 1X0

Supported by:
Black Duck Joint Venture
Canadian Wildlife Service
Ducks Unlimited Canada
Nova Scotia Department of Lands and Forests
Wildlife Habitat Canada

Publication No. 16

CONTENTS

CONTENTS

Page

I. INTRODUCTION

A. Background

The acidification of freshwater wetlands, through either natural or anthropomorphic processes, can have a drastic effect on the biological habitats and communities contained within these systems. The toxic effects imposed by heavy metals, which become more soluable at low pH, together with the ability of heavy metals to bind with and make unavailable essential plant nutrients, lead to changes in community structure and function that result in systems characterized by very low levels of both primary and secondary production. The problem of wetland acidification is most prominent in industrialized regions of the world where local geomorphology, particularly the presence of igneous bedrock of low solubility, leads to water systems having limited buffering capacity. In Nova Scotia it has been estimated that approximately 60 percent of the total land area has terrain characteristics highly sensitive to acid rain and an additional 25 percent of the landscape has a moderately high sensitivity to acid rain. A large proportion of the freshwater wetlands in Nova Scotia have little or no buffering capacity. This is probably typical of other areas of the Atlantic Maritimes as well, since the overall geomorphology is similar.

Managing acidic wetlands for aquatic wildlife is difficult because the major limiting factor is the lack of an adequate natural food supply. Artificial feeding of wildlife is costly and not generally considered to be logistically feasible on a large scale, particularly in remote areas. To manage these systems realistically requires a means of stimulating natural production processes in a way that results in sustained production. One approach to this is through the controlled addition of artificial fertilizers.

The concept of adding artificial fertilizers to enhance the productivity of acidic wetlands arose from observations that acidic lakes respond well to the addition of nutrients in terms of increased primary and secondary production and a much improved habitat for aquatic wildlife, especially ducks. This has prompted wildlife managers to suggest that this may prove a cost-effective management strategy for programmes designed to increase the abundance of waterfowl and other species of aquatic wildlife in acidic wetlands of low productivity. The application of this technique, however, requires careful consideration as to the situations where it is most likely to produce the desired results and, more importantly, of the potential this management strategy may have for producing environmental impacts inconsistent with the preservation and maintenance of viable and desirable habitats within and adjacent to the biological systems being fertilized. Accordingly, in the early spring of 1990, the Acadia Centre for Estuarine Research (ACER), in cooperation with the Black Duck Joint Venture, Canadian Wildlife Service, Ducks Unlimited Canada, Nova Scotia Department of Lands and Forests and Wildlife Habitat

Canada, began a three-year study to evaluate the potential and feasibility of rehabilitation of acidified freshwater wetlands through controlled artificial fertilization.

B. Objectives

The specific objectives of this project involve both short and long term components. The short-term (1-3 yr) objectives deal primarily with the assessment of artificial fertilization as a means of stimulating production in acidified water systems and the potential impact this may have on adjacent systems. Specifically, the short-term objectives are:

(1) to document the changes resulting from controlled artificial fertilization in terms of species composition and biomass of primary and secondary producers;

(2) to evaluate the effectiveness of controlled artificial fertilization in stimulating production processes;

(3) to document and evaluate the impacts, if any, of controlled fertilization on habitats and communities outside of the systems being fertilized and;

(4) to develop guidelines and recommendations useful in determining the conditions under which controlled fertilization can be considered an appropriate management technique.

The long-term (>3 yr) objectives include:

(1) determination of the long-term fate of added nutrients;

(2) comparison of waterfowl and other aquatic wildlife use on fertilized verses unfertilized sites and;

(3) comparison and cost-benefit analysis of controlled fertilization with other management strategies.

The approach adopted to meet the short-term objectives of this study was to select a number of small aquatic systems, similar to the type that would be used in rehabilitation management, and to spend the first year obtaining pre-fertilization baseline information. During the second year the sites will be divided into experimental and control units and the experimental units subjected to the addition of fertilizers. Monitoring of the effects of fertilization would begin at this time and continue into the third year.

This report presents the results of the first year of study and provides baseline data describing the general nature of the study sites in terms of their physical, chemical and biological characteristics. Most of this information is presented in summary form, either graphically as time series to illustrate seasonal trends, or as tables and bar diagrams to illustrate comparisons between sites. The data base upon which the summaries are based is available, but not included in this report because of its voluminous nature.

II. STUDY AREA

A preliminary survey of potential study areas within Nova Scotia revealed a number of watersheds that could be used for the study. For numerous reasons it was decided that the study be carried out in the vicinity of the Tobeatic Wildlife Management Area (TWMA). The main advantages of working in the Tobeatic area are primarily related to the existence of previous data bases on both waterfowl and water chemistry, especially for the wetlands of the adjacent Kejimkujik National Park, the availability of accommodations at no cost, and limited access by the general public allowing greater control over the study sites.

The TWMA is located in the central part of western Nova Scotia (Figure 1). It contains a variety of river systems, large lakes, ponds and other wetlands most of which are typically acidic and of low productivity. The underlying geomorphology consists mainly of igneous granodiorite bedrock.

The study began in early May 1990 with an extensive survey to locate and evaluate potential study sites. The major criteria used to select sites was: (1) reasonable accessibility; (2) low flushing rate; (3) small size (particularly volume) and; (4) low pH. The most difficult criteria to satisfy were accessibility and low flushing rate. Many of the wetland areas in the TWMA are inaccessible even by four-wheel drive vehicles, particularly those in the northwest section, and many form part of well-developed flowage systems and therefore have high flushing rates. We were, however, eventually able to identify ten potential study sites that were accessible and not part of large flowage systems. Two of these sites (Dunn and Morton Lakes), however, proved unsuitable because of high pH (>6.5), leaving a total of eight study sites. Although our original intention was to establish a total of twelve sites, it quickly became obvious that this was overly ambitious, not only in terms of finding suitable sites, but also in terms of the time that this would require for sample collection and processing.

Figure 2 shows the location of each site. All are within a 15 km radius of the Nova Scotia Department of Lands and Forest's camp at Pollard Falls where a 10 X 40 foot trailer, modified for use as a field laboratory, has been established and is being used as a base for field work.

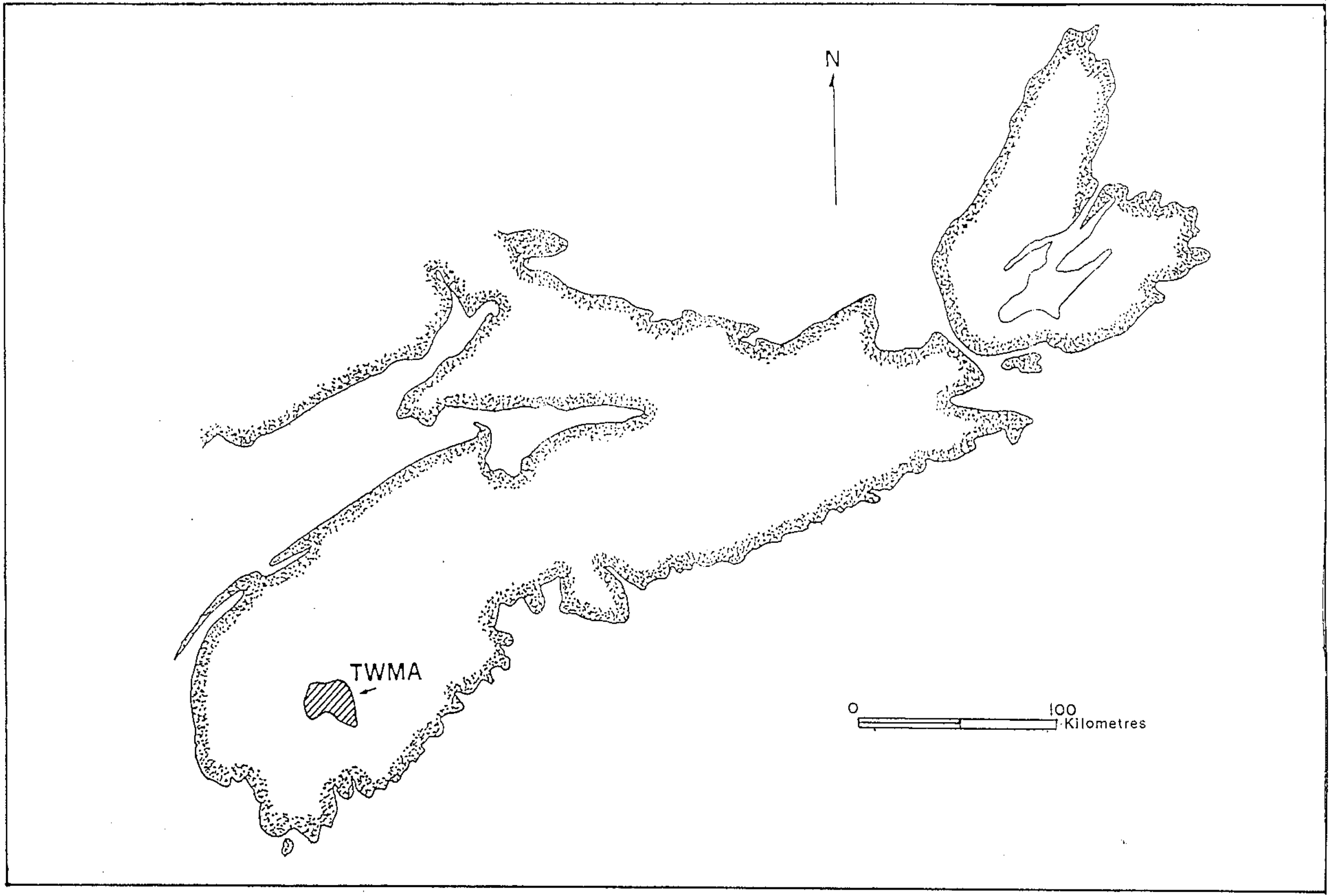


Figure 1. Map of Nova Scotia showing the location of the Tobeatic Wildlife Management Area (TWMA).

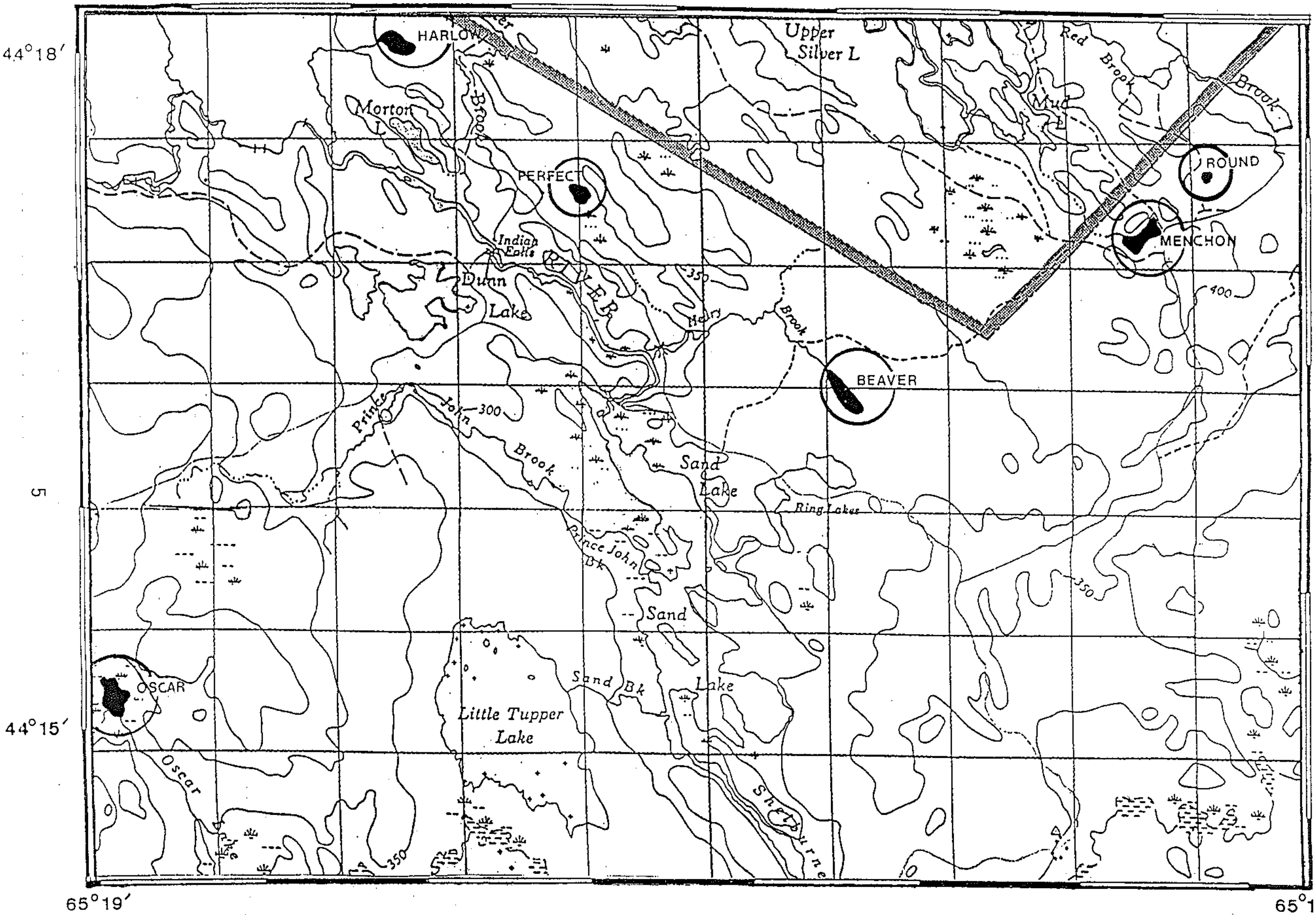


Figure 2. Location of six of the eight study lakes in the Tobeatic Wildlife Management Area.

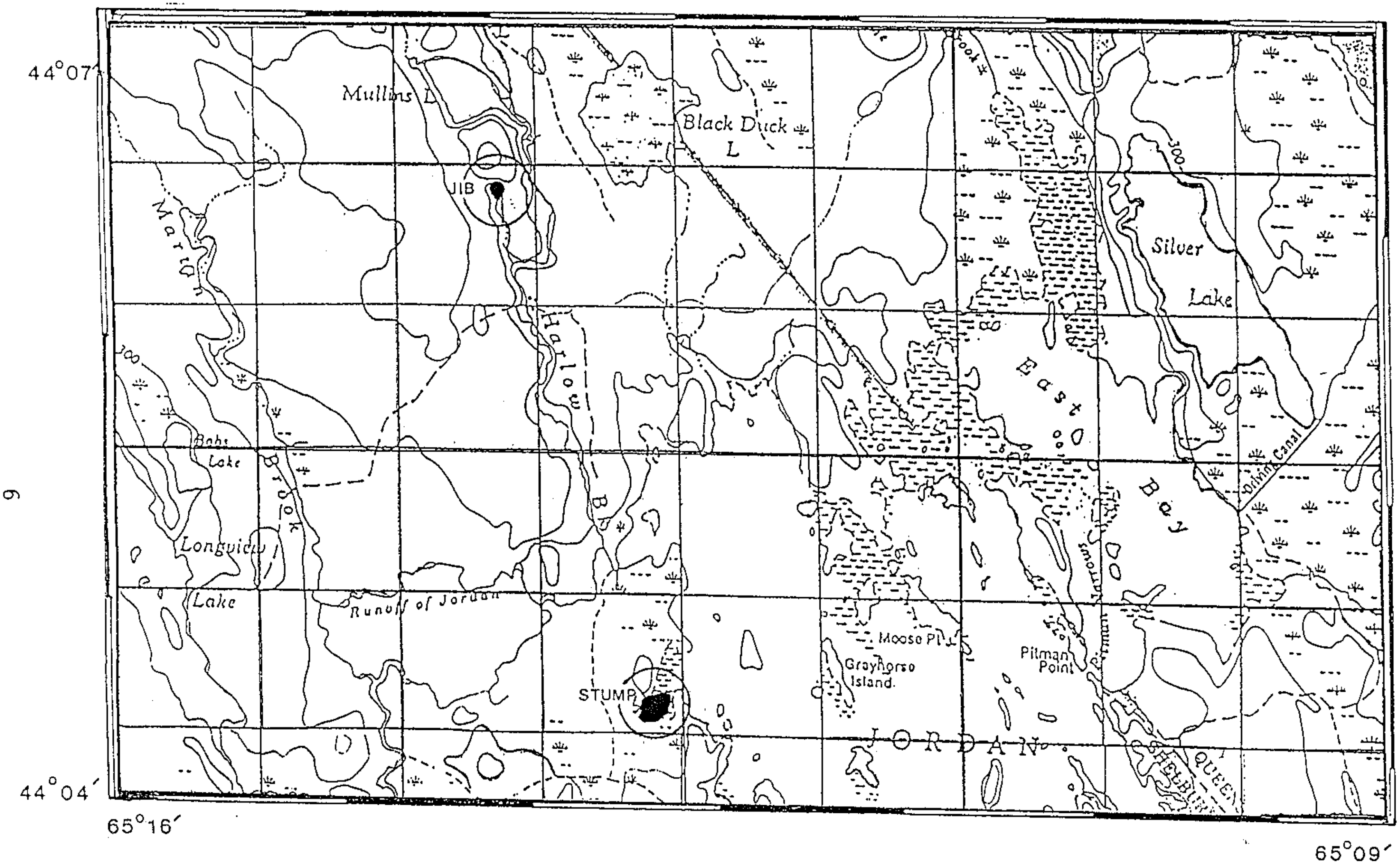


Figure 2 (cont't). Location of Stump and Jib Lakes in the Tobeatic Wildlife Management Area.

III. METHODS

A. Sampling Stations

At each site two distinct sampling stations were established, one located centrally and one located within the littoral zone. The central station was used to collect samples for parameters related to water quality and pelagic community composition. At two of the study sites (Harlow and Perfect), this station was provided with a pair of temperature data loggers, one at the surface and one at the bottom, to provide information on the seasonal development and breakdown of thermal stratification. The littoral station was equipped with a water level meter, insect emergence trap, periphyton sampler and minnow trap. This station was also used to collect benthic invertebrate samples. For those sites having an obvious outlet an additional station was established within the outlet which is sampled for water quality parameters only. In the case of Jib, its outlet is sampled just above where it intersects a larger brook (Harlow Brook) and a second sample, serving as a control, is taken from the larger brook just above where the outlet enters the brook.

Throughout the report the suffix (c) refers to results obtained at the central stations, and the suffix (o) to results obtained at the outlet stations.

B. Variables Sampled

The variables being sampled at each site are presented in Table 1 and include those typically used to characterize the physical, chemical and biological aspects of aquatic systems. The biological samples emphasize groups thought to be especially important to waterfowl populations in terms of food and cover, particularly aquatic insects and macrophytes.

C. Sample Collection and Analysis Techniques

A set of standardized procedures was developed for field sampling and laboratory analysis of samples. These are presented in Appendix A. In most cases the procedures follow standard limnological techniques, but in some instances slight modifications have been made to optimize sample collection and processing time. Analyses of the more labile chemical parameters (pH, dissolved oxygen and alkalinity) are carried out at the field laboratory immediately after collection. Other chemical analyses are carried out by the water chemistry laboratory of the Inland Waters Branch of the Canadian Department of Environment at Moncton, New Brunswick on samples that have been stored refrigerated.

Sample collection times were biweekly from May to mid-October. Each site was also visited once during November when a fish survey was conducted, and once in February to make observations on

TABLE 1. VARIABLES BEING MONITORED

I. Physical

1. Water level
2. Secchi Depth
3. Water Temperature (Depth profiles)
4. Suspended Particulate Matter

II. Chemical

By ACER:

1. Conductivity
2. pH
3. Alkalinity
4. Total Carbon Dioxide
5. Dissolved Oxygen (Surface and Bottom)
6. Hardness
7. Dissolved Phosphorous
8. Total Phosphorous

By CWS:

1. Total Ions
2. Turbidity
3. Apparent colour
4. Dissolved Calcium
5. Dissolved Magnesium
6. Alkalinity - Gran titration
7. Reactive Silica
8. Dissolved Organic Carbon
9. Total and Dissolved Nitrogen
10. Total and Dissolved Phosphorous

III. Biological

1. Chlorophyll a
2. Phytoplankton species composition
3. Periphyton abundance (by weight and chloryphyll a)
4. Zooplankton abundance and species composition
5. Insect emergence - abundance and composition
6. Benthic invertebrate abundance and composition
7. Small fishes
8. Aquatic macrophytes
9. Waterfowl and other aquatic wildlife (by observation)

winter ice conditions and measurements of dissolved oxygen concentrations under ice cover.

All data has been tabulated and input to a PC using SYSTAT (a data processing and analysis software package) and various statistical analyses, including determination of means and standard deviations of all parameters, has been carried out.

IV. RESULTS

A. Morphology

Over the course of the summer a bathymetric survey of each site was made. Table 2 lists the general morphometric characteristics of each site. Appendix B presents bathymetric maps of each site and the hypsographic curves used to calculate volumes. Morphologically, with the exception of Perfect and Round lakes, most of the sites are quite different from one another. Surface areas range from 0.35 to 9.15 ha and mean depths from 0.5 to 2.5 m. Three of the sites, Menchon, Perfect and Round, have no obvious inlets or outlets, and only Oscar and Stump have obvious inlets. All have relatively small values for shoreline development which reflects the lack of irregular shapes caused by shoreline indentations and protrusions. Round and Perfect lakes are nearly circular in shape. The percent of surface area above 1 m depth, which provides a measure of the potential for macrophyte development, ranges between 20 and 100 percent and is closely correlated to mean depth.

With the exception of Round Lake, all sites underwent a gradual decrease in depth over the summer (Appendix C). This decrease was considerable ranging between 15 and 25 cm and was greatest for Stump, the shallowest site, and least for Perfect, one of the deeper sites. Water levels at Oscar, the largest site, fluctuated the most. The data for Round Lake suggests this site behaves quite differently than the other sites. Although considerable fluctuation in water level was recorded, the general trend was an increase in water level over the summer. This data may be suspect, however, as there is reason to believe that the metering rod at this site was not securely anchored and may have moved during the study.

B. Drainage Basin Areas and Flushing Rates

Drainage basin areas, lake volumes and flushing rates are presented in Table 3. Flushing rates were calculated assuming an average annual precipitation of 80 cm yr^{-1}. Values ranged from a low of 3.4 to a high of 30.2 times yr^{-1}. The highest rate is for Oscar which is also the largest study site.

Table 2. Morphological characteristics of study sites.

SITE	Surface Area (sq m)	Volume (cu m)	Mean Depth (m)	Maximum Depth (m)	Maximum Breadth (m)	Maximum Length (m)	Mean Breadth (m)	Shoreline Length (m)	Shoreline Develop-ment	Develop-ment of Volume	Rela-tive Depth	Area above 1 m (%)
Oscar	91530.6	56821.5	0.6	1.5	487.5	312.5	187.8	1612.9	1.50	0.41	0.39	97.5
Menchon	30785.6	45587.8	1.5	3.5	286.0	150.2	107.6	871.5	1.40	0.42	1.58	20.0
Harlow	28850.4	58242.5	2.0	5.0	288.6	124.3	100.0	785.7	1.30	0.40	2.33	25.0
Beaver	18283.5	26307.6	1.4	2.5	316.4	91.0	57.8	741.1	1.55	0.58	1.46	25.0
Perfect	11904.5	19449.5	1.6	4.0	163.5	128.7	72.8	513.5	1.33	0.41	2.90	35.0
Jib	7032.4	8011.7	1.1	3.5	127.3	91.8	55.2	360.2	1.21	0.33	3.30	55.0
Round	3577.4	8876.6	2.5	5.0	81.8	56.7	43.7	218.8	1.03	0.50	6.61	25.0
Stump	10317.4	5278.0	0.5	0.7	102.6	130.3	79.4	358.3	0.99	0.78	0.57	100.0

Table 3. Drainage basin areas, volumes and flushing rates.

Site	Drainage Basin Area (m^2)	Volume (m^3)	Flushing Rate (times yr^{-1})
Beaver	588379	26308	17.9
Harlow	217561	58242	3.0
Jib	173195	8012	17.3
Menchon	309486	45588	5.4
Oscar	2144199	56822	30.2
Perfect	254316	19450	10.5
Round	167960	8877	15.1
Stump	22276	5278	3.4

C. Physical Characteristics

1. Temperature and Thermal Stratification

Seasonal temperature profiles reveal that, of the eight study sites, four (Harlow, Perfect, Round and Jib) exhibit significant seasonal thermal stratification of the dimictic type typical of temperate lakes, and that in all cases mixing is holomictic. Figures 3 and 4 present seasonal temperature isopleths for each of these sites. All were weakly stratified at the beginning of the study. The degree of stratification increased into the summer peaking at the time of maximum surface temperature. Stratification then decreased until about mid-October when fall overturn occurred and the lakes became isothermal. Surprizingly, Menchon Lake, which has considerable depth, did not show any sign of becoming stratified. This may be a result of its relatively greater exposure to wind induced mixing.

Surface water temperatures showed the same seasonal trends at all sites (Appendix D). Maximum temperatures occurred during late July and ranged between 25 and 30 C.

During late February all of the sites were covered with about 50 cm of ice and exhibited inverse thermal stratification.

2. Water Transparency

Water transparency was monitored using Secchi disk readings. Additional information on light attenuation is provided by measurements of apparent color, turbidity and suspended particulate matter (Table 4). With the exception of Menchon, which had an average Secchi depth of 2.5 m, most of the sites are characterized by low transparency. Beaver, Oscar and Stump all have average Secchi depths of <1 m and high values of apparent color, turbidity and suspended particulate matter. Perfect, Harlow, Round and Jib are intermediate in transparency with average Secchi depths ranging between 1 and 2 m. It is doubtful that the deeper sites have sufficient light to allow development of submersed benthic macrophytes within the lower parts of their basins. The low transparencies are primarily a result of light attenuation by dissolved organic matter. Most of the sites have relatively low levels of suspended particulate matter and are characterized by the brown water typical of lakes surrounded by drainage basins containing a large proportion of coniferous vegetation.

The outlets of Beaver, Harlow, Jib and Stump tend to be less transparent and have higher suspended particulate matter values than the corresponding central stations.

With the exception of Menchon and Stump, there was a considerable decrease in Secchi depths over the summer at the central sampling stations (Appendix E). This was most evident at

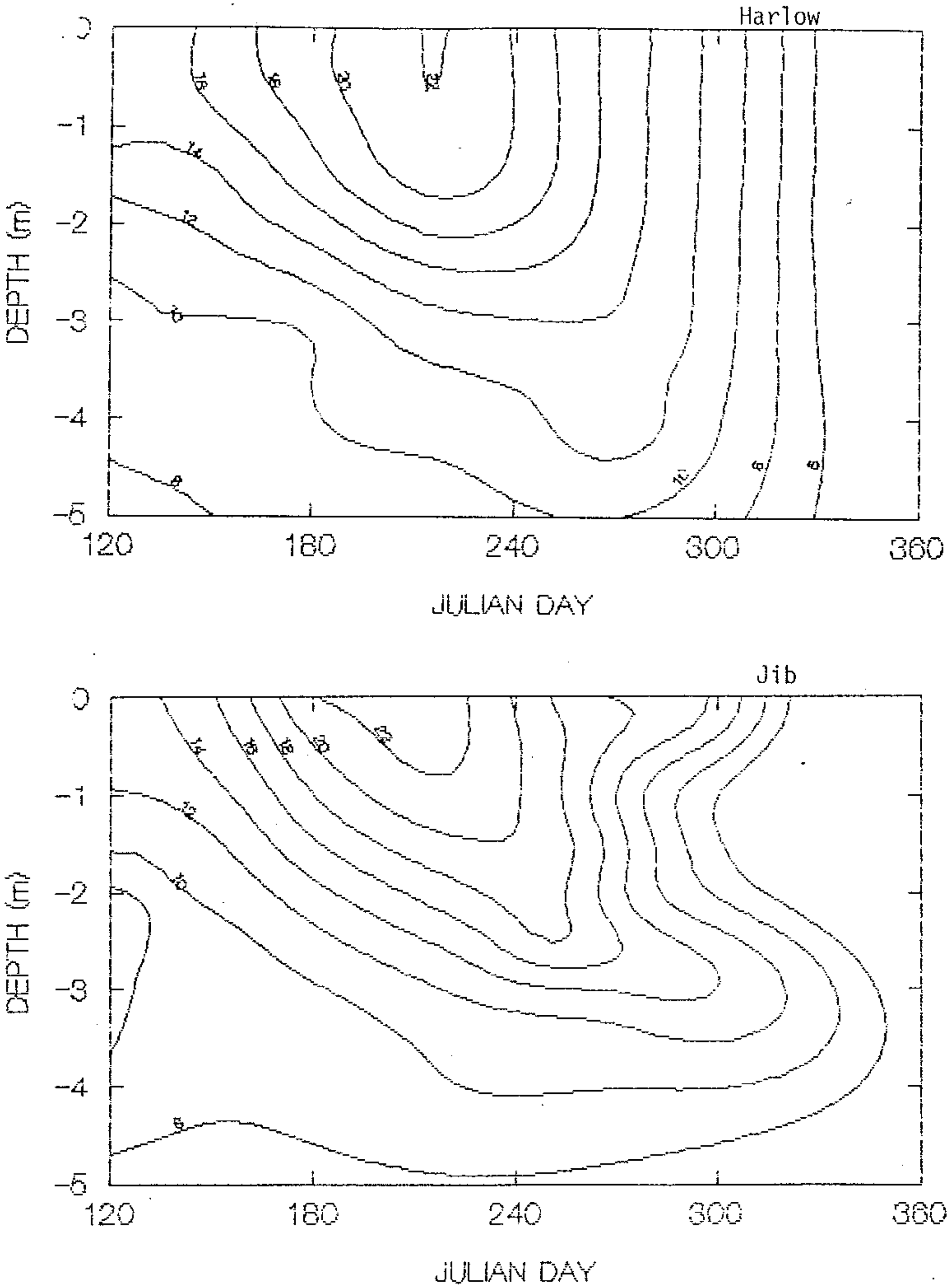


Figure 3. Temperature isopleths (°C) for Harlow and Jib Lakes.

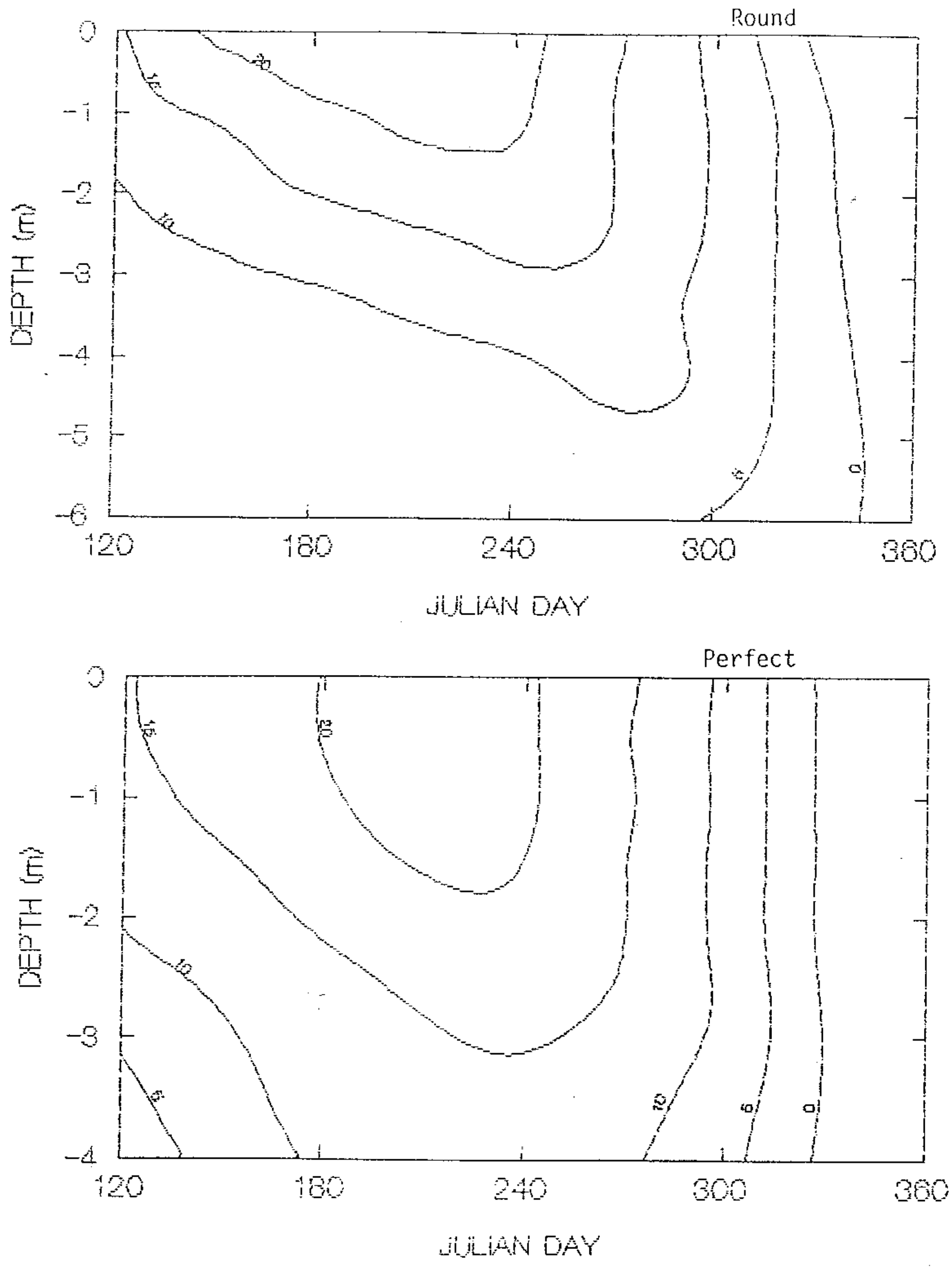


Figure 4. Temperature isopleths (°C) for Round and Perfect Lakes.

Table 4. Mean values of parameters related to water transparency.

Site	Turbidity (JTU's)	Colour (Hazen units) (Apparent)	SPM (mg/l)	Secchi (m)
Beaver(c)	0.72	213.3	2.3	0.6
Beaver(o)	1.90	282.0	5.0	0.4
Harlow(br)	1.03	135.0	-	-
Harlow(c)	1.20	127.0	3.5	1.2
Harlow(o)	0.89	115.7	3.9	0.6
Jib(br)	0.68	102.8	-	-
Jib(c)	0.52	73.7	2.8	1.8
Jib(o)	1.46	74.2	7.9	0.3
Menchon(c)	0.49	6.3	1.2	2.5
Oscar(c)	0.84	152.5	4.0	0.7
Oscar(o)	0.96	140.0	3.9	0.6
Perfect(c)	0.70	92.9	3.5	1.5
Round(c)	0.53	76.6	1.9	1.9
Stump(c)	1.15	105.0	12.3	0.6
Stump(o)	1.87	166.7	-	-

Round where Secchi depth decreased from 3.5 m in the spring to about 1 m by mid-summer.

3. Sediment Types

Although an extensive survey of sediment types within each site was not carried out, some sediment samples were collected in conjunction with determination of sediment phosphorous concentrations. All of the study sites contain sediments composed of a fine brown organic material of the *dy* type which is characteristic of brown-water dystropic lakes. Sediment organic content is relatively high, ranging between 40 and 77 percent, at all sites except Menchon which had a value of only 12 percent (Figure 5). Despite the high organic contents, there was little evidence of strong anaerobic conditions within the sediments at any of the study sites.

D. Chemical Characteristics

1. Conductivity and Hardness

Average values of conductivity and hardness (Table 5) reveal that all of the study sites contain very low salt concentrations. The values are typical of soft-water lakes. Mean values for conductivity ranged between 23.8 and 41.3 uSie cm^{-1}, and total hardness ranged from 1.9 to 8.5 mg $CaCO_3$. With the exception of Beaver and Jib, which showed a gradual increase over the summer, there were no consistent seasonal trends in conductivity (Appendix F). None of the study sites, including those that stratified, showed any evidence of variation in conductivity with depth.

2. Major Cations and Anions

Figures 6 and 7 present bar charts of the major cations and anions for each site. The major cation at all sites is Na^+ which accounts for about half of the total cations. Mg^{++} is second in abundance at all sites except Jib and Stump where it is exceeded by Ca^{++}. The major anion at all sites is Cl^- followed by SO_4^-. HCO_3^- is present in significant amounts only at Jib and Stump, although small amounts are also present at Beaver.

3. pH and Alkalinity

The mean pH and gran-alkalinity values of each study site are presented in Table 5. pH values range from 4.4 to 6.3 and gran-alkalinity from -1.58 to 3.03 mg l^{-1}. All sites have extremely limited buffering capacity. The highest values of both pH and alkalinity were recorded for Jib and Stump. Based on the results of anion content (Figure 7), all of this alkalinity is attributable to bicarbonate as neither carbonate nor hydroxide is present.

There was considerable seasonal variation in pH at most of the sites, but the nature of the variation differed among the sites

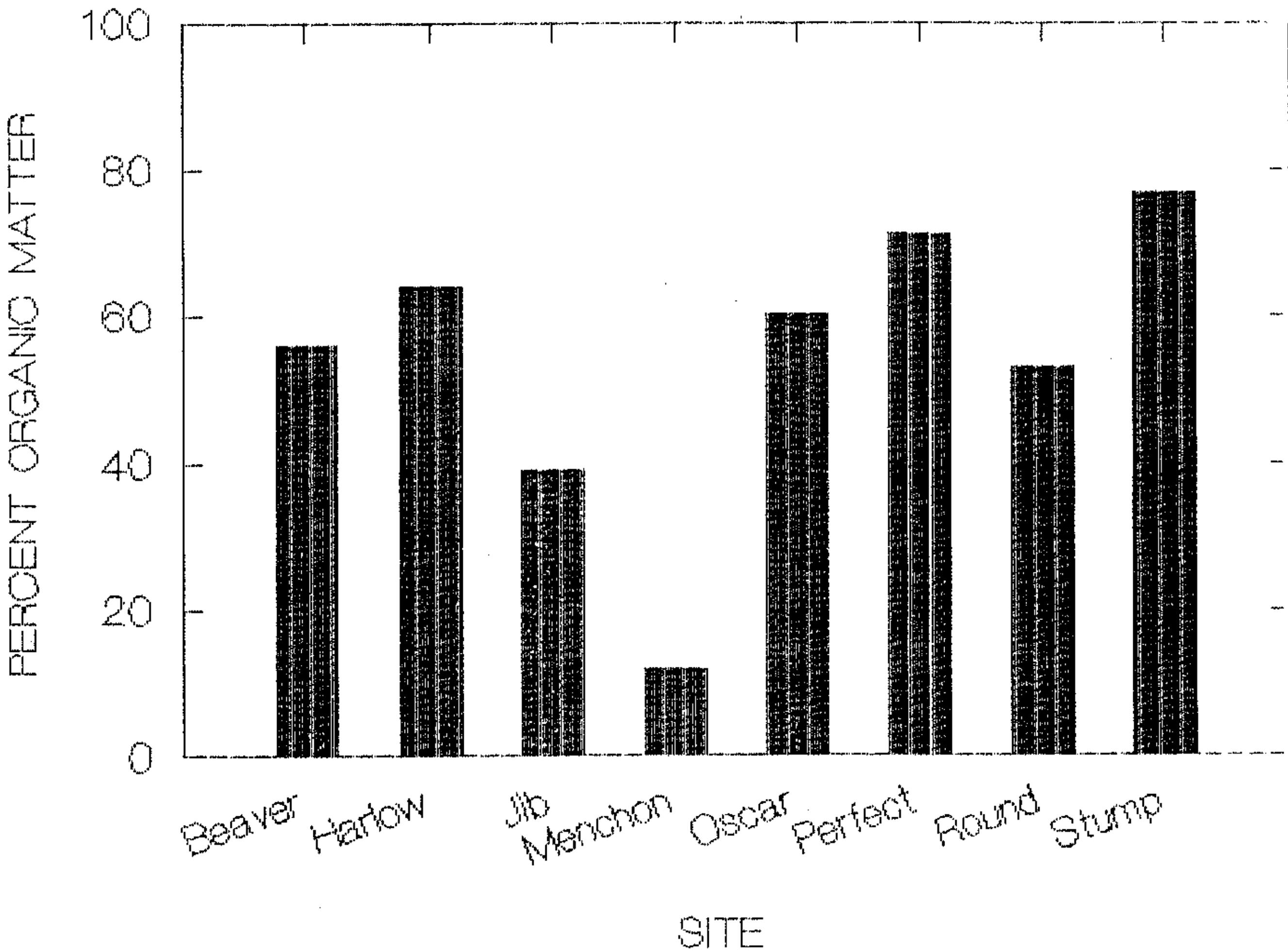


Figure 5. Percent organic matter content of sediments.

Table 5. Mean values of general chemical parameters.

SITE	Conductivity (uSie/cm)	Hardness (mg CaCO3)	pH	Gran-alkalinity (mg/l)
Beaver(c)	41.12	3.70	4.43	-1.58
Beaver(o)	41.32	3.40	4.44	-1.40
Harlow(br)	30.96	5.16	5.25	0.47
Harlow(c)	31.43	2.63	4.57	-1.07
Harlow(o)	31.34	2.50	4.56	-1.16
Jib(br)	35.99	7.57	5.91	1.10
Jib(c)	33.61	6.52	6.21	2.40
Jib(o)	37.24	8.48	6.31	3.03
Menchon(c)	23.76	1.85	5.03	-0.29
Oscar(c)	31.39	2.18	4.54	-1.04
Oscar(o)	29.86	1.67	4.50	-1.10
Perfect(c)	27.93	2.61	4.77	-0.33
Round(c)	31.02	2.82	4.77	-0.58
Stump(c)	25.85	4.60	5.77	2.18
Stump(o)	27.67	4.23	5.67	2.60

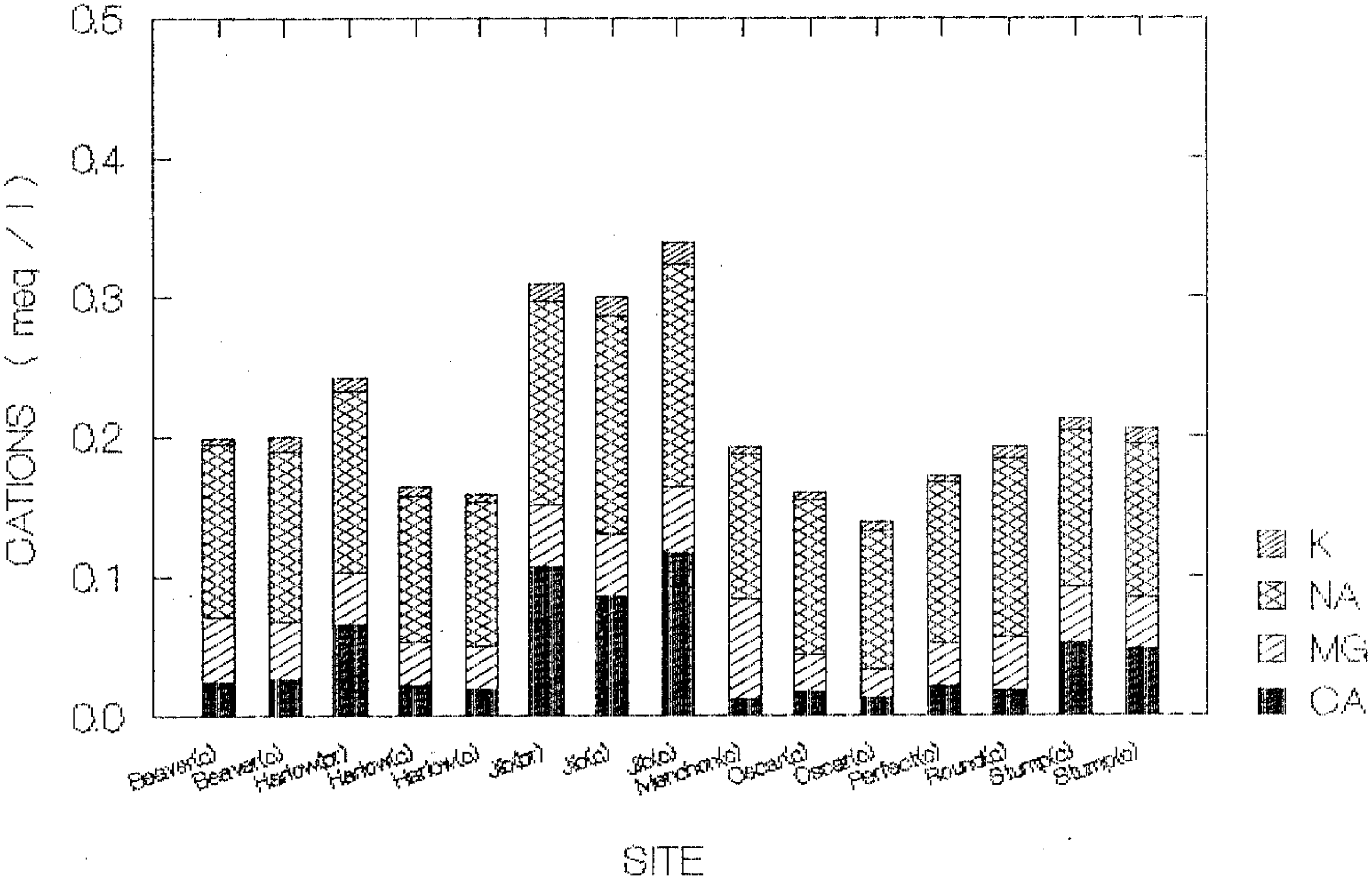


Figure 6. Mean values of major cations at each site.

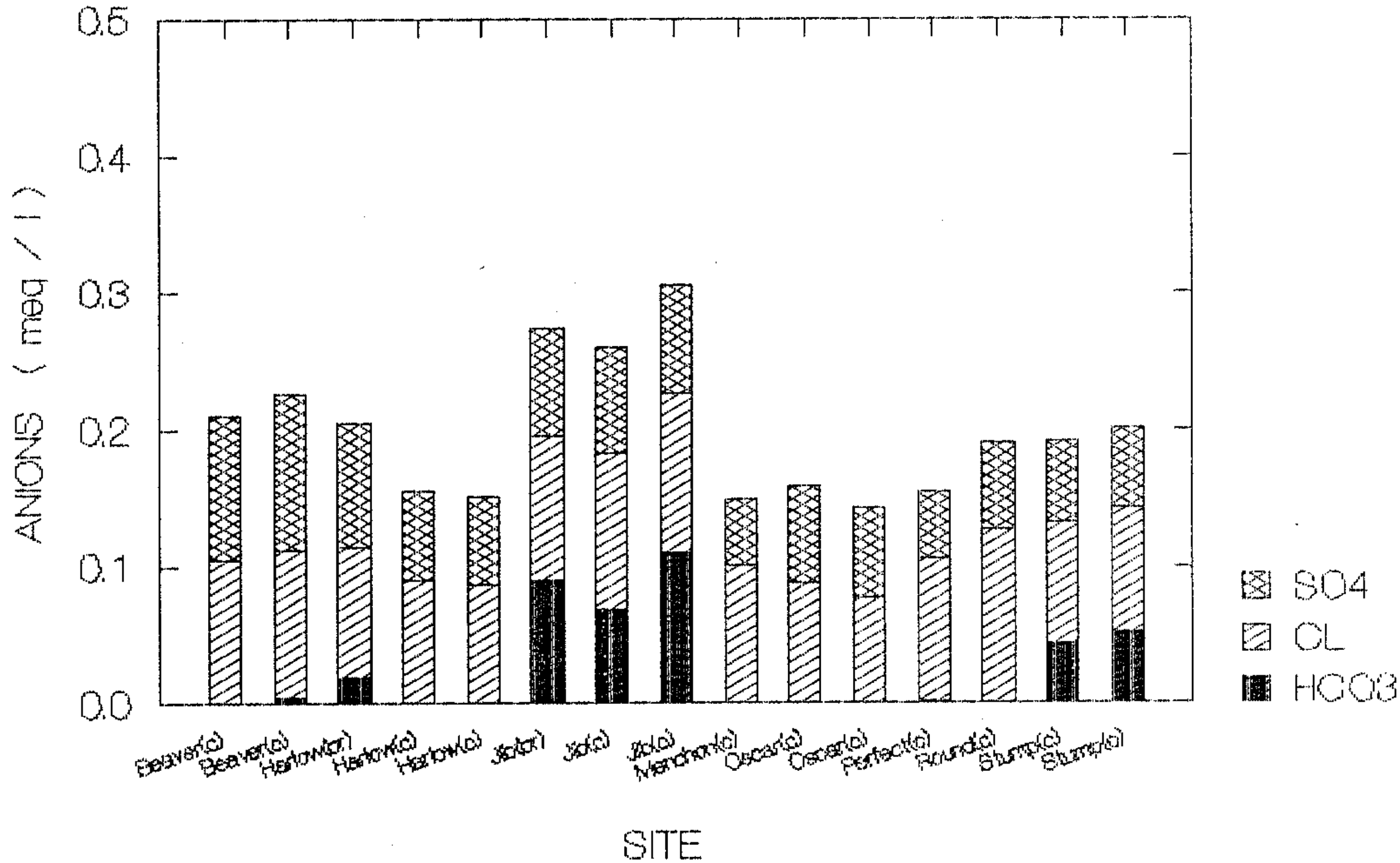


Figure 7. Mean values of major anions at each site.

(Appendix G). Jib, Oscar and Stump showed the least seasonal variation. The remaining sites showed an initial rapid increase during June, which may represent recovery from spring pH shock often observed and associated with snow melt. This was followed by a gradual decrease in pH over the summer.

4. Dissolved Oxygen

Water samples for determination of dissolved oxygen concentration were taken from the surface at all sites, and from the bottom at those sites having depths greater than 1 m. The values of surface samples varied between 4.9 and 8.9 mg l^{-1} with percent saturation ranging from 40.7 to 89.9. At three of the study sites (Harlow, Jib and Perfect) bottom oxygen concentration decreased to very low levels during the summer (Appendix H). These are also the sites that exhibit strong thermal stratification. Jib became the most strongly anaerobic having reached zero percent saturation by the end of June and remaining anaerobic until late August. Perfect became completely anaerobic at mid-July but this lasted for only a short while. A similar trend with maximum depletion of oxygen occurring during early August was exhibited by Harlow, but this system never became completely anaerobic. Round was particularly unusual in that although it stratified and showed a gradual decline in oxygen throughout the summer, its bottom waters never exhibited less than about 30 percent stratification.

A winter site visit during late February revealed surface dissolved oxygen concentrations ranging between 5.9 and 10.7 mg l^{-1} and percent saturation values of 40 to 78. Bottom dissolved oxygen concentrations ranged between 1.7 and 8.7 mg l^{-1} and saturation values between 12 and 65 percent (Figure 8). The lowest values were recorded at Perfect. These values indicate that, with the possible exception of Perfect, it is unlikely any of the study sites become anaerobic under conditions of winter ice cover.

5. Nutrients

The concentration of phosphorous is generally low at all sites at all times. Average values for total phosphorous (Figure 9) are generally <10 μg l^{-1} and fall within the range typical of oligotrophic systems. Only at the outlet of Beaver did total phosphorous appear to be significantly greater than at other sites.

Sediment phosphorous concentrations were also low (Figure 10) at all sites. There appears to be a good relationship between sediment phosphorous levels and total phosphate within the water column. Most of the sediment phosphorous is in the form of organic phosphorous suggesting that most of the available phosphorous in these systems is involved in biological cycling processes.

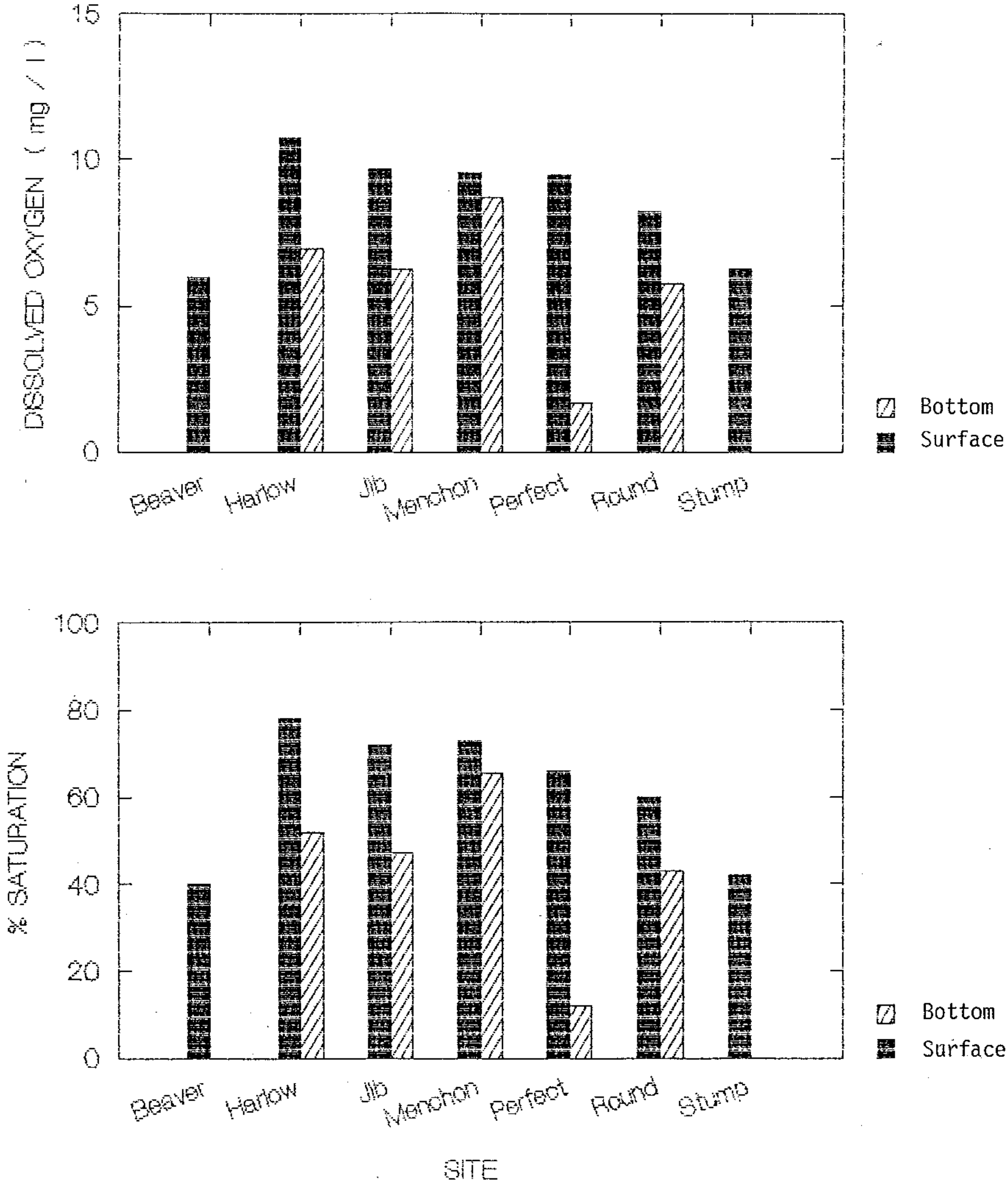


Figure 8. Dissolved oxygen concentrations and percent saturation during winter ice cover.

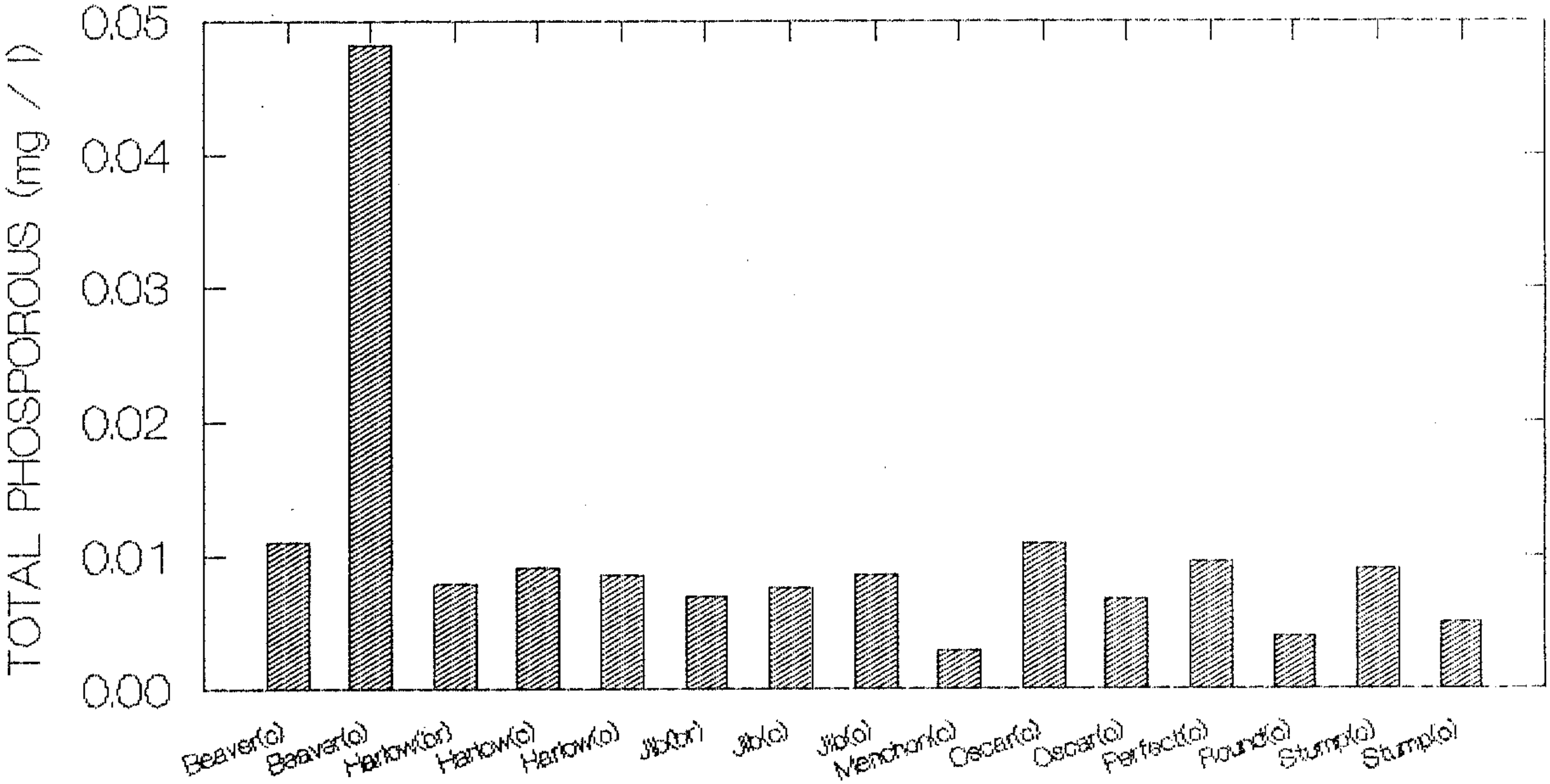


Figure 9. Mean values of total phosphorus at each site.

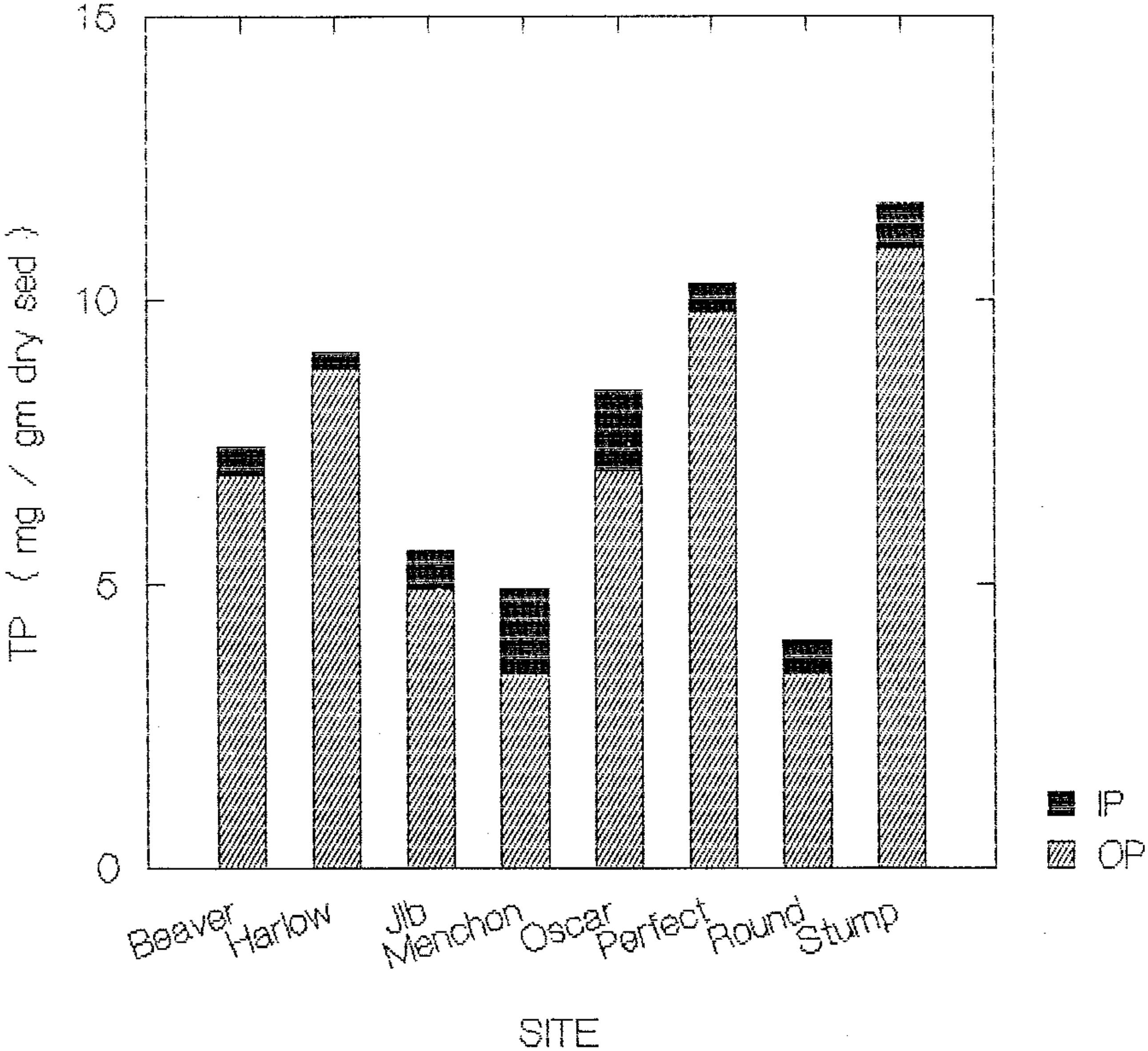


Figure 10. Sediment phosphorus concentrations at each site.

Total nitrogen values are also low, generally <0.5 mg l^{-1} (Figure 11). Most of the nitrogen is present as particulate as opposed to dissolved nitrogen. Mean values of N:P ratios ranged from 7.5 to 86.0 (Figure 12). The outlet at Beaver had the lowest value as a result of the exceptionally high phosphorous concentrations measured there. The highest value was recorded for the outlet at Stump and is a result of the high nitrogen concentrations measured there. The remaining N:P values fall in the range of 20 to 40. It is often assumed that nitrogen becomes limiting when N:P ratios fall below about 20. Five of the study sites, Beaver, Harlow, Jib, Oscar and Perfect, have N:P ratios very close to 20 suggesting that both nitrogen and phosphorous are limiting in these systems.

Silicate concentrations ranged from 0.3 to 4.7 mg l^{-1} (Figure 13). These values are quite high with regard to the nutrient requirements of phytoplankon and may be a reflection of the high humic content of these systems (humic acids are thought to enhance the solubility of silicon).

E. Biological Characteristics

1. Macrophytes

A survey to determine the species composition and relative abundance of the major macrophytes at each study site was conducted during early September. The results are presented as a series of maps (Appendix I).

There is considerable diversity in macrophytes, in terms of both species and abundance, among the study sites. Sixteen species of macrophytes were identified as being fairly common. Table 6 lists the major macrophytes present at each site. The most widely distributed macrophytes are *Nuphar variegatum* and *Nymphaea odorata* which were present at six of the study sites. The least common species were *Lobelia dortmata, Eliocharis robbinsii, Rhyncospora alba, R. capiteellata* and *Sparganium americum,* each of which occurred at only one site. The least macrophyte diversity was at Beaver which is densely colonized by *Sphagnum* sp. The greatest diversity occurs at Menchon and Oscar.

Figure 14 presents the abundance, in terms of percent of lake surface area covered, of emergent, floating leaved and submerged macrophytes at each study site. The abundance of all groups is closely related to mean depth and is greatest at Oscar and Stump, the shallowest sites. Submerged macrophytes are greatest in abundance at Beaver and Menchon. Beaver, as mentioned previously is heavily colonized by *Sphagnum*. The high abundance of submerged macrophytes at Menchon is due largely to its high transparency and a large portion of its benthos is covered by *Utricularia vulgaris*. Most of the other sites lack the water clarity required to support submerged macrophytes.

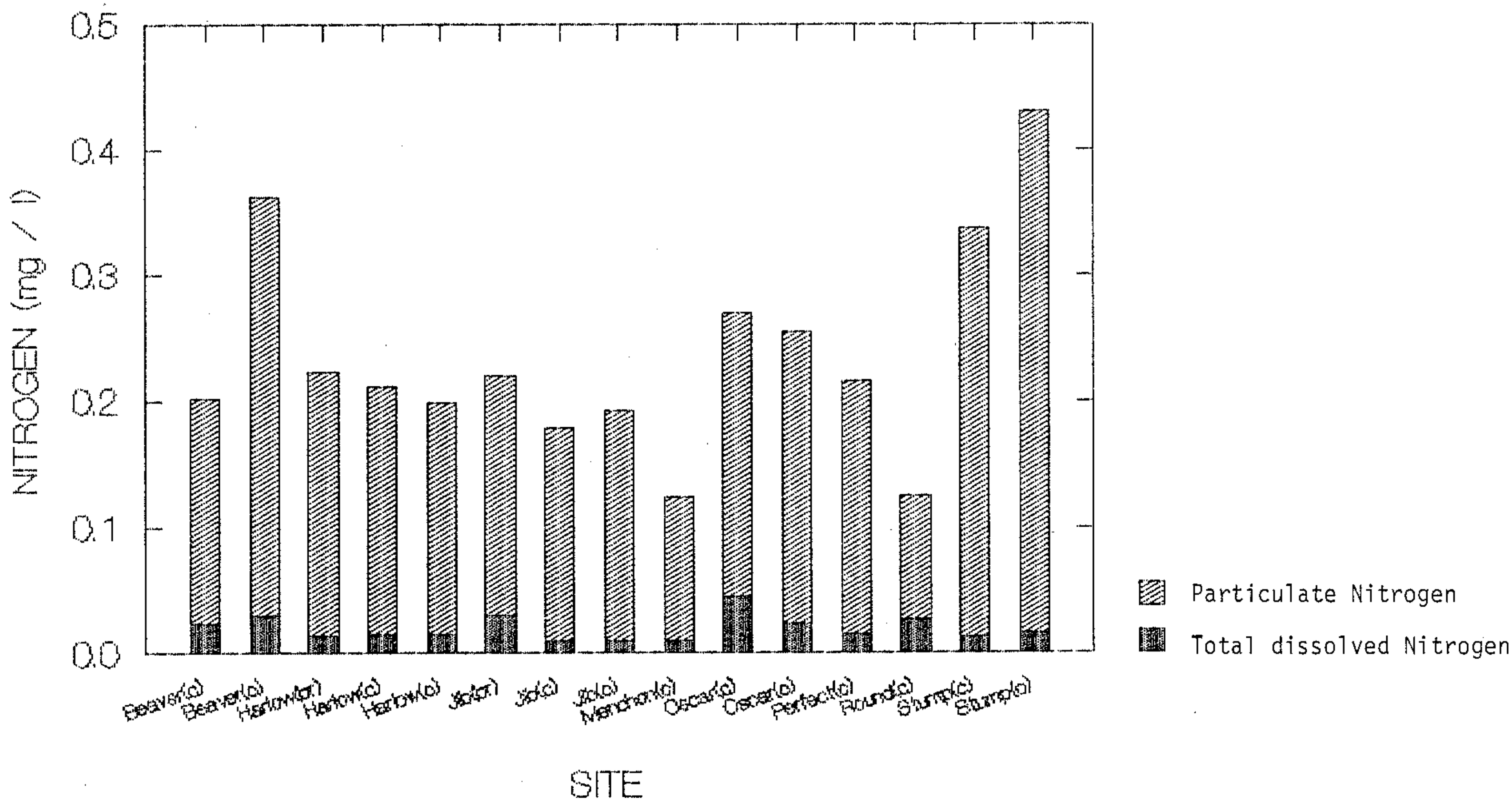


Figure 11. Mean nitrogen values at each site.

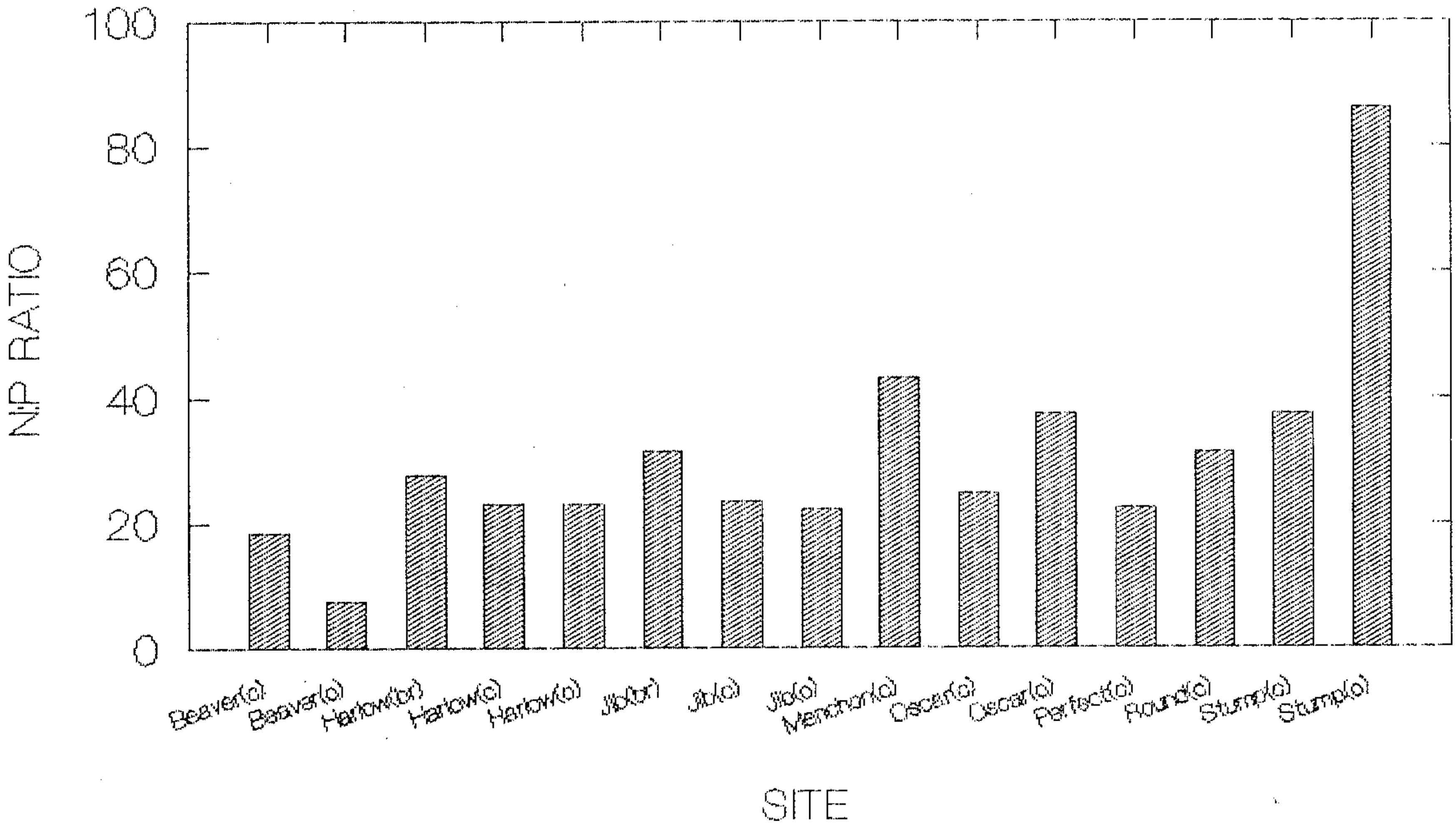


Figure 12. Mean N:P values at each site.

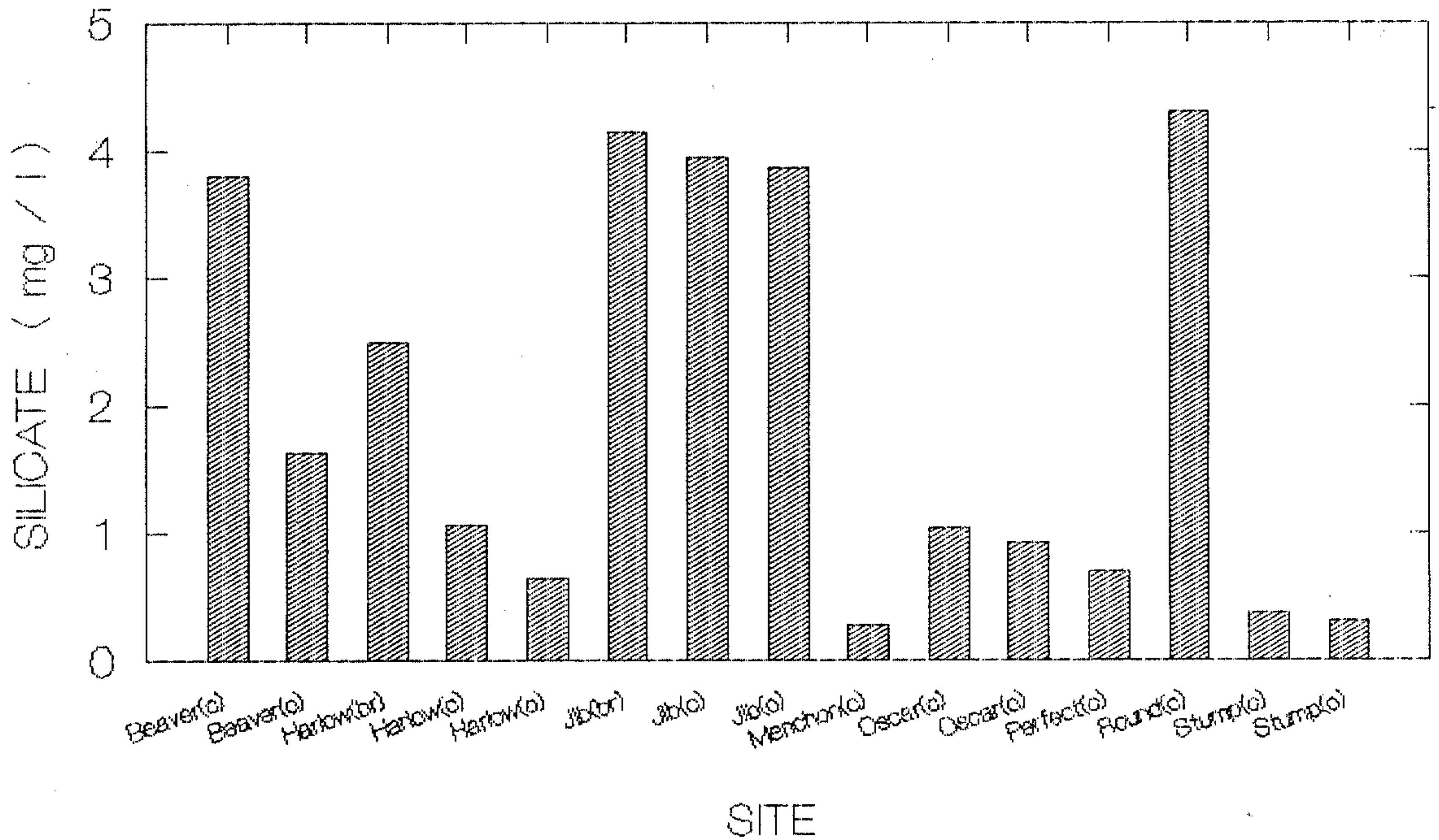


Figure 13. Mean silicate concentrations at each site.

Table 6. Major macrophytes at each site.

	BEAVER	HARLOW	MENCHON	JIB	OSCAR	PERFECT	ROUND	STUMP
Scirpus subterminalis				x	x	x		x
Sphagnum sp.	x							
Utricularia vulgaris	x		x				x	
Brasenia schreberi					x			
Eriocaulon septangulare			x			x		
Lobelia dortmata			x					
Nuphar variegatum		x	x	x	x	x	x	
Nymphaea odorata			x	x	x	x	x	x
Carex sp.							x	
Eliocharis robbinsii				x				
Juncus canadensis					x	x		
Juncus militaris					x			
Pontederia cordata		x	x	x				x
Rhyncospora alba							x	
Rhyncospora capitellata							x	
Sparganium americum								x

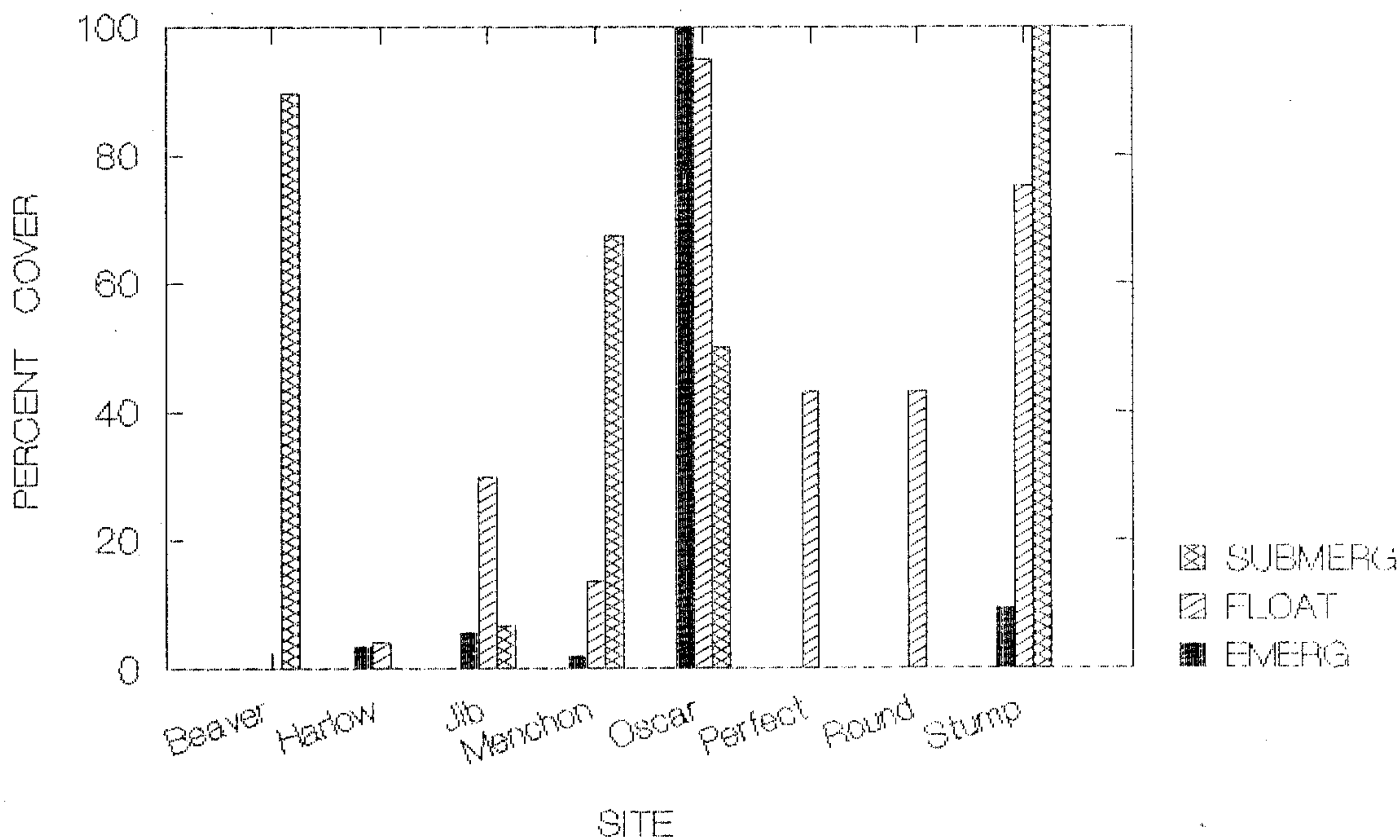


Figure 14. Percent cover of major macrophyte groups.

2. Significant Plants

The southwestern portion of Nova Scotia, including the general area of the TWMA, has been identified as a region in which a distinctive and rare plant community, commonly referred to as the Atlantic coastal plain flora, occurs. Many of the plants making up this community are considered to be rare or endangered species, and there is concern that alteration of wetland habitats, particularly infertile wetlands where many of these species occur most commonly, poses a serious threat to their preservation. It therefore became important to determine if any of the study sites contained plant communities of this type and throughout the course of the study routine observations were made to document the plant species occurring along the shoreline of each of the study sites.

Table 7 lists plant species collected within and around each of the study sites that may be considered as being significant. None of the study sites appear to contain species that are typical of the more rare coastal plain flora. This is not surprizing since the preferred habitat of the coastal plain flora is considered to be gently sloping sand and gravel beaches. Without exception, all of the study sites have steep shorelines and organic substrates.

3. Phytoplankton

Although phytoplankton samples for species composition were collected routinely at all of the study sites, these have not been completely analyzed. This analysis is the subject of a student specials problems project and will be reported on at a later time.

Mean phytoplankton chlorophyll *a* and phaeophytin values for each study site are presented in Figure 15. Mean chlorophyll *a* concentrations at the centre stations ranged from a low of 0.6 $\mu g\ l^{-1}$ to a high of 3.6 $\mu g\ l^{-1}$. The lowest values were recorded for Beaver and Menchon and the highest for Perfect and Stump. The highest value was recorded at the outlet of Harlow. This may be a result of benthic algae having been resuspended into the water column while samples were being taken at the shallow outlets. The high suspended particulate matter concentrations typical of the outlet stations support this possibility.

At Menchon chlorophyll *a* and phaeophytin concentrations were about equal, but at all other sites phaeophytin concentrations were about twice chlorophyll *a* concentrations. The low ratio of chlorophyll *a* to phaeophytin indicates that a large proportion of the plant pigments are in a degraded form and suggests the presence of a relatively unhealthy phytoplankton population, particularly as a result of nutrient limitation.

Although most of the study sites exhibited seasonal peaks in chlorophyll a levels, the trends were not consistent (Appendix J). None of the study sites, including those that stratified, exhibited seasonal peaks of the type characteristic of lakes

Table 7. Significant plant species at each study site.

	BEAVER	HARLOW	MENCHON	JIB	OSCAR	PERFECT	ROUND	STUMP
Calopogon pulchellus				x	x	x		
Cyprepidium acaule					x			
Decodon verticillates	x					x	x	
Eriocaulon septangulare		x	x	x	x			
Habenaria blephariglottis					x	x		x
Hypericum virginicum		x		x	x			
Lobelia Dortmanna			x					

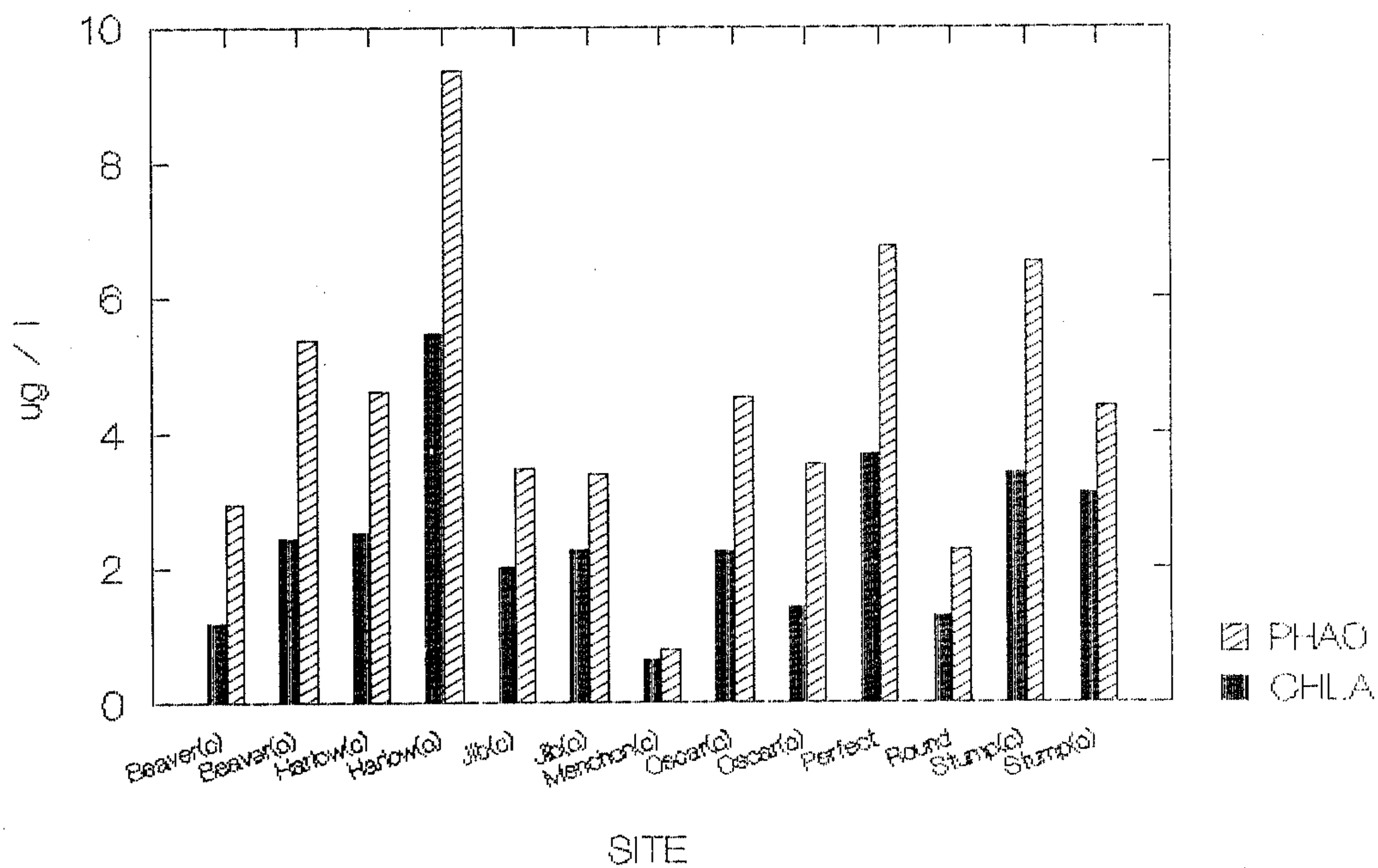


Figure 15. Mean chlorophyll a and phaeophytin concentrations at each site.

having a spring and fall phytoplankton bloom. The most common seasonal trend was a mid-summer peak.

4. Periphyton

Estimates of the potential for periphyton growth at each study site were obtained by measuring the rate of colonization of periphyton on glass microscope slides suspended in the water column above the littoral zone. The results, expressed as mean µg chlorophyll *a* slide^{-1} month^{-1}, are presented in Figure 16. The highest rates, measured at Jib, Round and Stump, were considerably greater than those measured at the other sites which differed little from one another. There does not appear to be any clear relationship between the rate of periphyton growth and the level of phytoplankton chlorophyll *a* at the central stations.

5. Zooplankton

Mean zooplankton numbers over the sampling period were generally low at all sites ranging between about 5 and 35 individuals per litre (Figure 17). Zooplankton were most abundant at Oscar and least abundant at Menchon. With the exception of the unusually high numbers at Oscar, zooplankton abundance shows a strong relationship with mean chlorophyll *a* concentration.

There is considerable diversity among sites in the composition of the zooplankton community. Cladocerans dominated the adult zooplankton at all sites except Jib, Menchon and Perfect. Jib and Menchon were dominated by calanoid copepods and at Perfect rotifers were the dominant adult group. Cyclopoid copepods constituted only a small proportion of the zooplankton at all sites and rotifers were present in very small numbers at Beaver, Menchon and Stump. Although immature copepods were present at all sites, they were particularly abundant at Jib and Perfect.

6. Emergent Insects

The emergent insect samples were dominated by dipterans at all sites except Round, which had greater numbers of coleopterans, and Beaver, which had about equal numbers of hemipterans (Figure 18). Most other insect groups were present in only small numbers. Of the dipterans, most were chironimids, although at Menchon and Stump significant numbers of ceratopognids and chaoborids, respectively, were recorded (Figure 19). Numbers of other insect groups recorded from emergent trap samples are presented in Figures 20 and 21.

At each site there was a strong seasonal variation in the number of insects collected (Appendix K). Most sites had a peaks during June and August. Emergence was exceptionally strong at Menchon during late August. This one event is responsible for the large mean value shown by Menchon in Figure 18.

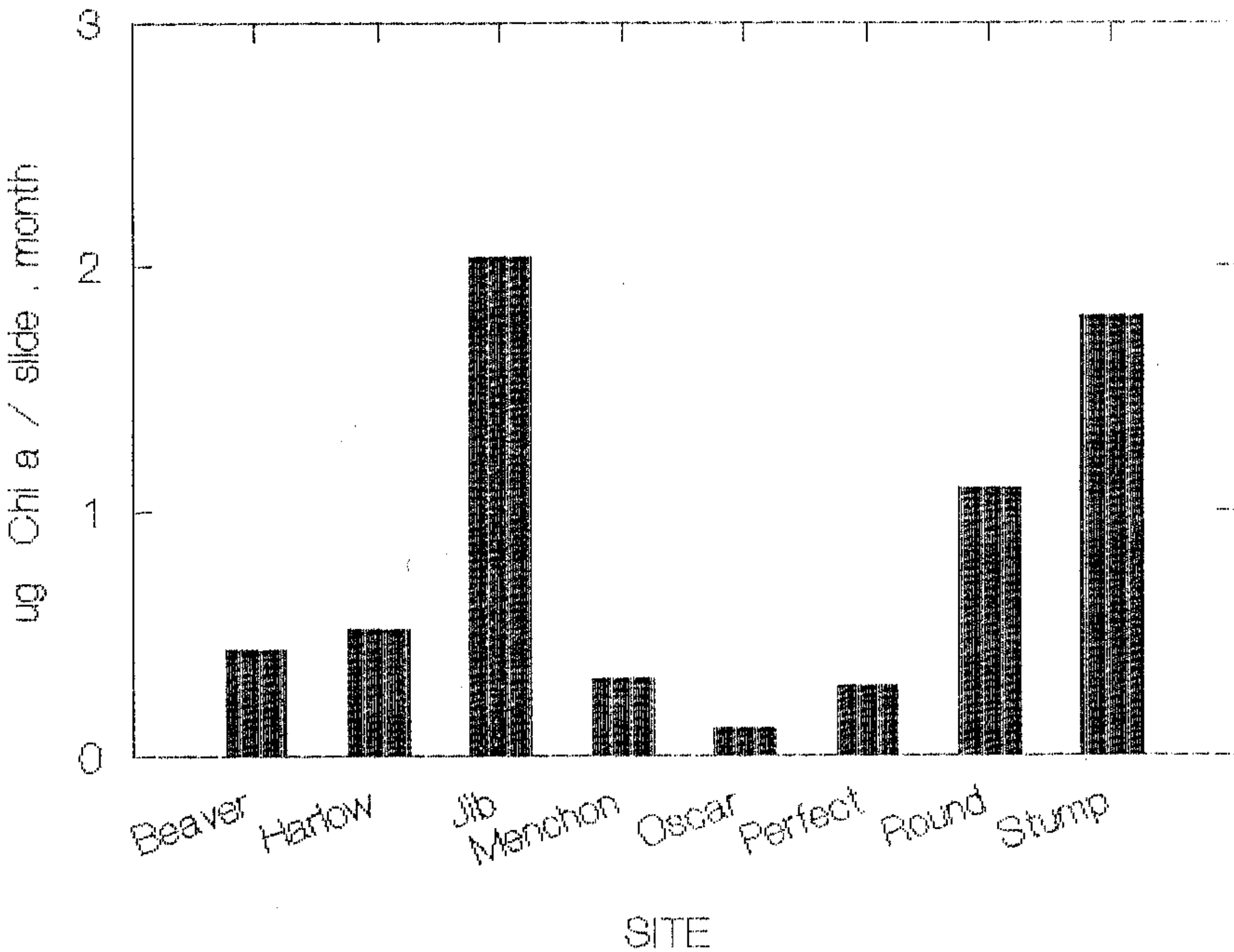


Figure 16. Mean monthly periphyton growth at each site.

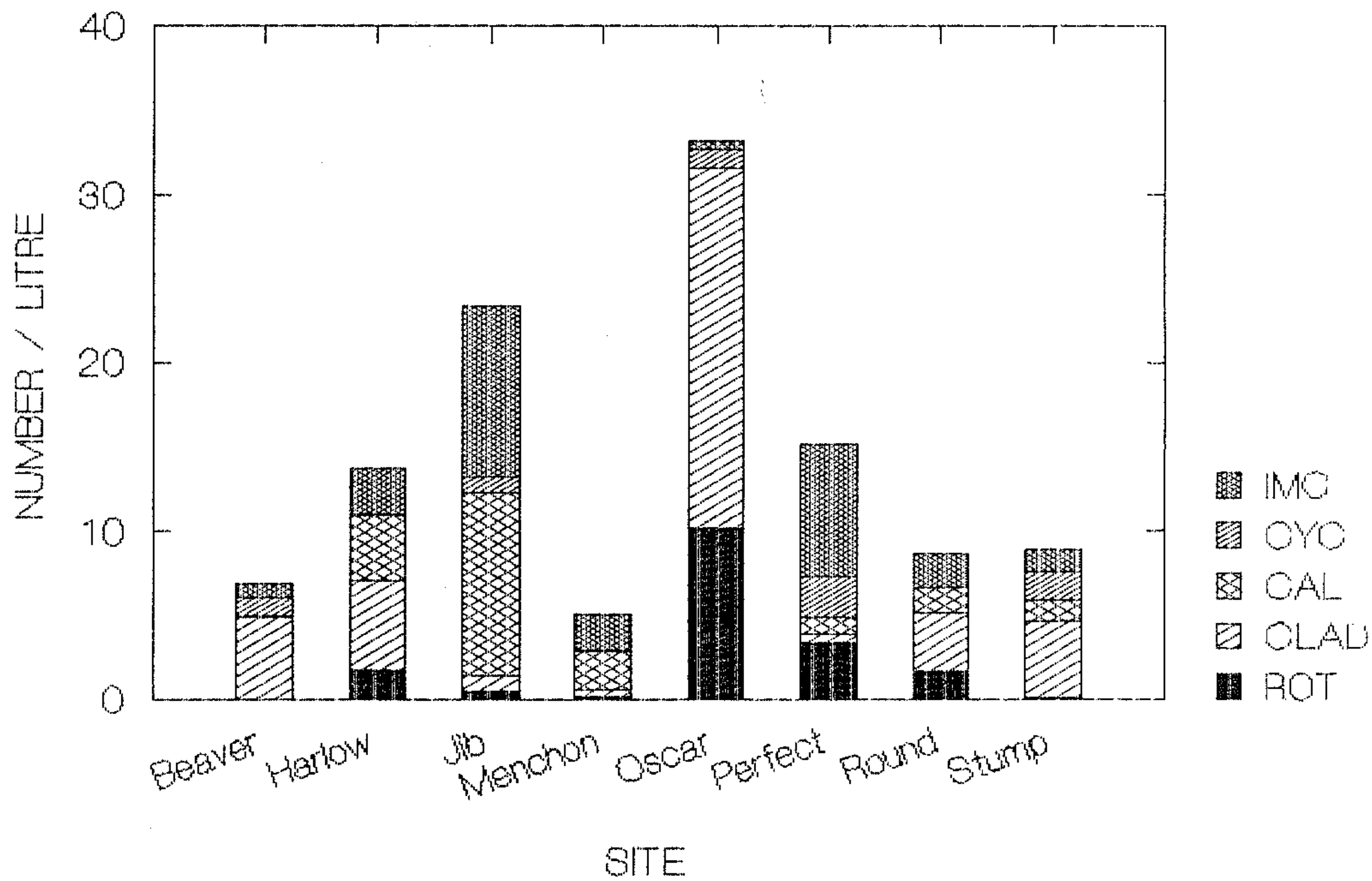


Figure 17. Mean zooplankton numbers and composition at each site.

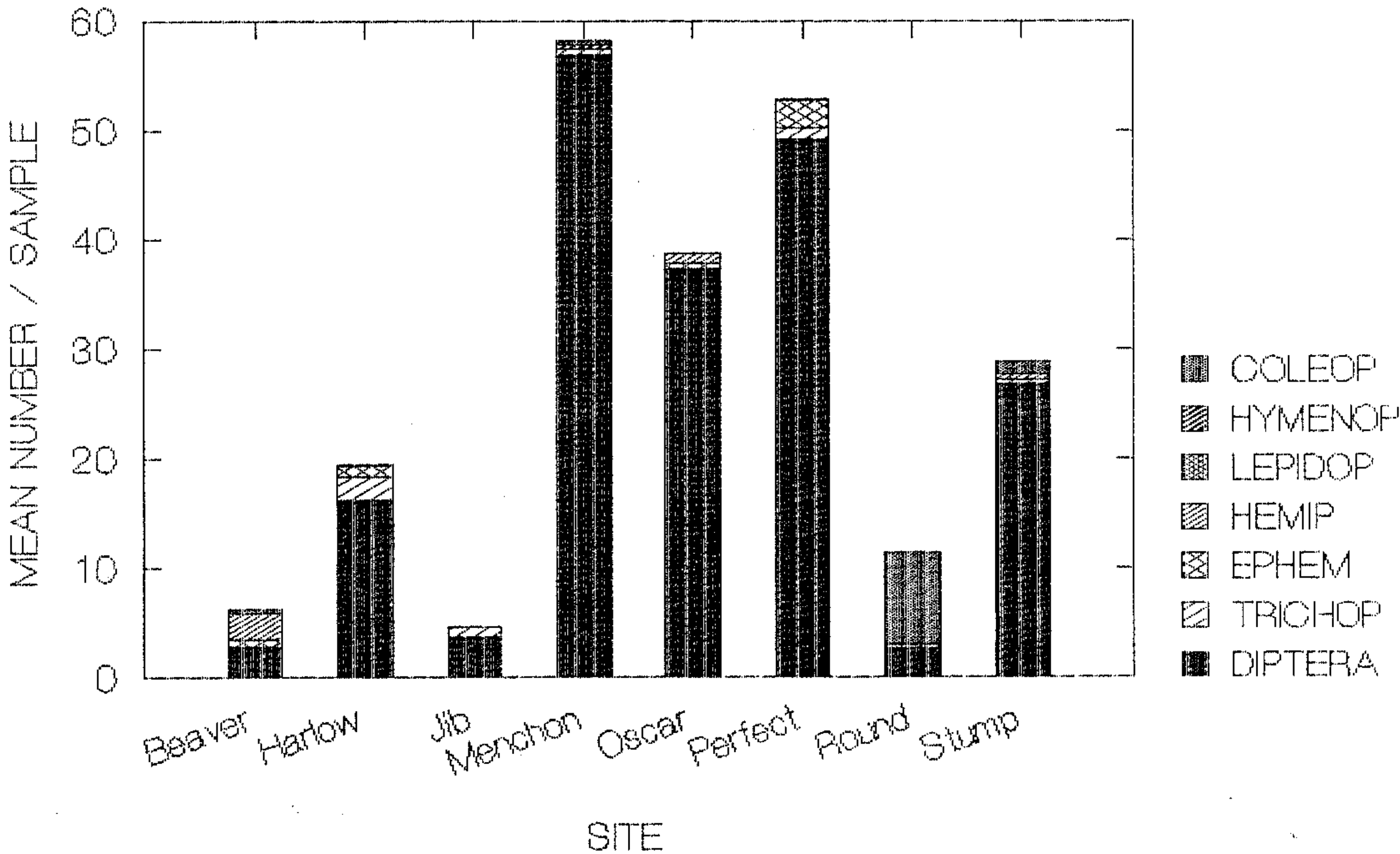


Figure 18. Mean number of insects collected in emergence traps.

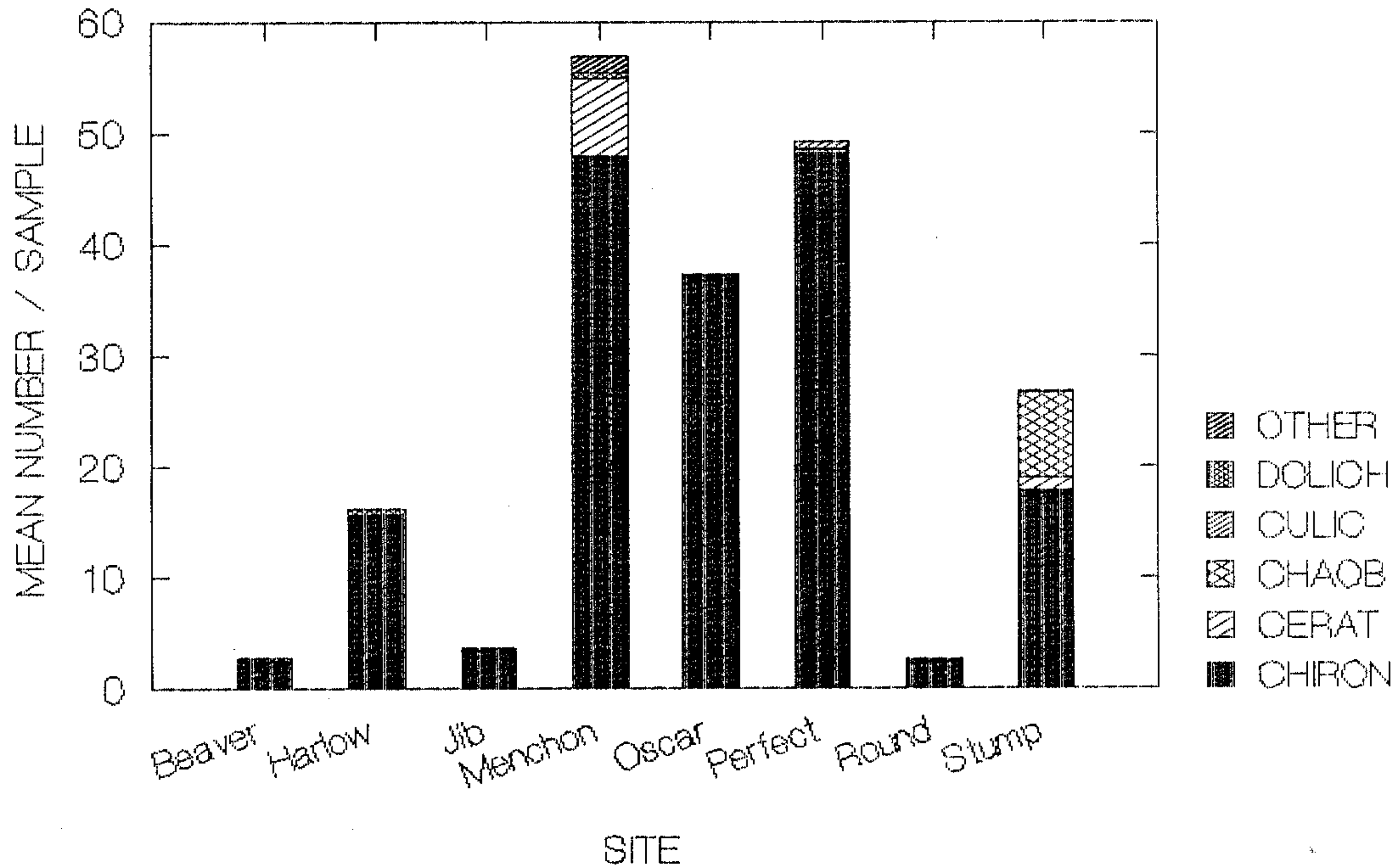


Figure 19. Mean number of dipterans collected in emergence traps at each site.

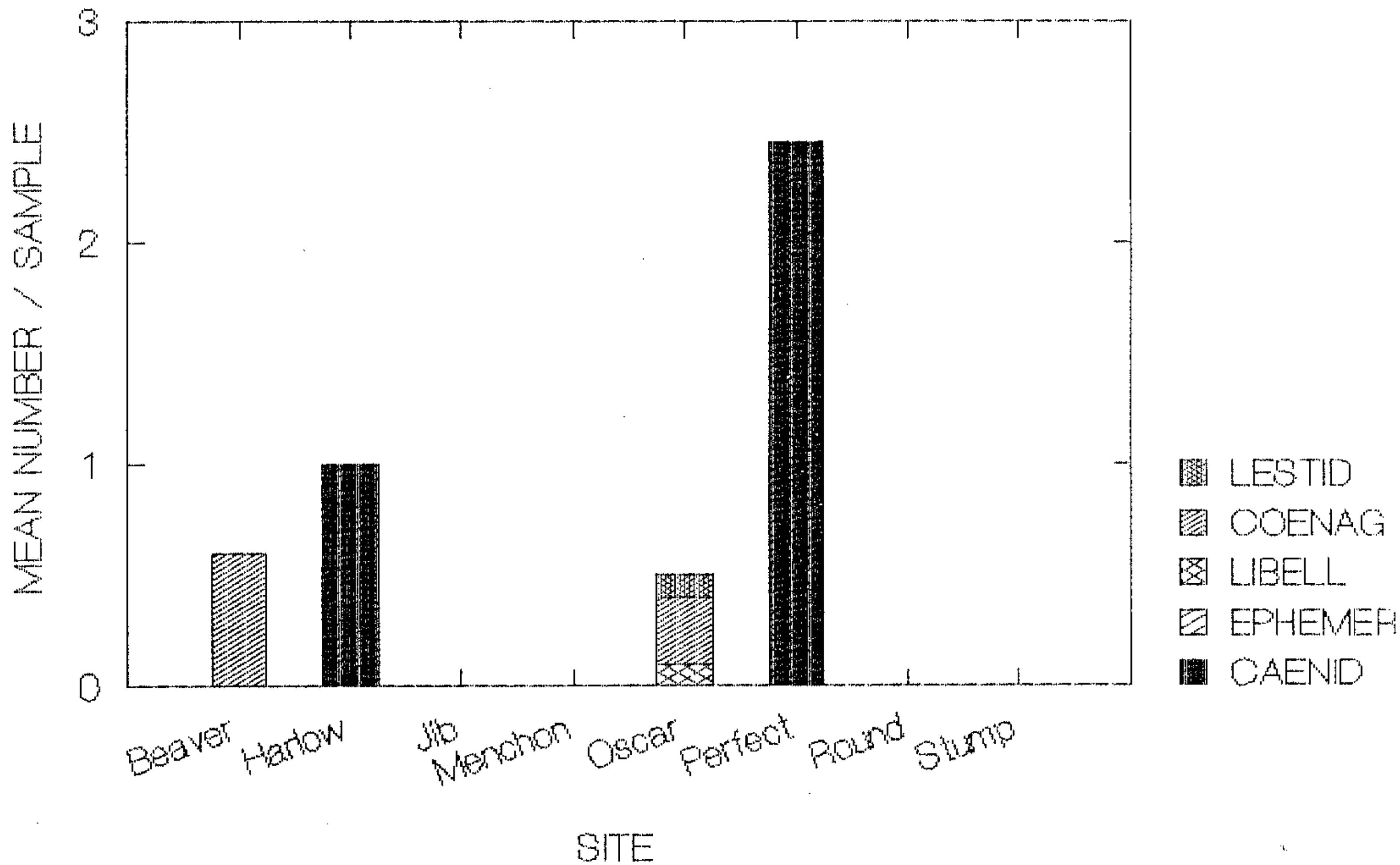


Figure 20. Mean number of ephemeropterans collected in emergence traps at each site.

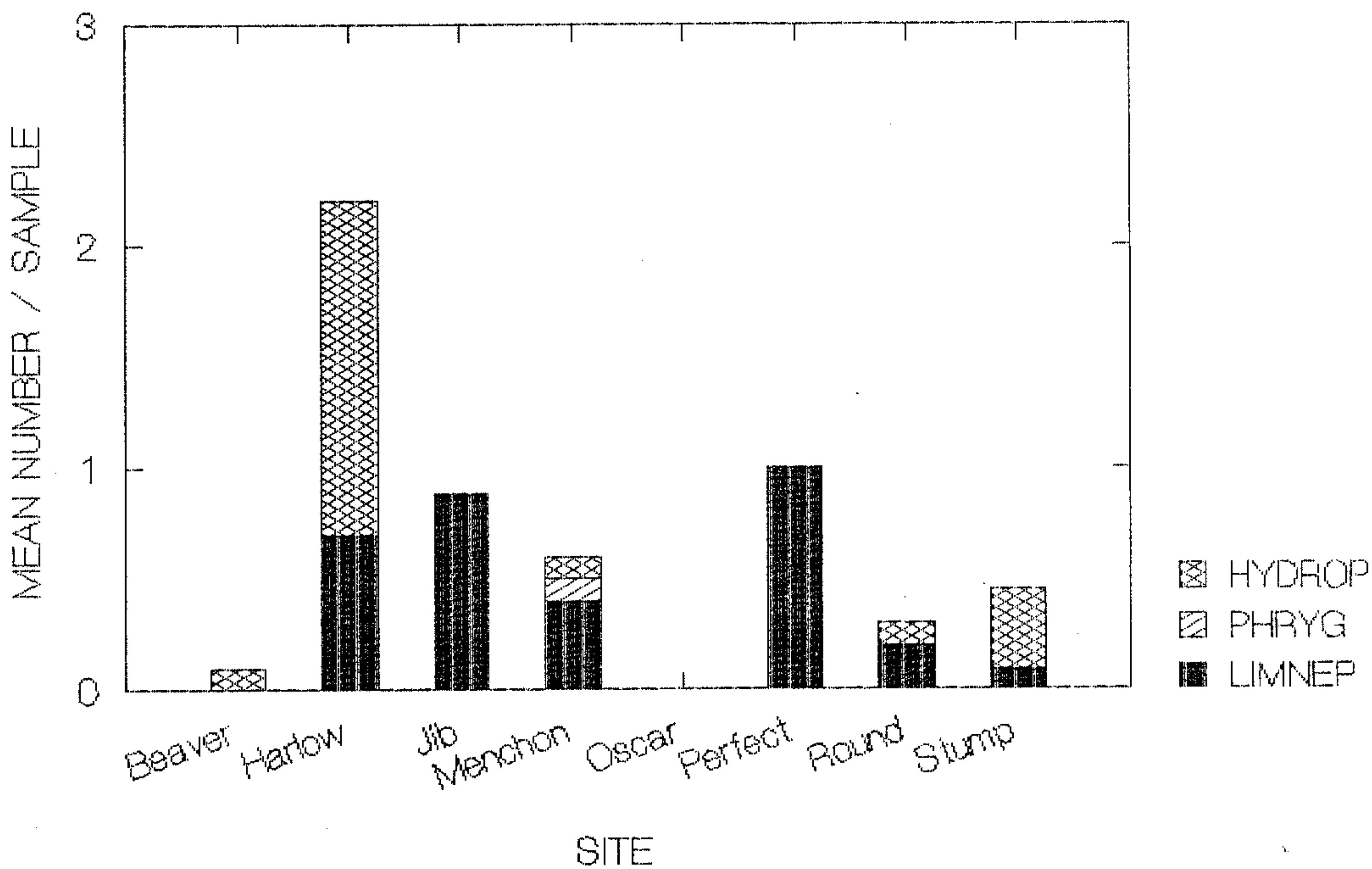


Figure 21. Mean number of trichopterans collected fin emergence traps at each site.

7. Benthic Invertebrates

The major groups of benthic invertebrates collected in benthic sweep samples included crustaceans, molluscs, insects and mites. At all sites except Jib the samples were dominated by insects (Figure 22). At Jib, crustaceans were the most abundant group and the numbers of insects collected per sample were about equal to the number of mollusks. Significant numbers of mollusks were also recorded from Stump, but at the other sites they were either totally absent, or if present were found at very low densities. Mites were most abundant at Perfect, but even here the numbers were very low.

Benthic crustacean numbers and species composition varied considerably among sites (Figure 23). At Jib, Menchon and Round amphipods greatly exceeded isopods, and at Harlow and Perfect isopods exceeded amphipods. The remaining sites, Beaver, Oscar and Stump, had very low numbers of both groups.

The major mollusk group at both Jib and Stump was a bivalve, *Sphaeridium* sp. The other mollusk groups, all gastropods, occurred in about equal numbers (Figure 24). Small numbers of *Lymnae* sp. occurred at Beaver, and small numbers of *Planoba* sp. occurred at Menchon.

The numbers and composition of benthic insects collected at each site are generally in good agreement with that recorded from the insect emergence traps. The most abundant group at all sites was the dipterans (Figure 25). The highest numbers were recorded at Perfect and the lowest numbers at Jib. Odonates were generally second in abundance although at Harlow tricopterans were present in greater numbers.

8. Minnow Trap Collections

The minnow traps collected a diversity of organisms. Aside from small fish, amphibians, and some of the larger aquatic insects, were also collected. Figure 26 presents the total number of each major group of organisms collected at each study site over the entire study period.

Fish were recorded from minnow trap collections at all sites except Beaver, Menchon and Oscar (Figure 27). The greatest number of fish were collected at Perfect and these consisted mainly of catfish (*Ictalurus nebulosus*). Harlow and Jib also had relatively large numbers of fish. These were mainly yellow perch (*Perca flavescens*) but catfish were also present. At Round, only catfish were collected. Eels (*Anguilla rostrata*) were present at both Jib and Stump, but were absent in collections from other sites. Killifish (*Fundulus diaphanus*) were found only at Harlow and sticklebacks (*Pungitius pungitius*) only at Perfect and Stump.

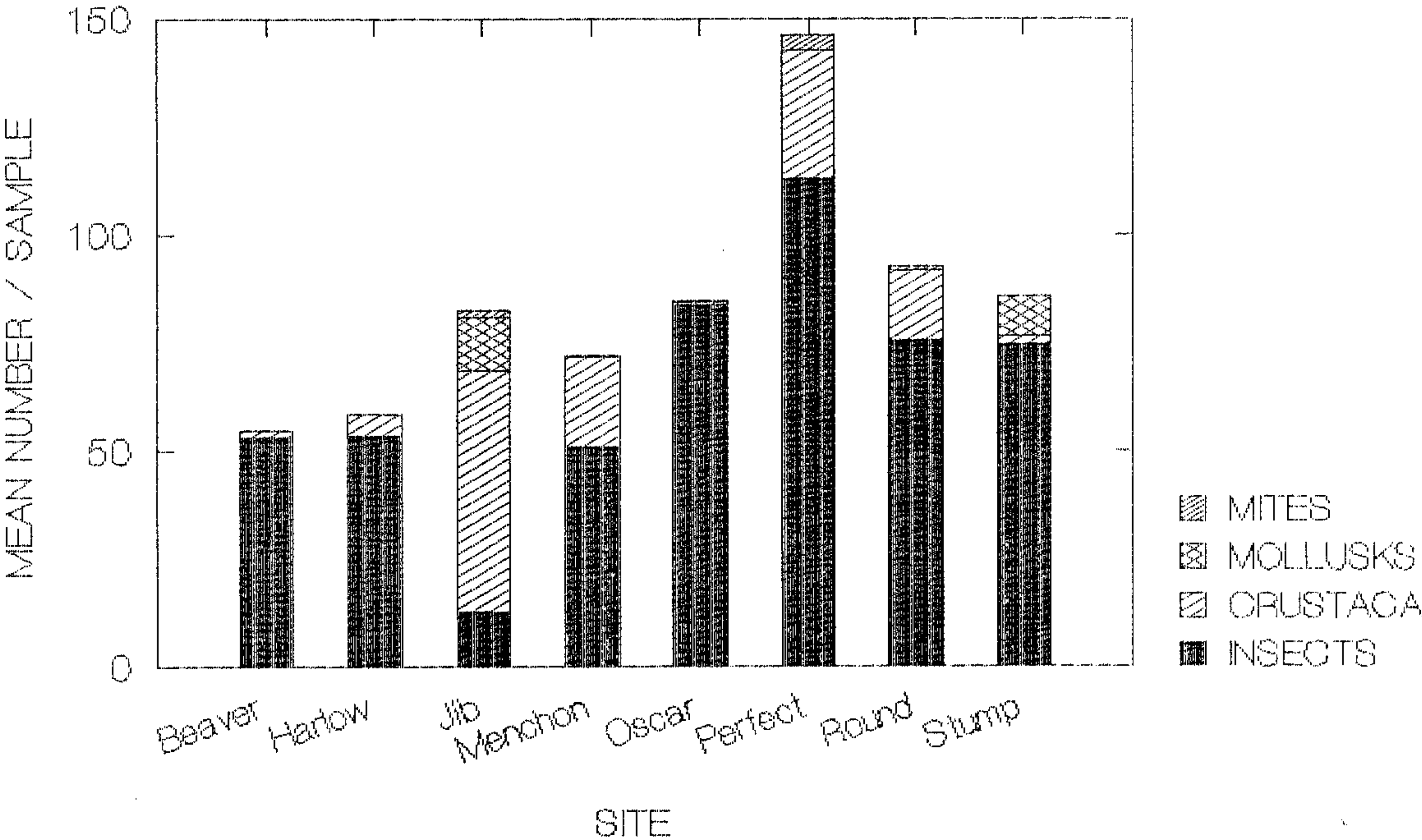


Figure 22. Mean number of major animal groups collected in benthic sweeps.

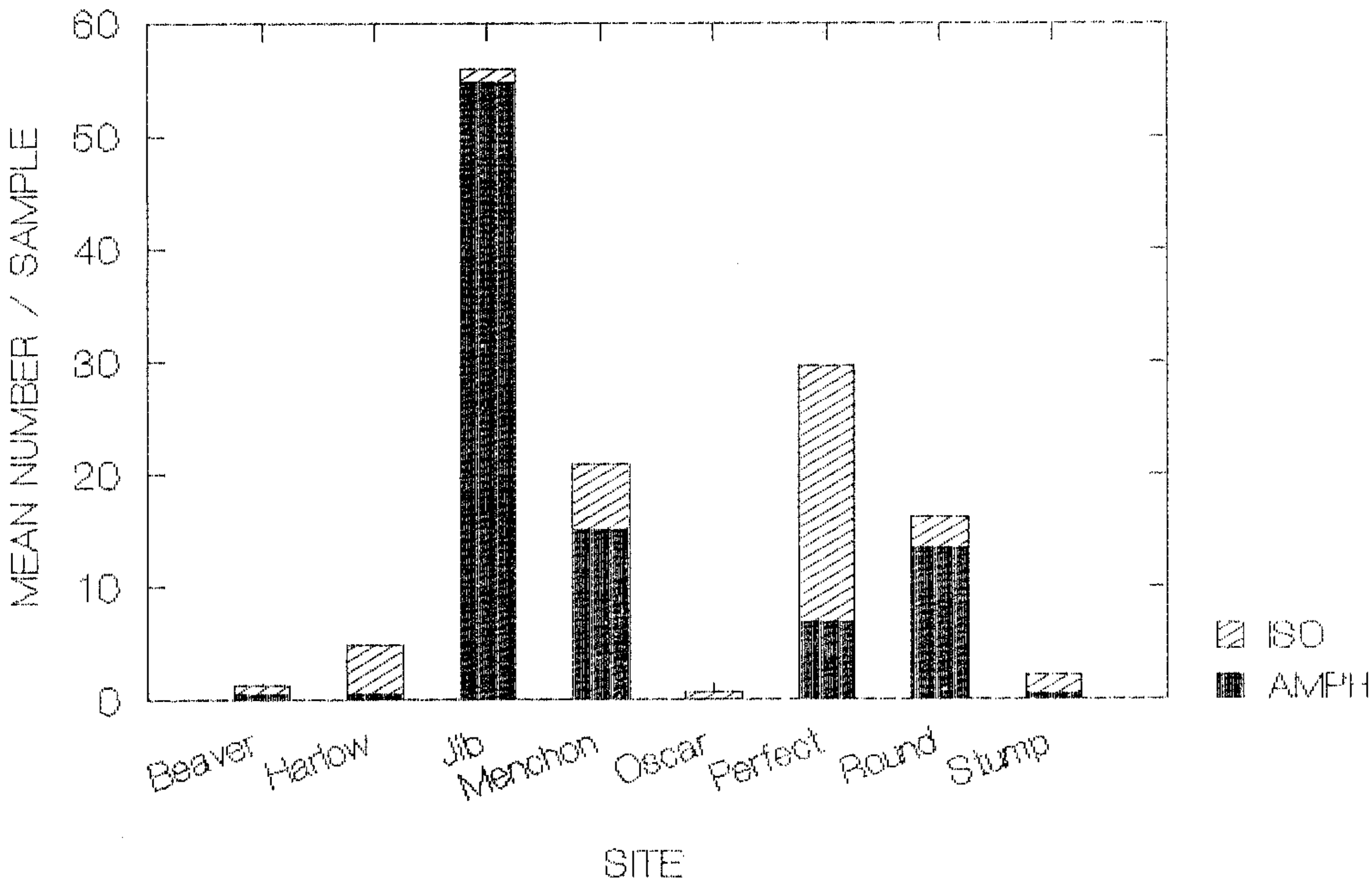


Figure 23. Mean number of crustacean groups collected in benthic sweeps.

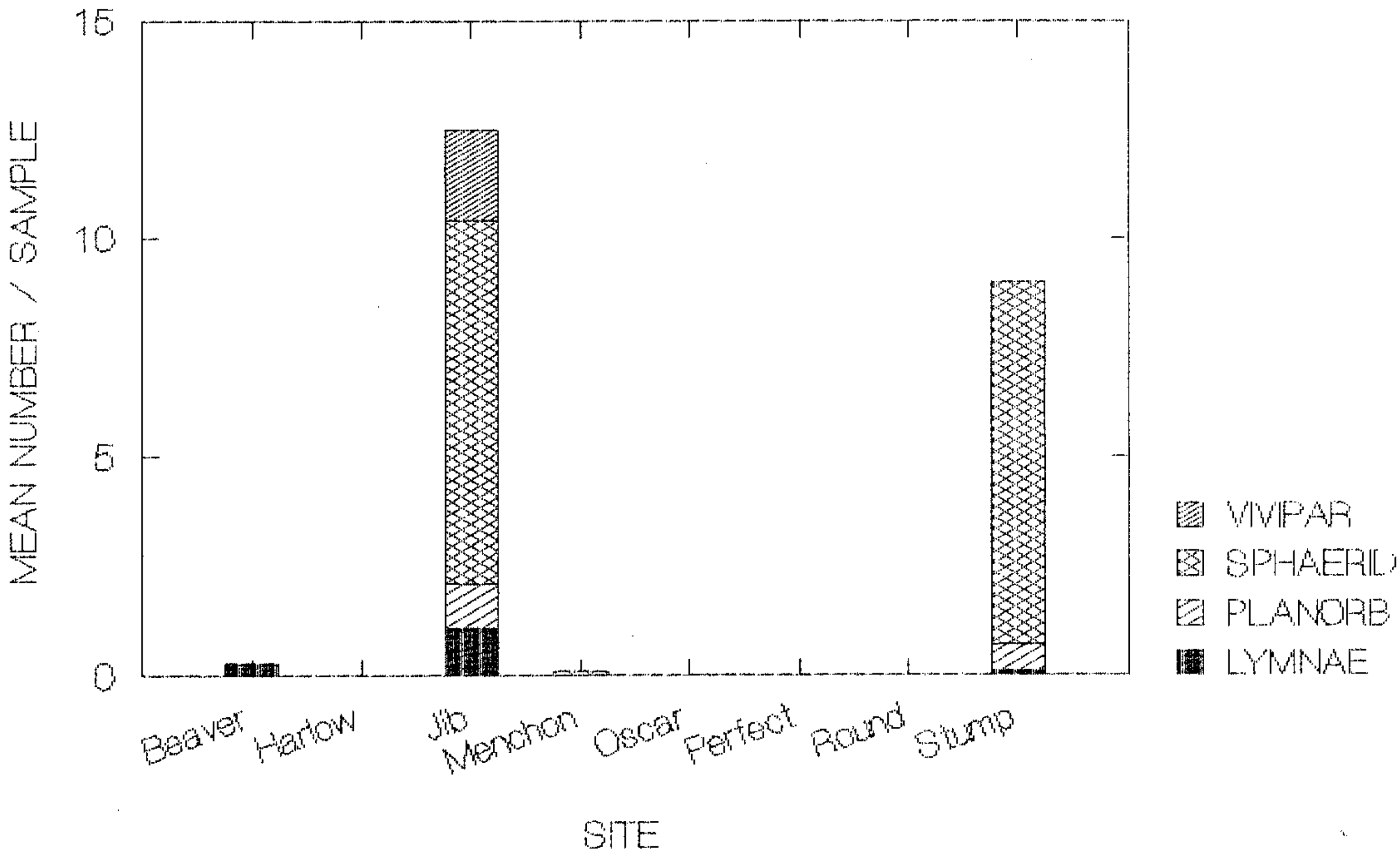


Figure 24. Mean number of major mollusk groups collected in benthic sweeps.

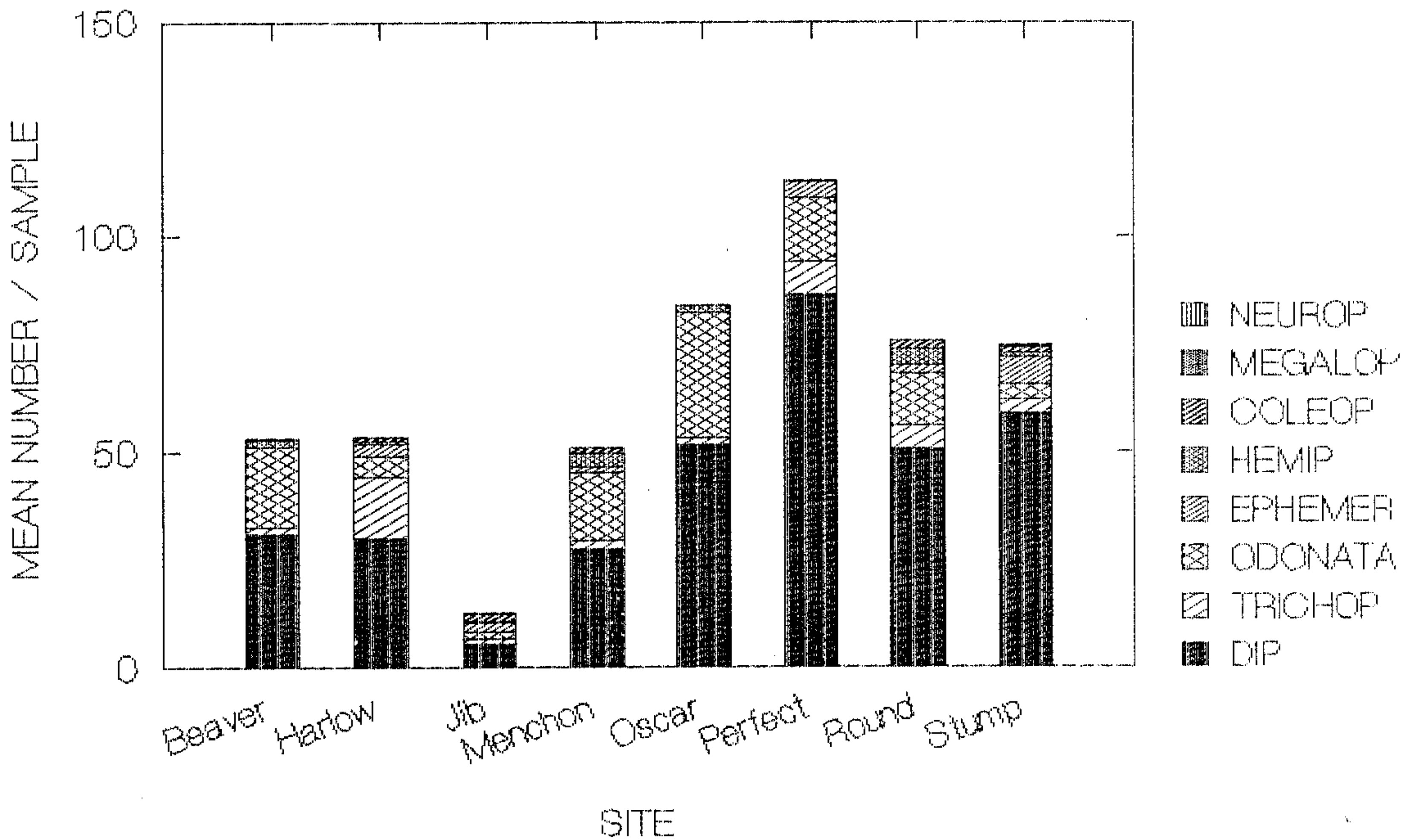


Figure 25. Mean number of major insect groups collected in benthic sweeps.

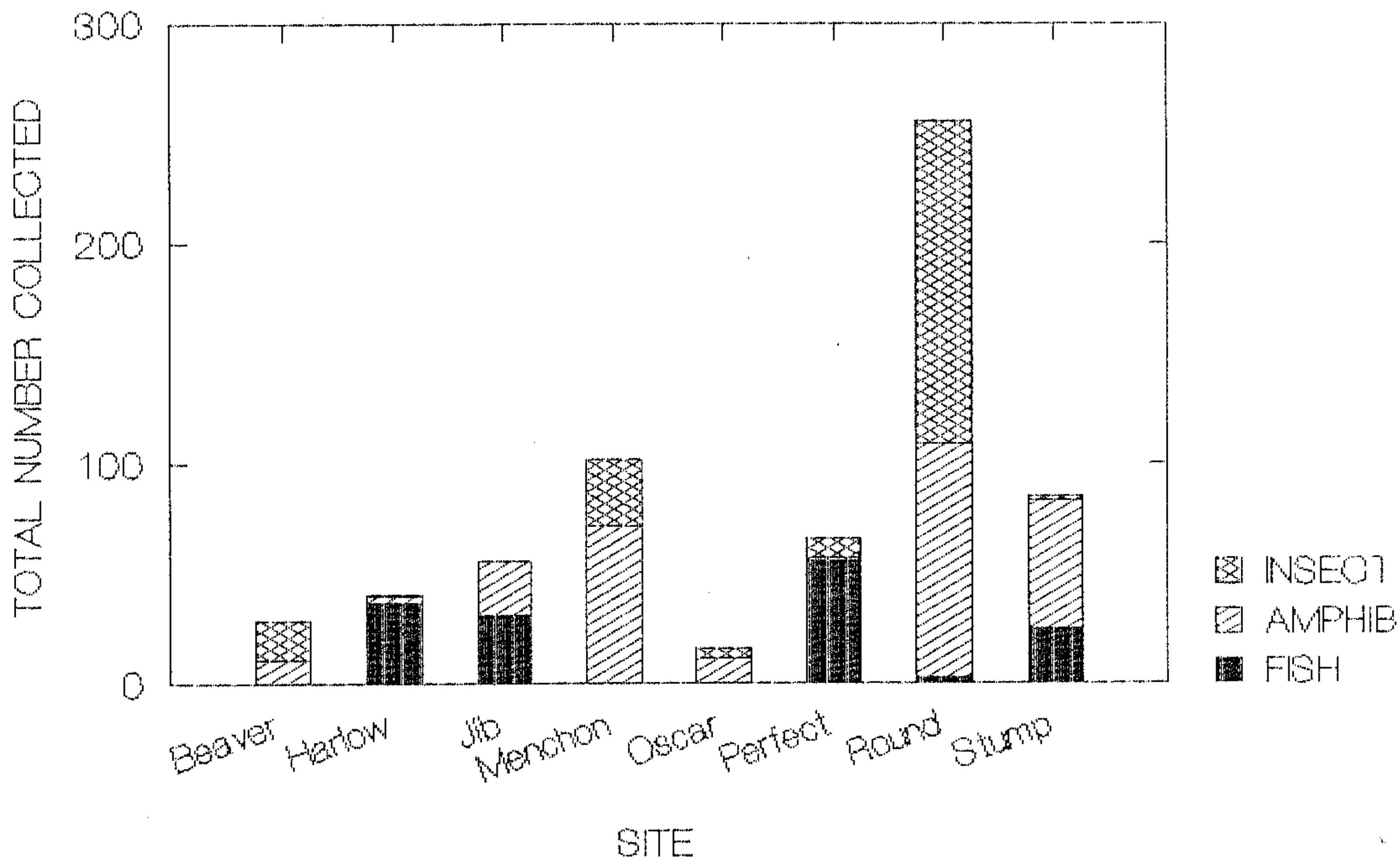


Figure 26. Total number and major groups of organisms collected in minnow traps.

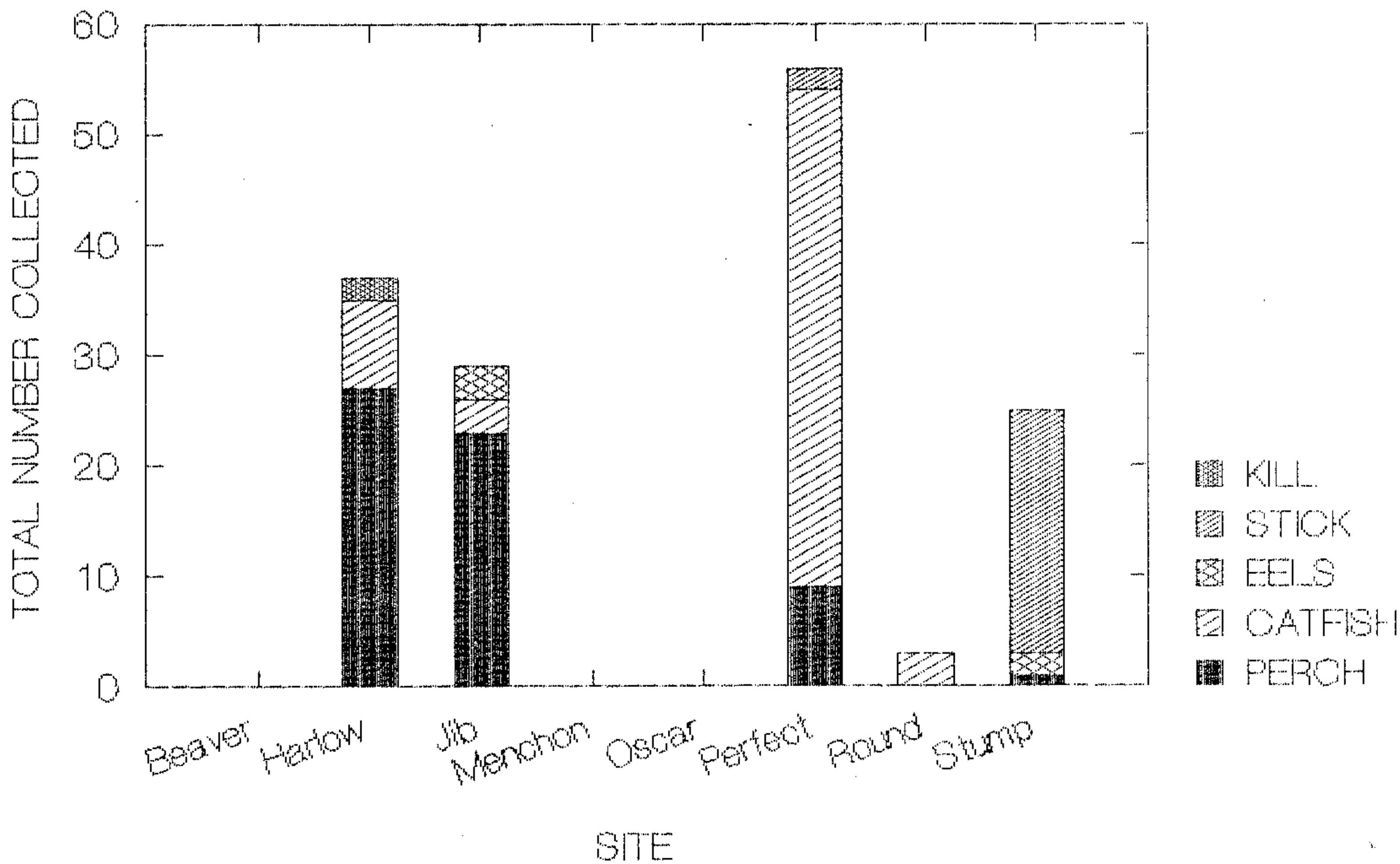


Figure 27. Total number and kind of fish collected in minnow traps.

The major amphibians collected in the minnow traps included tadpoles and newts (Figure 28). Tadpoles were collected at all sites but were most abundant at Round and Jib. Newts (*Notophthalmus viridescens*) were absent at Beaver and Harlow and most abundant at Menchon, Stump and Round.

The insects collected by the minnow traps included mainly the larger beetles, particularly belostomids and dytiscids, but some odonates and hemipterans were also collected (Figure 29). The collections from Round had the greatest numbers for all groups of insects. Significant numbers of insects were also collected at Beaver and Menchon but these were mainly the larger beetles. Collections from Harlow, Jib, Oscar and Stump always had very low numbers of insects.

9. Fish

During the fall, (November 13-14), a fish survey was conducted at each site using a 100 m long multipanel experimental gillnet having mesh sizes of 0.5, 1.0, 1.5 and 2.0 in. The net was placed in the centre of each site and allowed to remain overnight. Fish were captured at only three of the eight study sites. The greatest number were captured at Jib and included 16 suckers (*Catastomus* sp; average size 22.3 cm), five yellow perch (*Perca flavescens;* average size 18.3 cm) and two brook trout (*Salvelinus fontinalis;* average size 21.8 cm). At Harlow two perch (average size 25.7 cm) and one chub (*Semotilus* sp.; 18.0 cm) were caught, and at Oscar four chub were caught (average size 11.8 cm).

10. General Observations on Other Wildlife

Throughout the course of the field work general observations were made on the occurrence of organisms commonly associated with wetlands, particularly ducks, amphibians, reptiles and aquatic mammals. These observations are summarized in Table 8.

Ducks were commonly observed at all sites except Harlow, Jib, and Stump. Black ducks were common to Beaver and Oscar, but it was never determined if brood were produced at either of these sites. All sites except Harlow contained observable numbers of frogs and only at Jib and Oscar were turtles commonly observed. At none of the sites were aquatic mammals observed, although Oscar appeared to contain an active beaver lodge.

11. Species Diversity

In an effort to compare sites with respect to the diversity of species present in each community sampled, Shannon-Weaver diversity indices were calculated for the zooplankton, emergence trap, benthic sweep and minnow trap collections. The indices are based on major taxonomic groups (Families and Orders) rather than species, and as such are not true species diversity indices. The indices cannot be used to make comparisons of diversity between

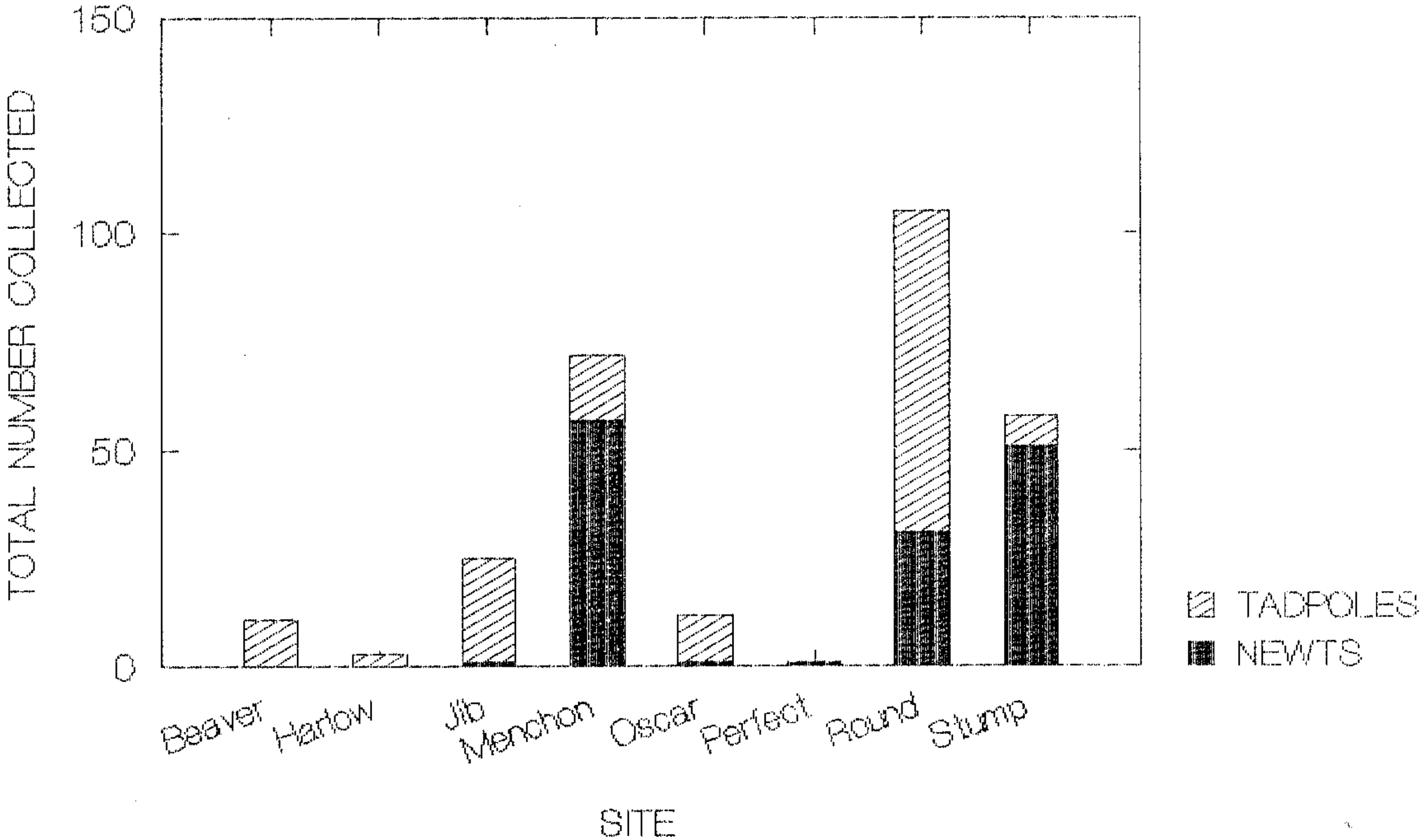


Figure 28. Total number and kinds of amphibians collected in minnow traps.

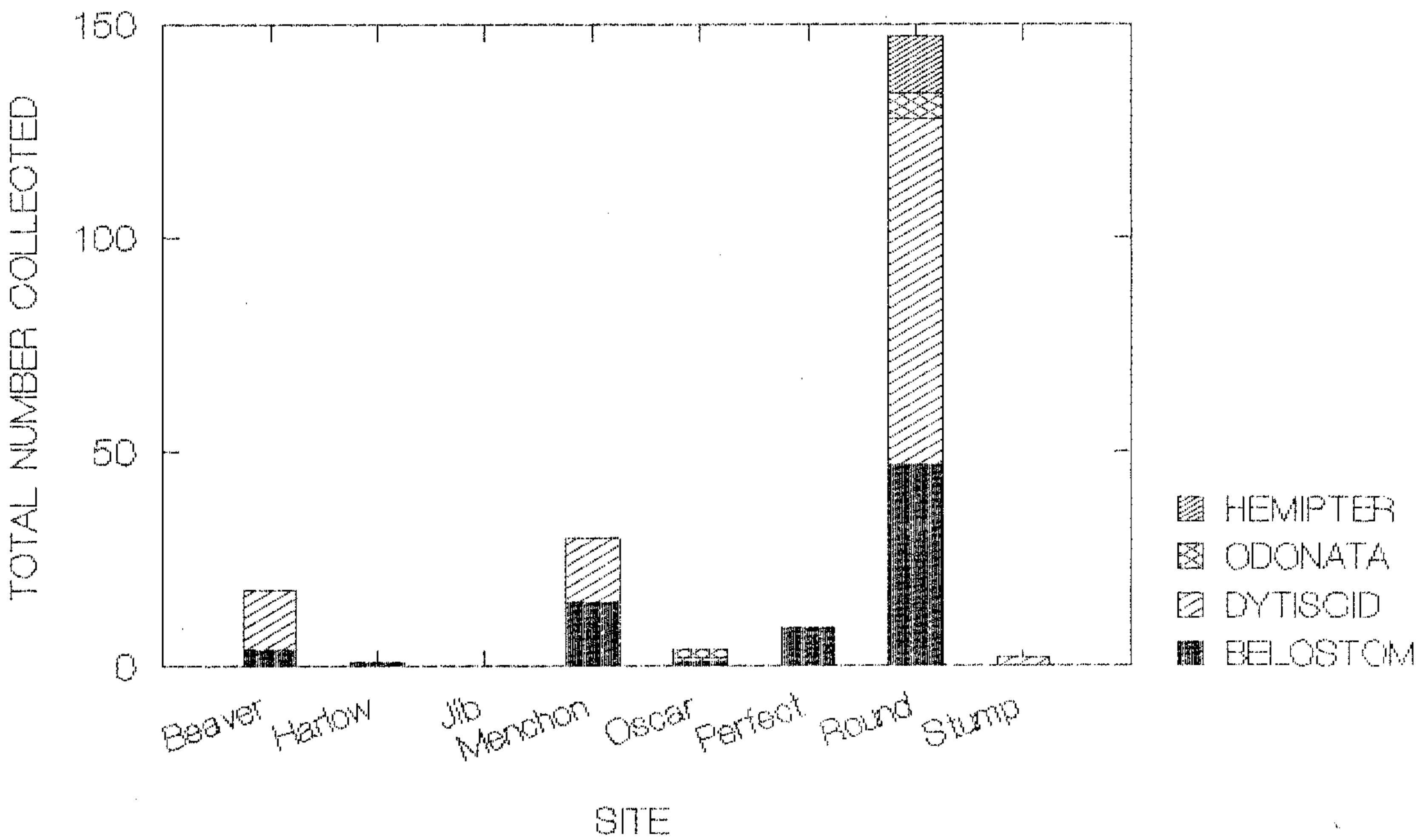


Figure 29. Total number and kinds of insects collected in minnow traps.

Table 8. Observations of ducks, amphibians and reptiles at the Tobeatic study lakes.
D = Dominant, C = Common, R = Rare, A = Absent

	Beaver	Harlow	Jib	Menchon	Oscar	Perfect	Round	Stump
Black Duck	C	R	R	R	C	R	R	R
Common Merganzer	R	R	R	C	C	C	C	A
Hooded Merganzer	R	R	R	A	R	A	A	A
Ringneck Duck	R	A	R	C	R	A	A	A
Spotted Sandpiper	A	A	A	A	R	A	A	A
Belted Kingfisher	A	A	A	A	R	A	A	C
Unidentified ducks	C	R	R	A	R	A	A	A
Common Grackle	A	A	A	A	A	A	A	C
Painted Turtles	A	R	C	D	C	A	A	A
Bullfrogs	C	R	C	C	C	C	C	C
Green Frogs	C	R	C	C	C	C	C	C
Garter Snakes	A	A	A	A	R	A	R	A

the different community types, but they are useful for comparing the diversity of each community between sites.

Figure 30 presents a summary of each site with respect to the diversity of the four community types. In general, the differences between sites are relatively small. The largest differences are in the emergent insect community. This was very low at Oscar and highest at Beaver. The minnow trap and zooplankton collections were relatively uniform in diversity among sites. Benthic invertebrate density was greatest at Round and lowest at Oscar and Perfect.

V. DISCUSSION

The sites chosen for this study all have a number of important similarities. All are characterized by low biomass and productivity of both pelagic and benthic communities. All, excepting Menchon, are typical brown-water dystropic systems having low water transparency and low levels of nutritionally important elements. A large proportion of their organic matter supply is probably allochthonous material consisting of resistant humic substances, largely of terrestrial plant origin, present in the form of dissolved and colloidal materials. Their sediments are highly organic and benthic community development is very limited. None of the sites, with the possible exception of Jib, appear to support important fish or other wildlife populations.

In many other respects, however, there is a great deal of diversity among the sites. Morphologically there is a great range in depth, surface area, volume, flushing rate and the presence of inlets and outlets. Physically, four of the sites undergo thermal stratification and four do not. Of those that do, three become anaerobic and one does not. Chemically, the main differences are in terms of pH and buffering capacity. Two of the sites, Jib and Stump, have a pH and buffering capacity that does not allow them to presently be classified as typical acidic systems.

Despite the morphological, physical and chemical differences, the biological differences are not that great. All are low productivity systems and many of the species present, particularly the invertebrates, are common to all the systems.

From the viewpoint of determining the response of low productivity wetlands to artificial fertilization, the diversity of the study sites could be used to advantage since it will allow an evaluation of changes in a wide variety of systems, and thereby increase the reliability of extrapolating the results of this study to other sites. This same diversity, however, will make it difficult to divide the study sites into experimental and control units which is desirable from the viewpoint of experimental design. This problem will have to be resolved before the next field season begins.

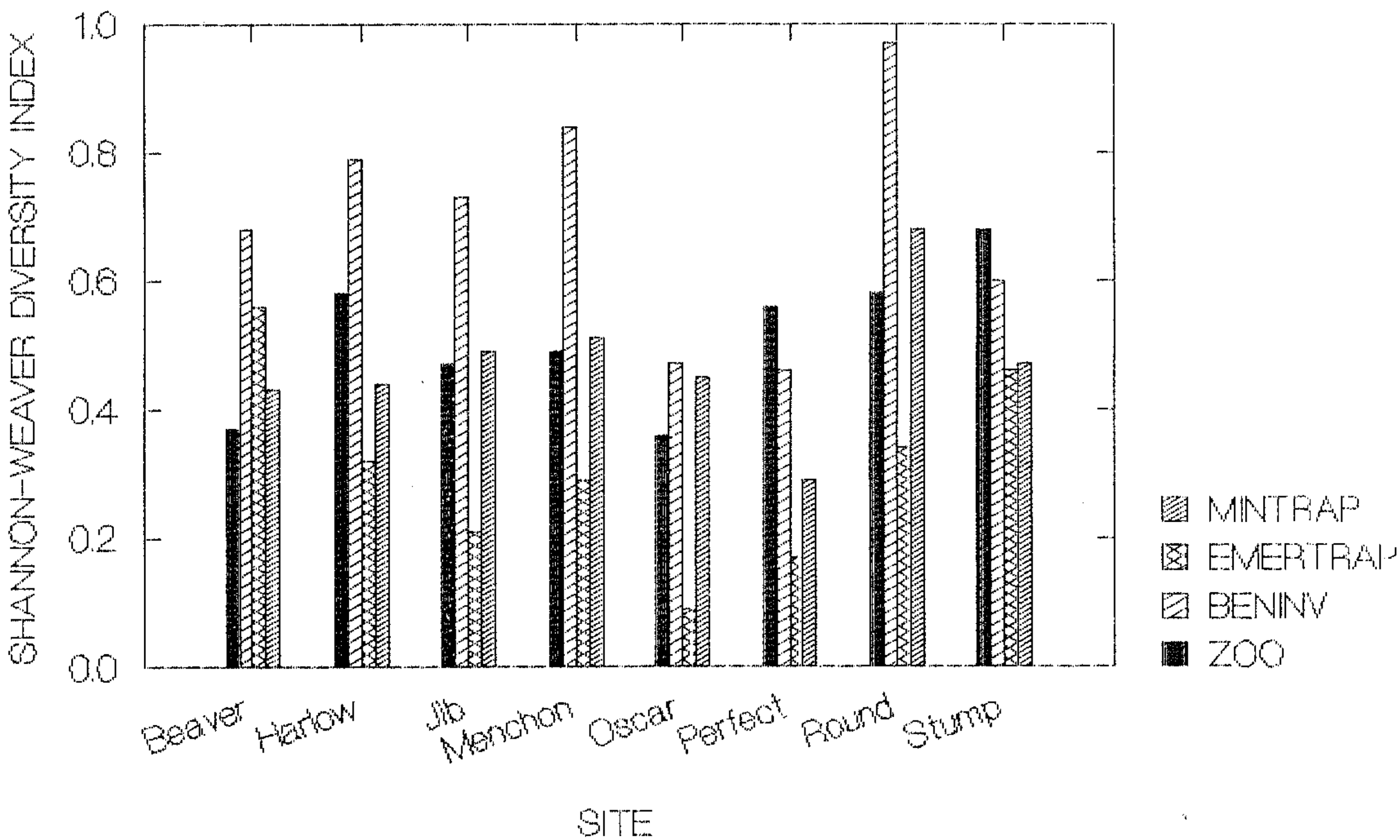


Figure 30. Shannon-Weaver species diversity indices for zooplankton, benthic invertebrates and emergence and minnow trap samples.

VI. ACKNOWLEDGEMENTS

This report was prepared with the help of Nancy House, Michelle Walters and Darlene Feener. The field crew consisted of Nancy House (field supervisor), Mike Parrish, Shelly Porter and Michelle Walters. Reg Melanson of the Nova Scotia Department of Lands and Forests provided valuable logistic support in the field. Dr. Joseph Kerekes of the Canadian Wildlife Service arranged for the chemical analysis of water samples which was carried out by the Inland Waters Branch of the Canadian Department of Environment at Moncton, N. B.

APPENDIX A

SAMPLE COLLECTION AND ANALYSIS PROCEDURES

I. FIELD PROCEDURES

Each site has a centre station and an outlet station if an outlet exists. The following procedures are carried out at each station with the exception that phytoplankton and zooplankton samples are not collected at the outlet.

1. Water level: Each site has been provided with a marked stake. Changes in water level are simply recorded as present water level in reference to the water level at the time the stake was installed.

2. Water temperature: Water temperature profiles are measured at half-meter intervals using a YSI-SCT meter.

3. Secchi Depth: A Secchi disk is used to estimate the depth to which light penetrates the water column. Two readings are made; the depth at which the Secchi disk disappears and the depth at which is reappears. The average of the two is the Secchi disk depth. All readings are made from the shady side of the boat.

4. Suspended Particulate Matter (SPM): One liter water samples are collected from the surface. At the field laboratory the sample is vacuum filtered through a pre-weighed Millipore 0.45 µm acetate filter and stored in a petri dish for further processing at ACER.

5. Conductivity: Conductivity profiles are measured at half-meter intervals using a YSI-SCT meter.

6. Water chemistry: (1) A one liter water sample is collected from the surface and returned to the field laboratory for analysis of pH, alkalinity and hardness. A portion of this sample is stored refrigerated for phosphorous analysis at ACER. (2) An additional one-liter water sample taken from the surface is stored refrigerated for subsequent analyses by CWS.

   pH is measured with a portable Fisher Model 910 pH meter.

   Alkalinity is measured by titration of a 50 ml sample with 0.01 N Sulfuric Acid to the Bromo Cresol Green - Methyl Red endpoint.

   Total hardness is measured by titration of a 10 ml sample with EDTA using Eriochrome Blue I as the end-point indication.

7. Dissolved Oxygen: Dissolved oxygen samples are collected from the surface and bottom in 300 ml BOD bottles using a Van Dorn water sampler. Samples are fixed in the field and upon return to the field laboratory are stored under water until titration using the Winkler technique.

8. Chlorophyll: A one-liter water sample is collected from the surface for chlorophyll analysis. At the field laboratory the sample is filtered through a Watman GF/C filter under low vacuum and rinsed with 1 ml of a saturated magnesium carbonate solution. The filters are stored frozen in petri dishes until further analysis at ACER.

9. Phytoplankton Species Composition: A 20 ml water sample is collected from the surface and fixed with Lugol's iodine solution for subsequent analysis using an inverted microscope.

10. Periphyton: Periphyton growth is monitored by suspending pre-weighed glass microscope slides contained in trays that float approximately 10 cm below the water's surface. Slides are left in place for periods of two or four weeks at which time they are collected and stored in a dissicator for later analysis of weight and chlorophyll content.

11. Zooplankton Abundance and Species Composition: Zooplankton samples are collected by pouring a known volume of water (100 l) through a Wisconsin plankton net. The sample is then transferred to a Mason jar and fixed with conc. formalin.

12. Insect Emergence: One insect emergence trap is located at each lake. The trap is cone-shaped and made of fibreglass door screening. The apex of the cone leads into an open ended bottle having a plastic funnel attached to the lower end. The bottle contains a killing and preserving agent. During each sampling the trapped insects are transferred to a collection jar and preserved in Kahle's solution.

13. Benthic Invertebrates: Benthic invertebrate samples are collected using a sweep net. Each sample consists of five figure-eight sweeps. Samples are preserved in 70% ethanol.

14. Small Fishes: Small fishes and other small aquatic animals are monitored by minnow trap collections.

15. Aquatic Macrophytes: Observations are made during each site visit on the presence and abundance of aquatic macrophytes. During August an extensive macrophyte survey of each site will be made.

16. General Observations: During each site visit general observations are made with regard to the presence of wildlife, particularly those typically associated with wetlands.

II. LABORATORY PROCEDURES

The following procedures are carried out at the ACER laboratory:

1. Suspended Particulate Matter: SPM filter samples are oven dried for 24 hr at 70°C and then weighed. Results are reported in mg/l.

2. Phosphorous: Total and dissolved phosphorous samples are processed by the ammonium molybdate method. Total phosphorous is determined by digestion with potassium pusulfate and autoclaving at 15 psi and 120°C for 30 minutes.

3. Chlorophyll: Phytoplankton chlorophyll samples are processed by acetone extraction of chlorophyll collected on Watman GF/C filters. Samples are extracted for 24 hr refrigerated and in the dark. The concentration of chlorophyll is measured in a spectrophotometer using a 5 cm path length cuvette. Absorbance is read at 480, 510, 630, 647, 664 and 750 nm and, after acidification with HCl, reread at 664 and 750 nm for determination of phaeopigments. Total chlorophyll, as well as chlorophyll a, b and c are calculated using the tricolormetric equations presented in Parsons and Maita (A Manual of Chemical and Biological Methods for Seawater Analysis, Pergamon Press, 1984).

5. Periphyton: Periphyton samples are analyzed in two ways: (1) after drying by desiccation, the glass slides containing the periphyton samples are weighed and the amount of periphyton recorded as the increase in weight of the slide and (2) the slide is scraped clean of periphyton and the scrapings are extracted in acetone for measurement of chlorophyll using the same procedure as for phytoplankton.

6. Species Abundance and Composition:

   a. Phytoplankton samples are enumerated using an inverted microscope after beng settled in settling chambers for 24 hrs.

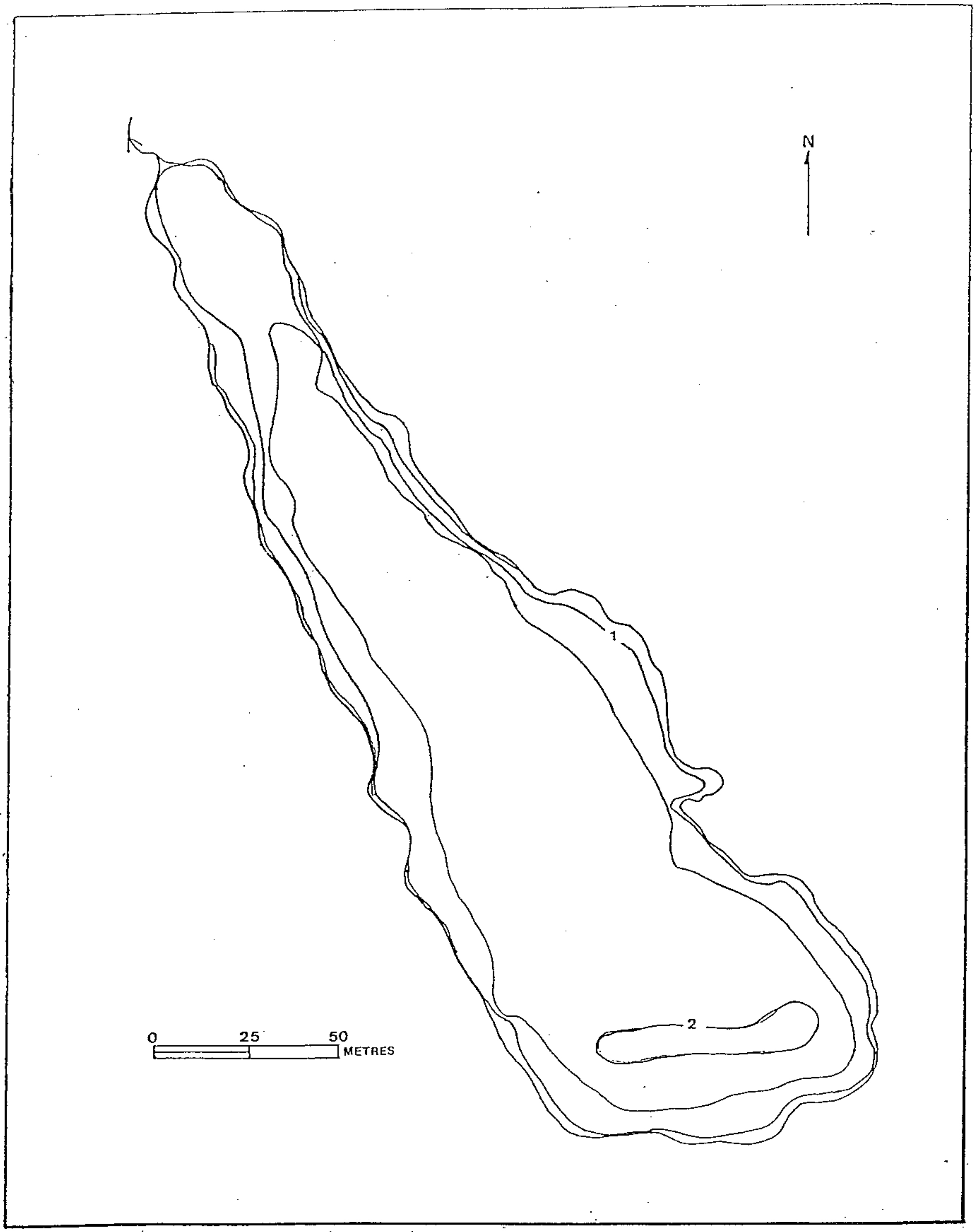
   b. Zooplankton samples are enumerated using a stereo microscope. If required, subsamples are drawn using 2 or 10 ml sub-samples.

   c. Emergent insects are enumerated by microscope counts.

   d. Benthic invertebrate samples are sorted and enumerated by microscope.

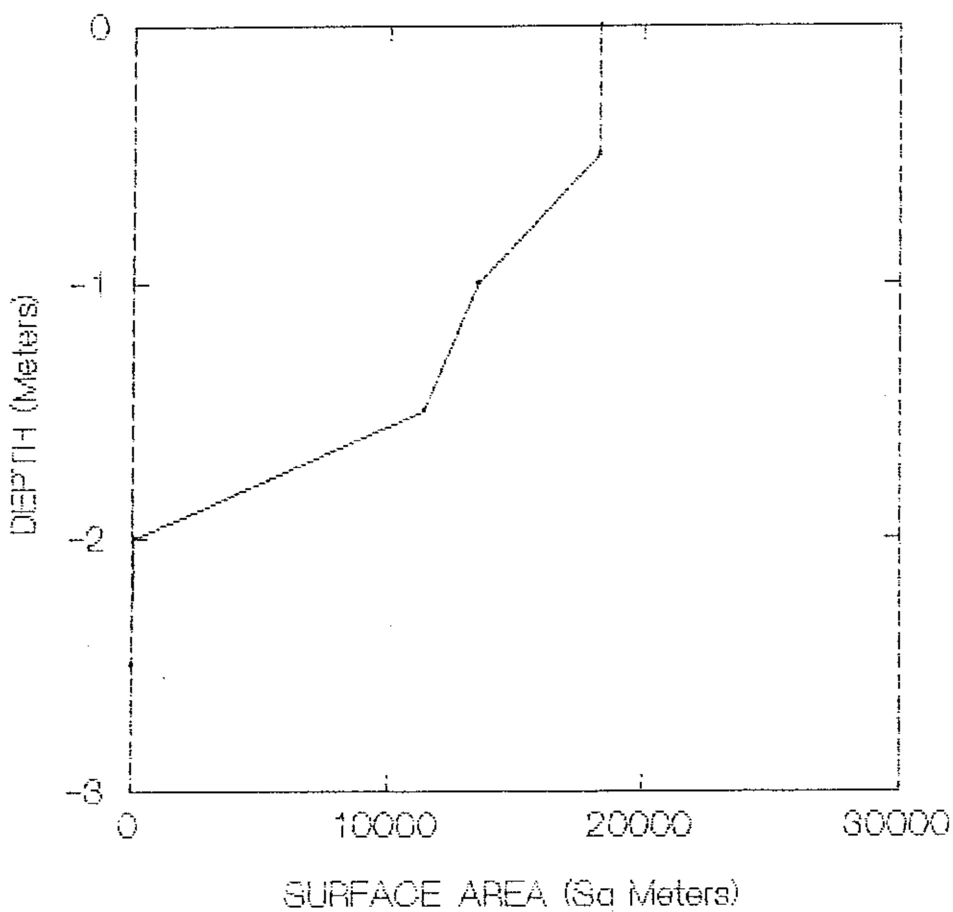
APPENDIX B

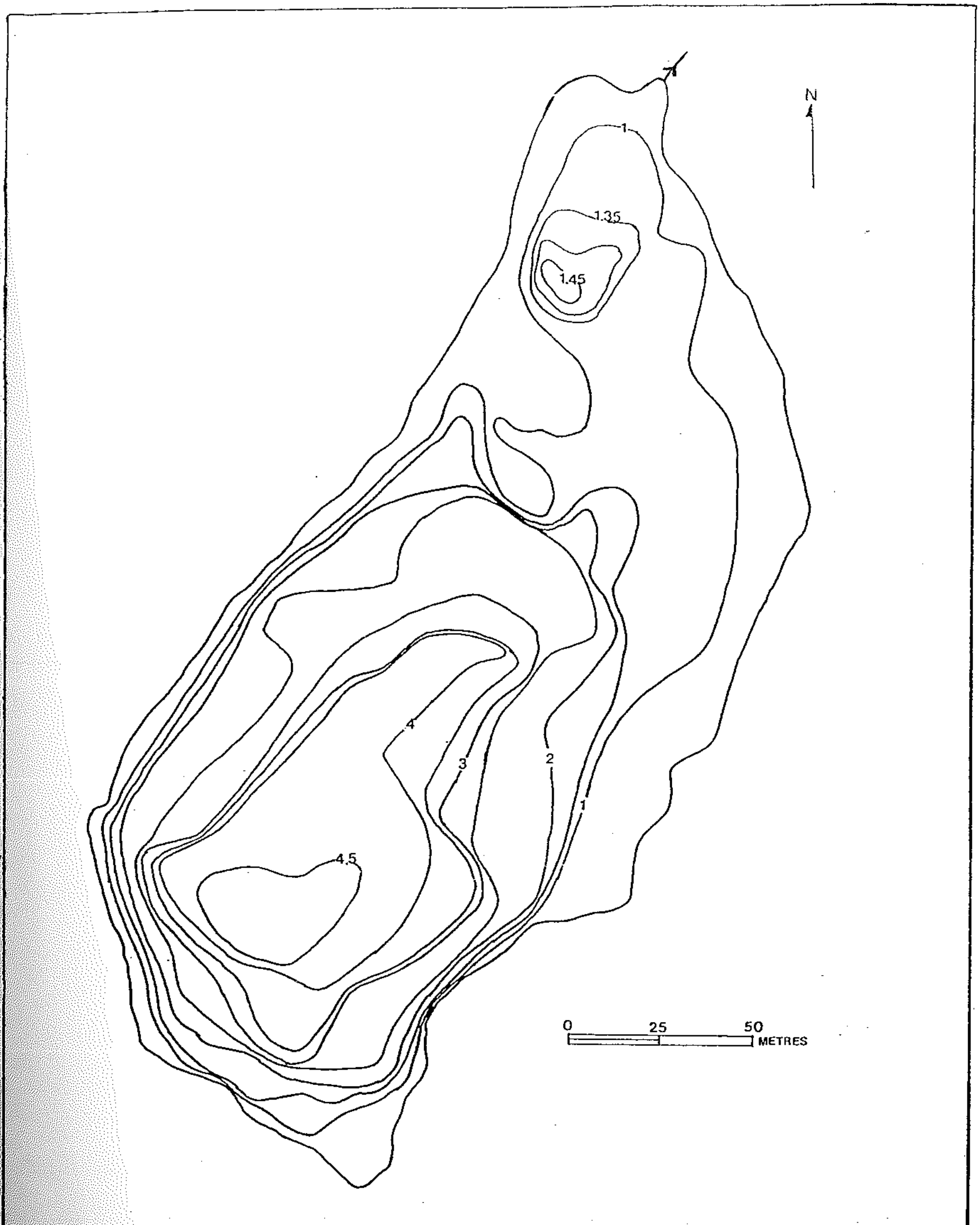
BATHYMETRIC MAPS AND HYPSOGRAPHIC CURVES



Bathymetric map of Beaver Lake. Depth contours are in 0.5 m intervals.

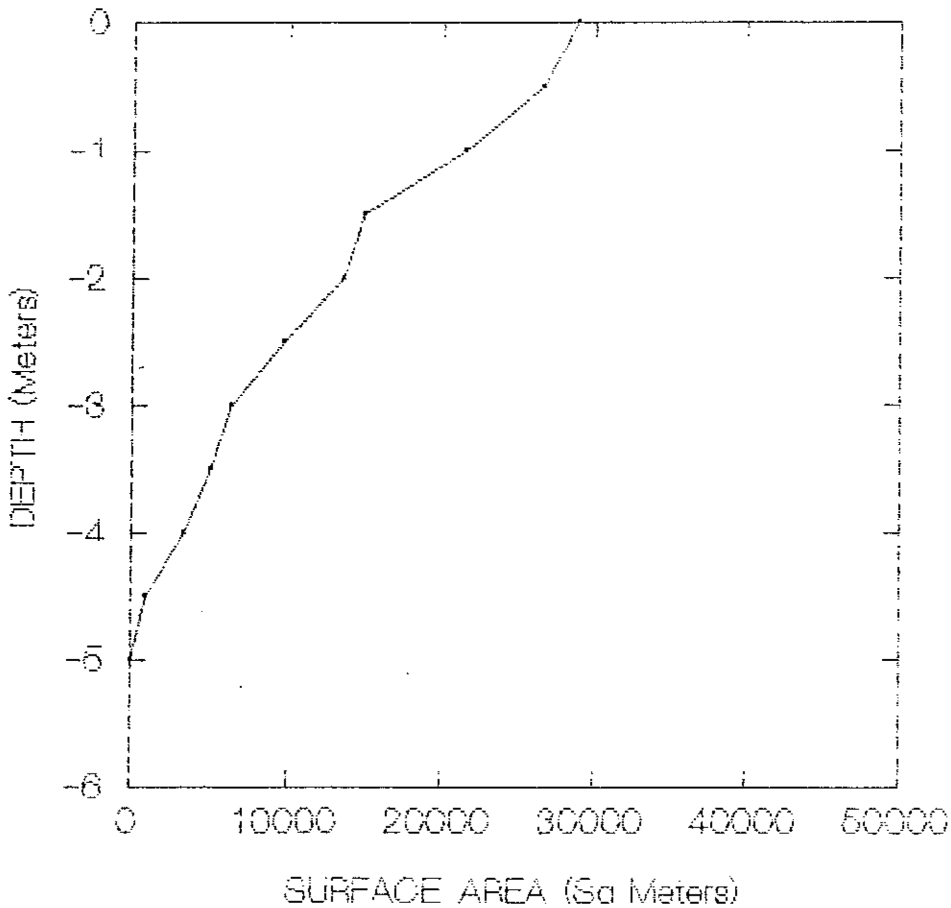
Hypsographic Curve of Beaver Lake

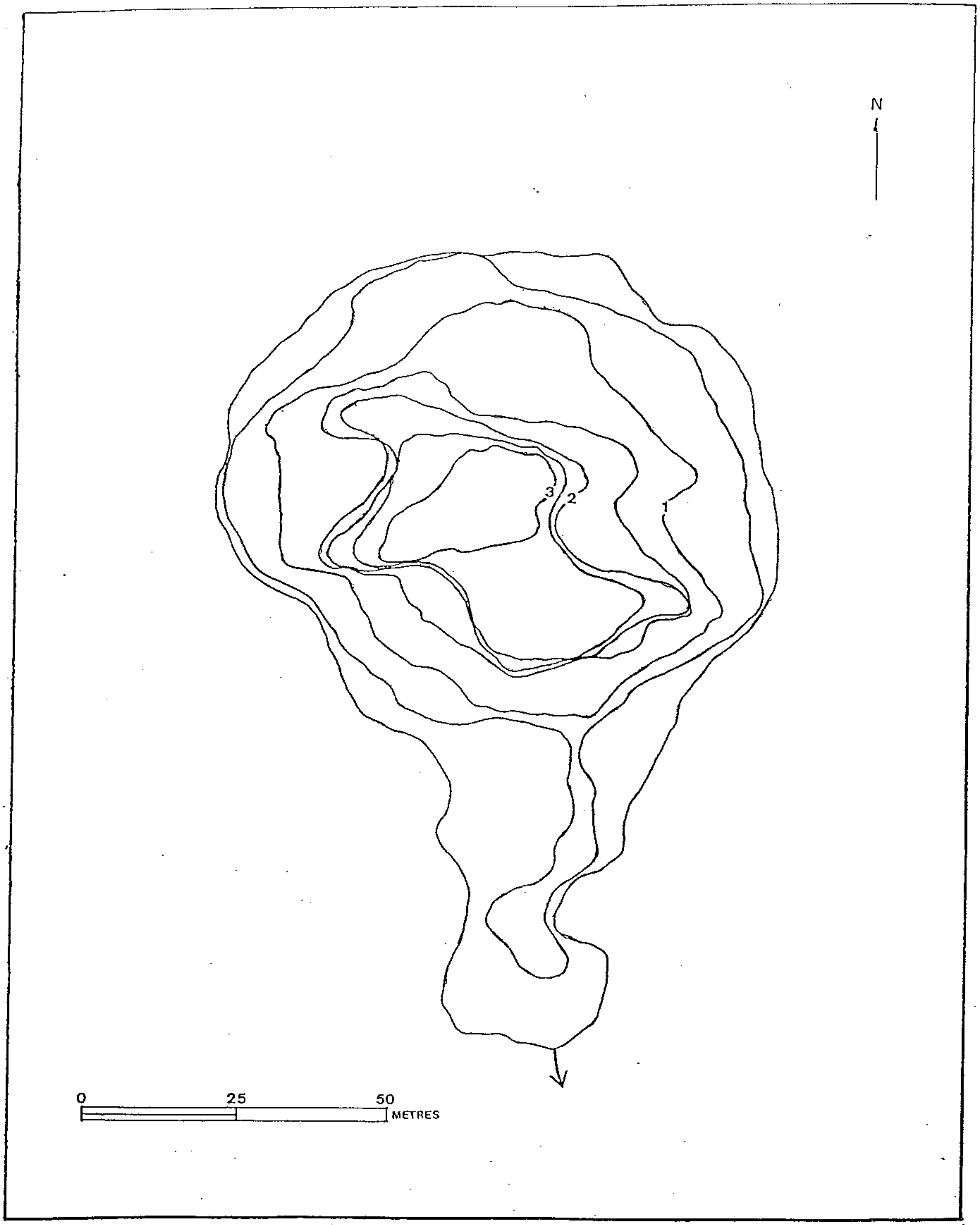




Bathymetric map of Harlow Lake. Depth contours are in 0.5 m intervals.

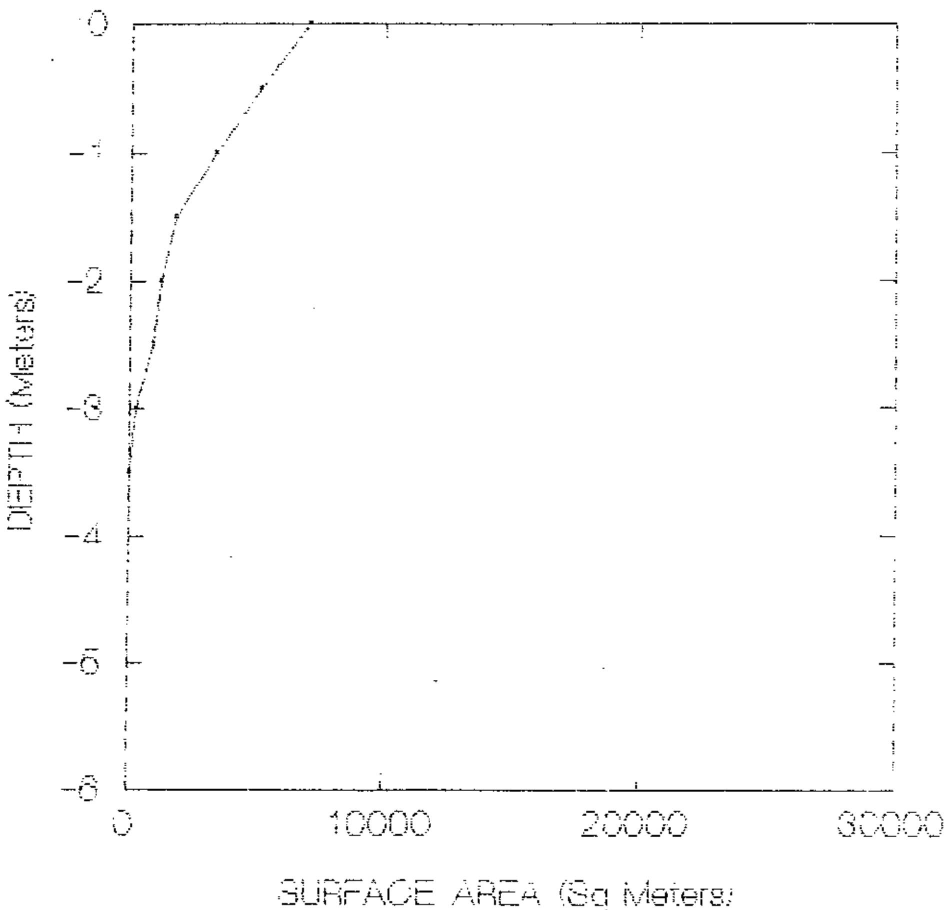
Hypsographic Curve of Harlow Lake

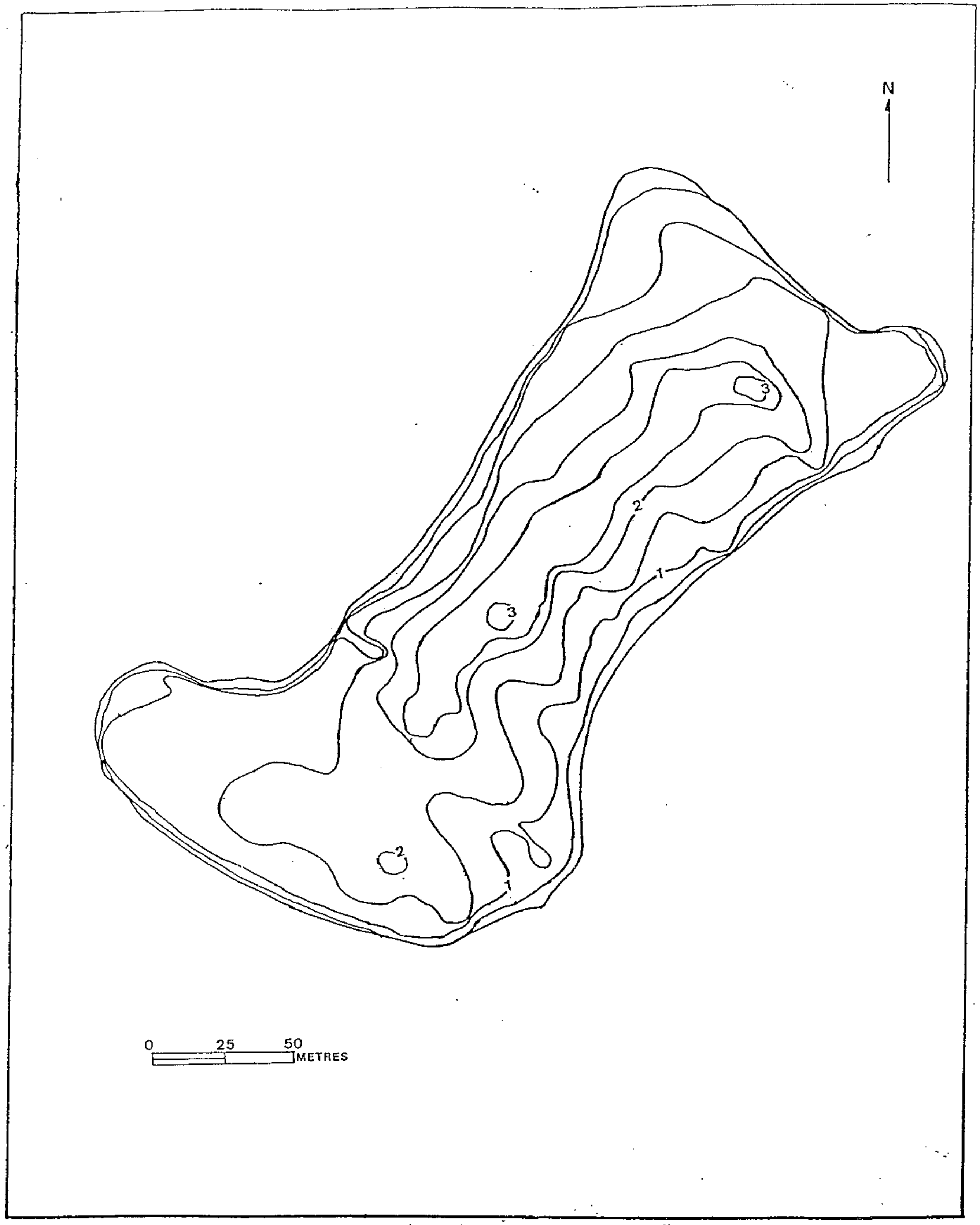




Bathymetric map of Jib Lake. Depth contours are in 0.5 m intervals.

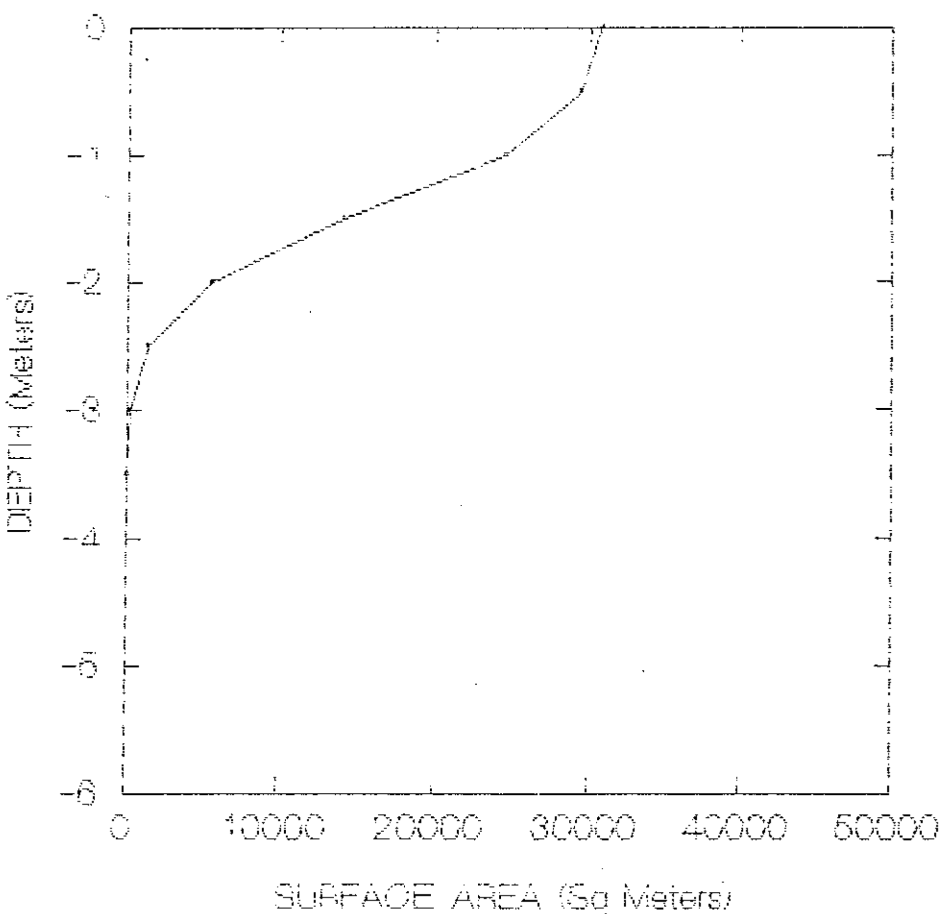
Hypsographic Curve of Jib Lake

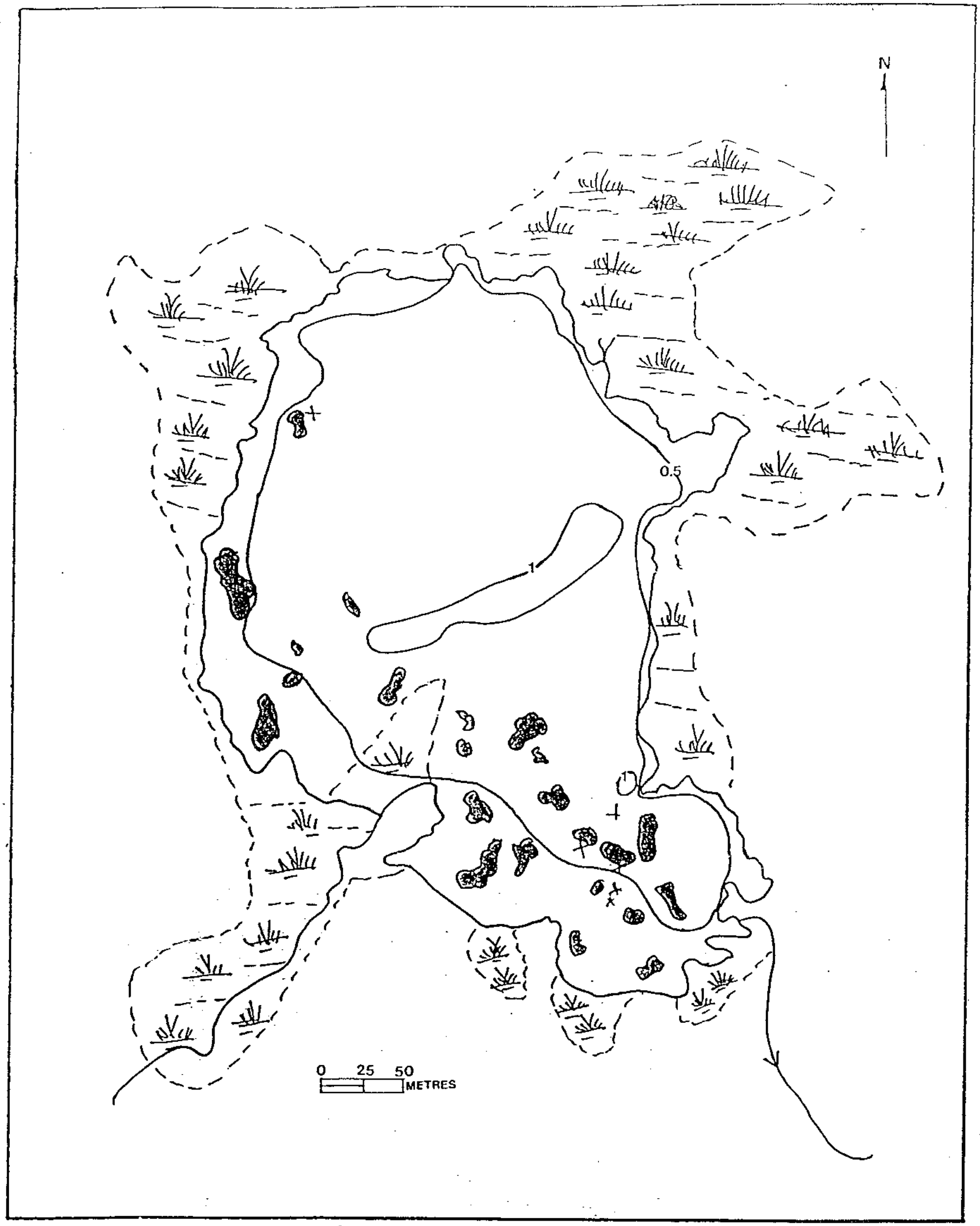




Bathymetric map of Menchon Lake. Depth contours are in 0.5 m intervals.

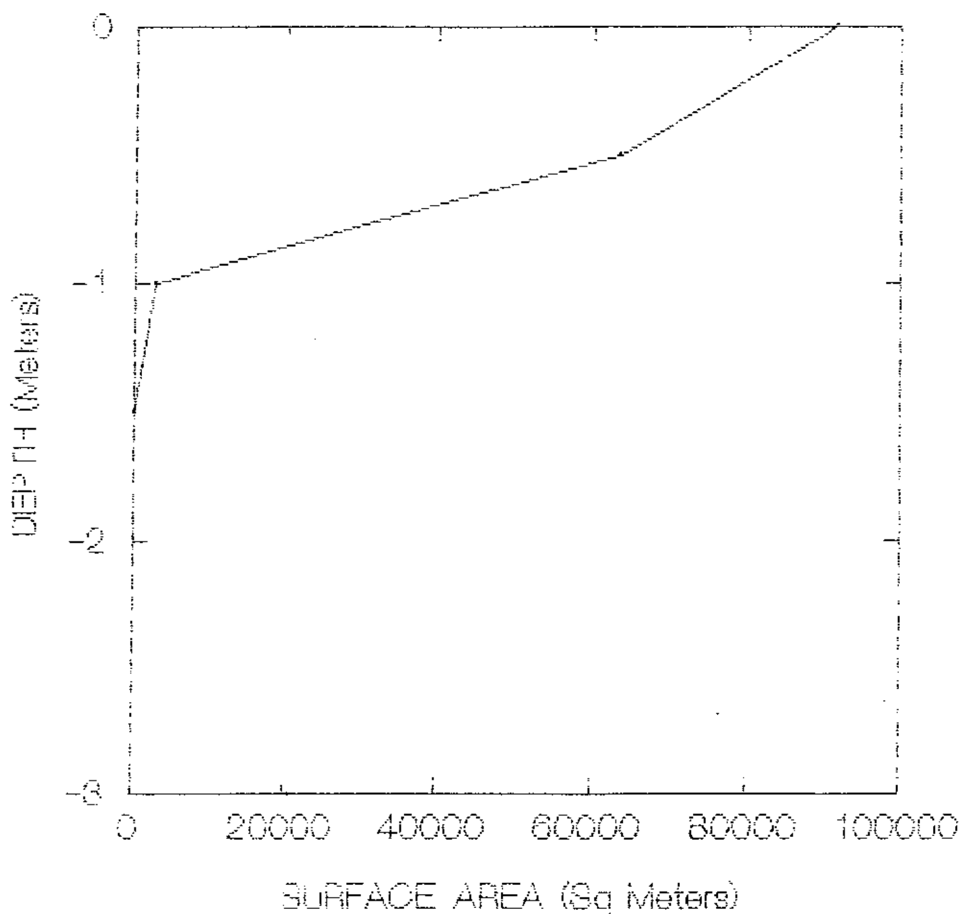
Hypsographic Curve of Menchon Lake





Bathymetric map of Oscar Lake. Depth contours are in 0.5 m intervals.

Hyposographic Curve of Oscar Lake



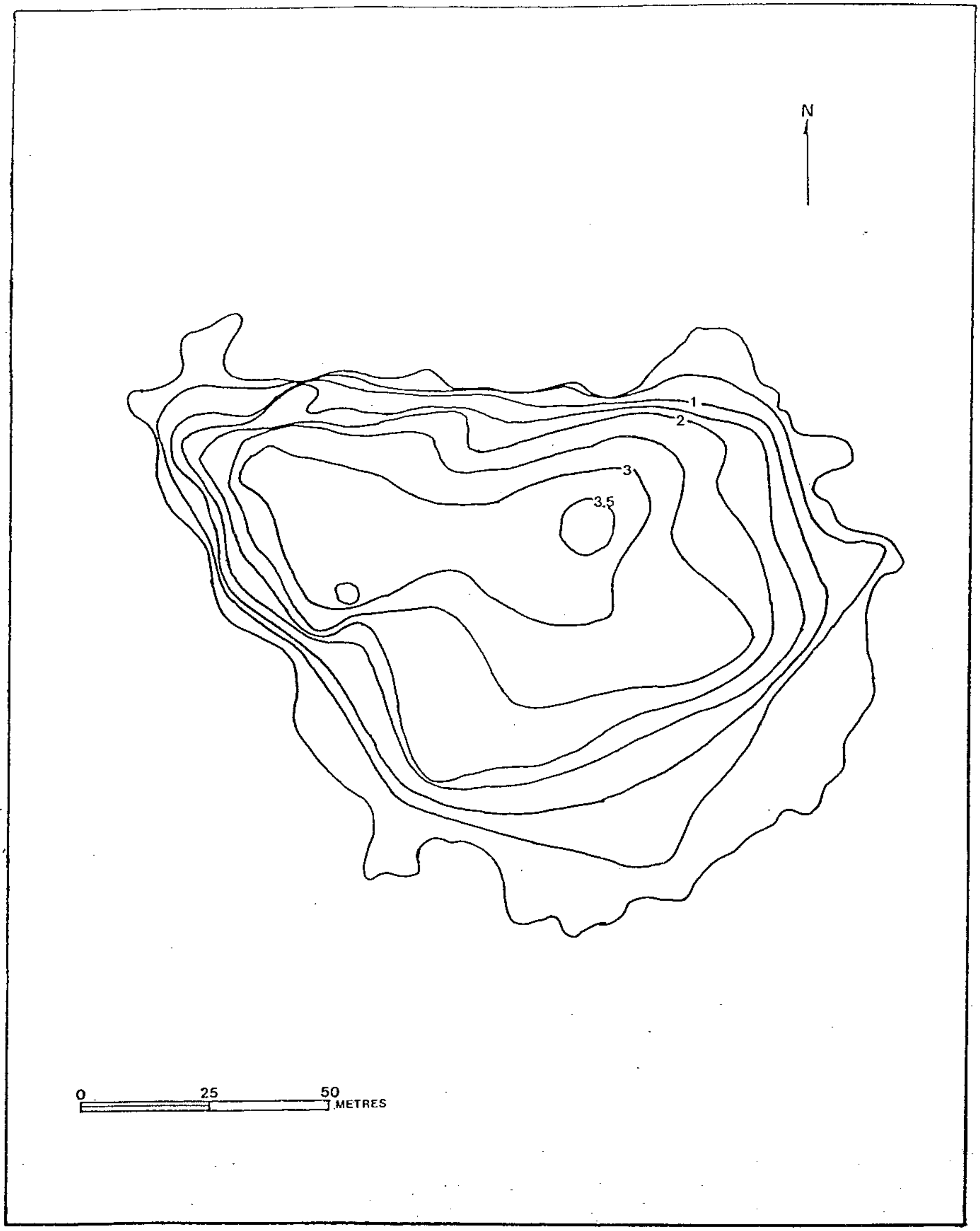
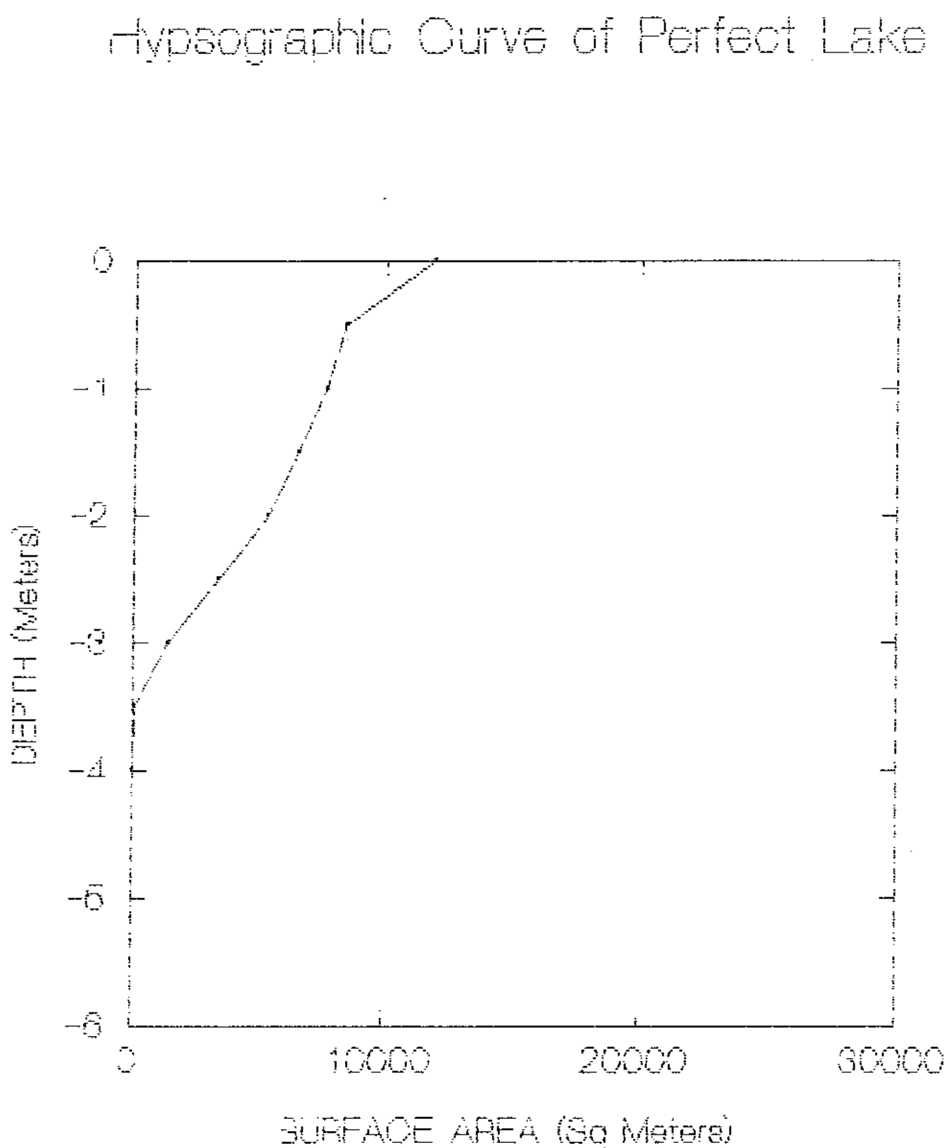


Figure . Bathymetric map of Perfect Lake. Depth contours are in 0.5 m intervals.


Hypsographic Curve of Perfect Lake
DEPTH (Meters)
0
-1
-2
-3
-4
-5
-6
0
10000
20000
30000
SURFACE AREA (Sq Meters)

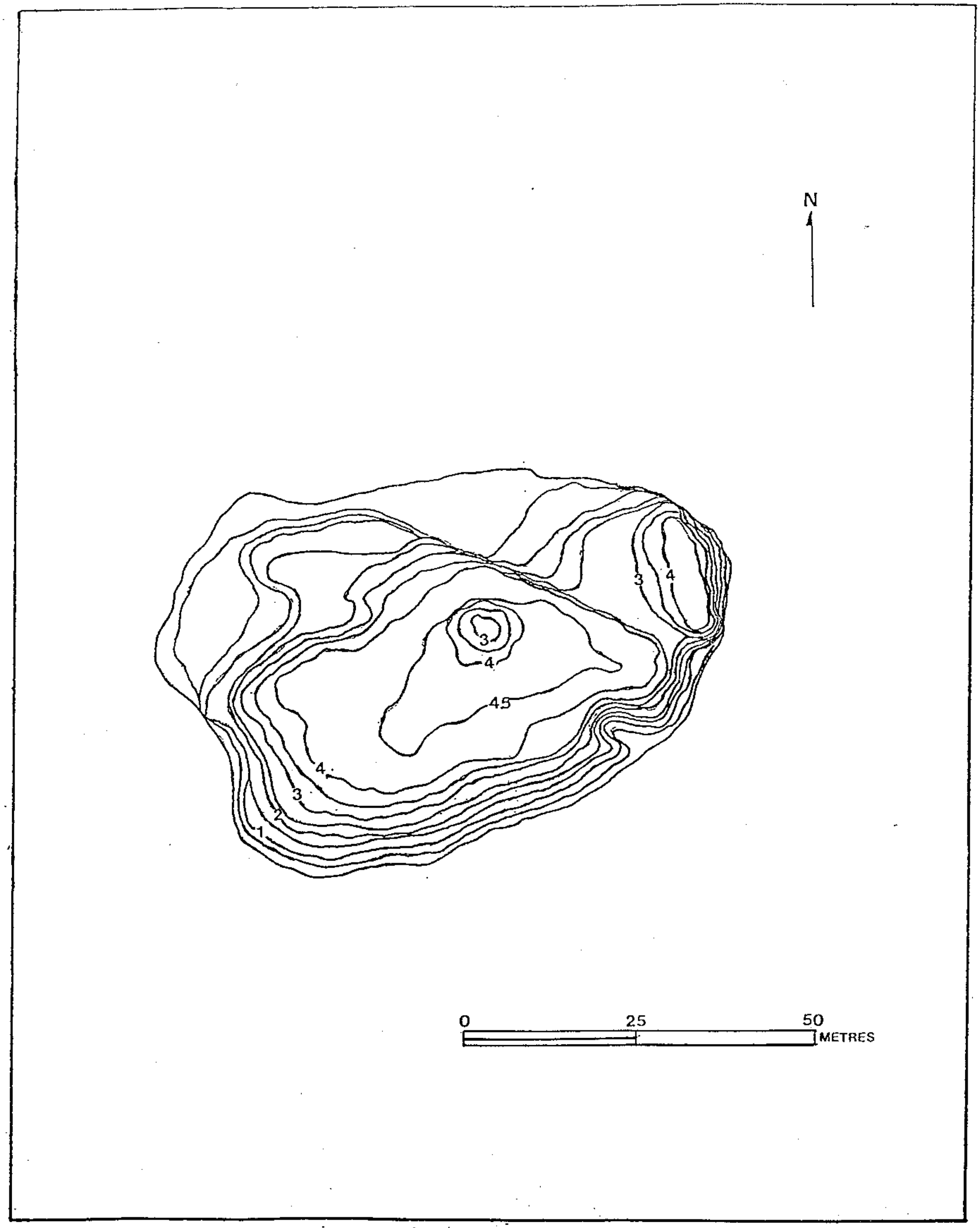
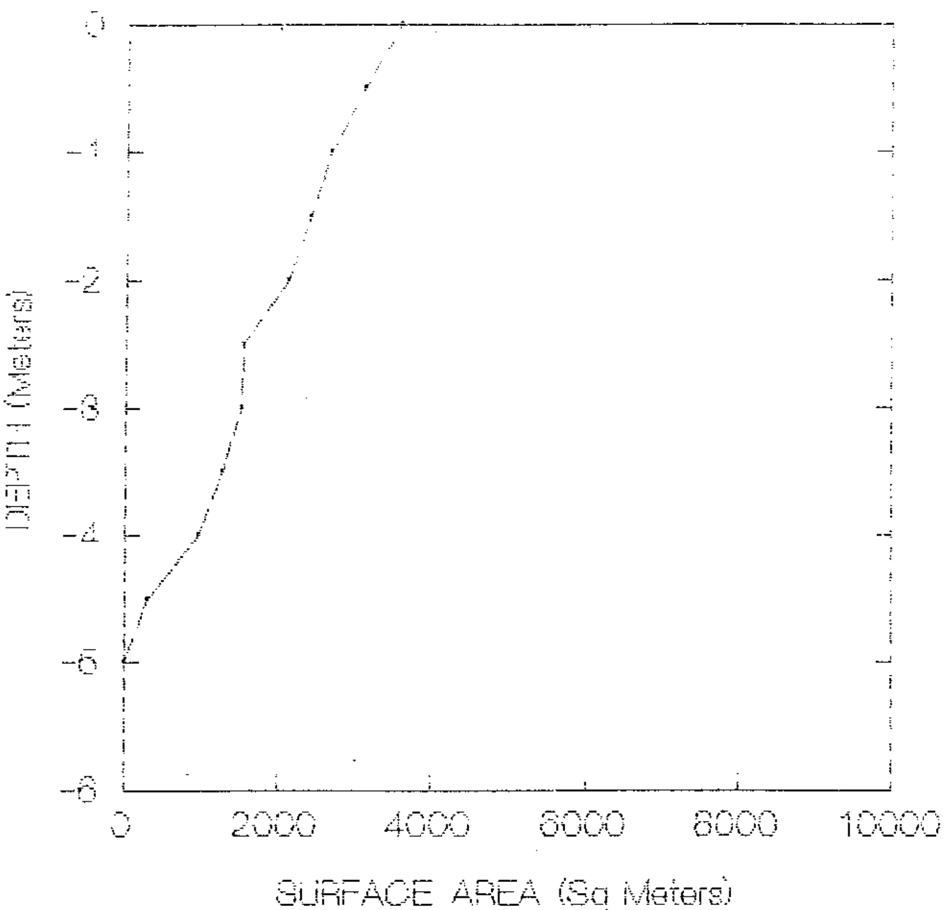
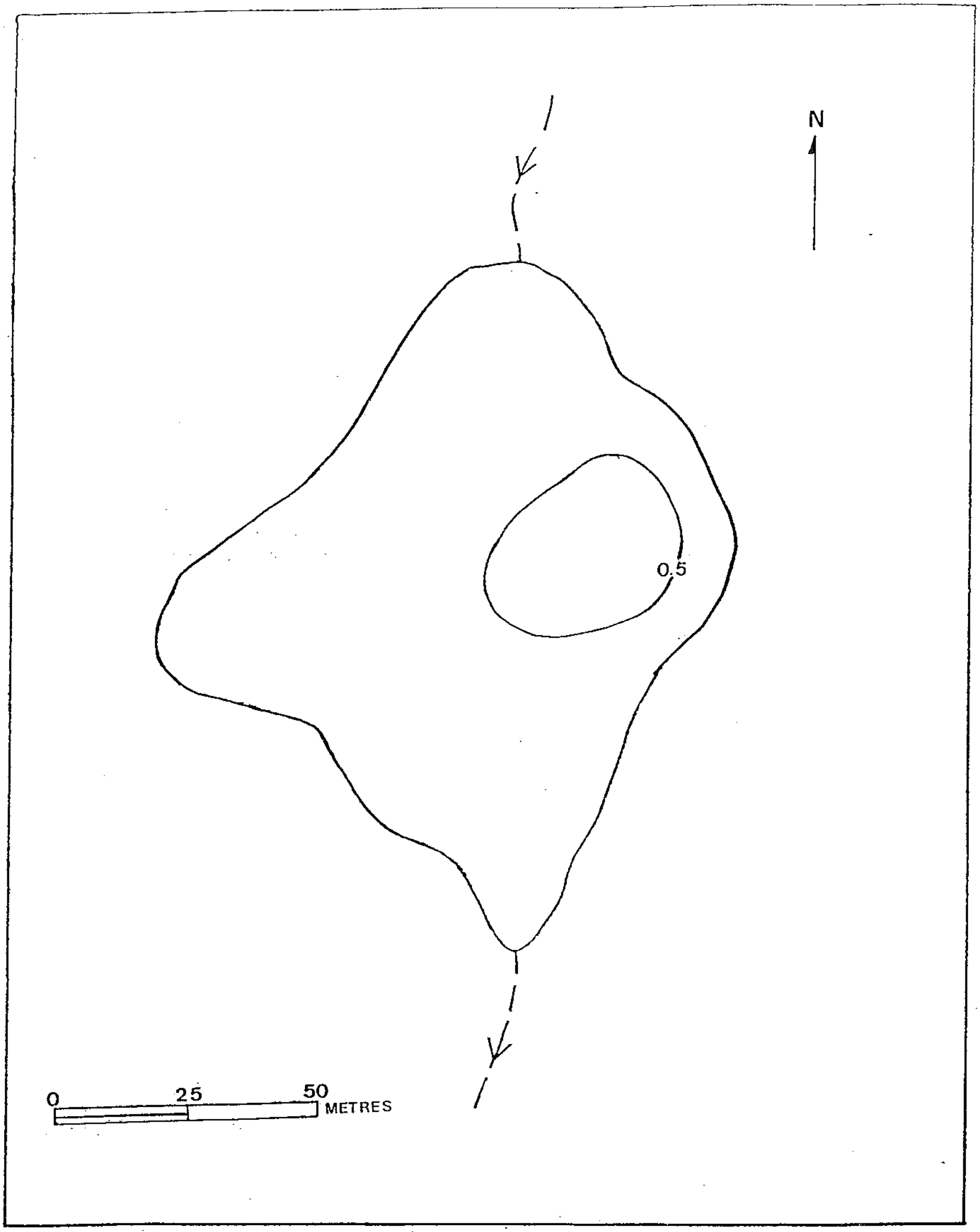


Figure 3 Bathymetric map of Round Lake. Depth contours are in 0.5 m intervals.

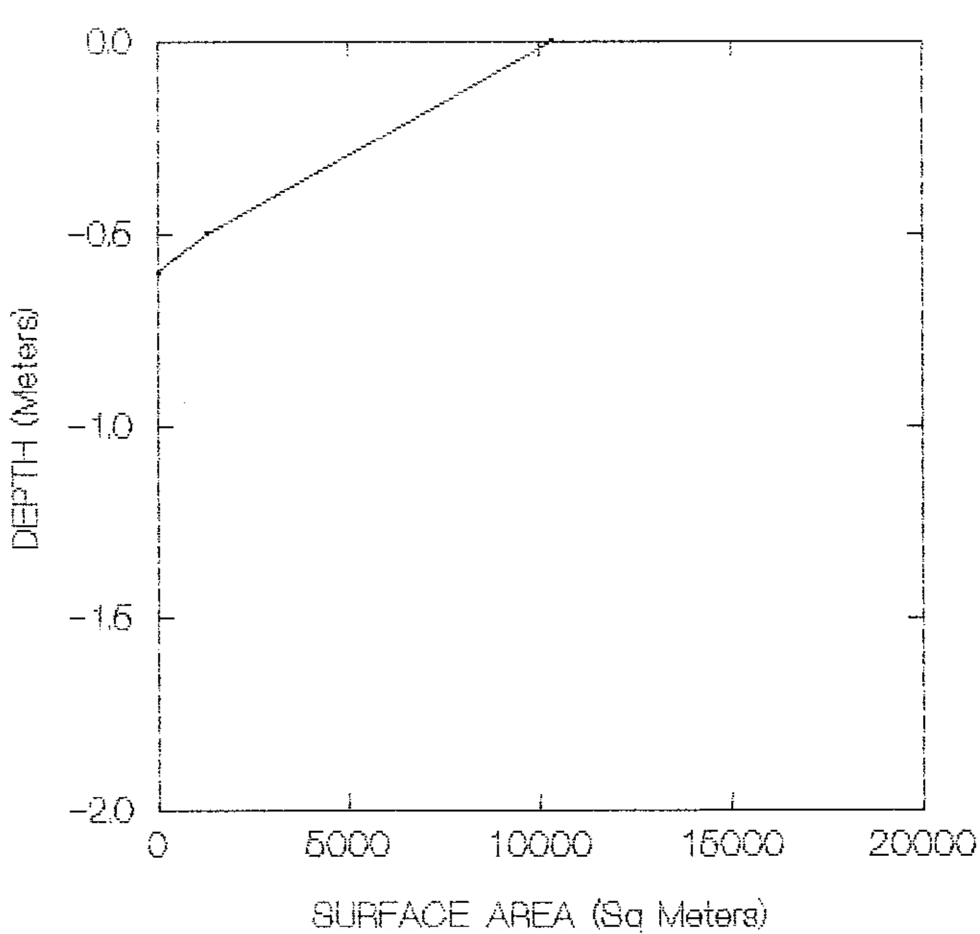
Hypsographic Curve of Round Lake





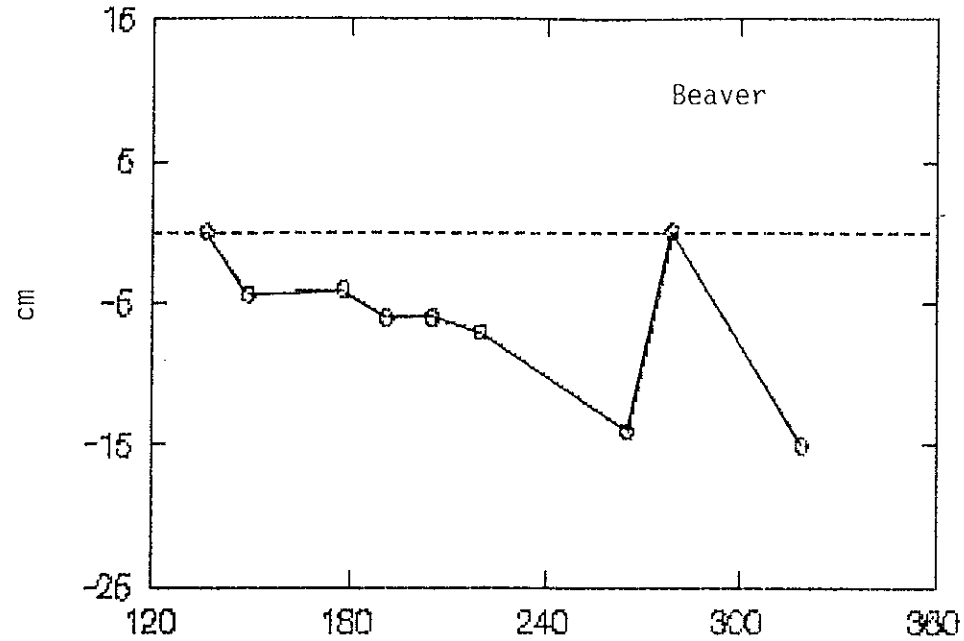
Bathymetric map of Stump Lake. Depth contours are in 0.5 m intervals.

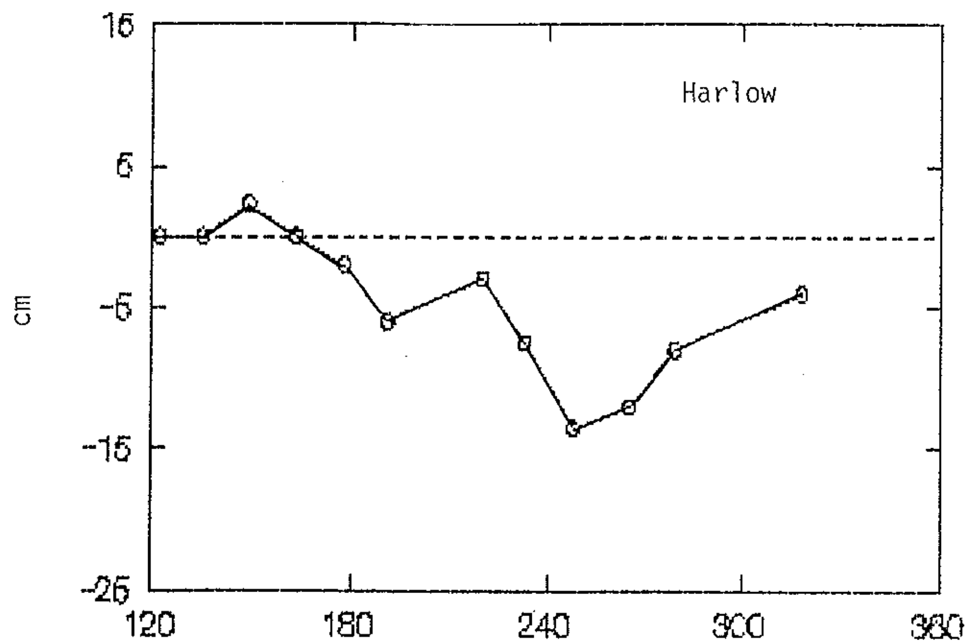
Hypsographic Curve of Stump Lake



APPENDIX C

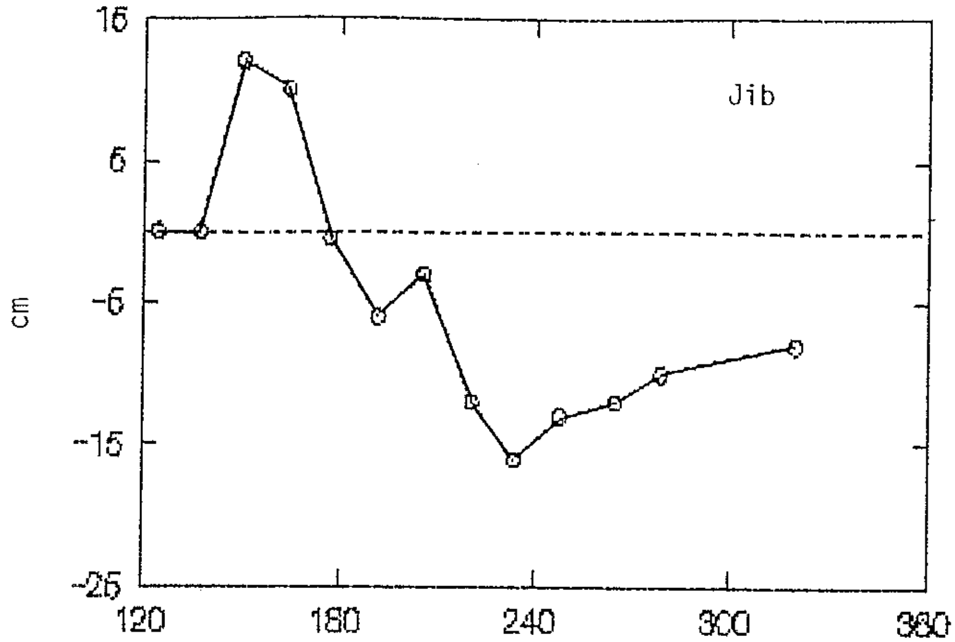
VARIATIONS IN WATER LEVELS

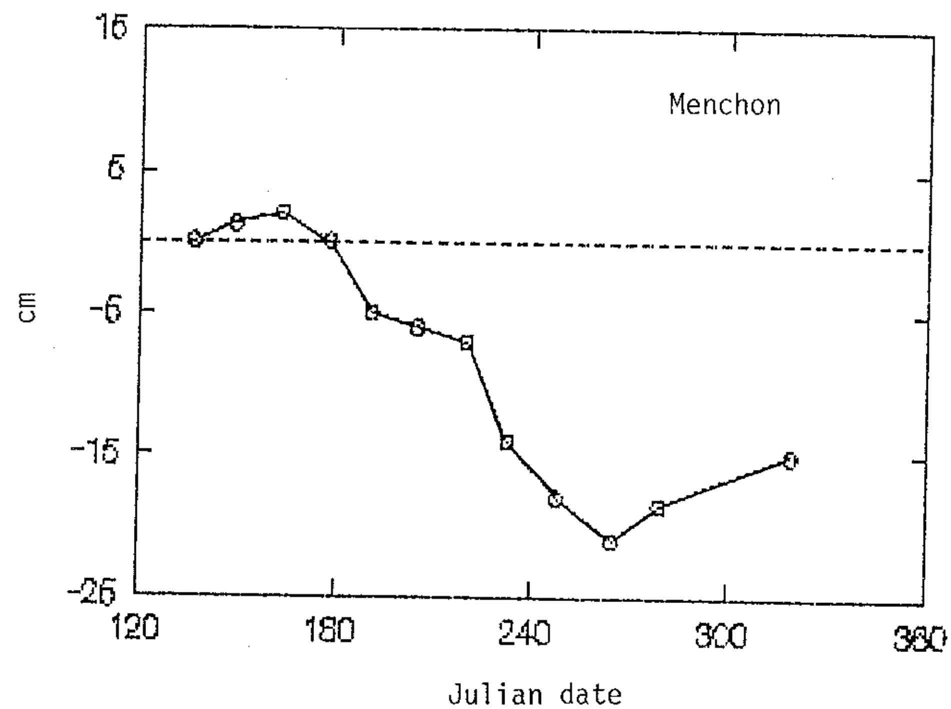




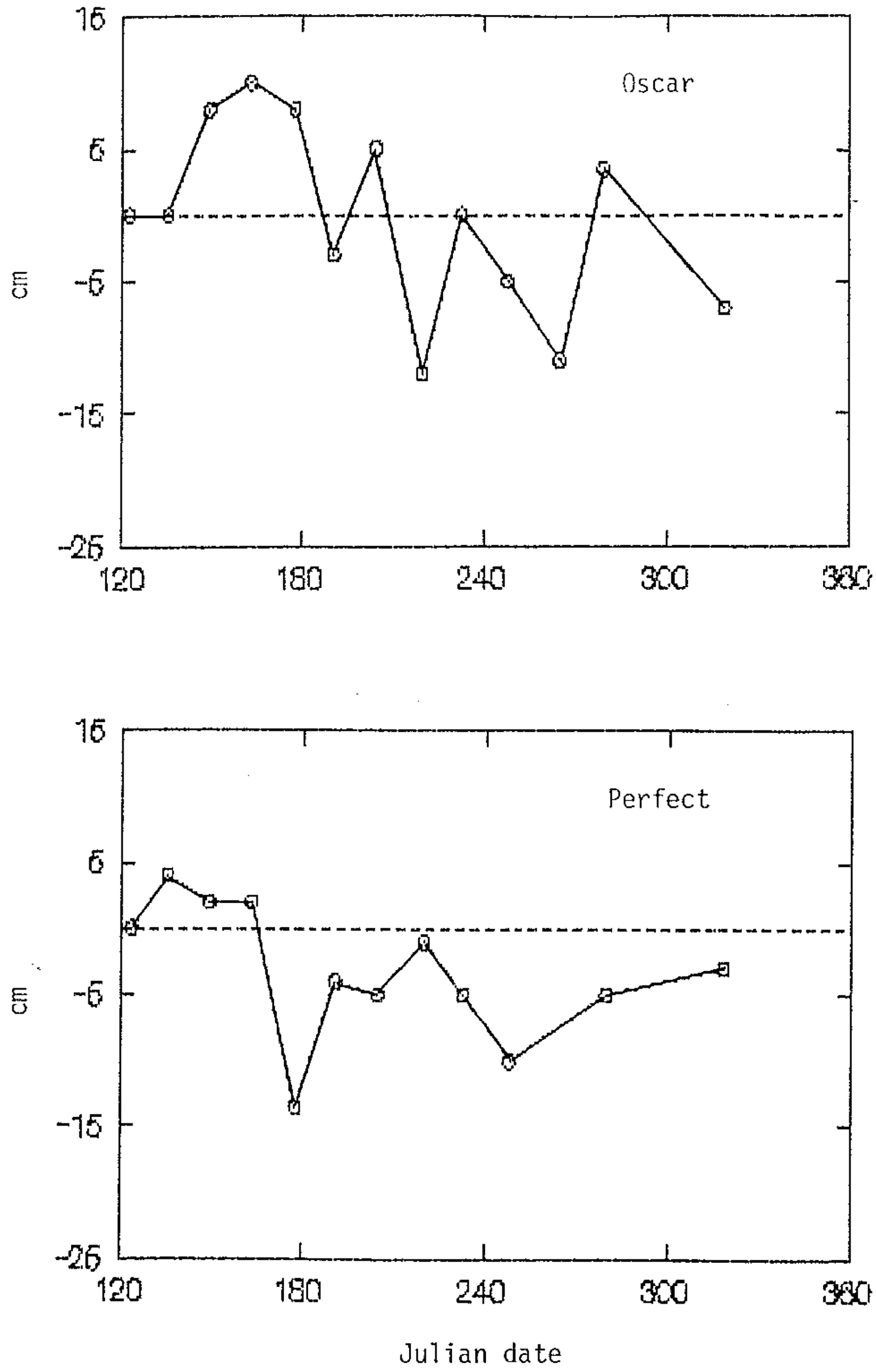
Julian date

Deviation of water level from the depth measured on 15 May 1990 for Beaver and Harlow Lakes.

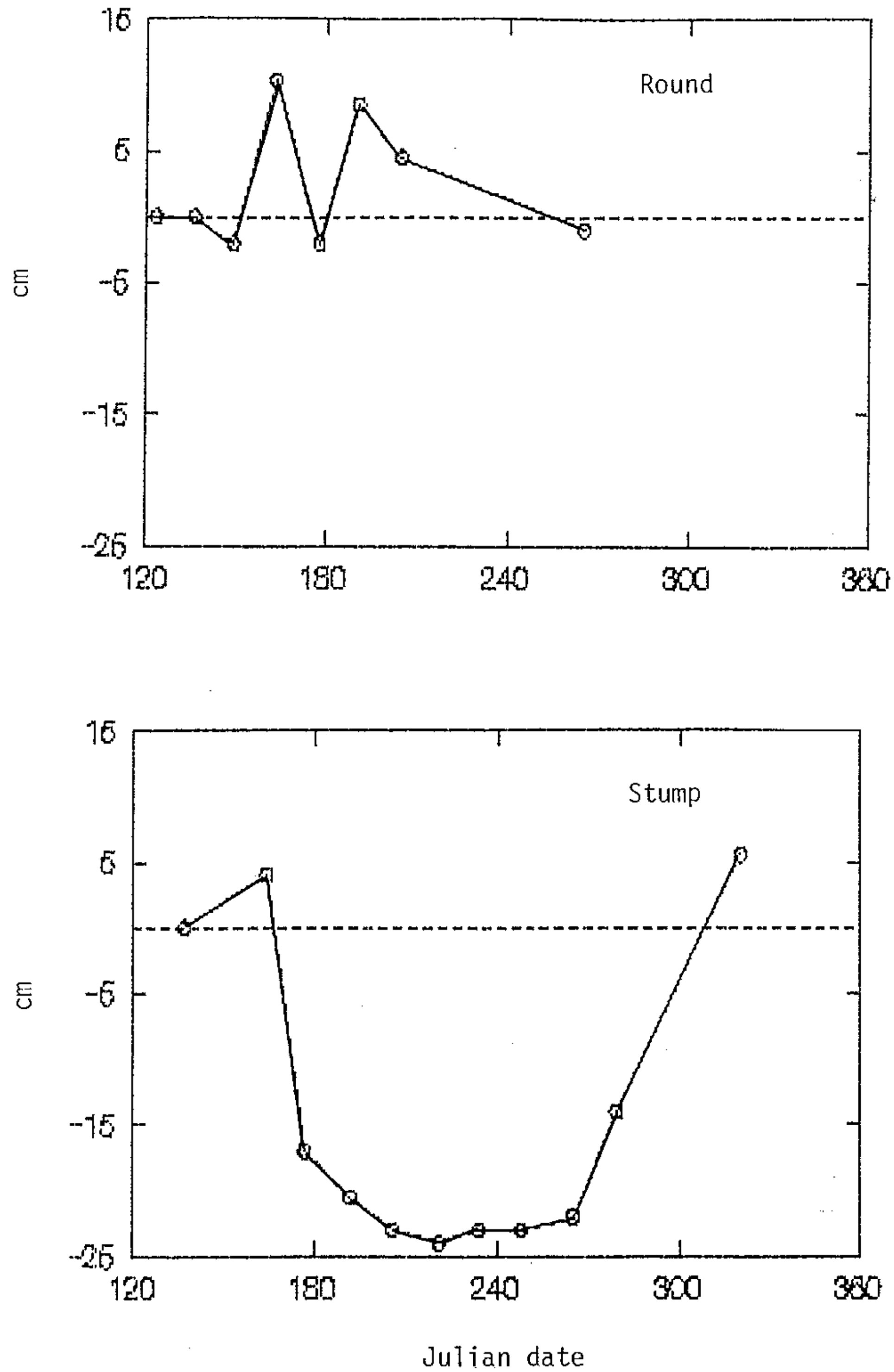




Deviation of water level from the depth measured on 15 May 1990 for Jib and Menchon Lakes.



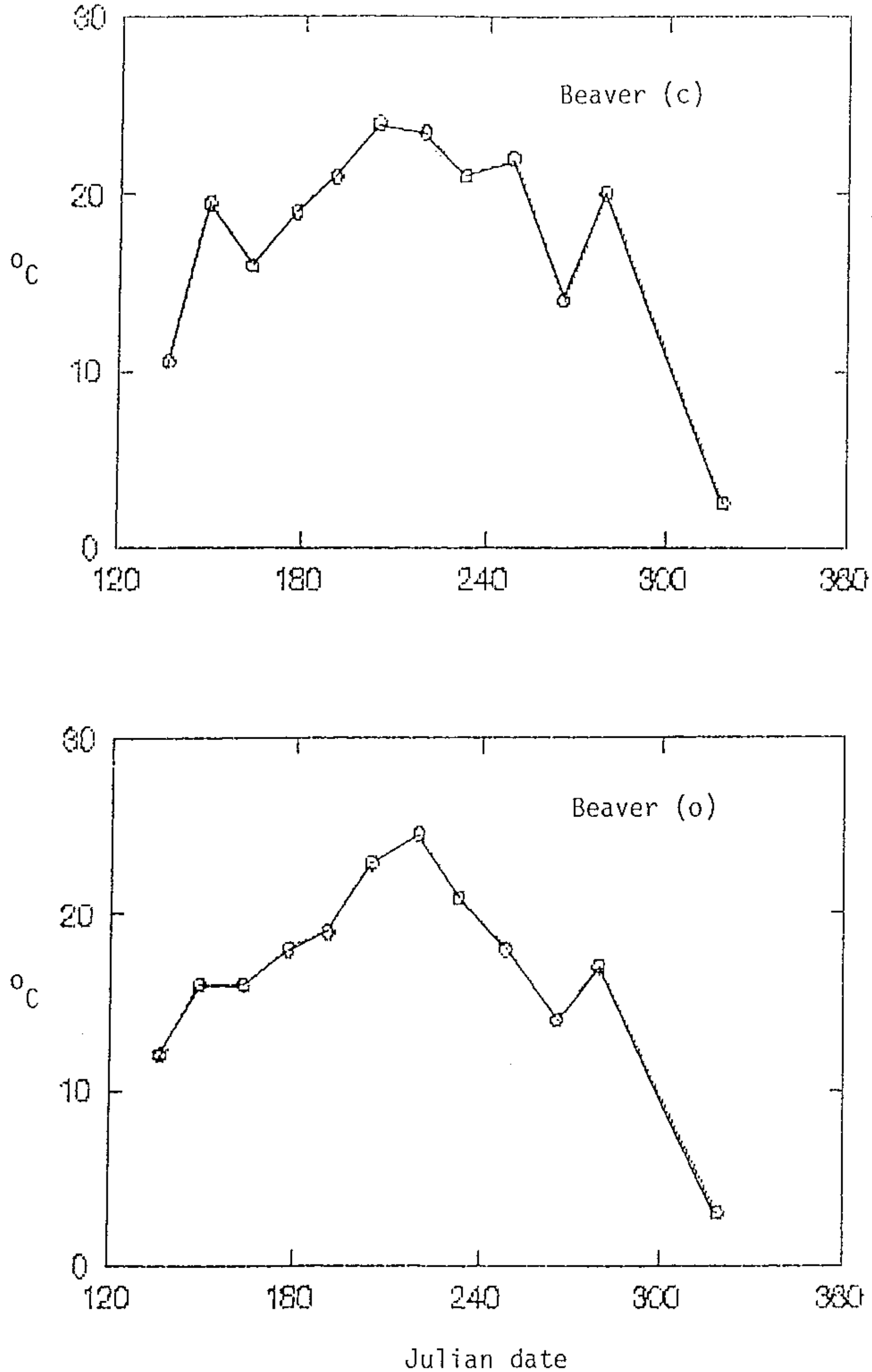
Deviation of water level from the depth measured on 15 May 1990 for Oscar and Perfect Lakes.



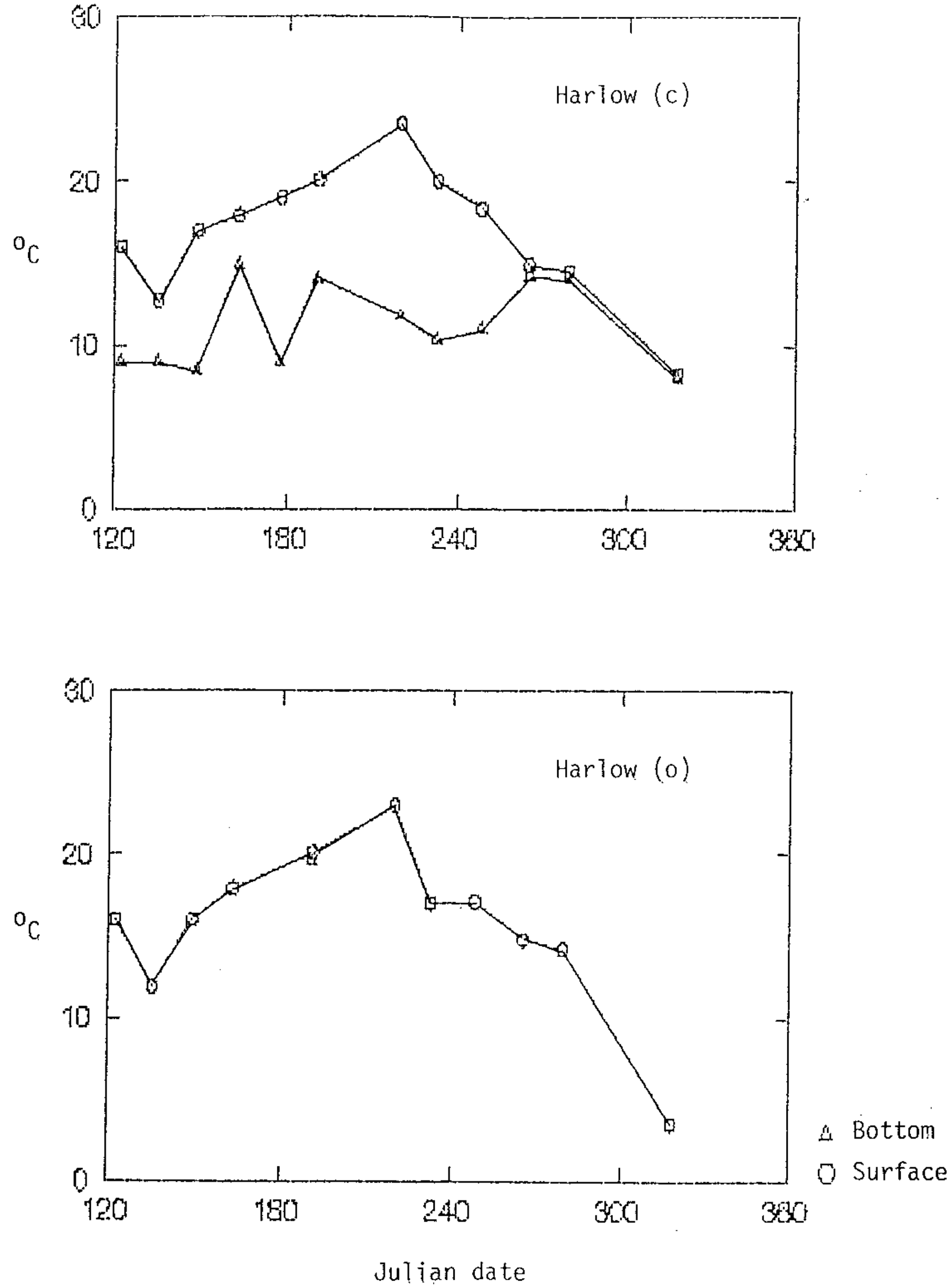
Deviation of water level from the depth measured on 15 May 1990 for Round and Stump Lakes.

APPENDIX D

SEASONAL VARIATIONS IN WATER TEMPERATURE



. Variation in surface water temperature in Beaver Lake.



Variations in surface and bottom water temperatures in Harlow Lake.

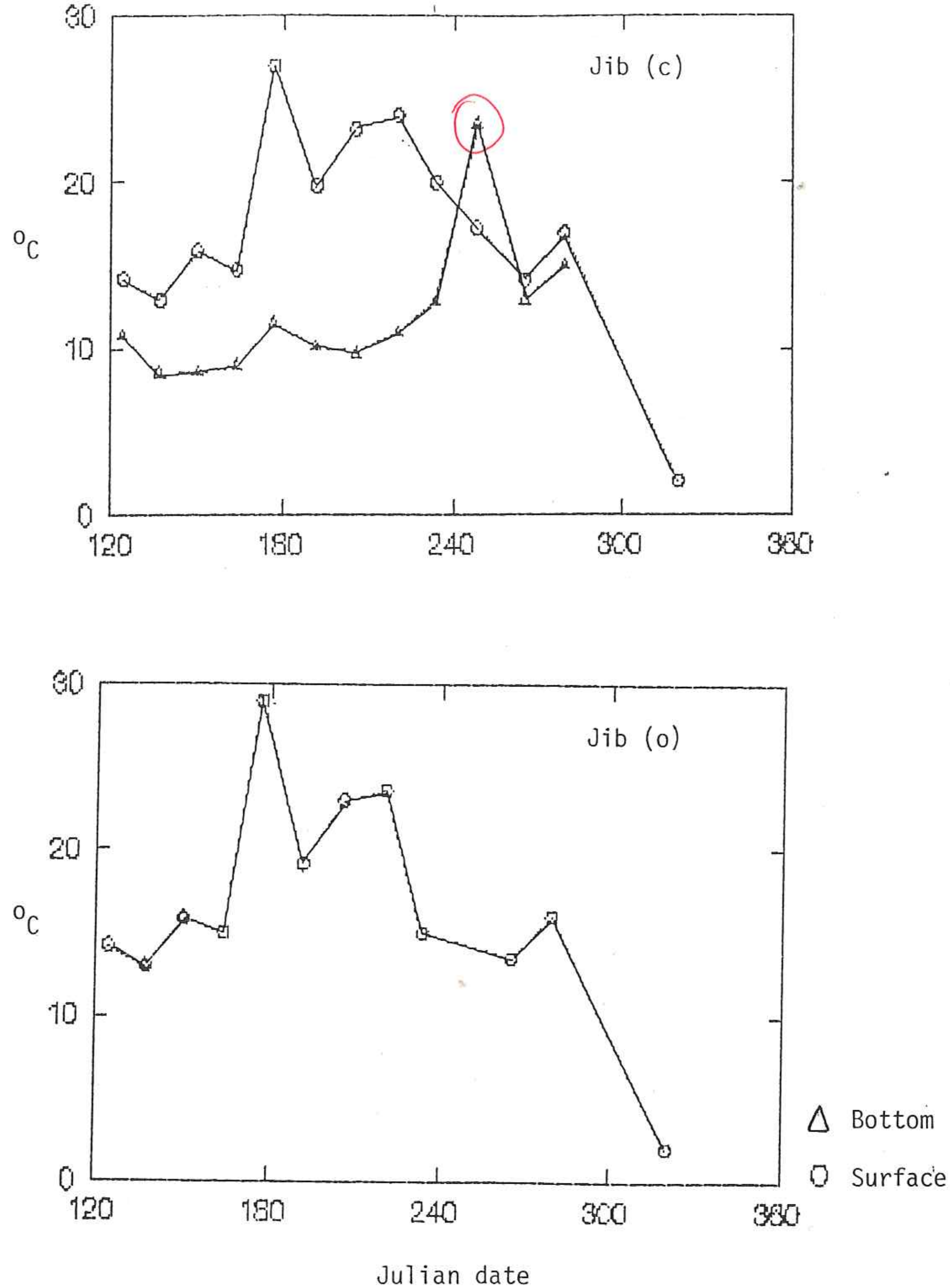
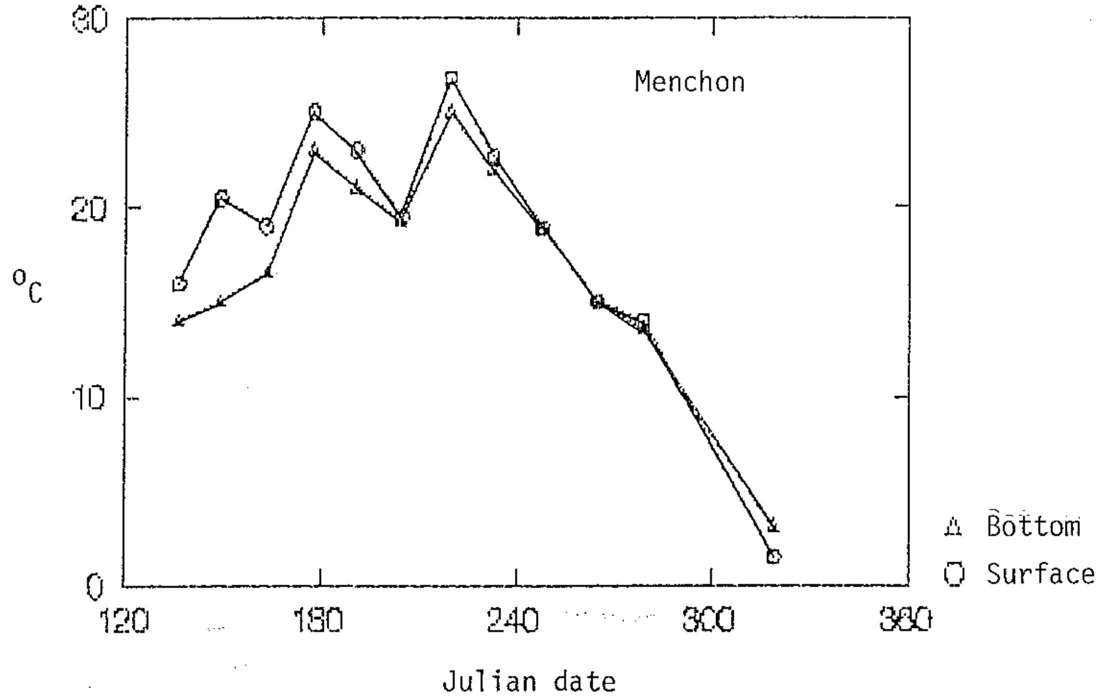


Figure Variation in surface and bottom water temperatures in Jib Lake.



Variation in surface and bottom water temperatures in Menchon Lake.

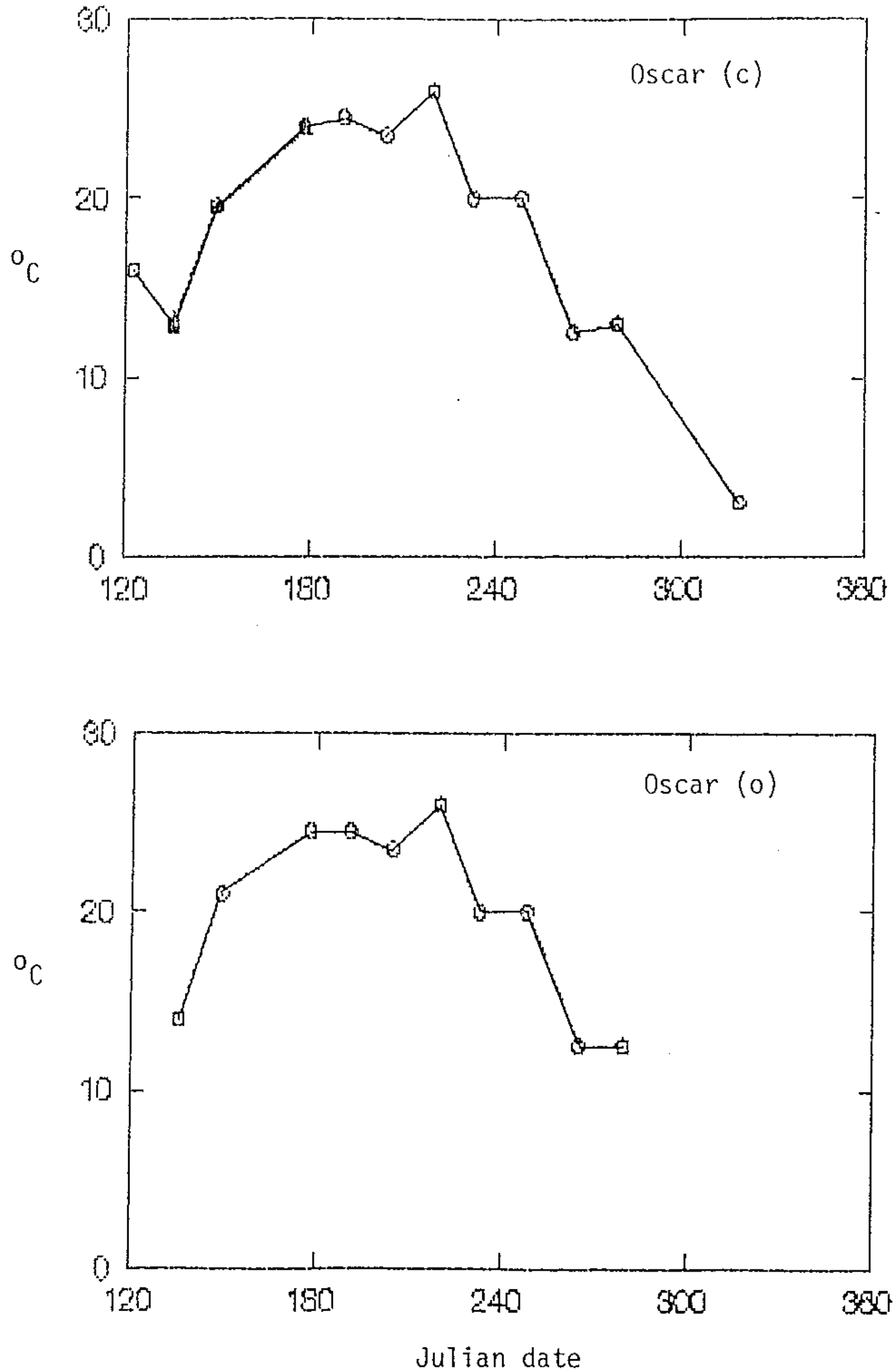


Figure Variation in surface water temperature in Oscar Lake.

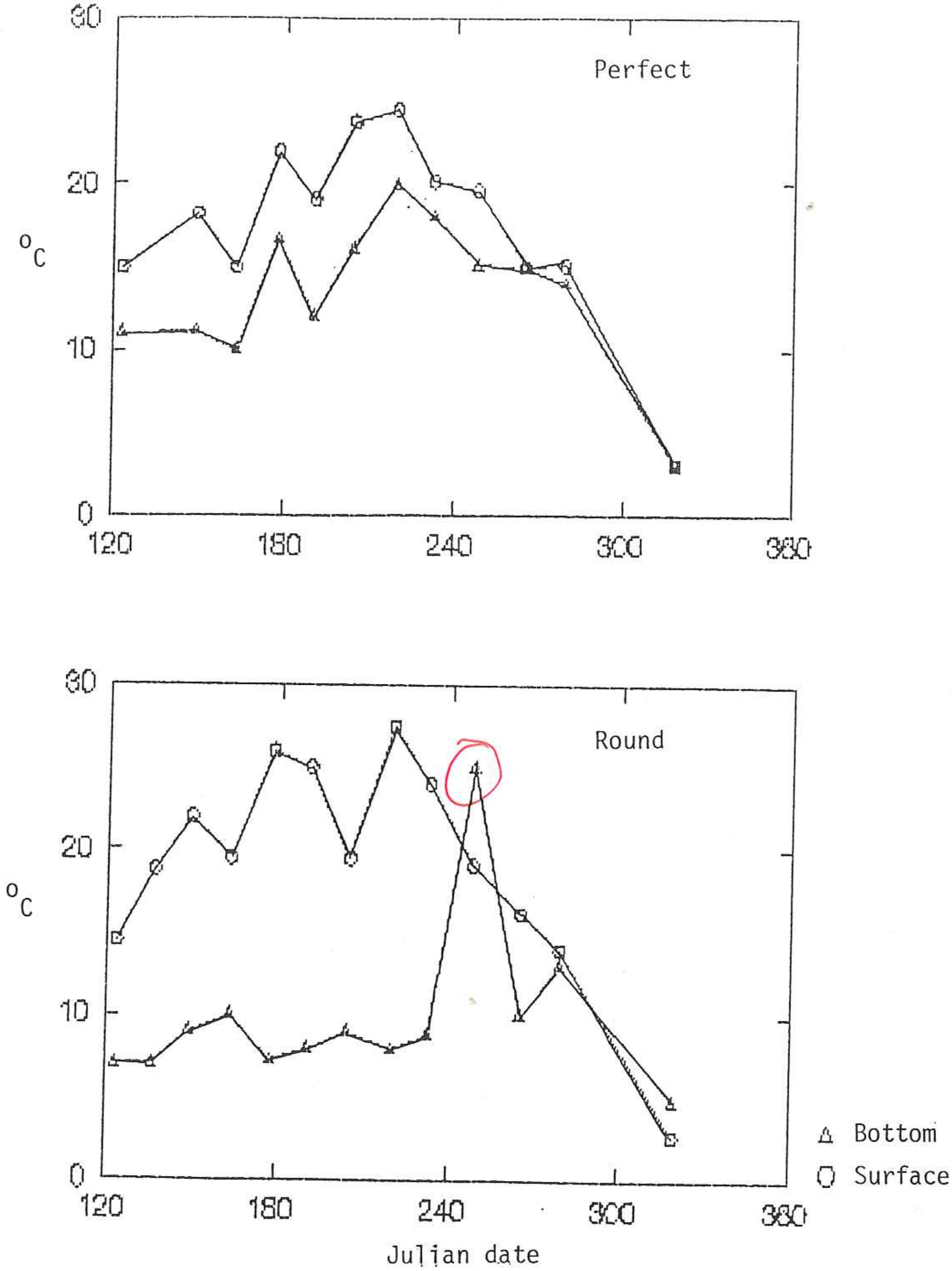


Figure . Variation in surface and bottom water temperatures in Perfect and Round Lakes.

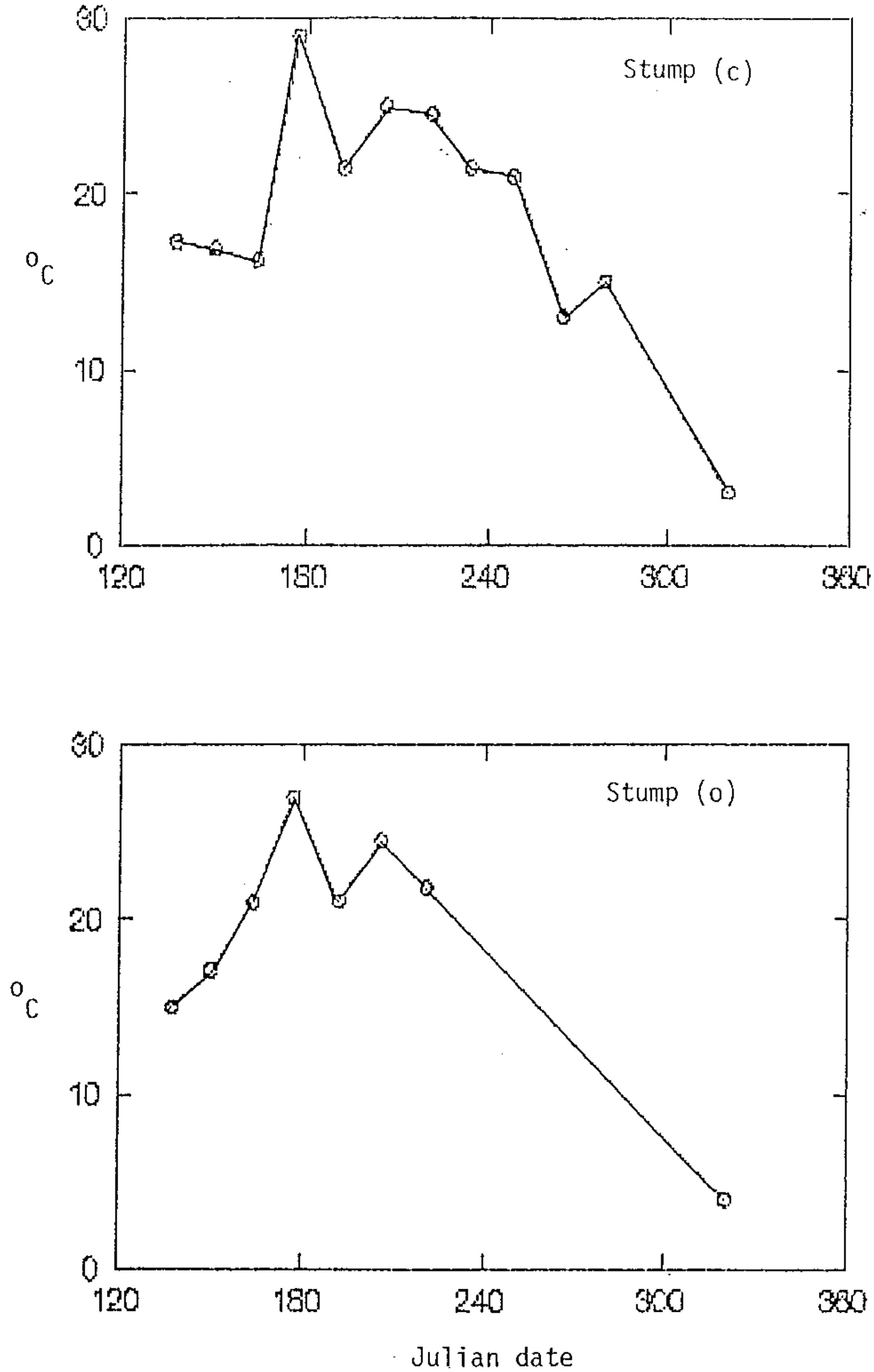
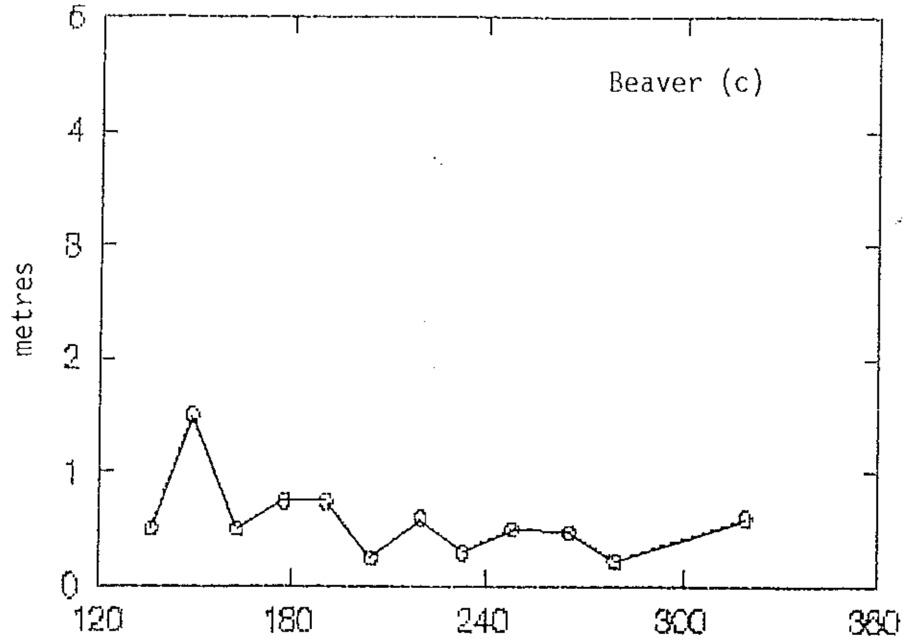
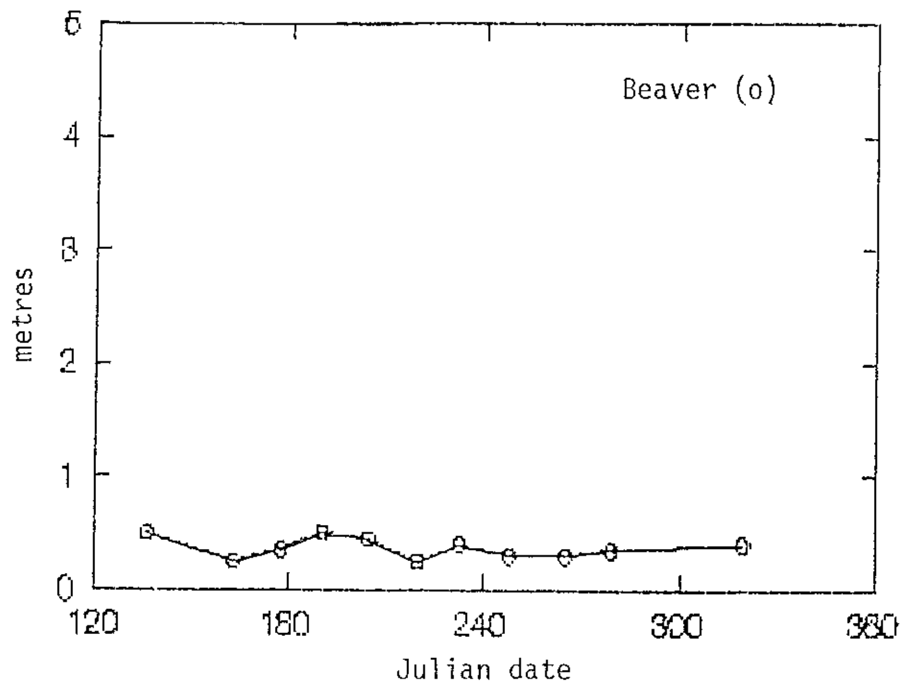


Figure . Variation in surface water temperatures for Stump Lake.

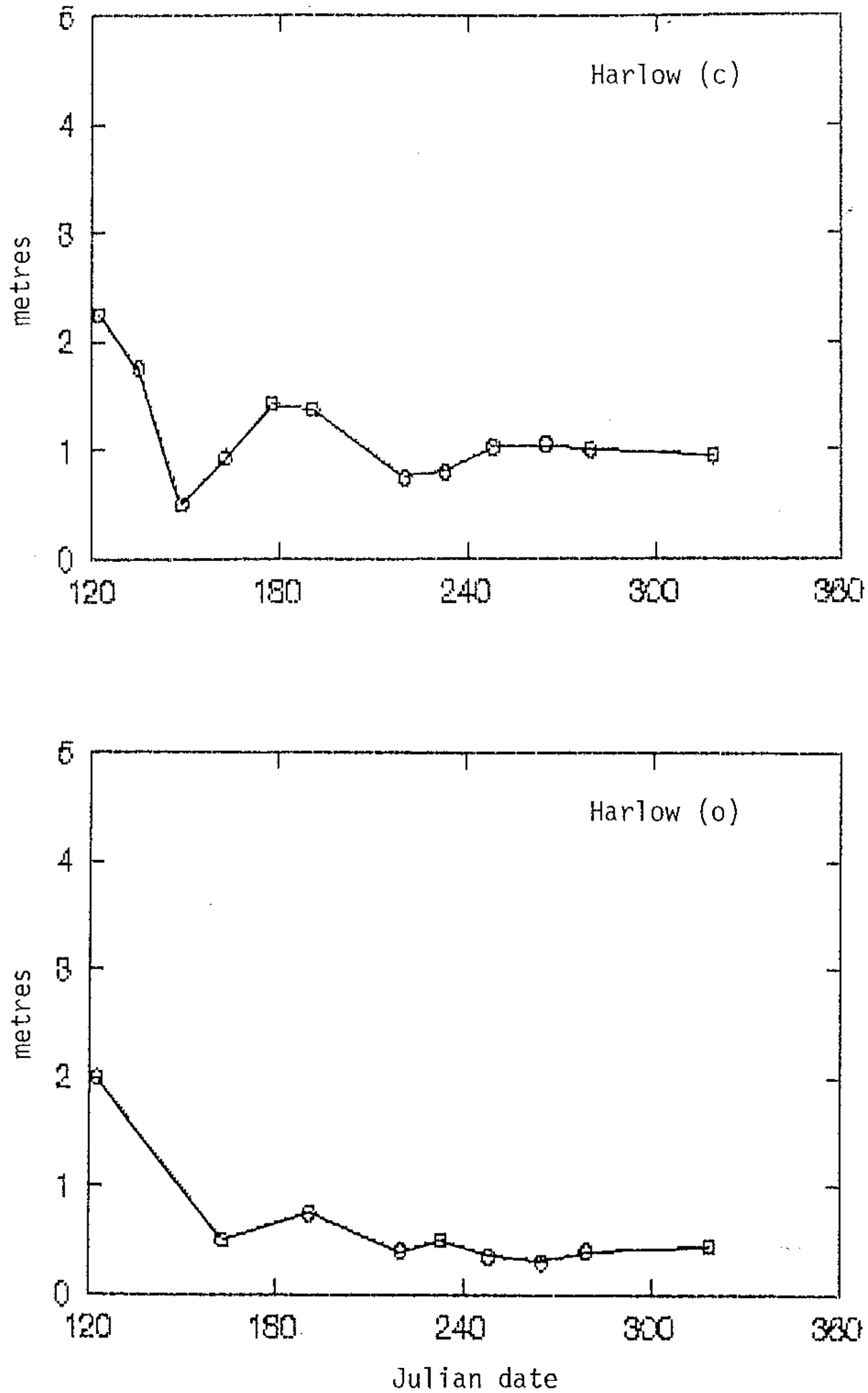
APPENDIX E

SEASONAL VARIATIONS IN SECCHI DISK DEPTHS

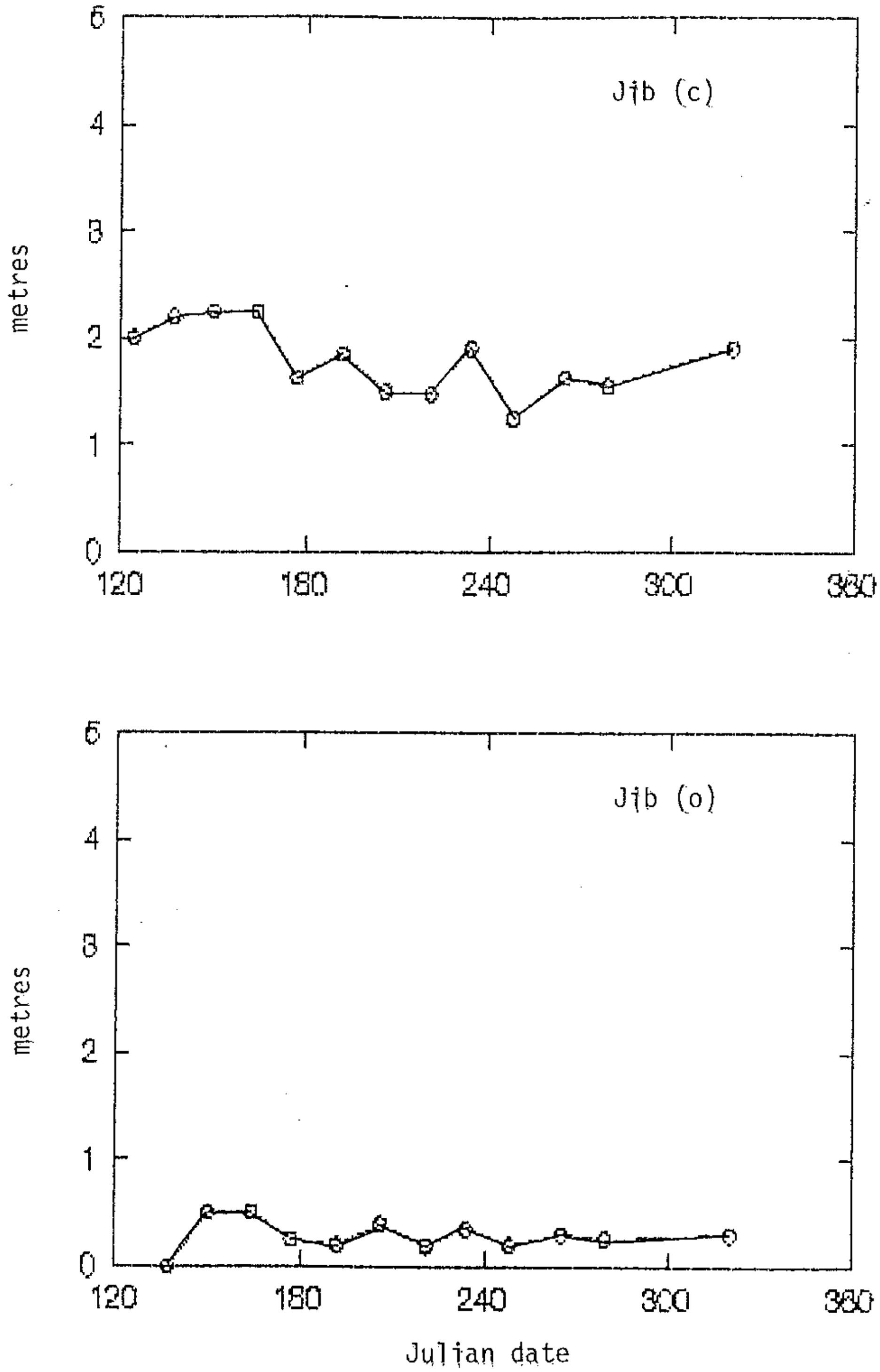




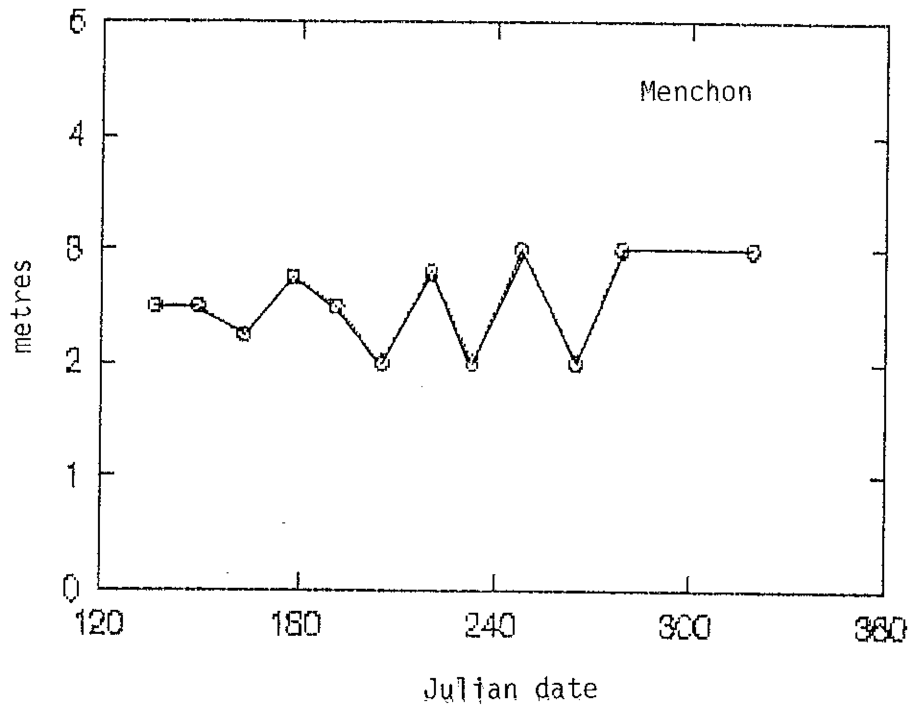
Seasonal changes in light penetration depths (m) measured with a Secchi disk for Beaver Lake.



Seasonal changes in light penetration depths (m)
measured with a Secchi disk for Harlow Lake.



Seasonal changes in light penetration depths (m) measured with a Secchi disk for Jib Lake.



Seasonal changes in light penetration depths (m)
measured with a Secchi disk for Menchon.

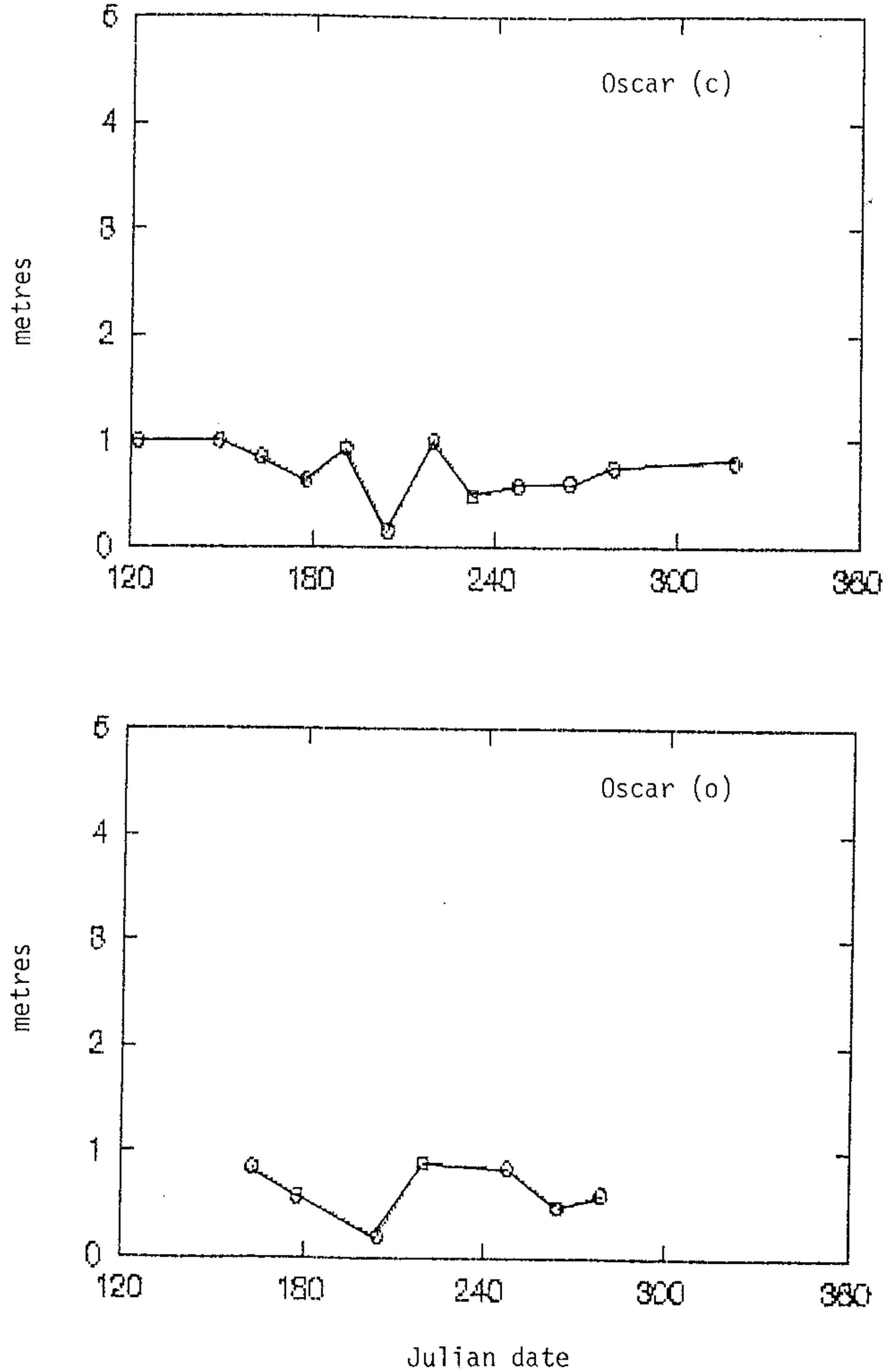


Figure Seasonal changes in light penetration depths (m) measured with a Secchi disk for Oscar Lake.

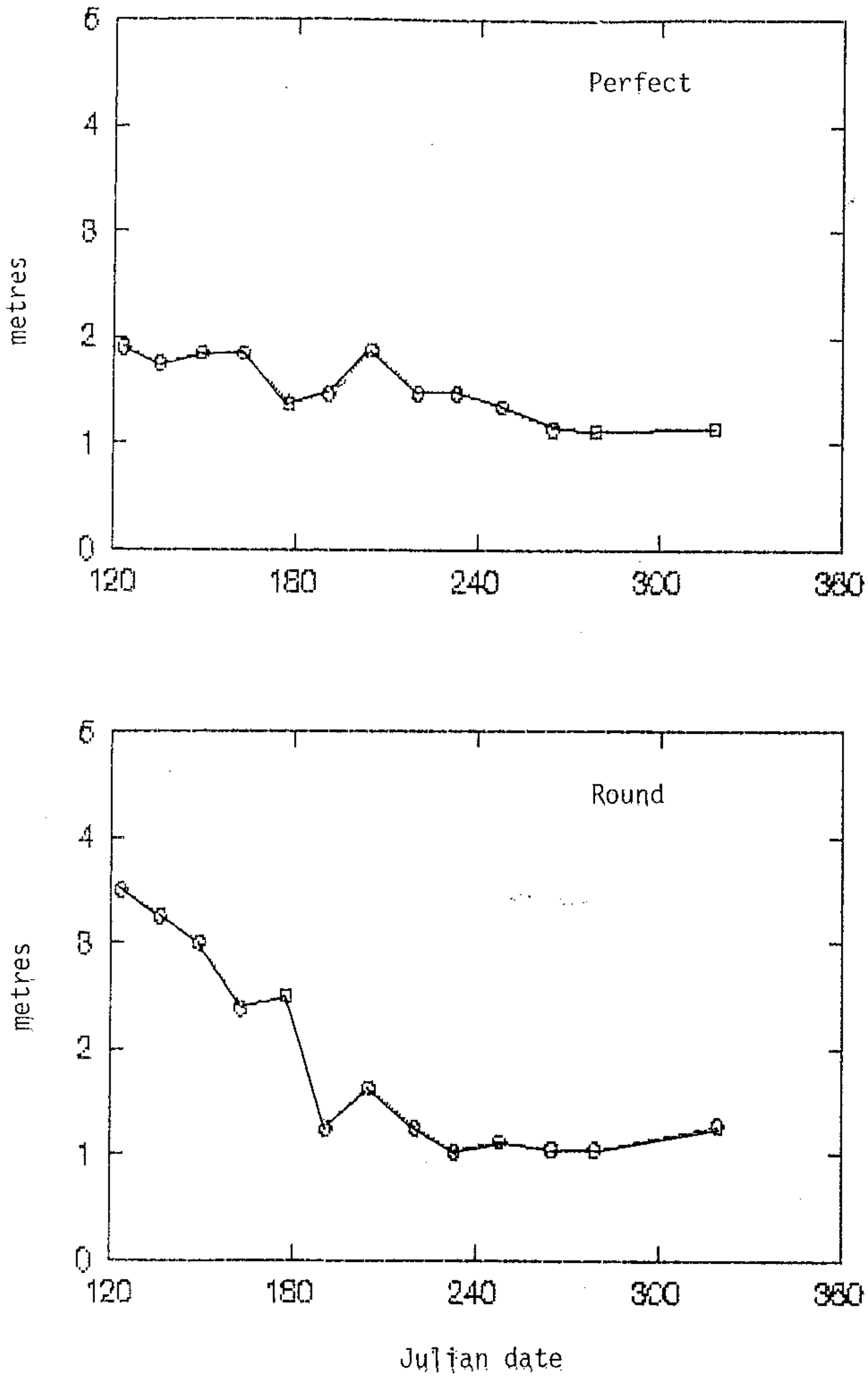
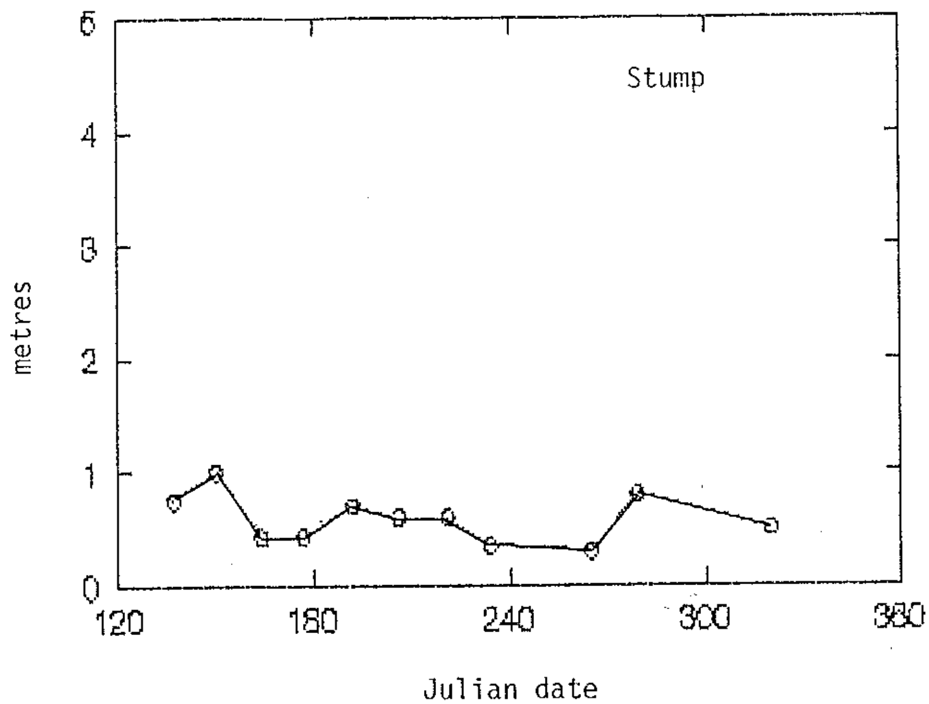


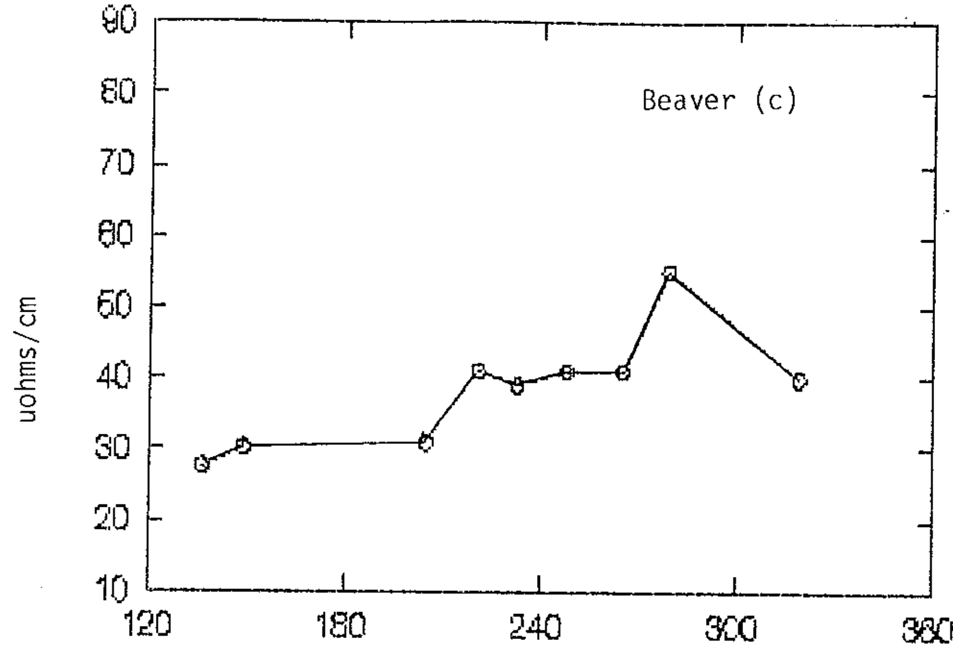
Figure . Seasonal changes in light penetration depths (m) measured with a Secchi disk for Perfect and Round Lakes.

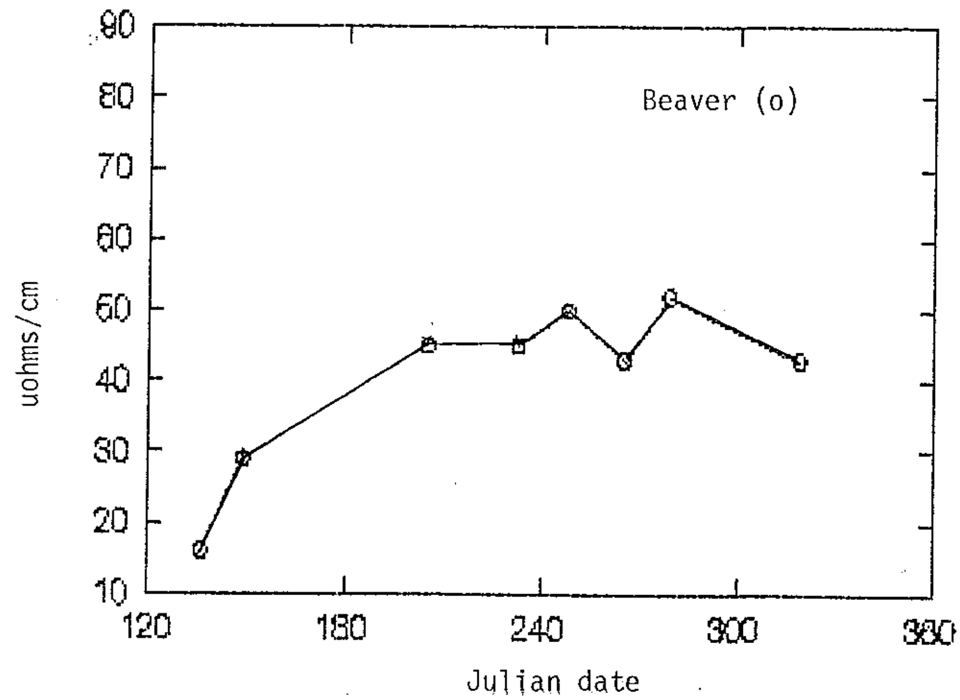


Seasonal changes in light pentration depths (m) measured with a Secchi disk for Stump Lake.

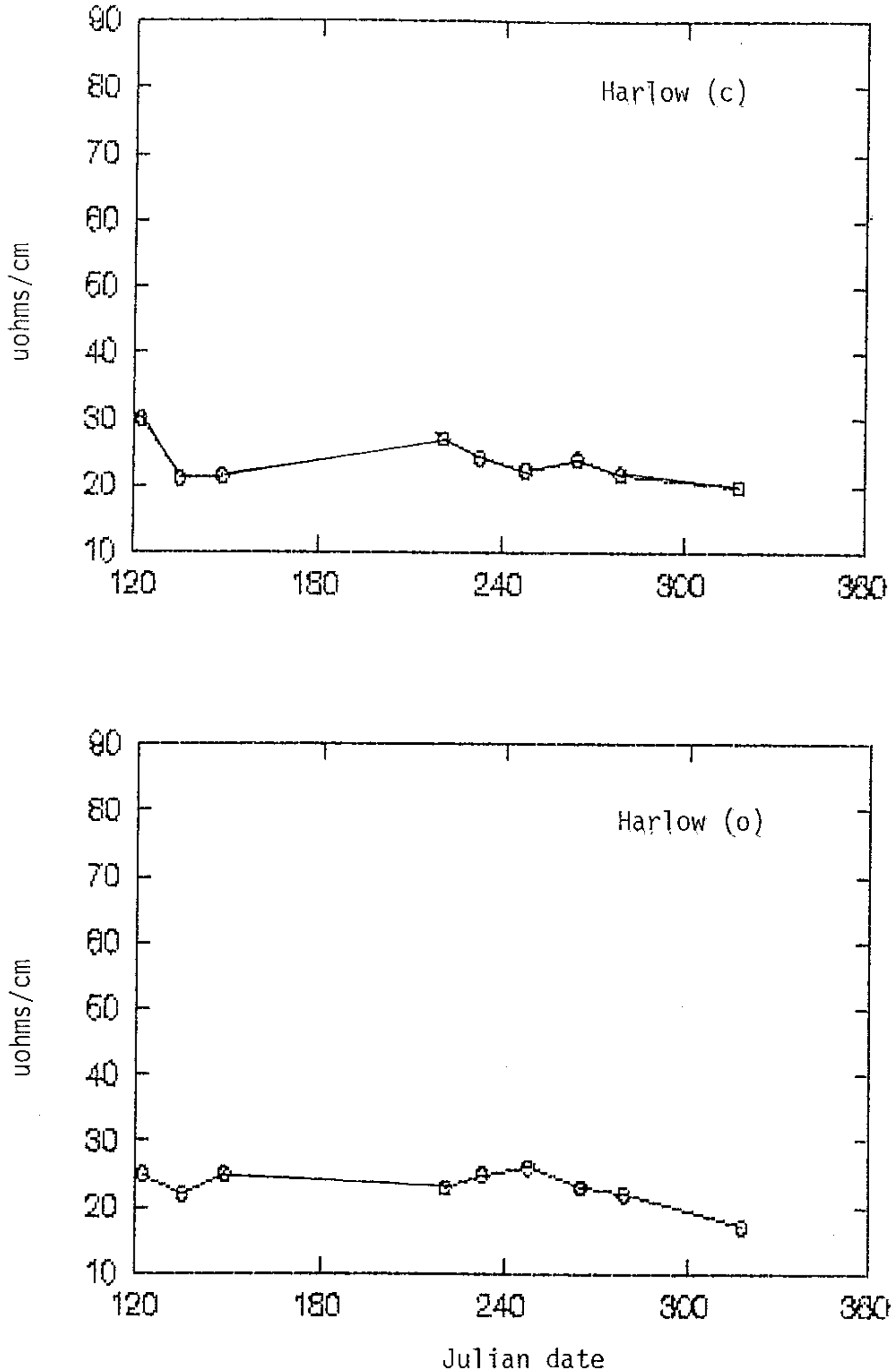
APPENDIX F

SEASONAL CHANGES IN CONDUCTIVITY

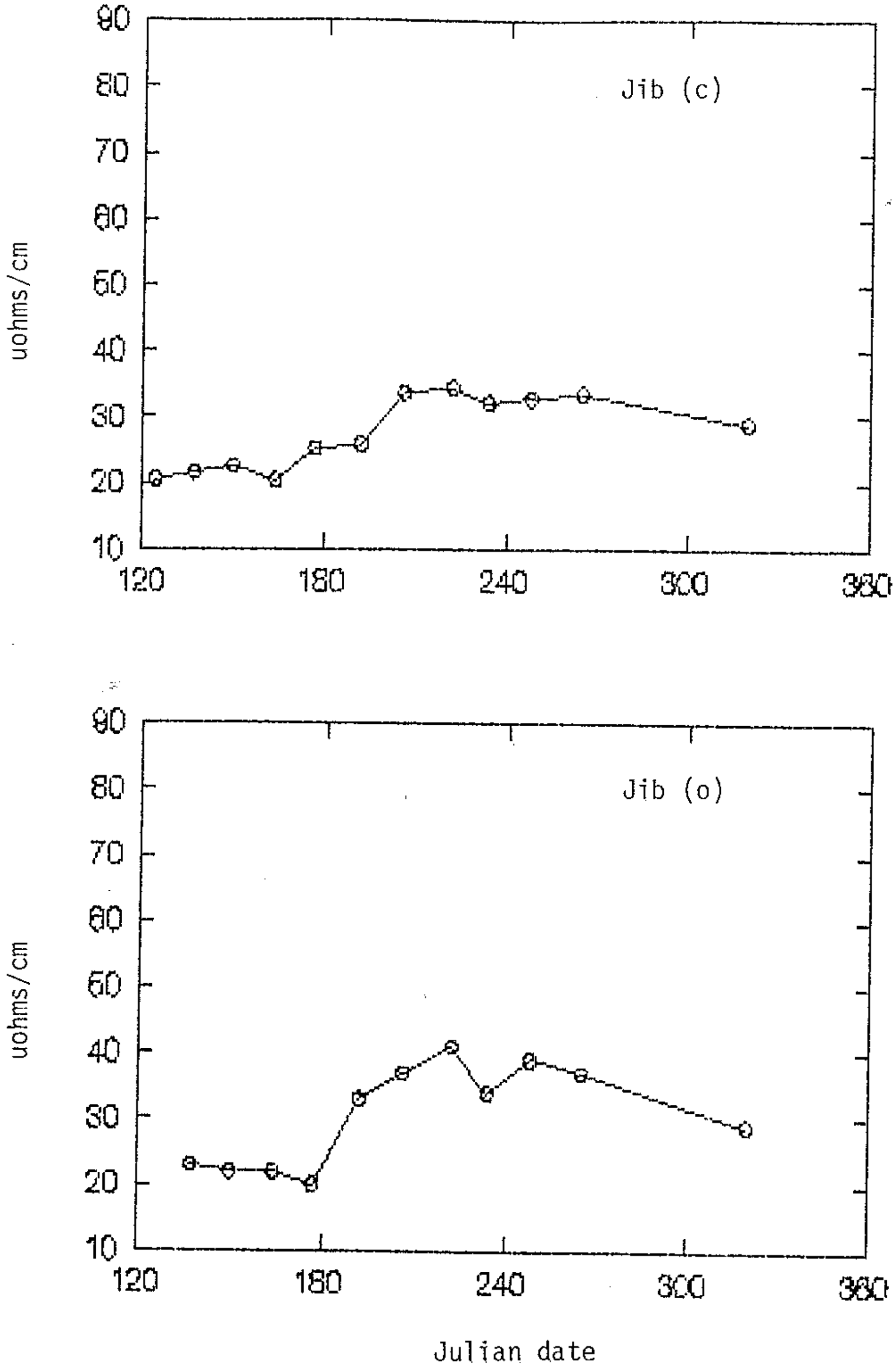




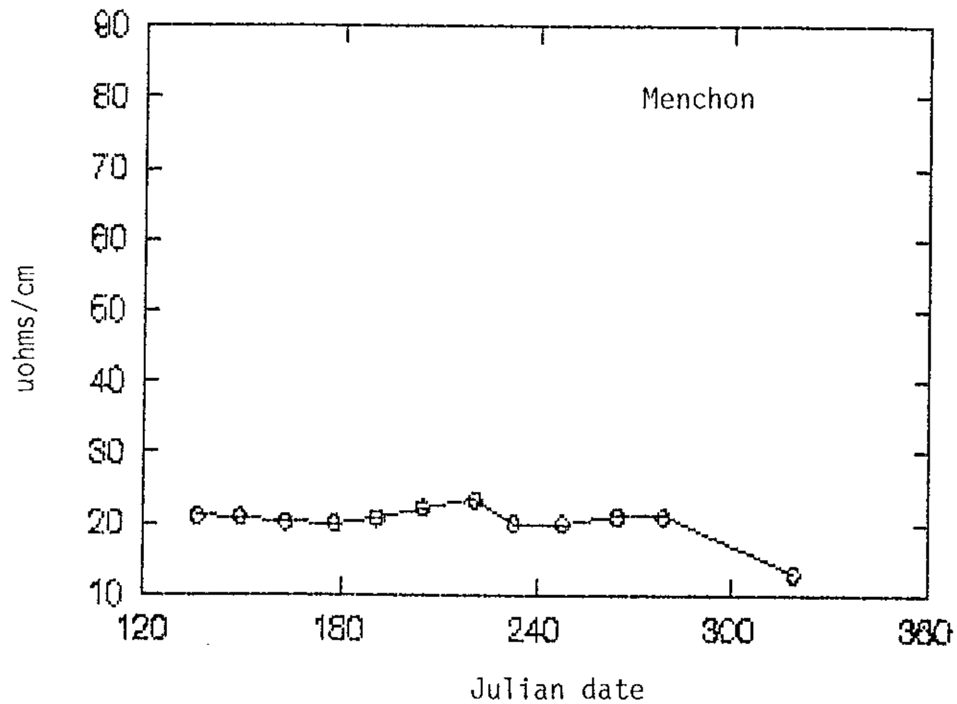
Changes in conductivity (uohms/cm) in Beaver Lake.



Changes in conductivity (uohms/cm) for Harlow Lake.



Changes in conductivity (uohms/cm) for Jib Lake.



Changes in conductivity (uohms/cm) for Menchon Lake.

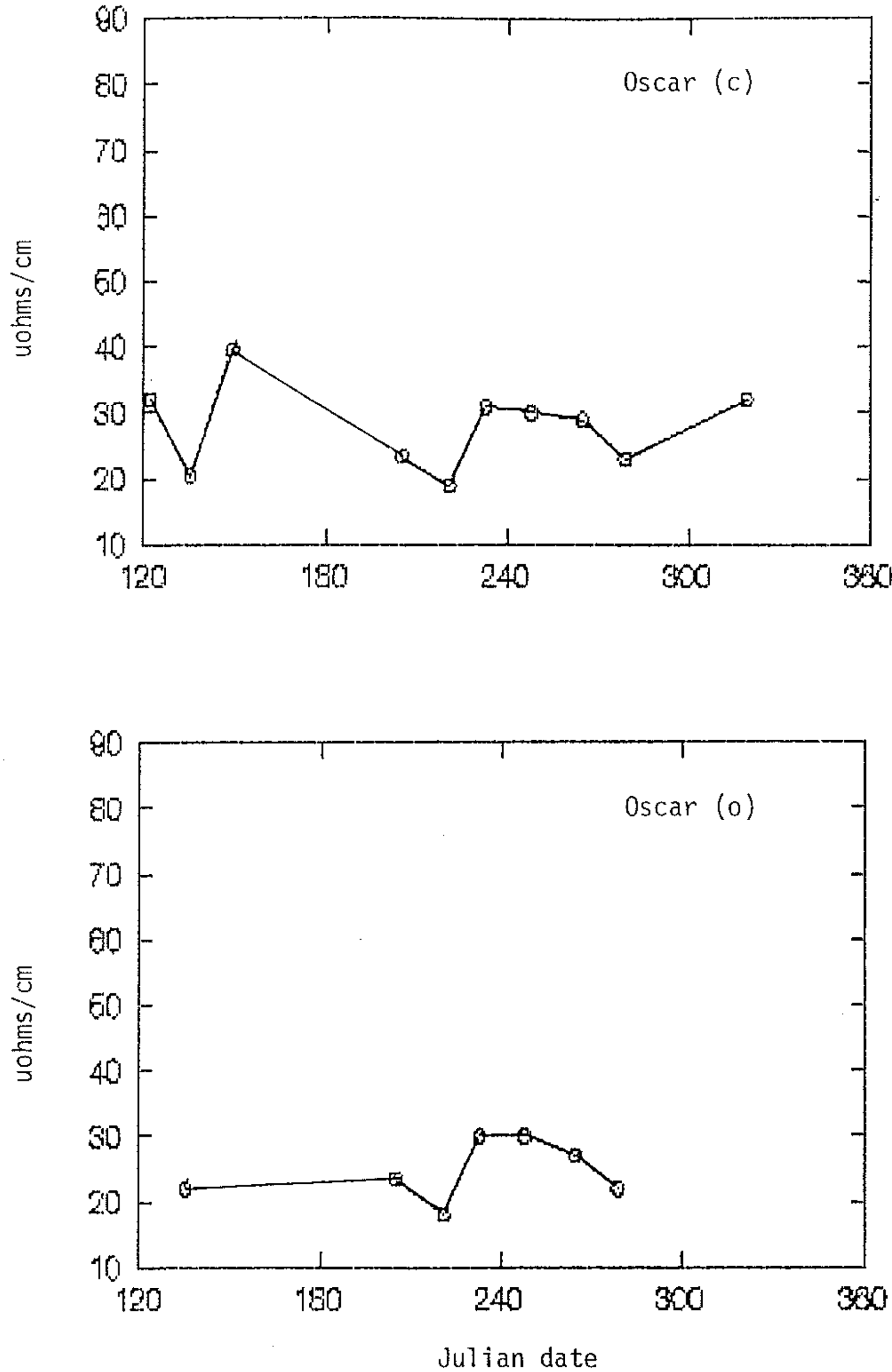
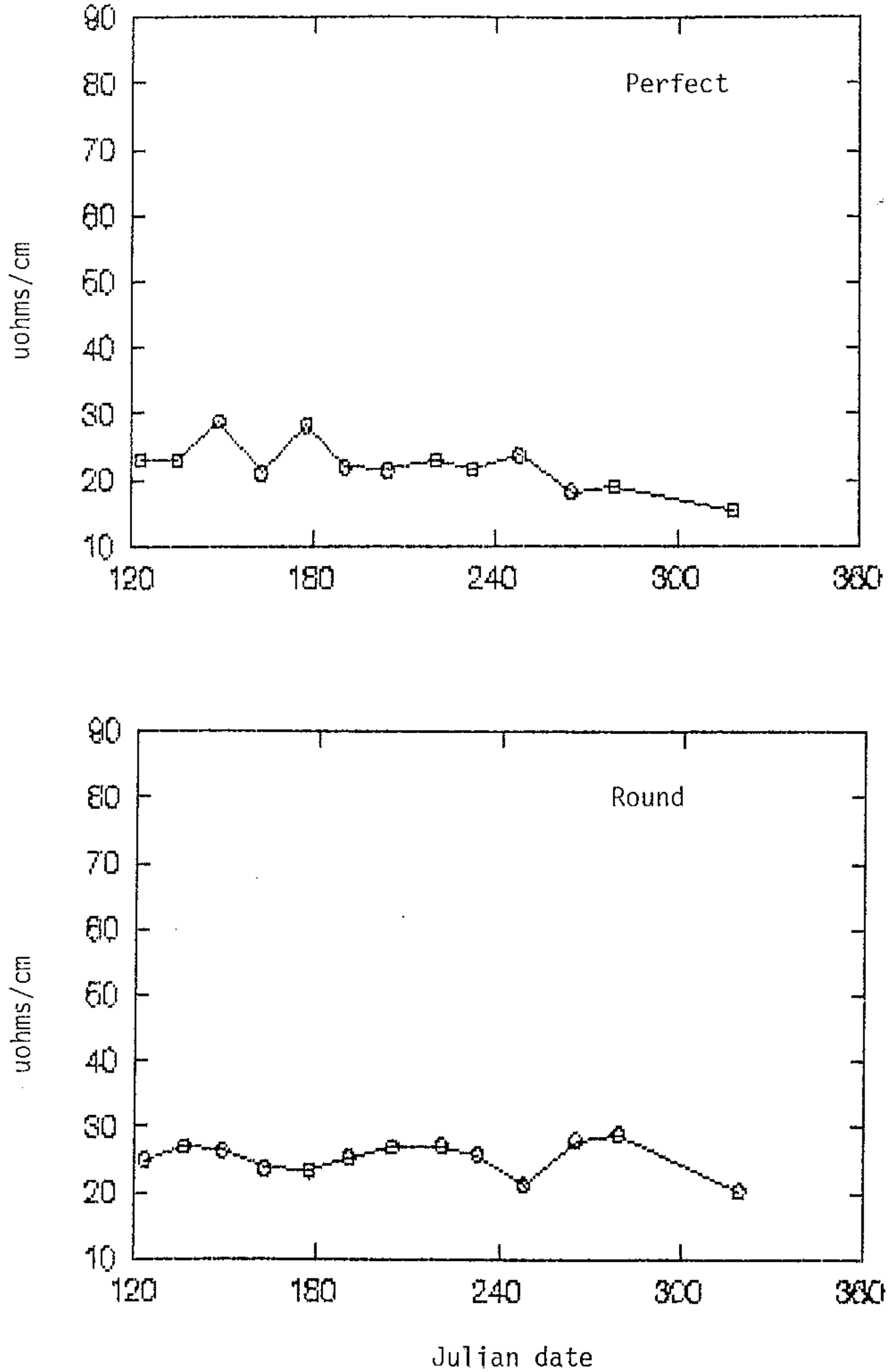
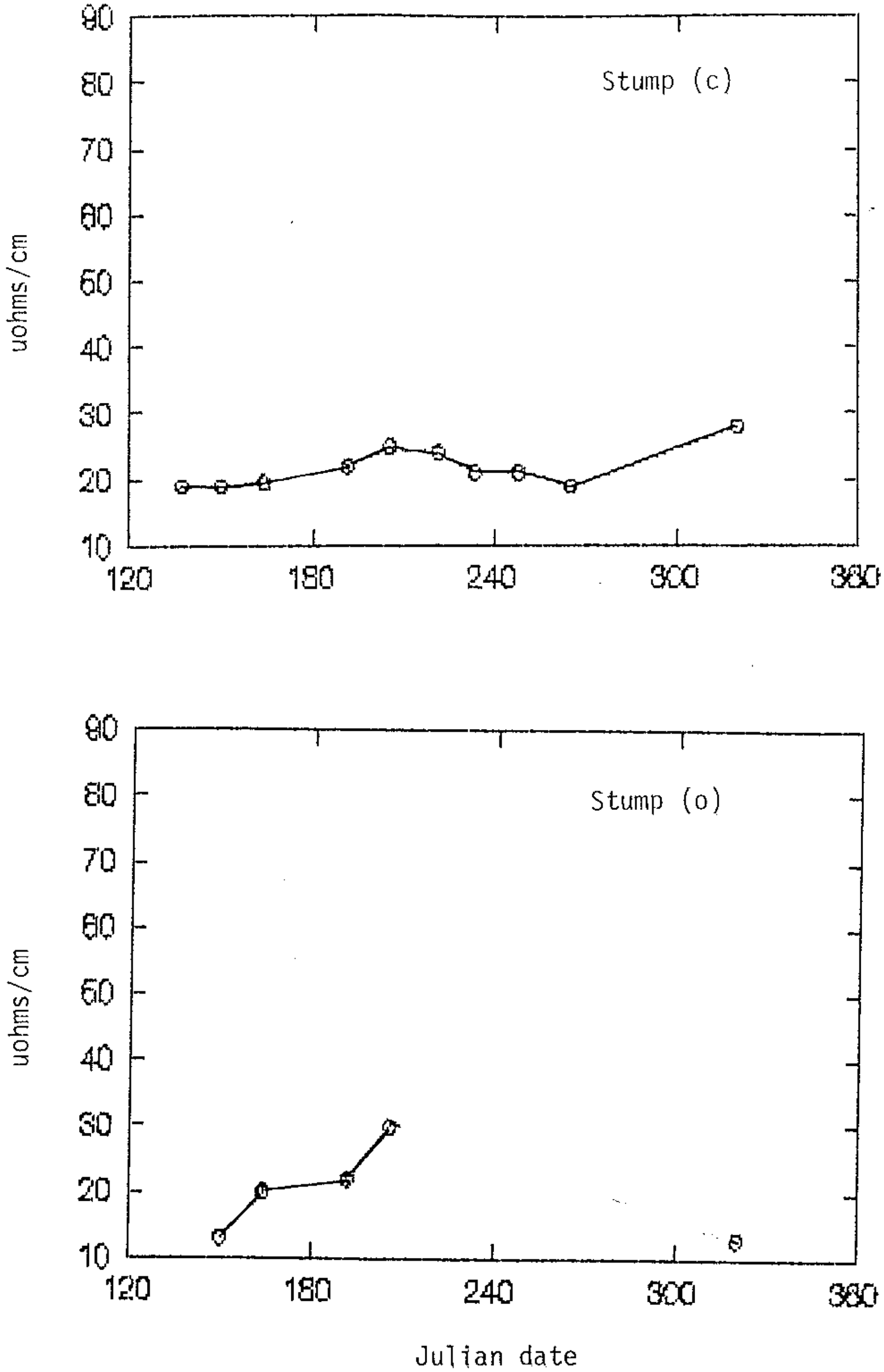


Figure . Changes in conductivity (uohms/cm) for Oscar Lake.



Changes in conductivity (uohms/cm) for Perfect and Round Lakes.



Changes in conductivity (uohms/cm) for Stump Lake.

APPENDIX G

SEASONAL VARIATION IN pH

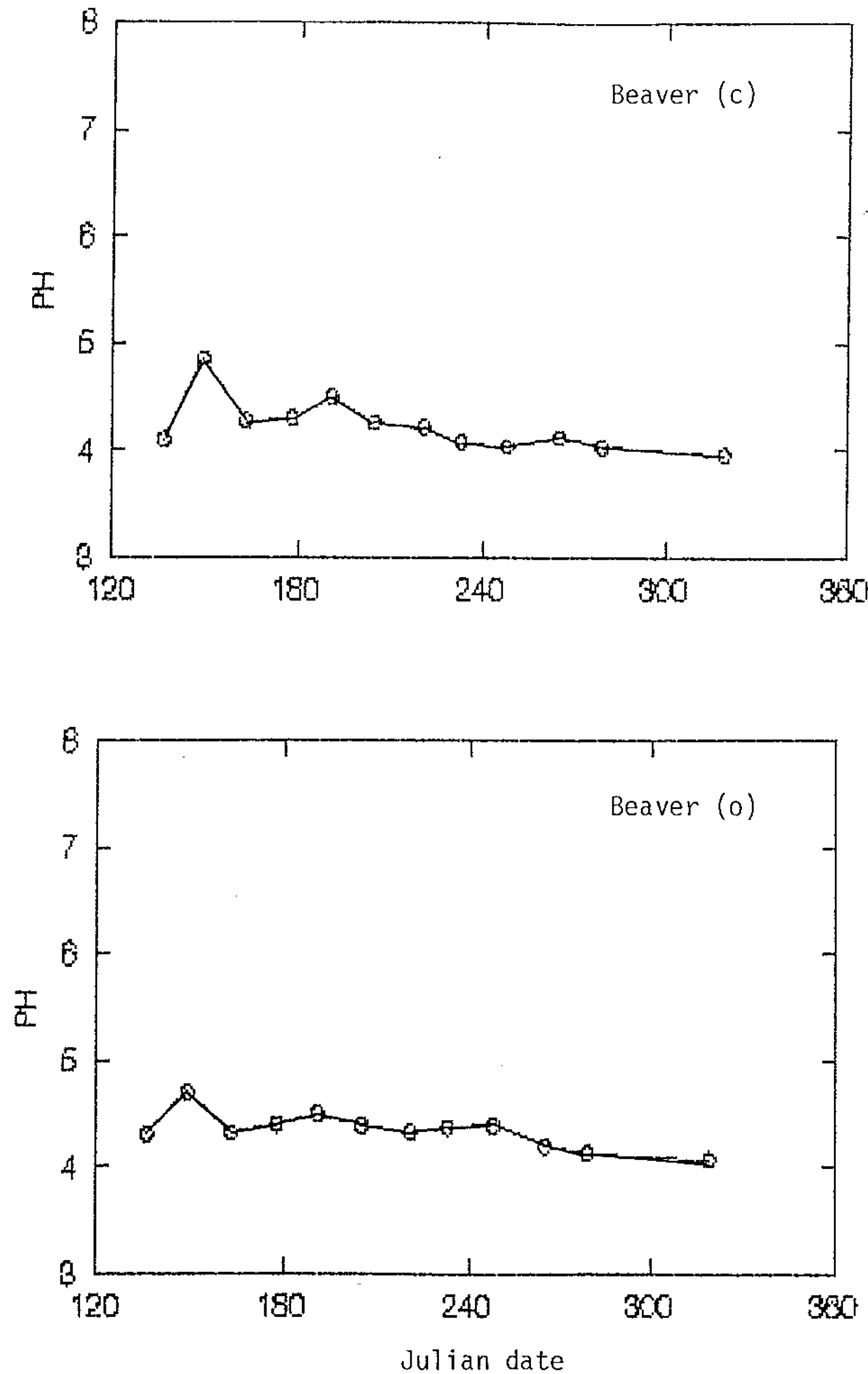
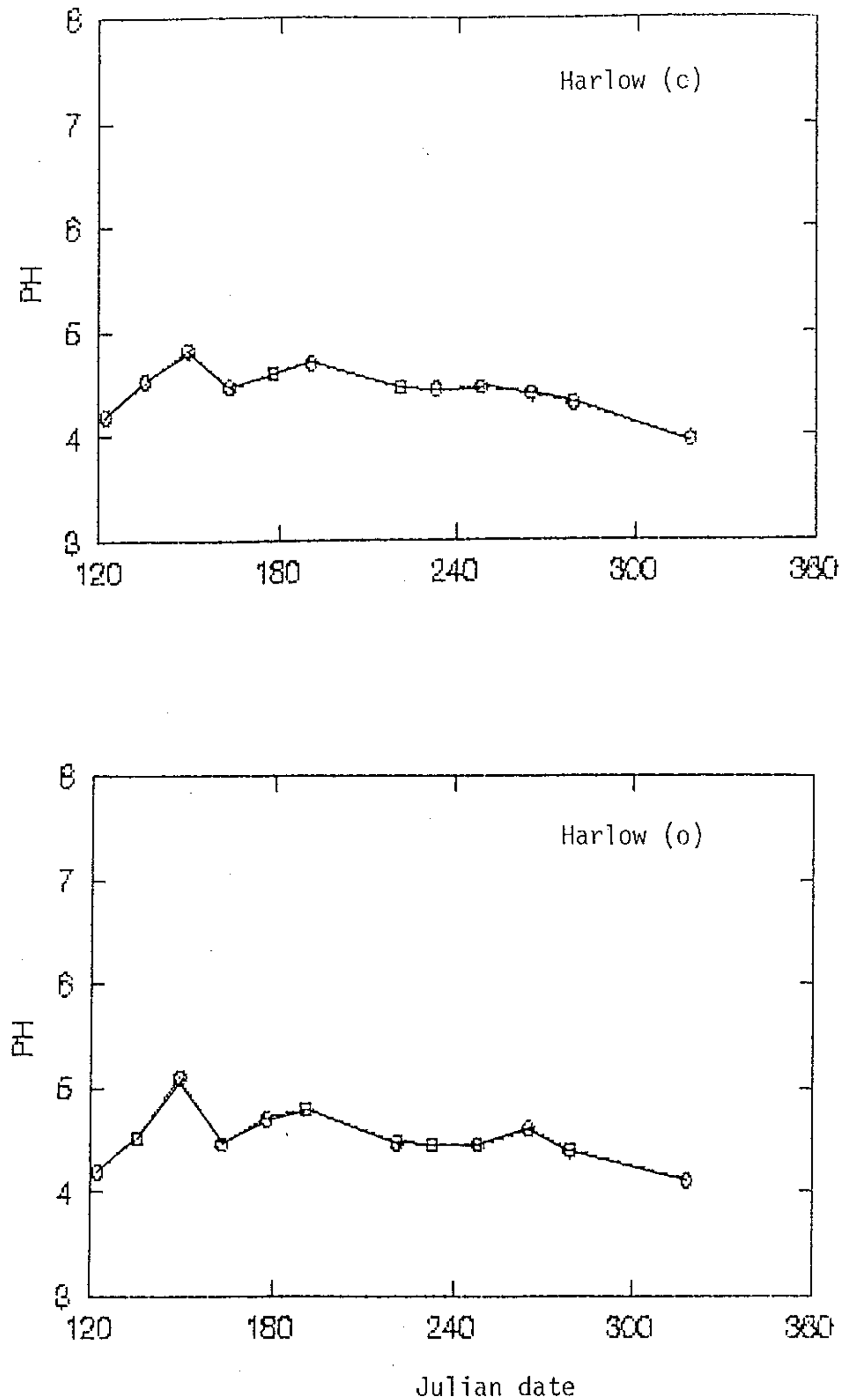
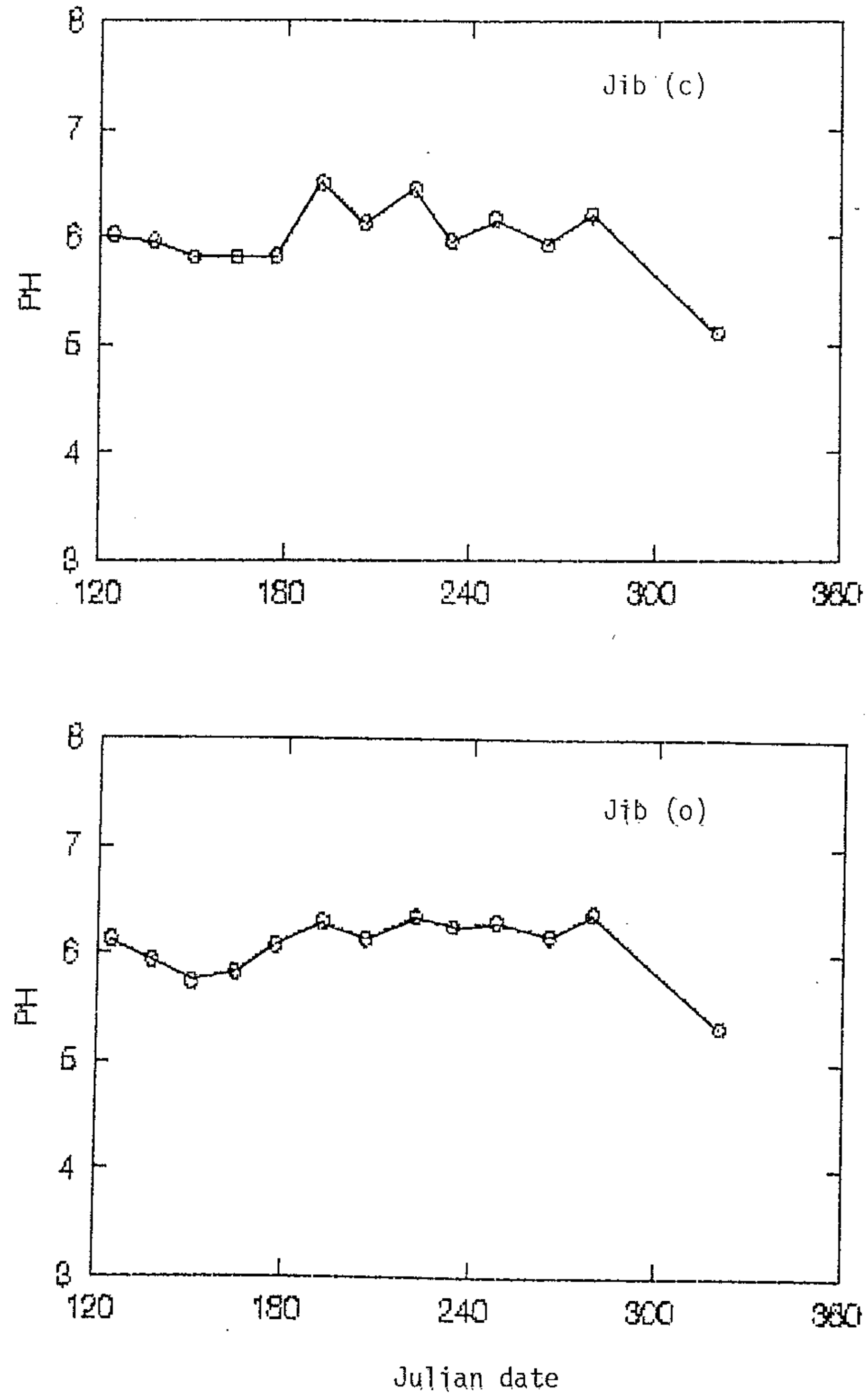


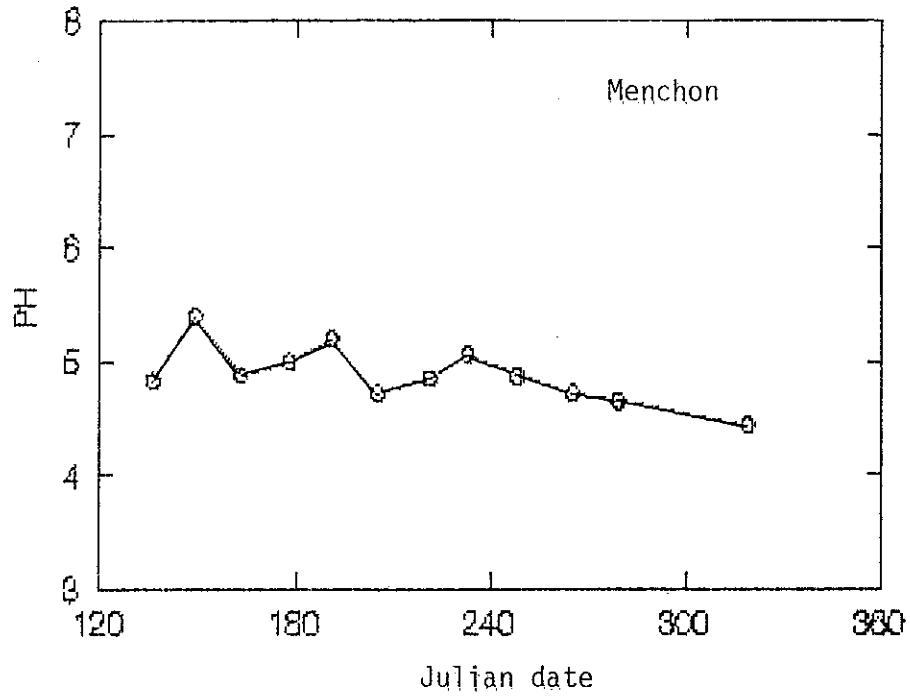
Figure . Seasonal pH values for Beaver Lake.



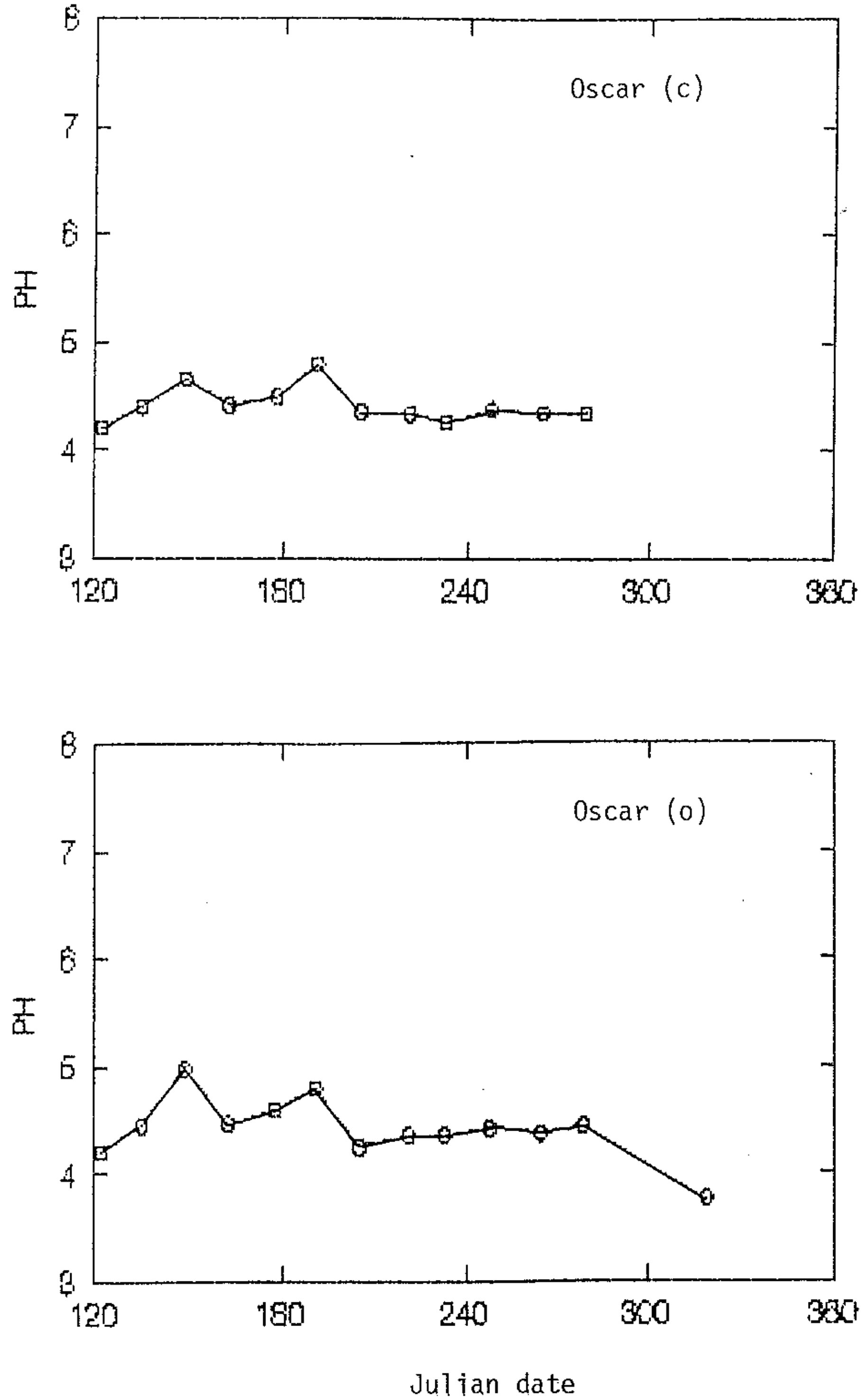
Seasonal pH values for Harlow Lake.



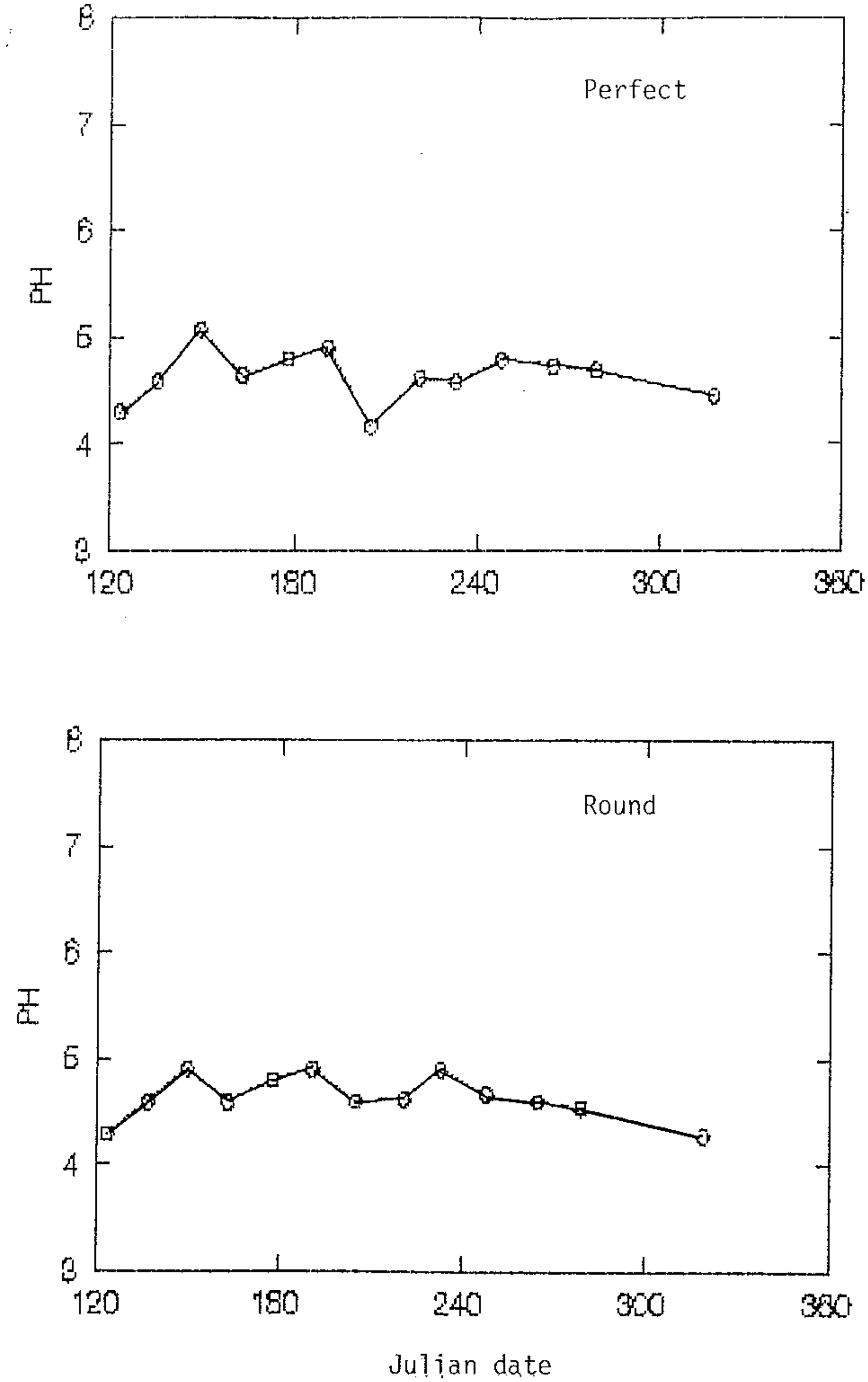
Seasonal pH values for Jib Lake.



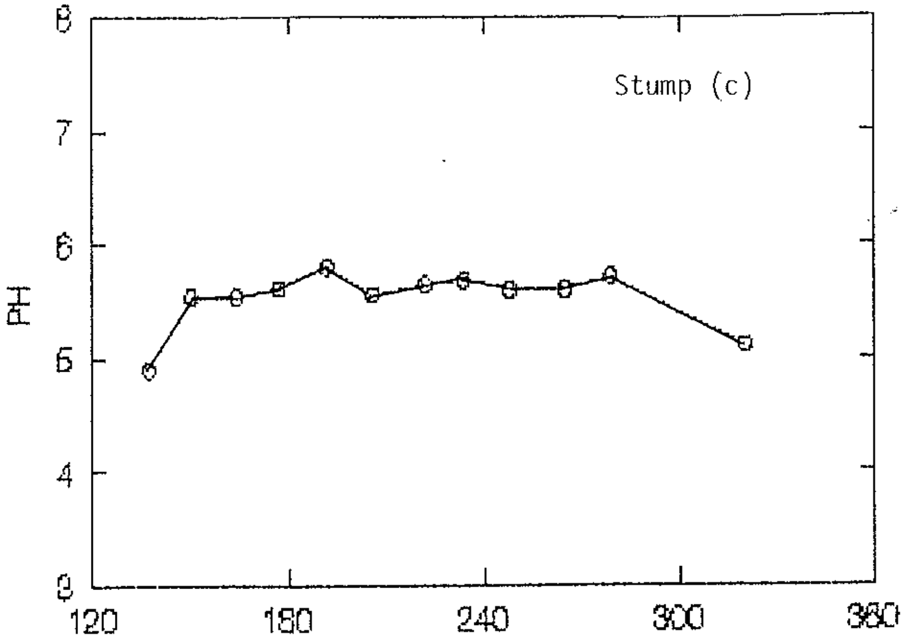
Seasonal pH values for Menchon Lake.

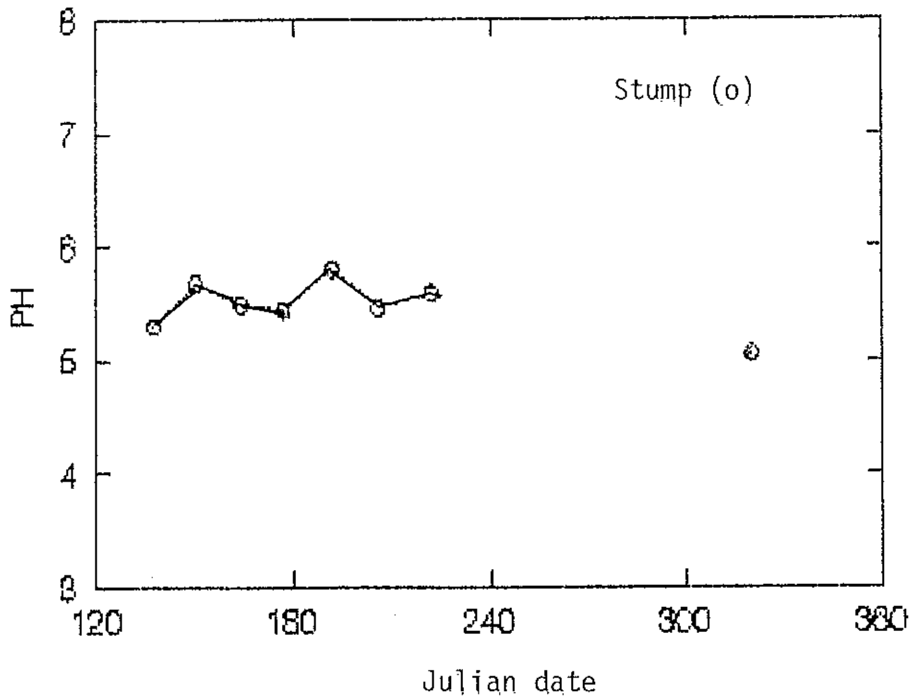


F ure . Seasonal pH values for Oscar Lake.



Seasonal pH values for Perfect and Round Lakes.

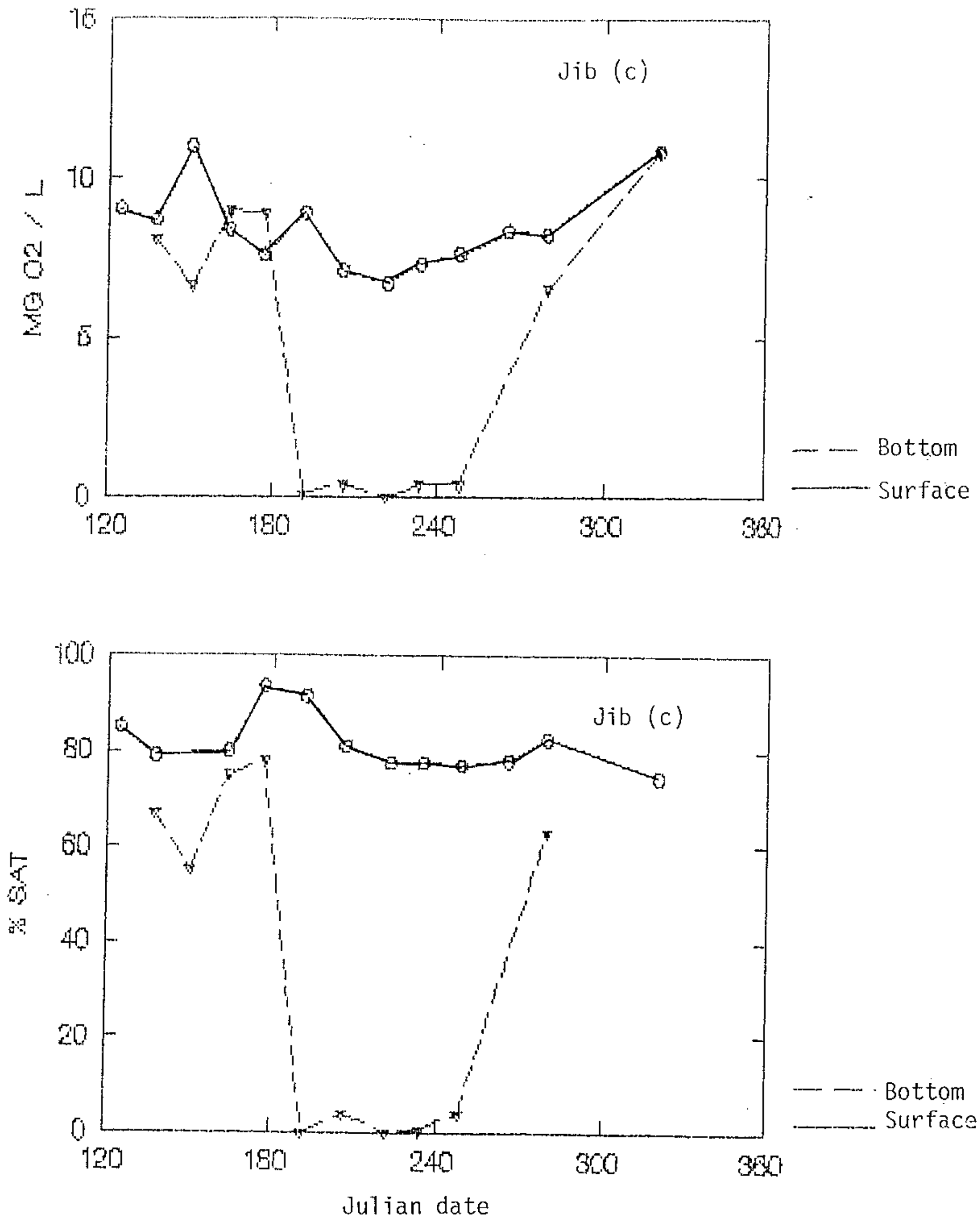




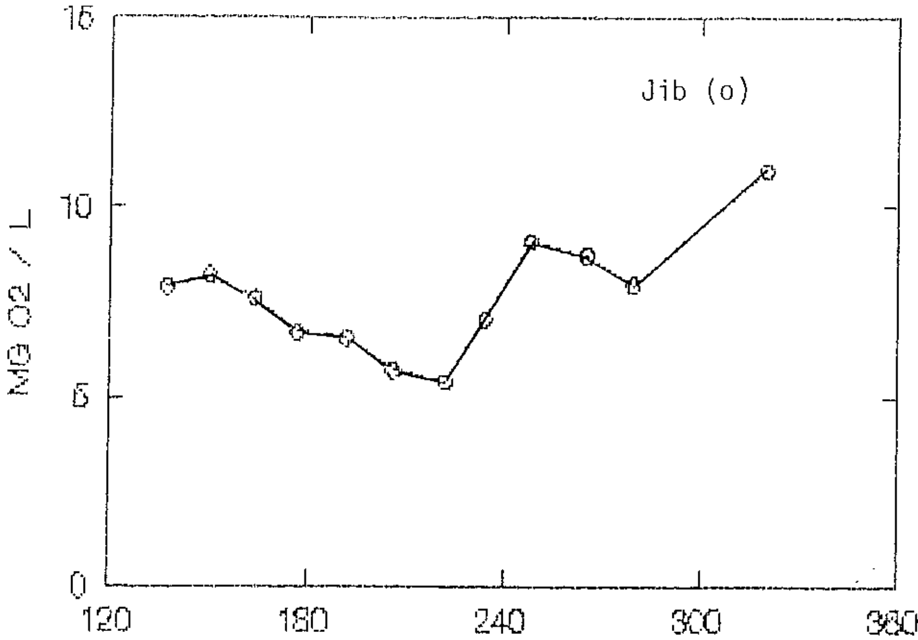
Seasonal pH values for Stump Lake.

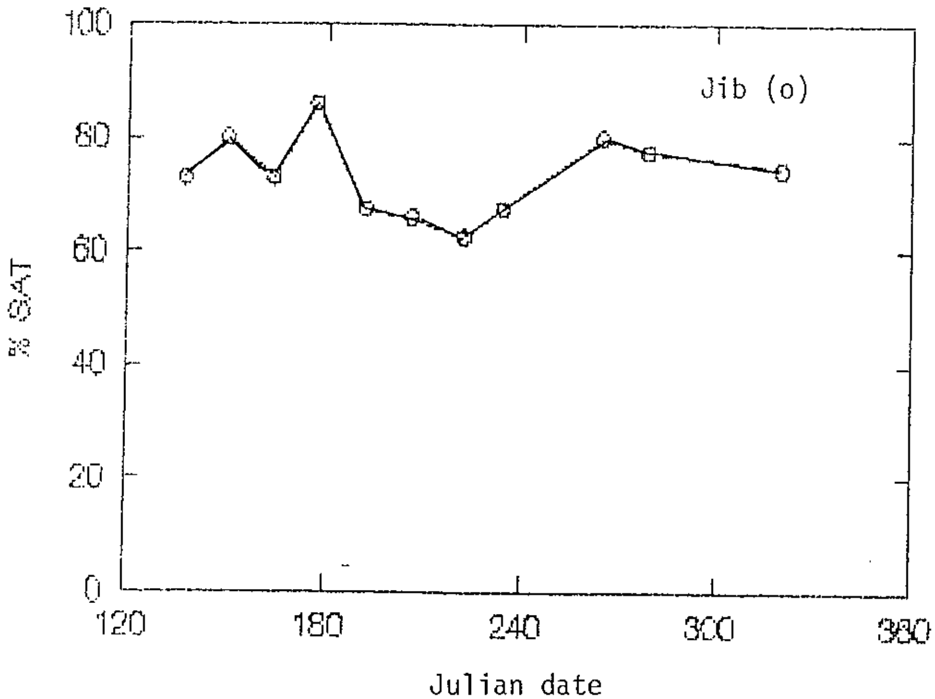
APPENDIX H

SEASONAL VARIATION IN OXYGEN CONCENTRATION AND PERCENT SATURATION

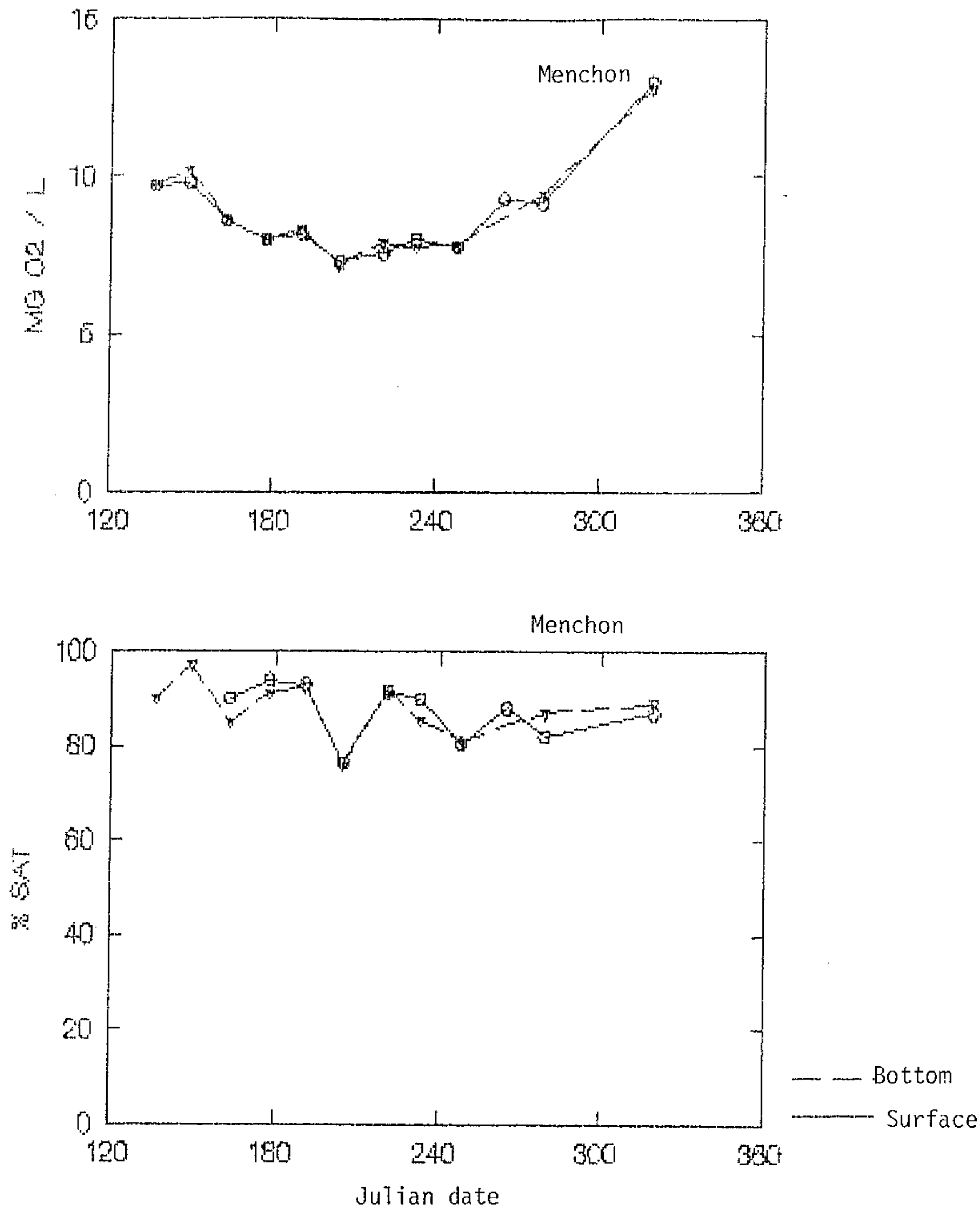


Seasonal variation in dissolved oxygen (mg O_2/ L) and percent saturation in Jib Lake (centre).

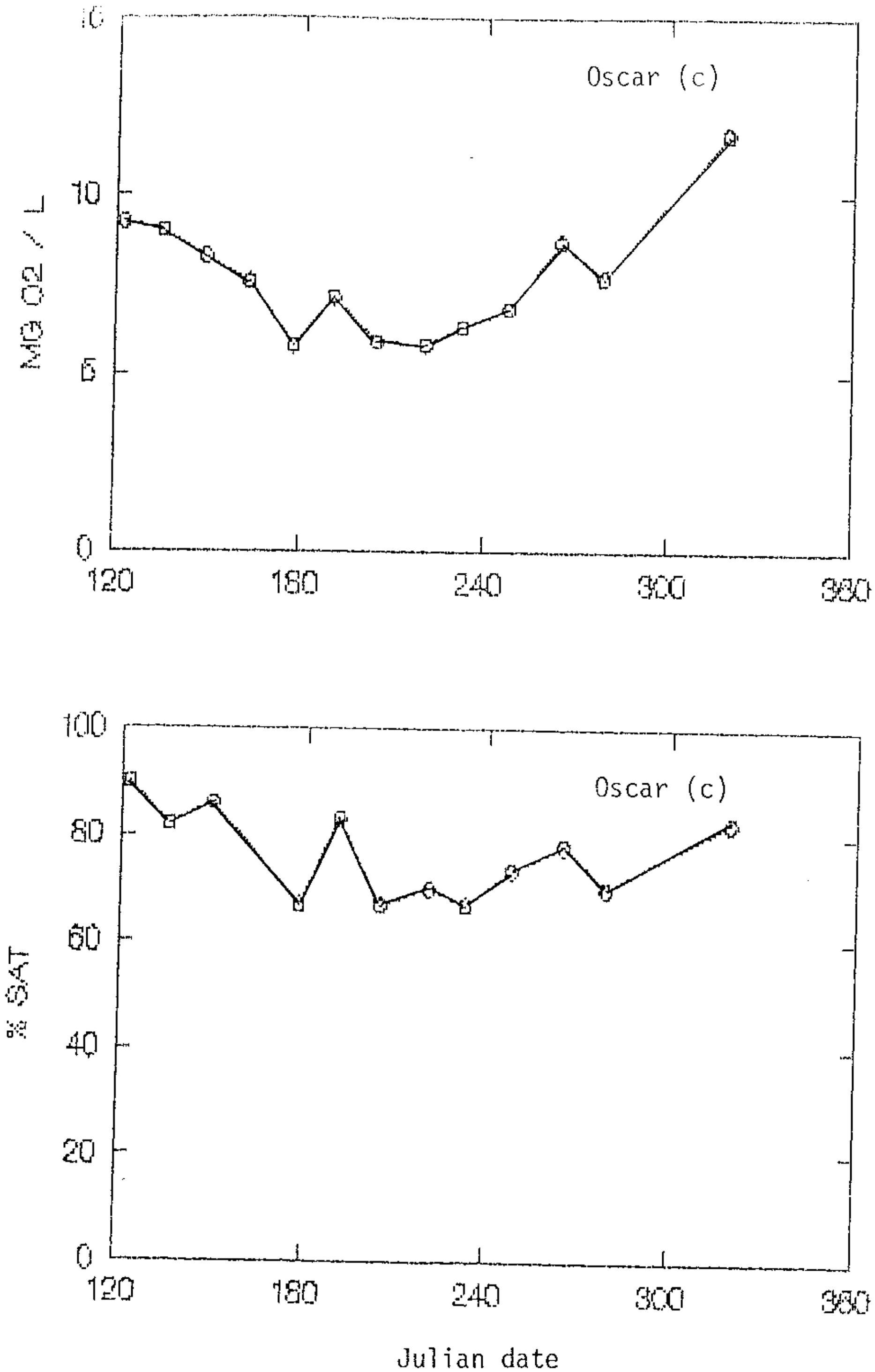




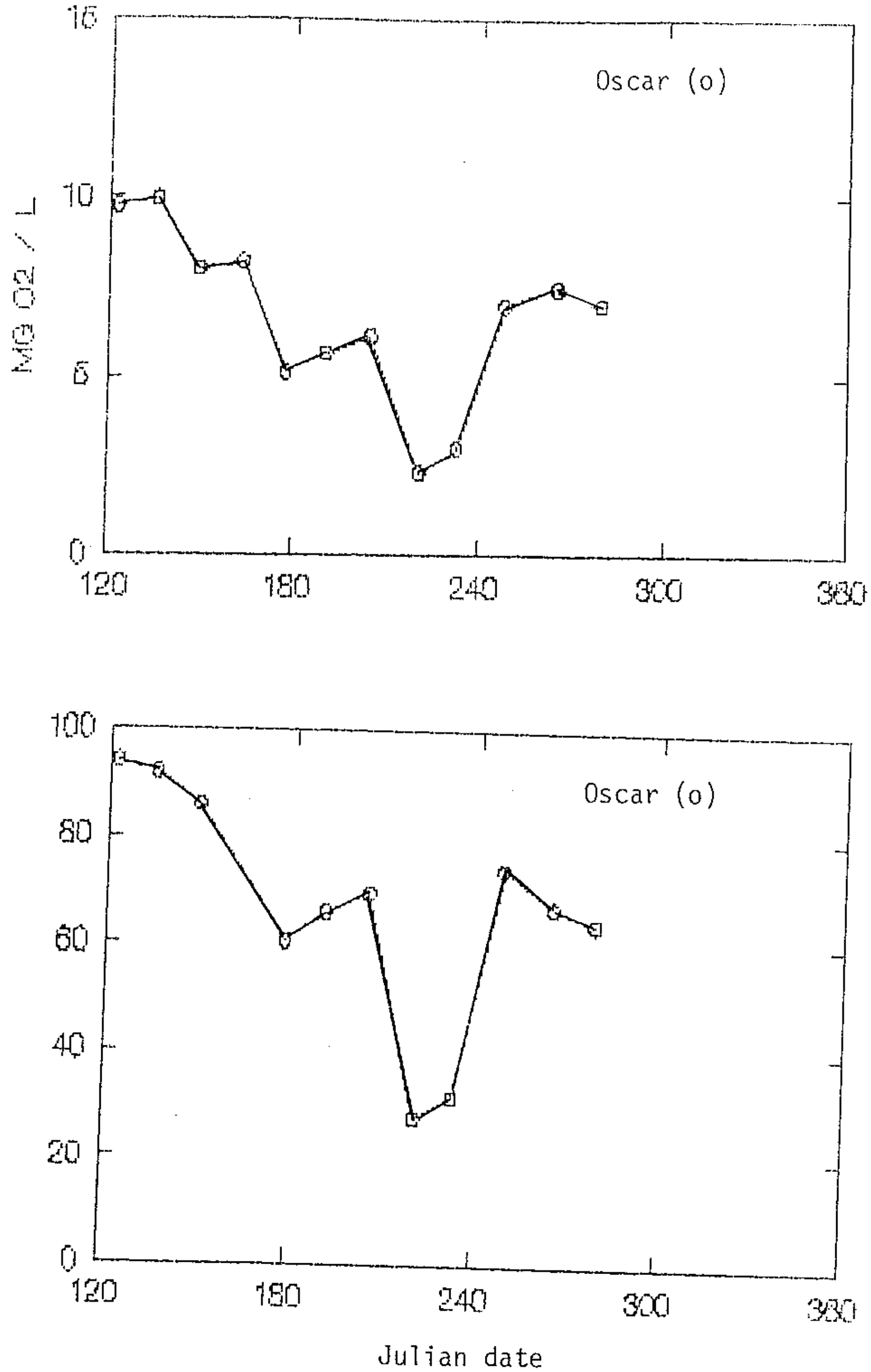
Seasonal variation in dissolved oxygen (mg O_2/L) and percent saturation in the outlet of Jib Lake.



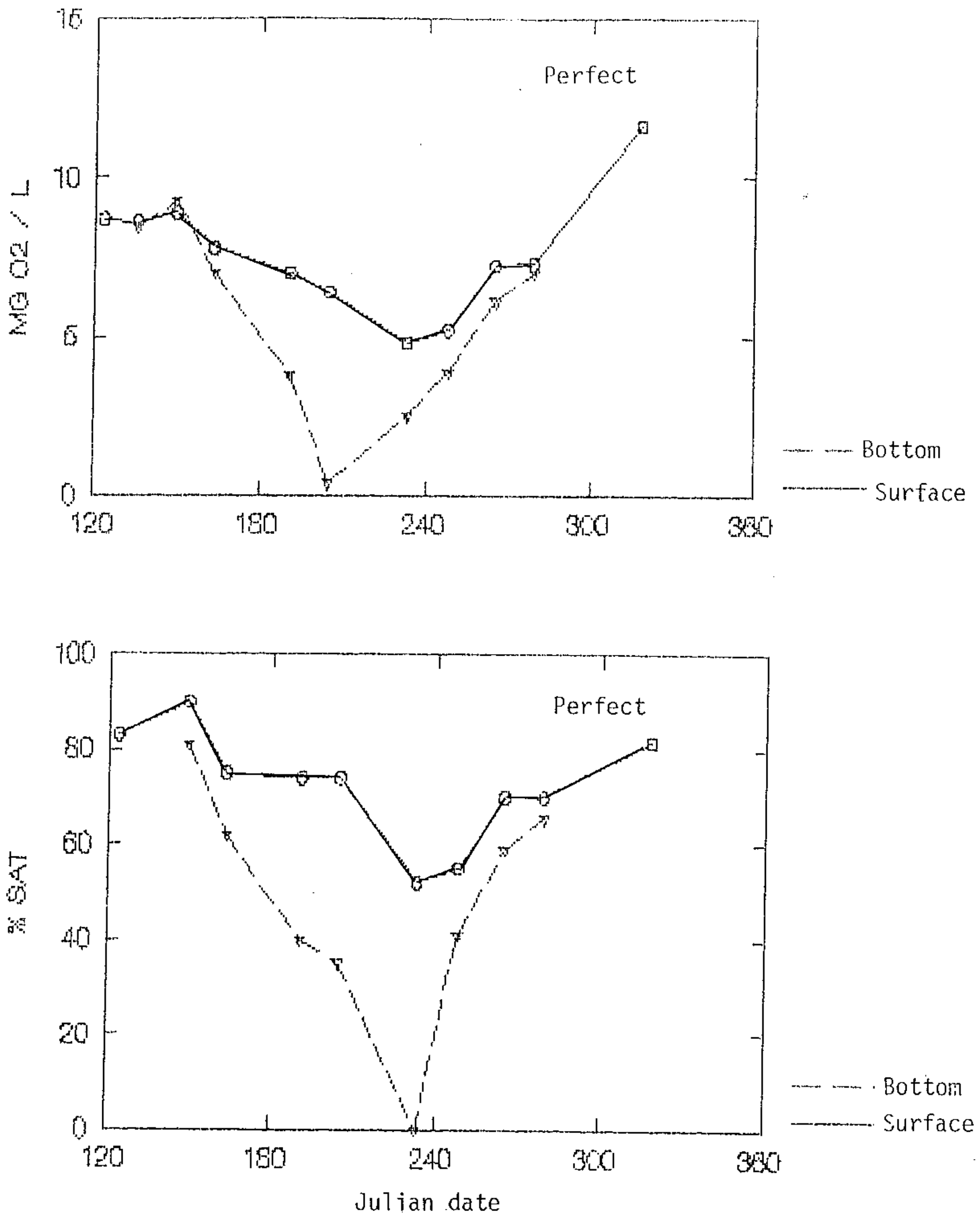
Seasonal variation in dissolved oxygen (mg O_2/L) and percent saturation in Menchon Lake (centre).



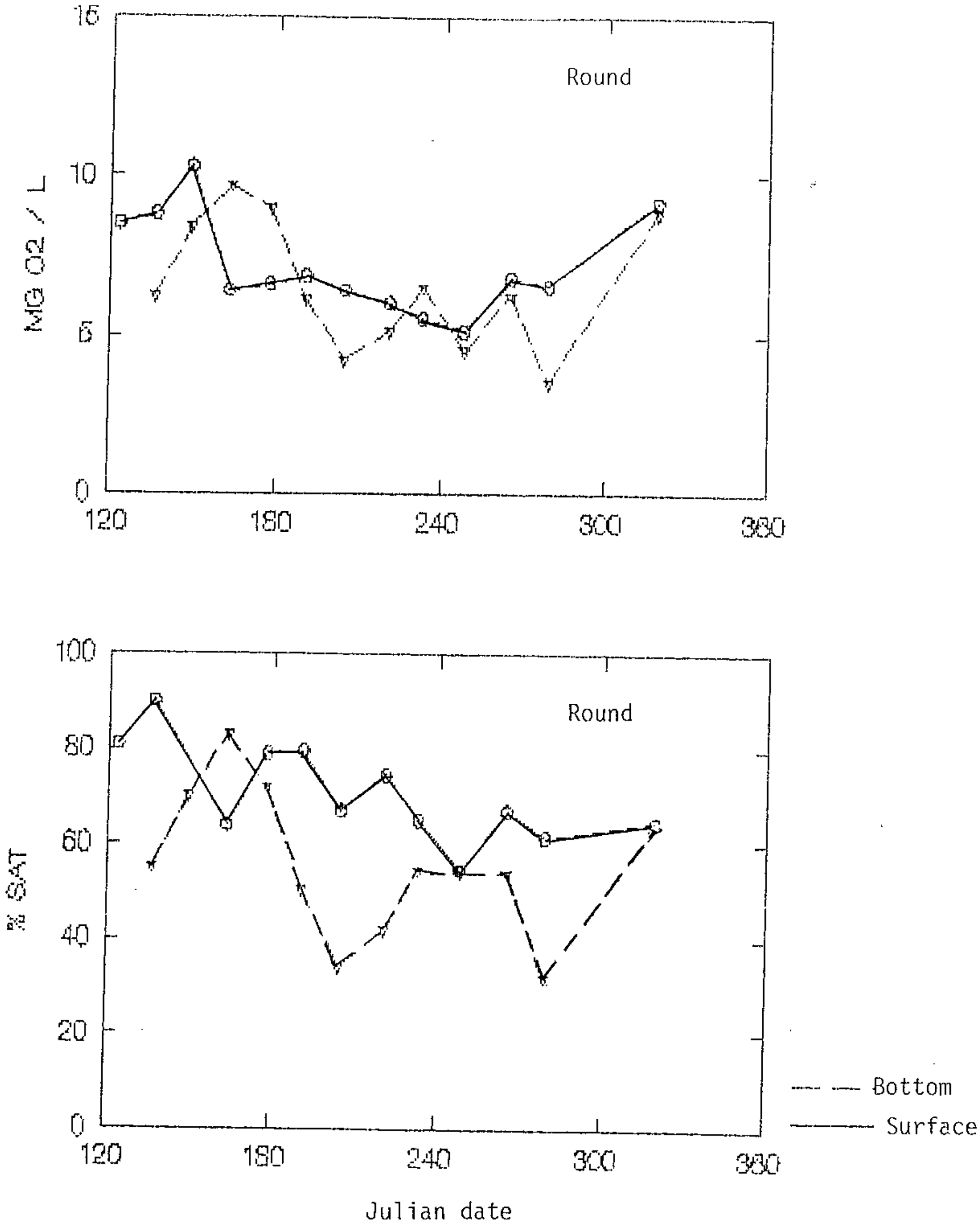
. Seasonal variation in dissolved oxygen (mg O_2/L) and percent saturation in Oscar Lake (centre).



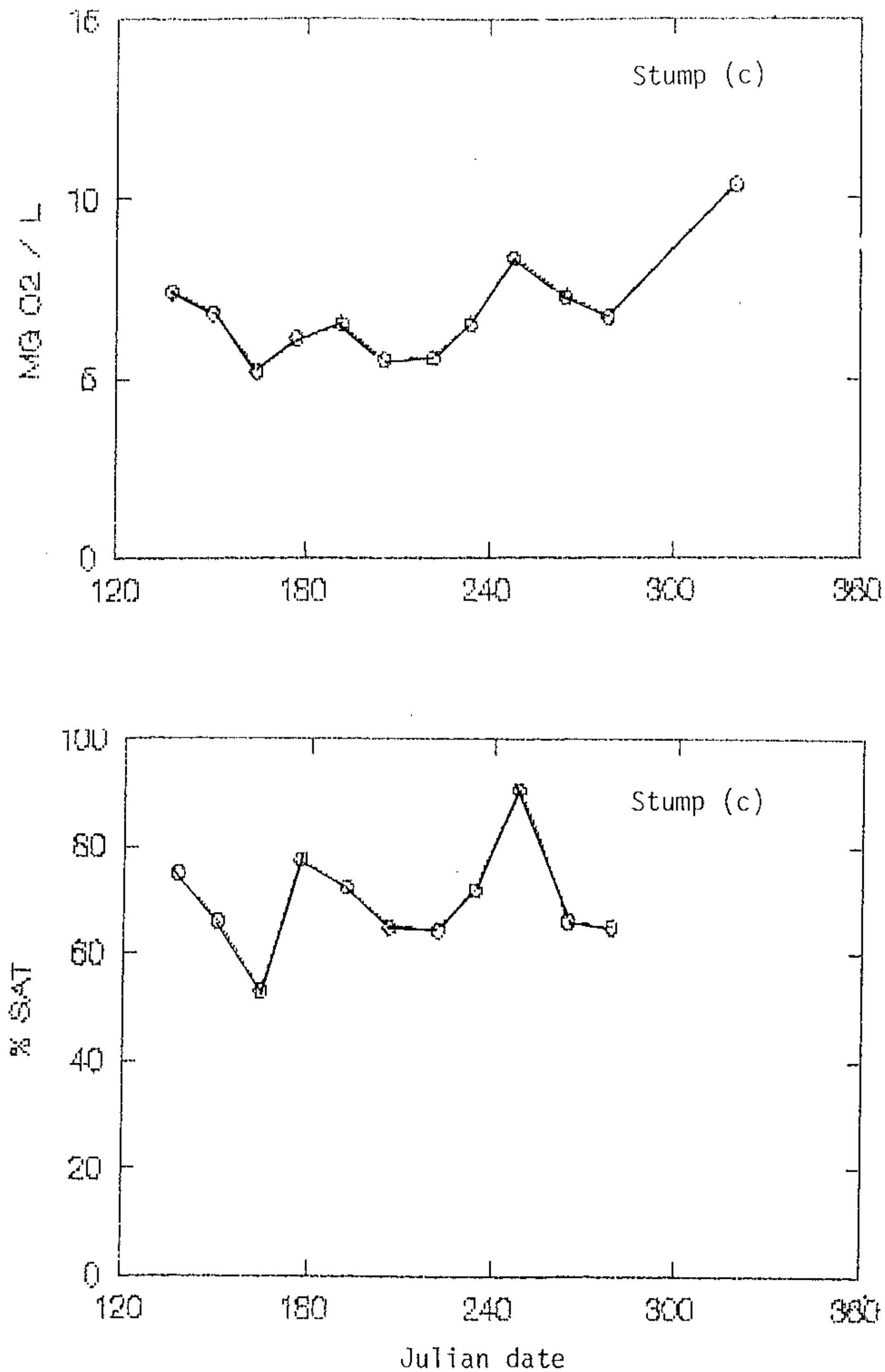
Seasonal variation in dissolved oxygen (mg O_2/L) and percent saturation in the outlet of Oscar Lake.



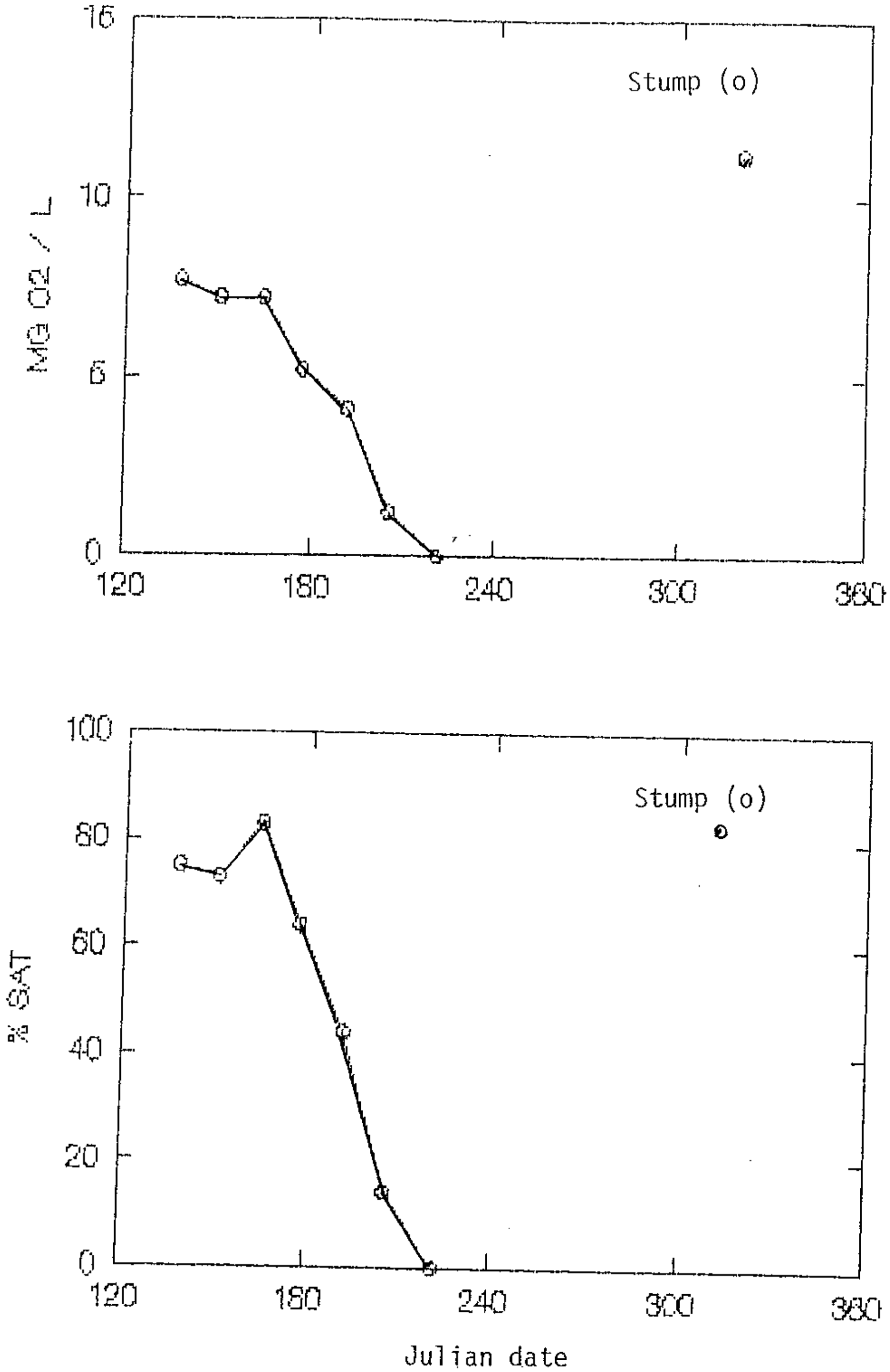
Seasonal variation in dissolved oxygen (mg O_2/L) and percent saturation in Perfect Lake (centre).



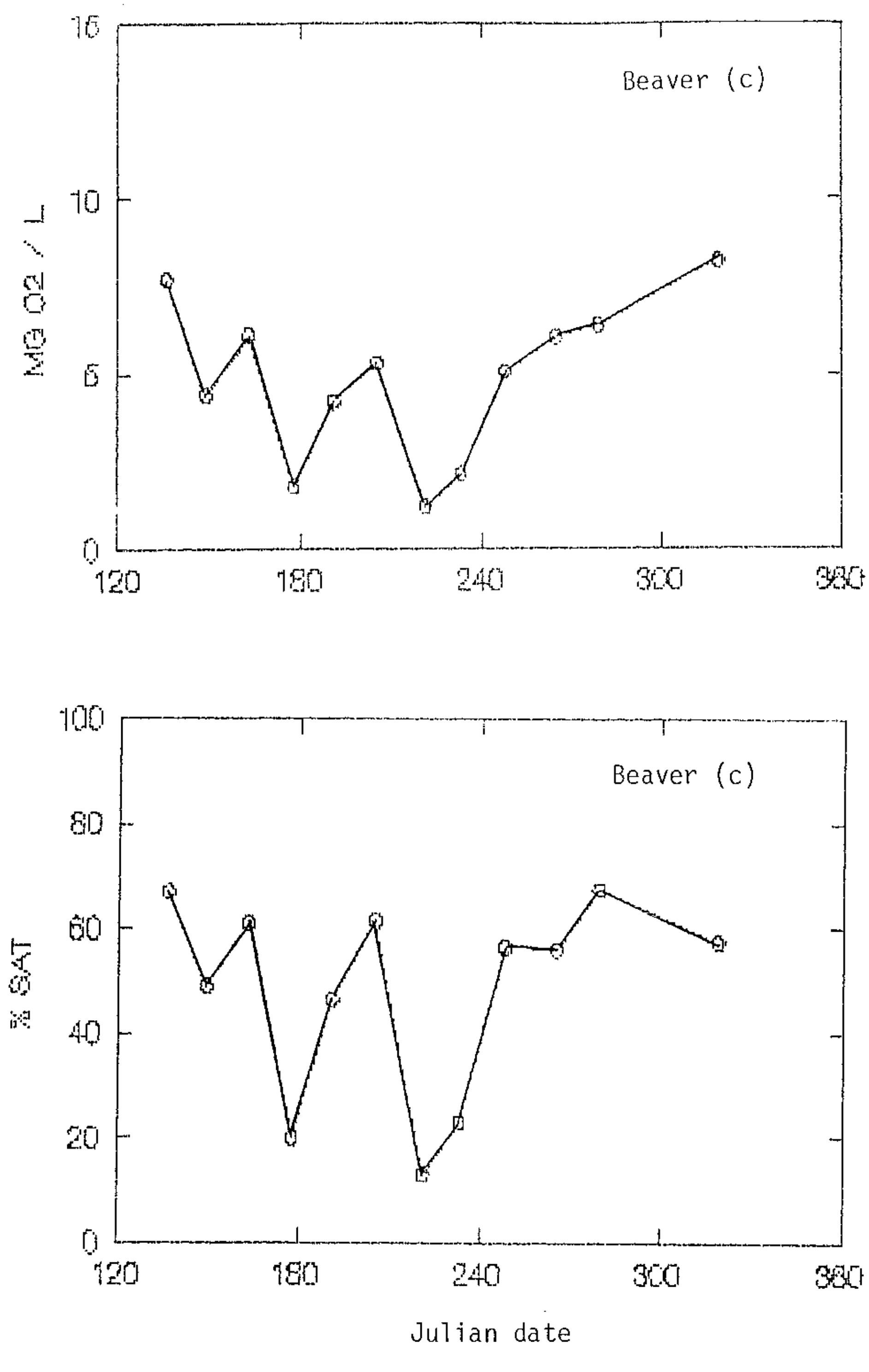
Seasonal variation in dissolved oxygen (mg O_2/L) and percent saturation in Round Lake (centre).



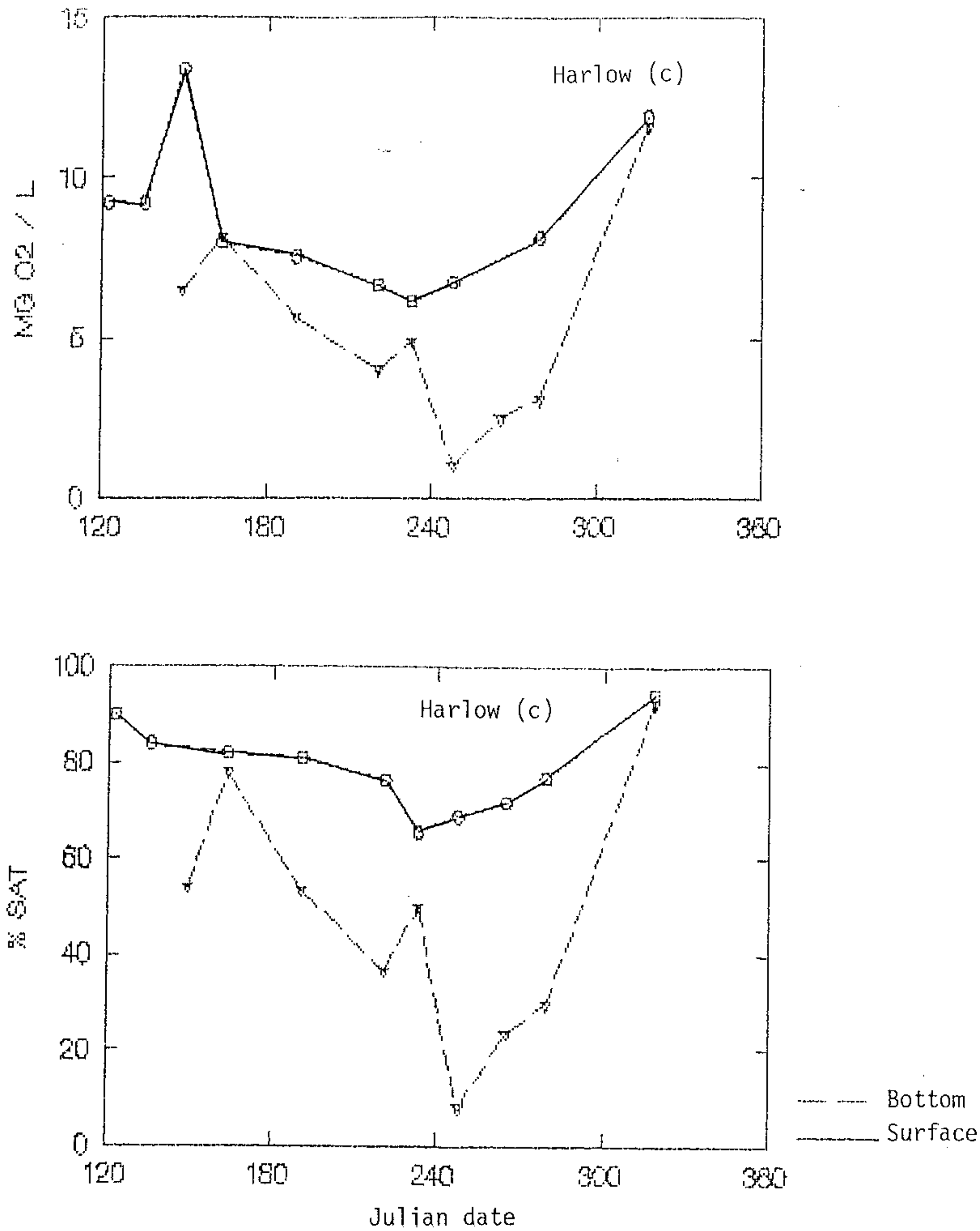
Seasonal variation in dissolved oxygen (mg O_2/ L) and percent saturation in Stump Lake (centre).



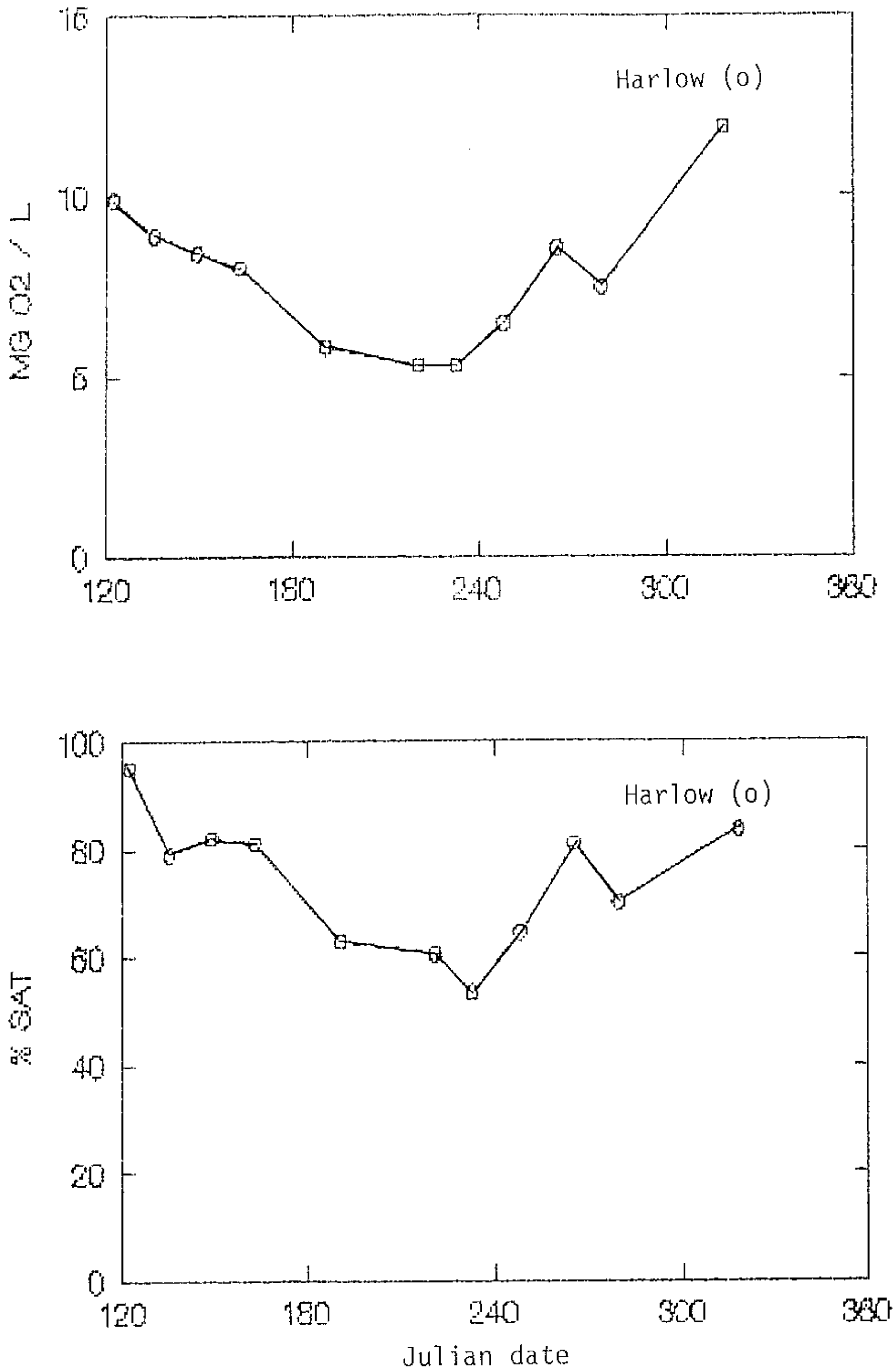
Seasonal variation in dissolved oxygen (mg O_2/L) and percent saturation in the outlet of Stump Lake.



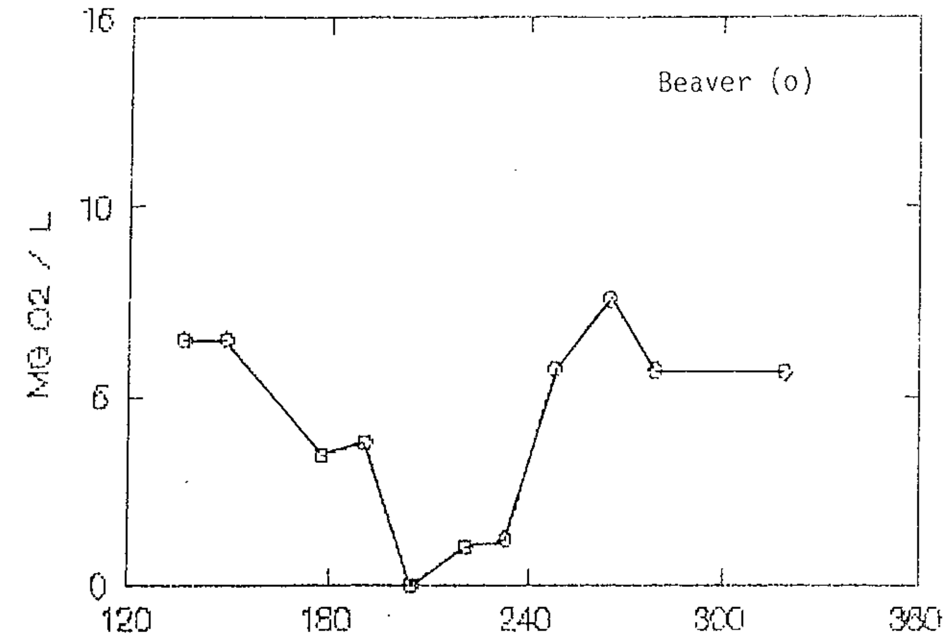
Seasonal variation in dissolved oxygen (mg O_2/L) and percent saturation for Beaver Lake (centre).

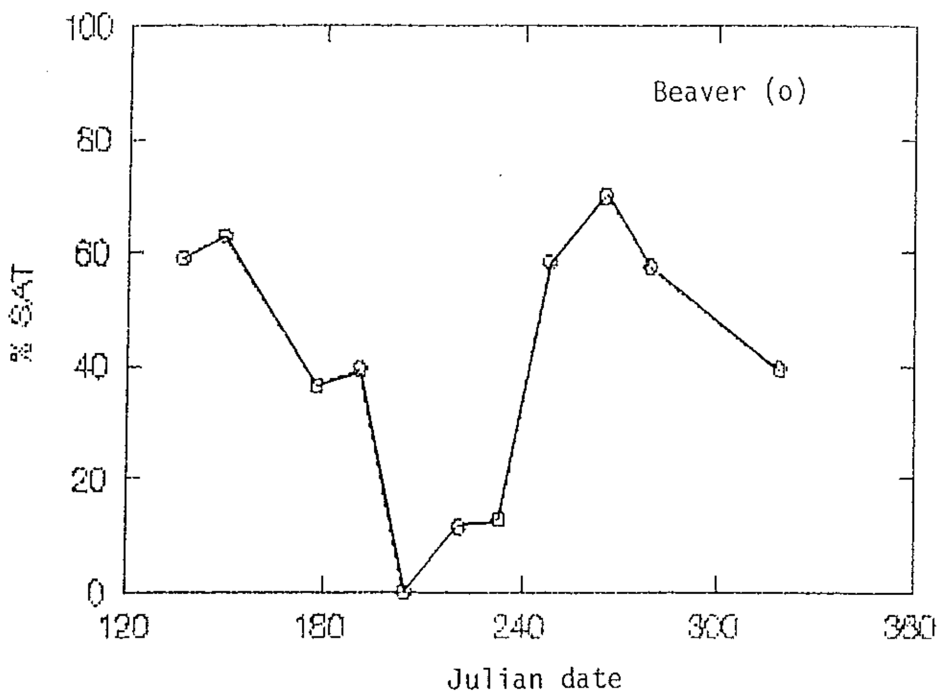


Seasonal variation if dissolved oxygen (mg O_2/L) and percent saturation in Harlow Lake (centre).



Seasonal variation in dissolved oxygen (mg O2/L) and percent saturation in the outlet of Harlow Lake.

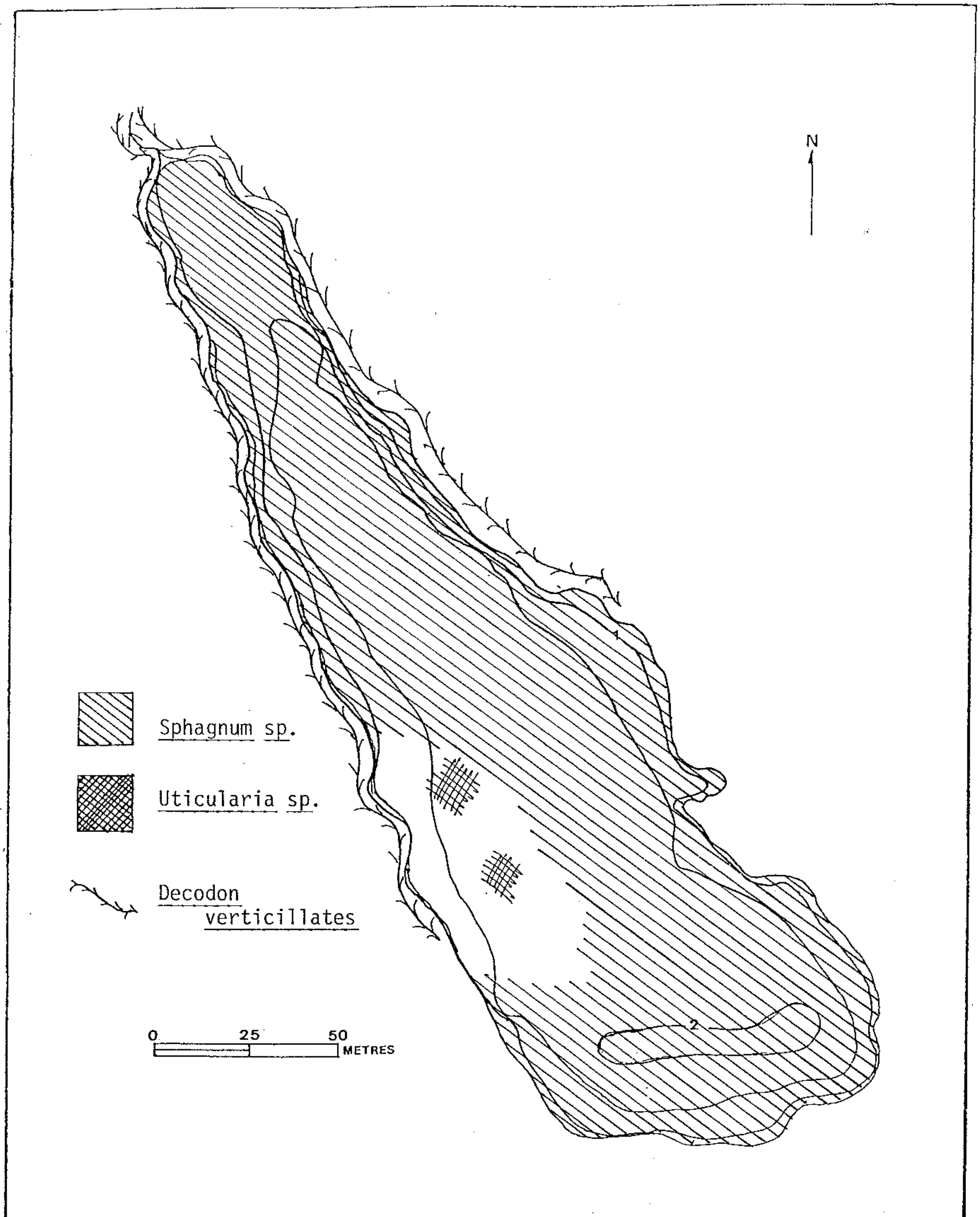




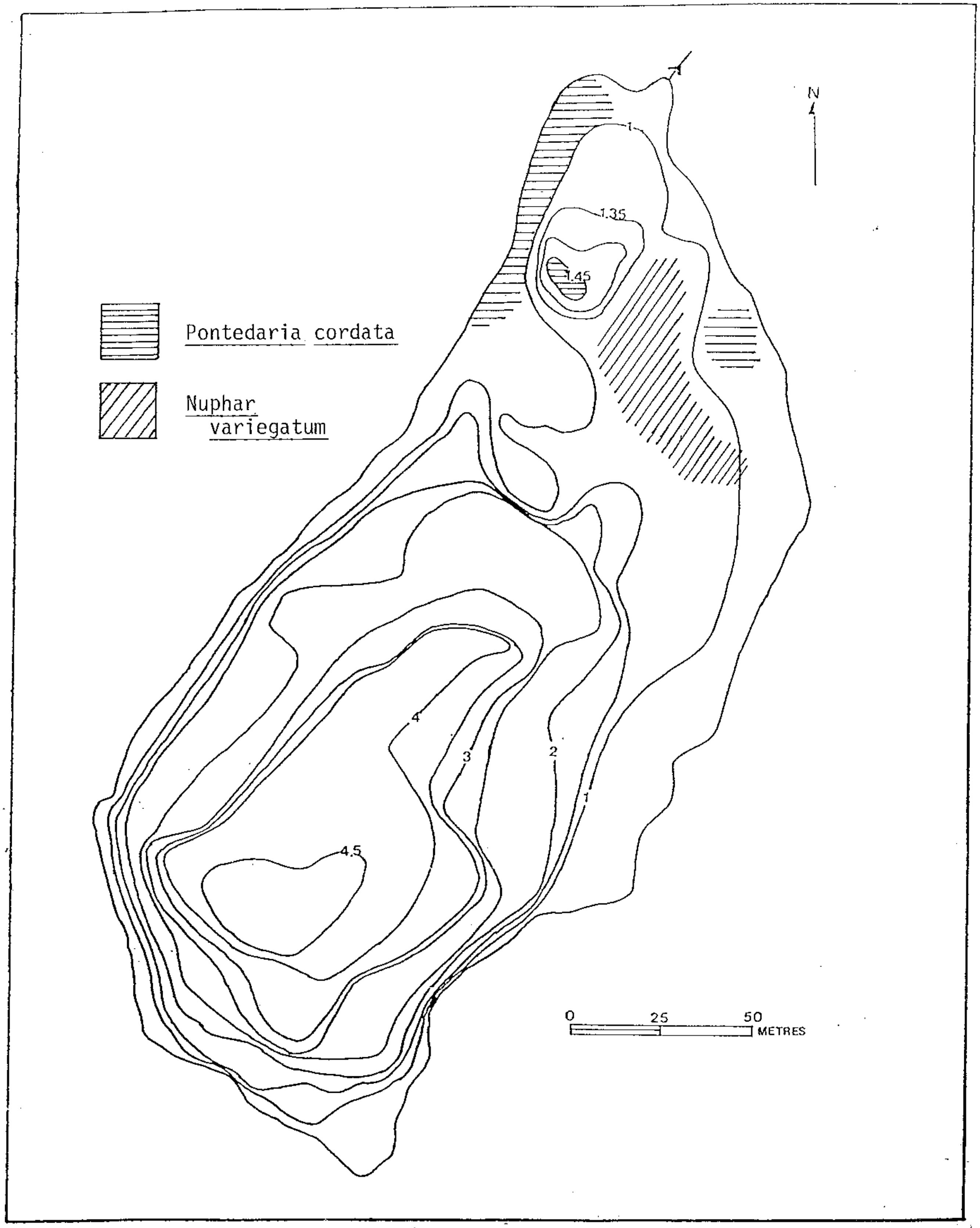
Seasonal variation in dissolved oxygen (mg O_2/ L)
and percent saturation for the outlet of Beaver Lake.

APPENDIX I

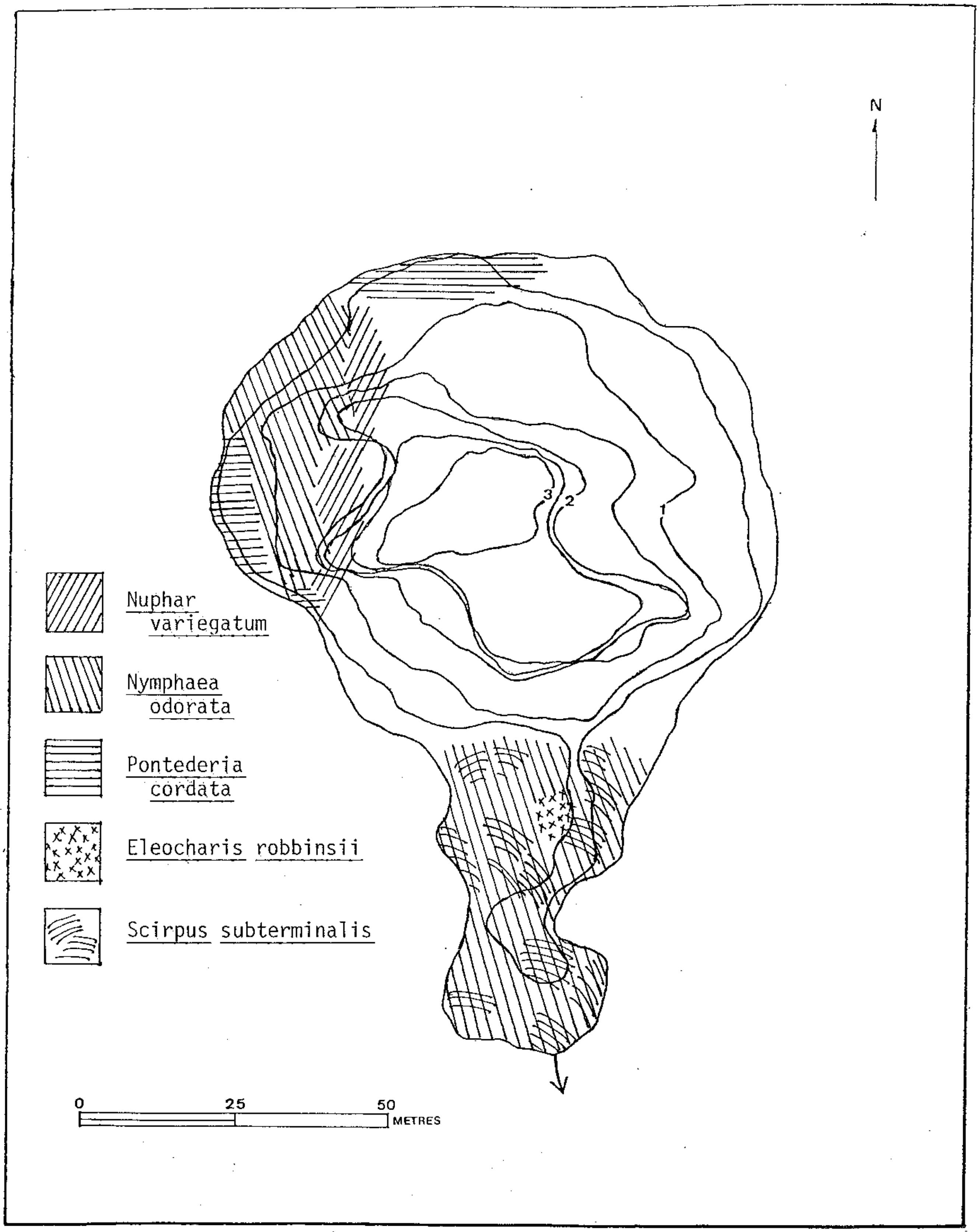
DISTRIBUTION AND SPECIES COMPOSITION OF MAJOR MACROPHYTES



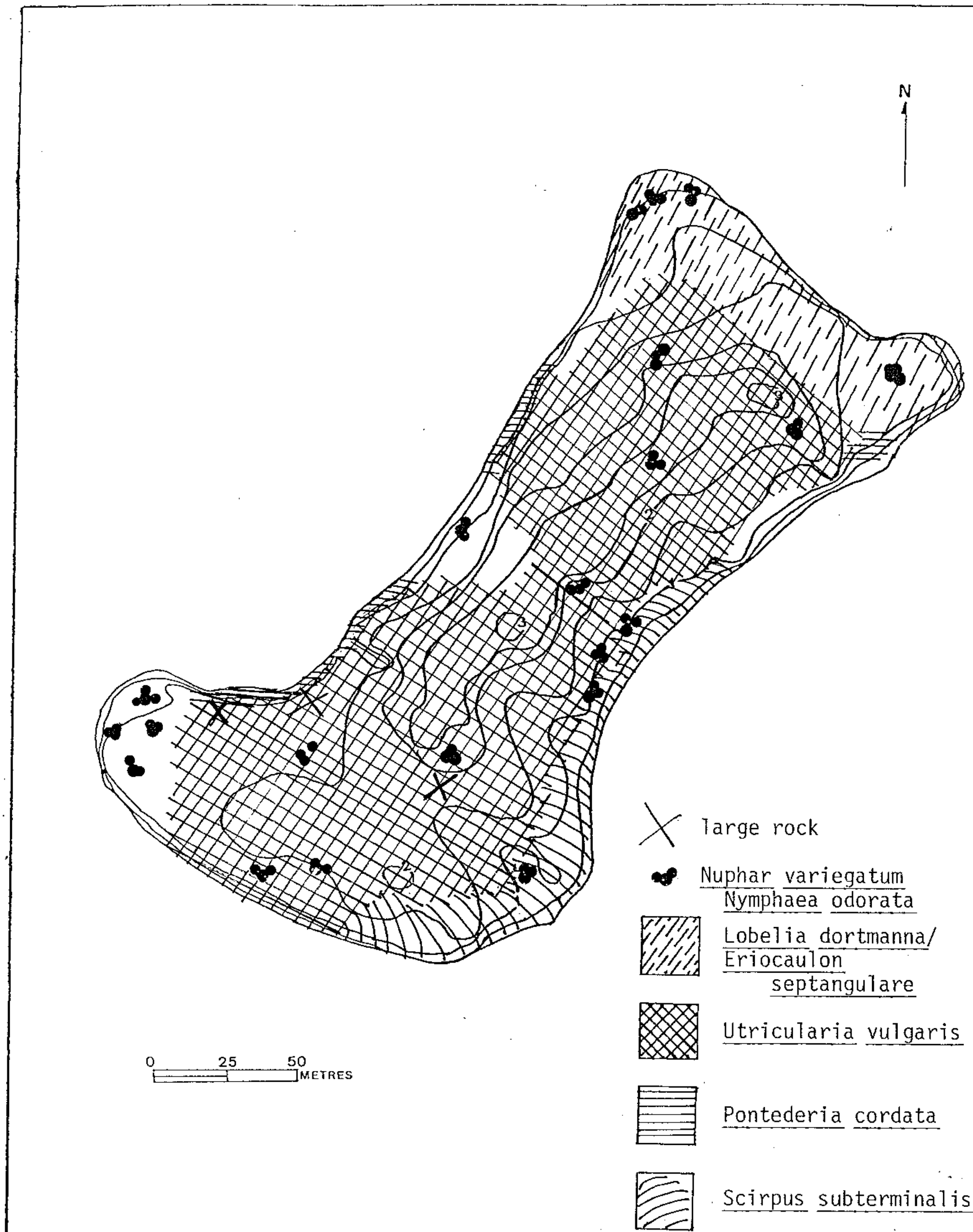
The distribution of the dominant submerged and emergent macrophytes in Beaver Lake.



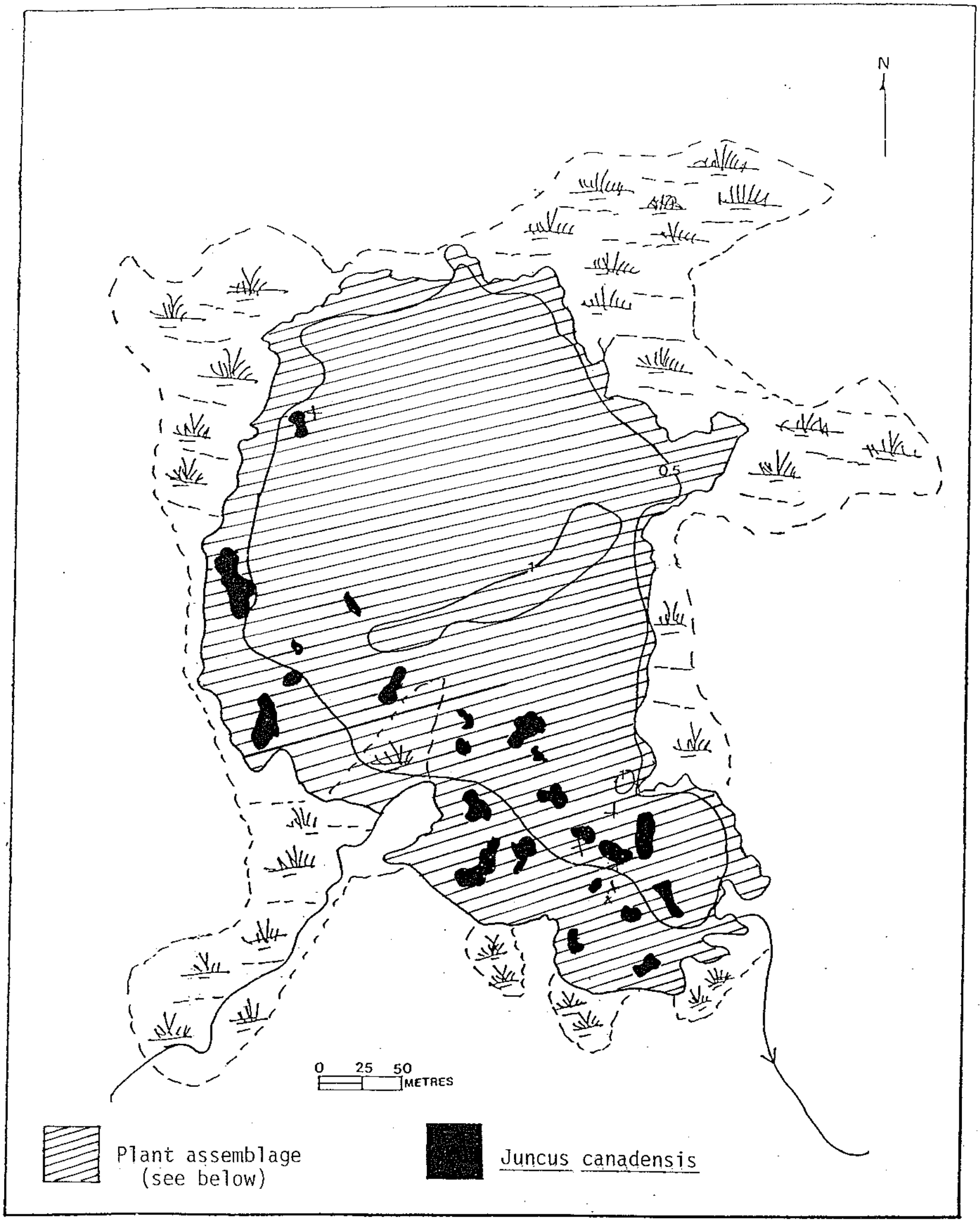
The distribution of the dominant submerged and emergent macrophytes in Harlow Lake.



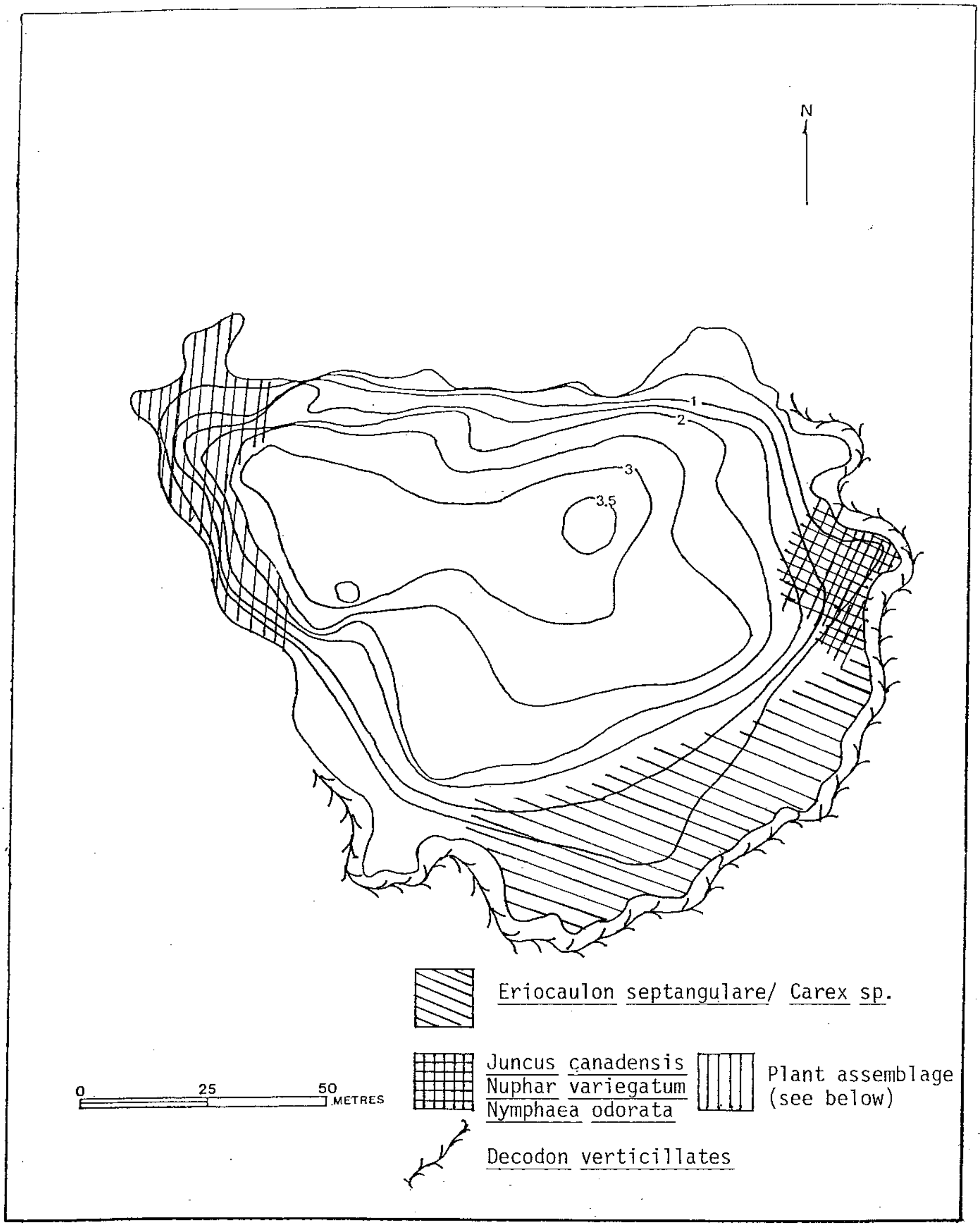
The distribution of the dominant submerged and emergent macrophytes in Jib Lake.



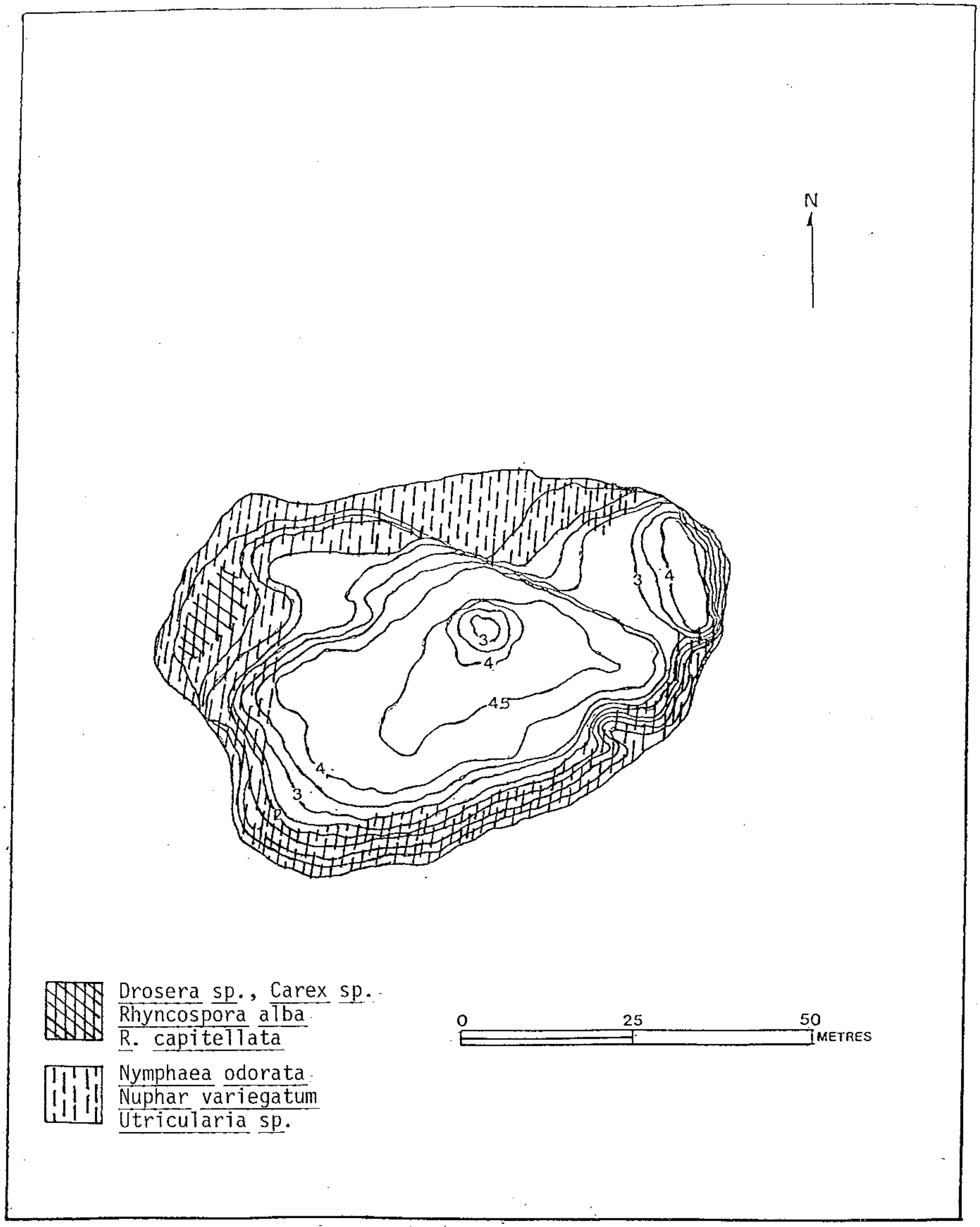
The distribution of the dominant submerged and emergent macrophytes in Menchon Lake.



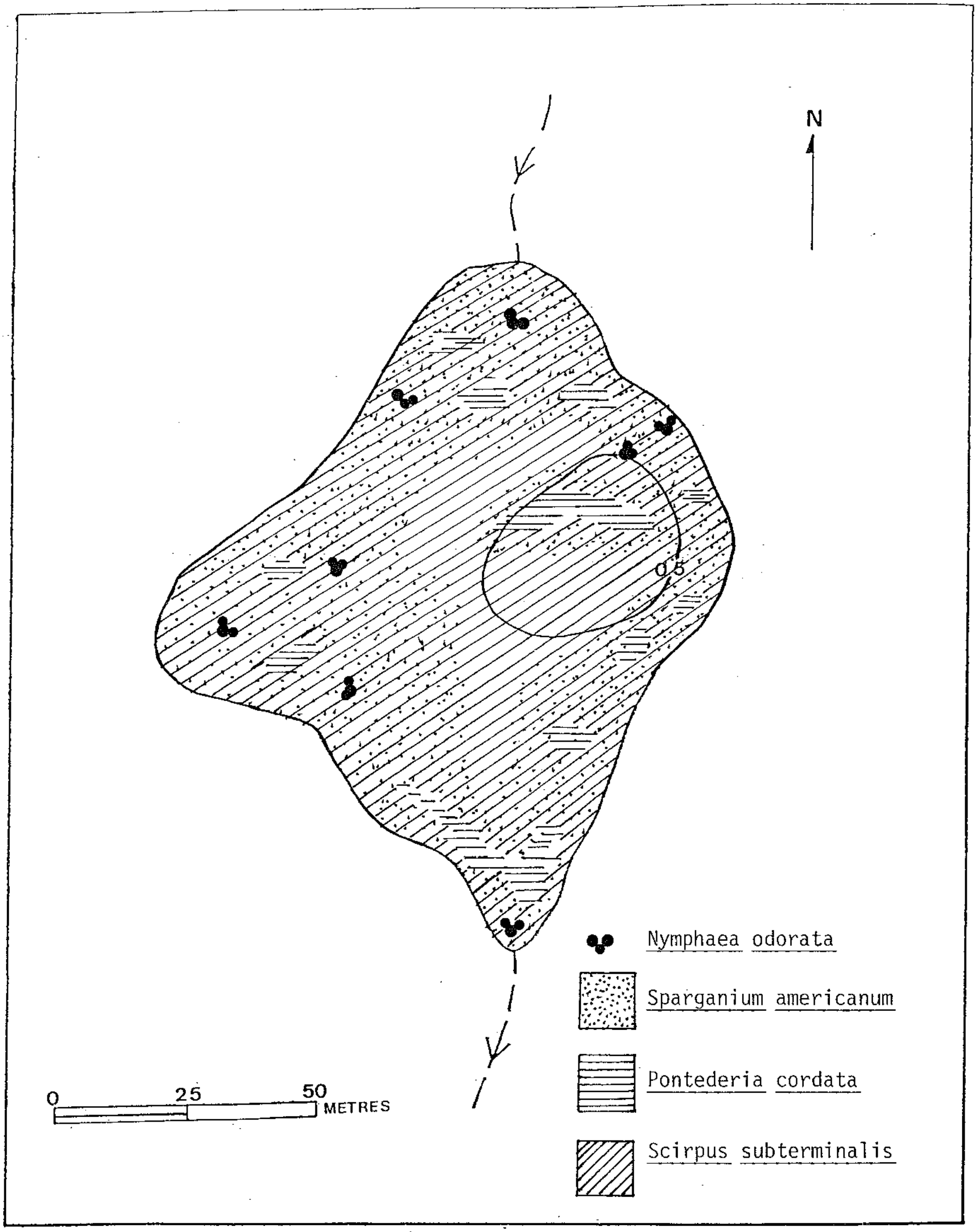
The distribution of the dominant submerged and emergent macrophytes In Oscar Lake. Plant assemblage: Juncus militaris, Brasenia schreberi, Nymphaea odorata, Nuphar variegatum, and Scirpus subterminalis.



The distribution of the dominant submerged and emergent macrophlytes in Perfect Lake. Plant assemblage: Nuphar variegatum, Nymphaea odorata, Utricularia sp and Scirpus subterminalis.



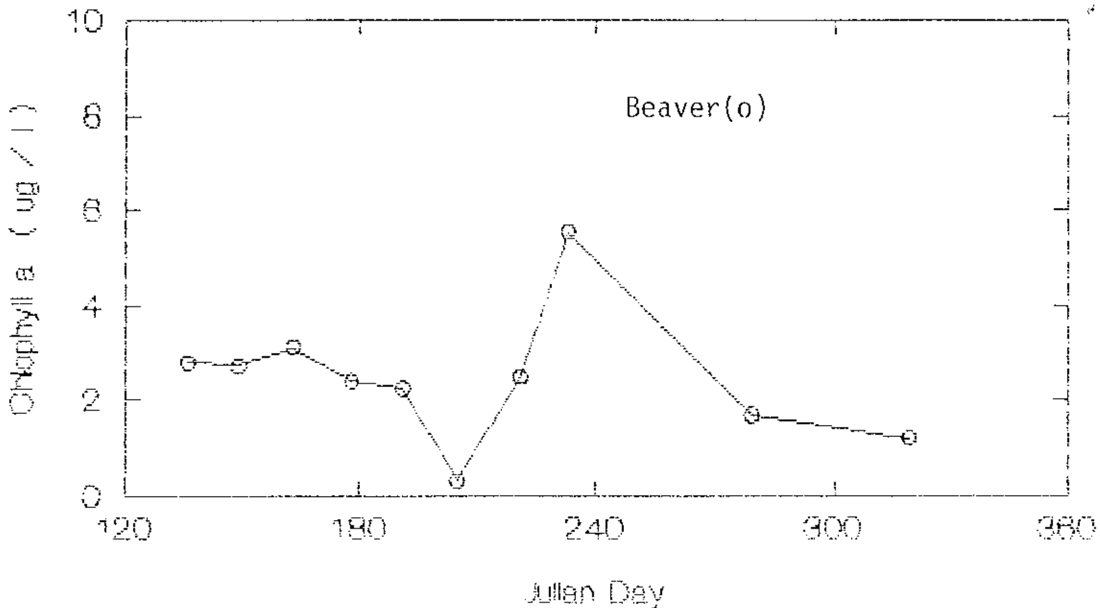
The distribution of the dominant submerged and emergent macrophytes in Round Lake.

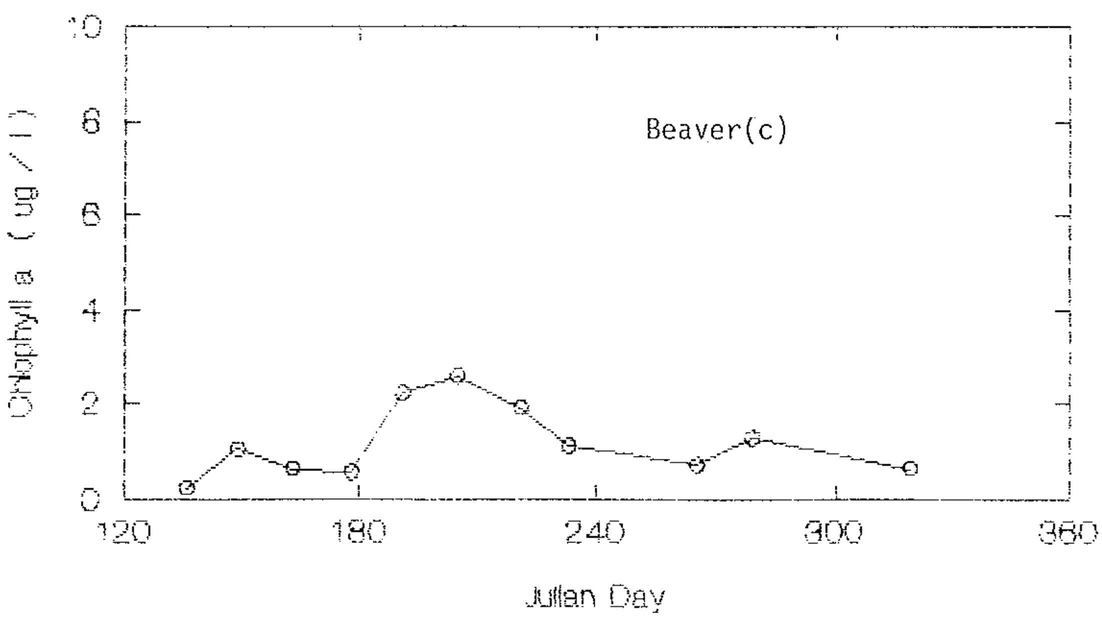


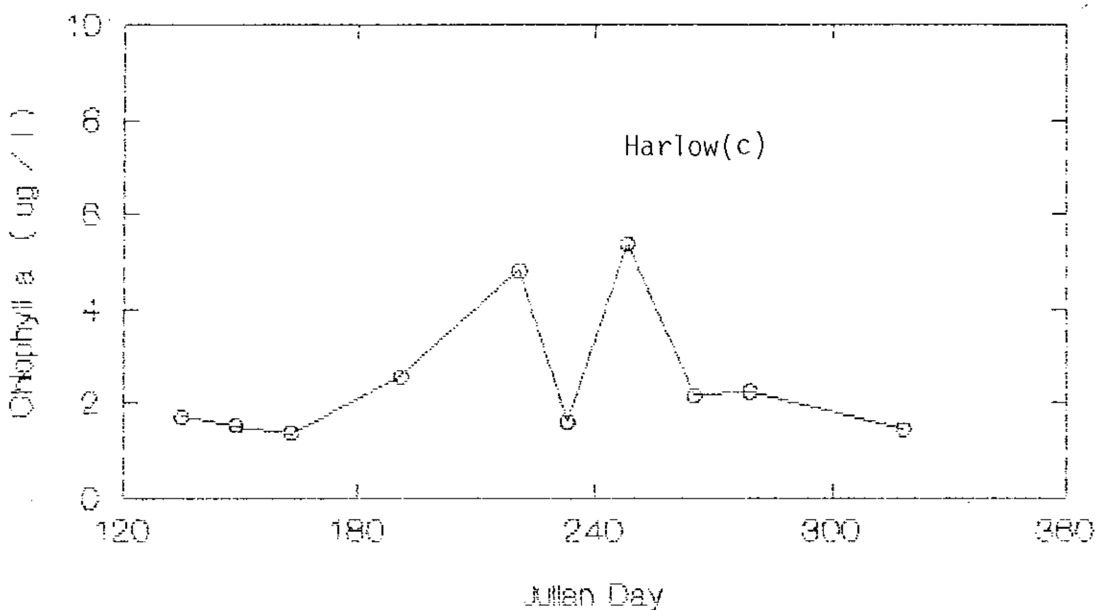
The distribution of the dominant submerged and emergent macrophytes in Stump Lake. Note: tree stumps are abundant throughout the lake.

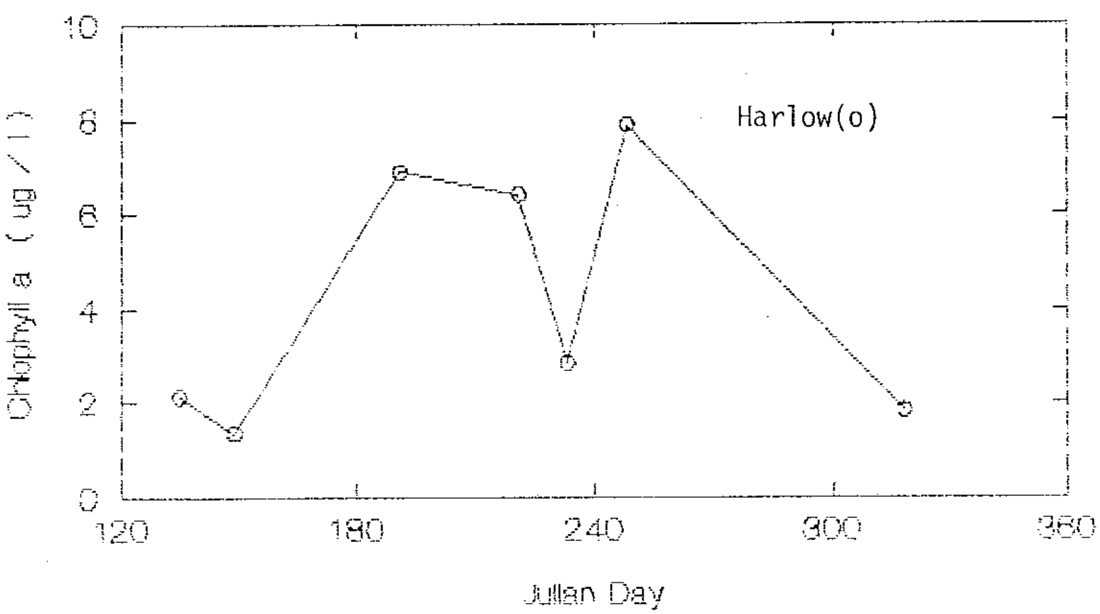
APPENDIX J

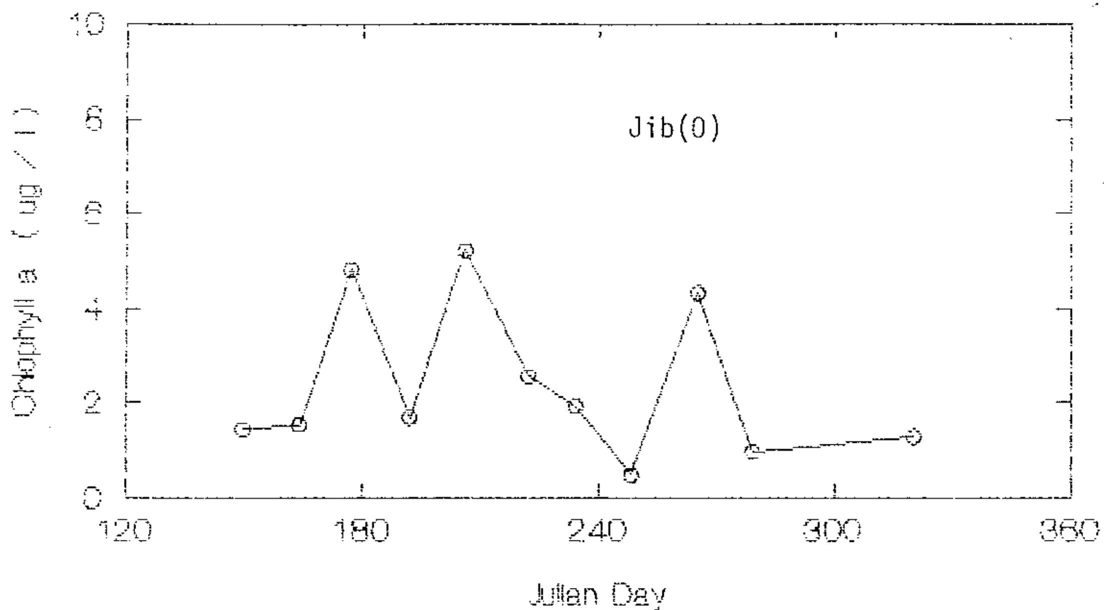
SEASONAL VARIATIONS IN CHLOROPHYLL *a*

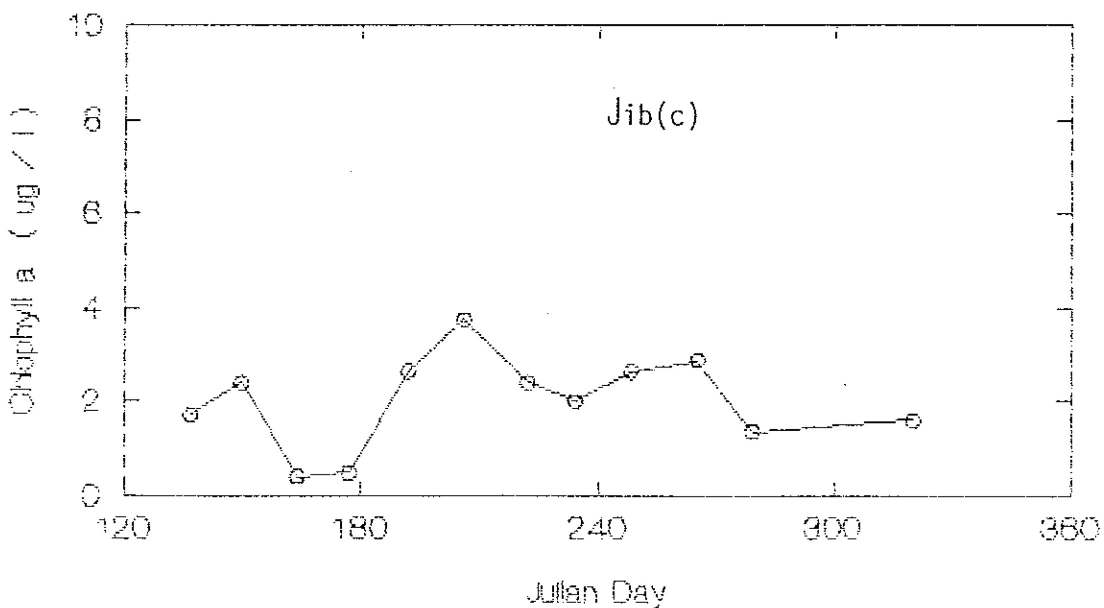

Beaver(o)
Chlophyll a (ug / l)
Julian Day
0
2
4
6
8
10
120
180
240
300
360

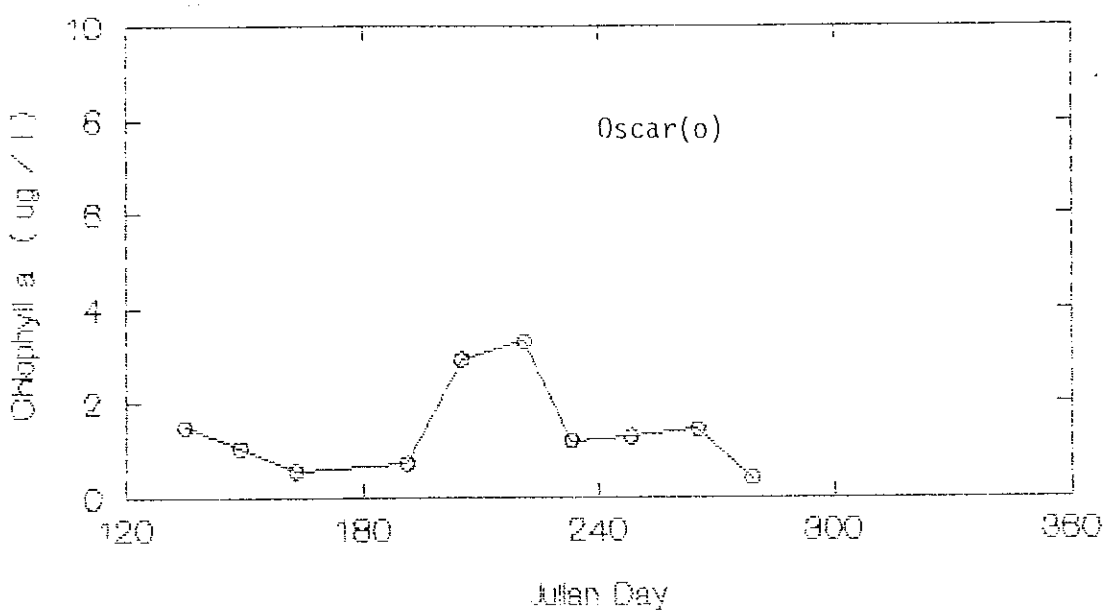

Beaver(c)
Chlophyll a (ug / l)
Julian Day
0
2
4
6
8
10
120
180
240
300
360

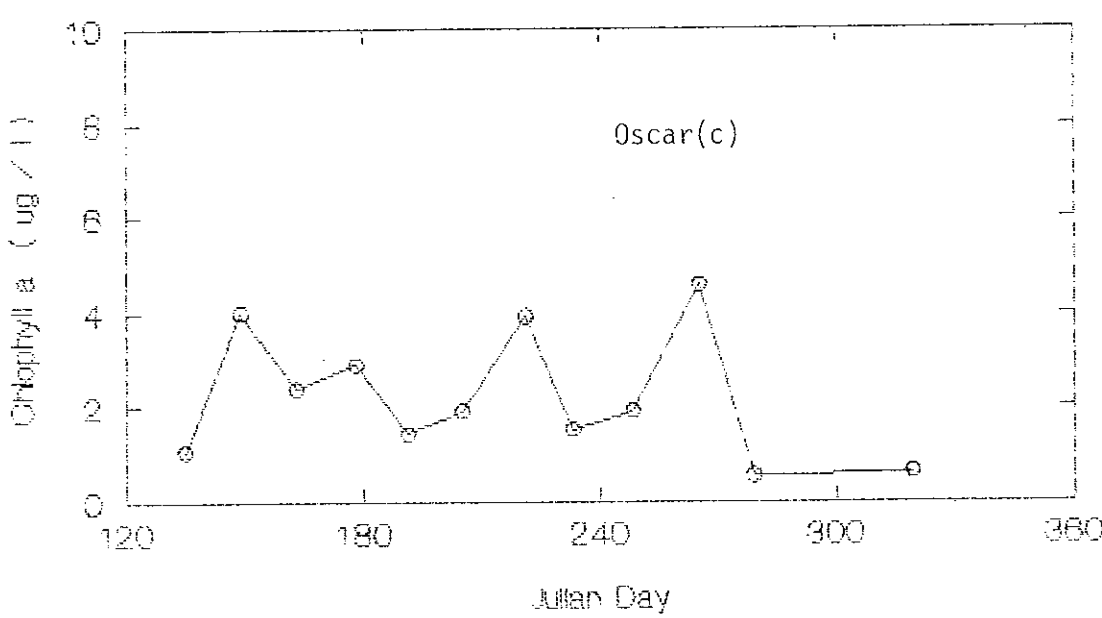

Harlow(c)
Chlophyll a (ug / l)
Julian Day
0
2
4
6
8
10
120
180
240
300
360

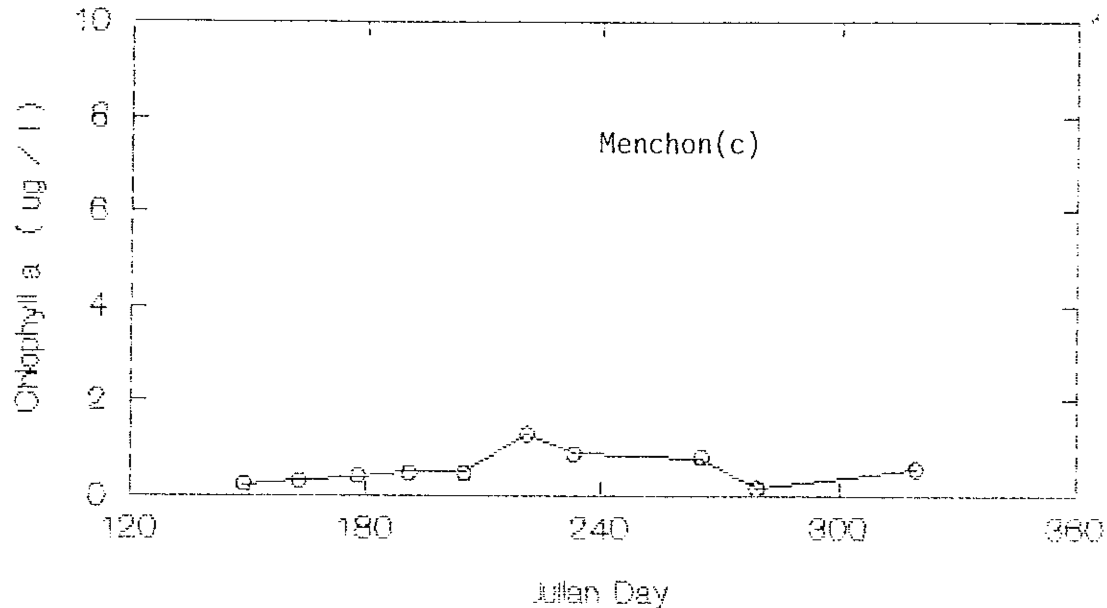

Harlow(o)
Chlophyll a (ug / l)
Julian Day
0
2
4
6
8
10
120
180
240
300
360


Jib(0)
Chlophyll a (ug / l)
Julian Day
0
2
4
6
8
10
120
180
240
300
360

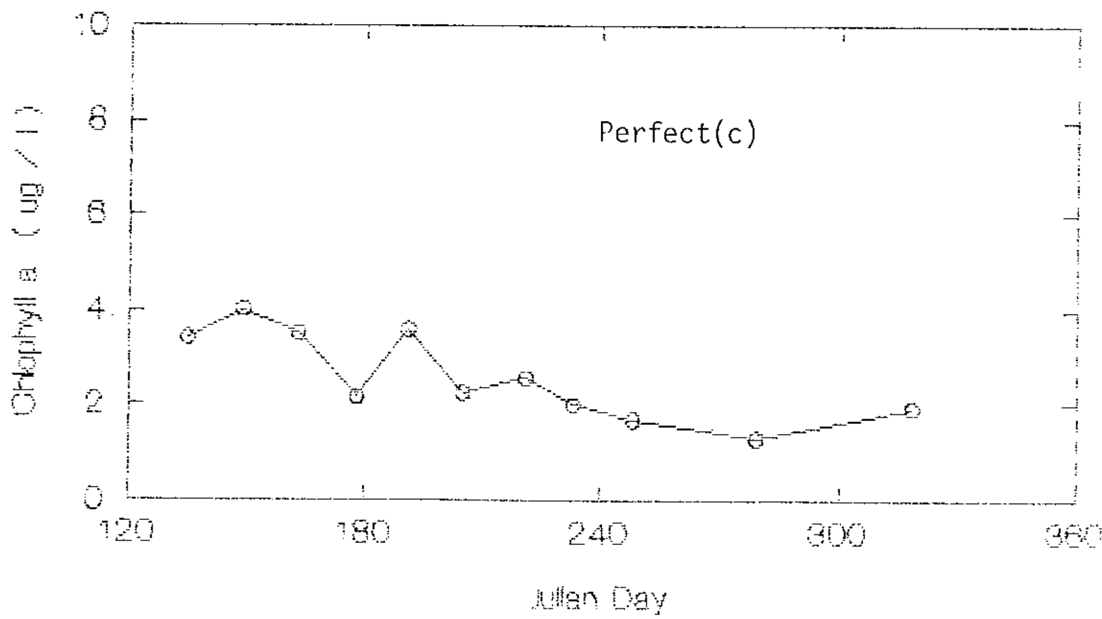

Jib(c)
Chlophyll a (ug / l)
Julian Day
0
2
4
6
8
10
120
180
240
300
360


10
6
6
4
2
0
Chlophyll a (ug / l)
Oscar(o)
120
180
240
300
360
Julian Day

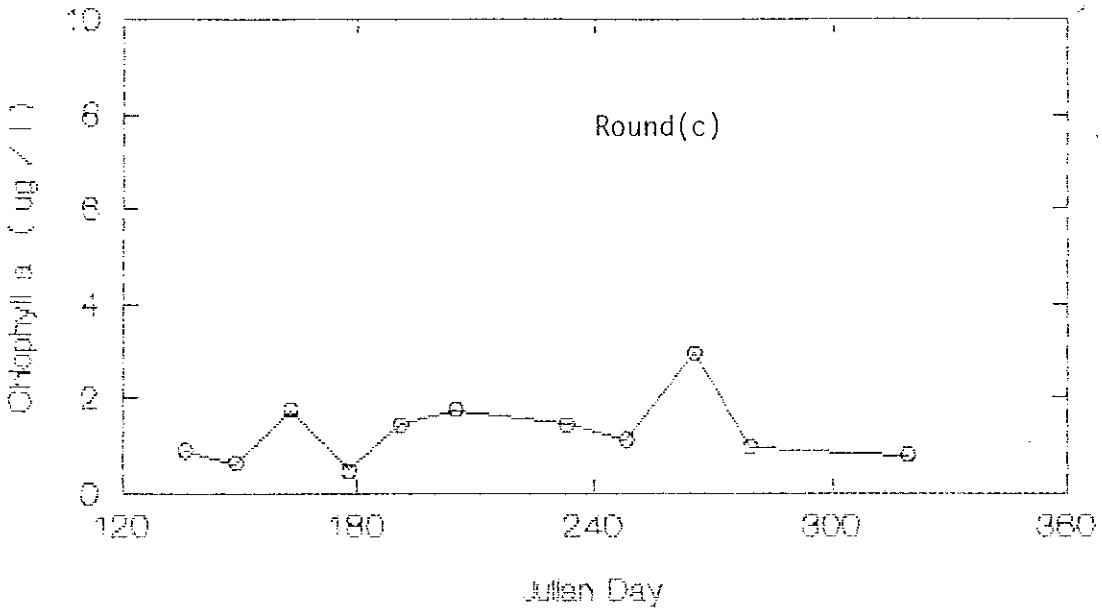

10
8
6
4
2
0
Chlophyll a (ug / l)
Oscar(c)
120
180
240
300
360
Julian Day



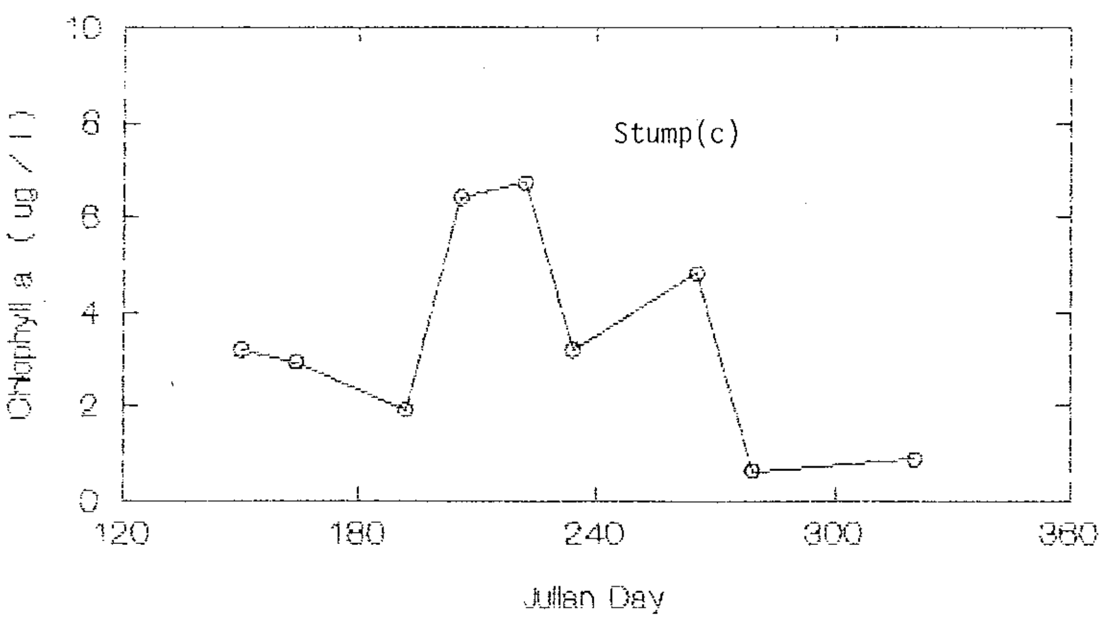
Menchon(c)
Chlorophyll a (ug / l)
Julian Day



Perfect(c)
Chlorophyll a (ug / l)
Julian Day



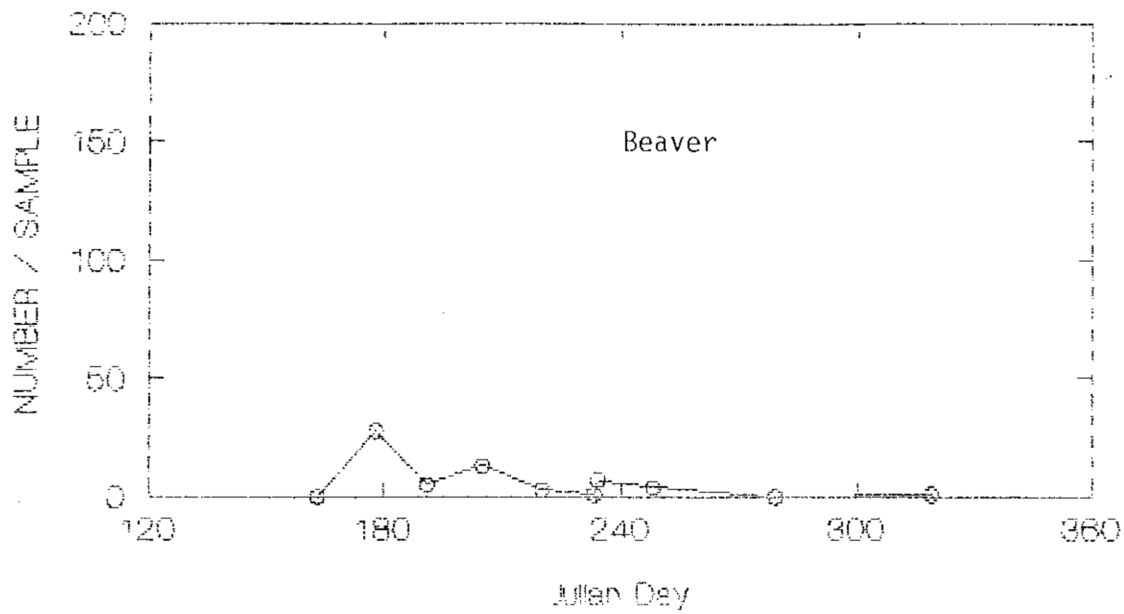
Round(c)
Chlorophyll a (ug / l)
Julian Day

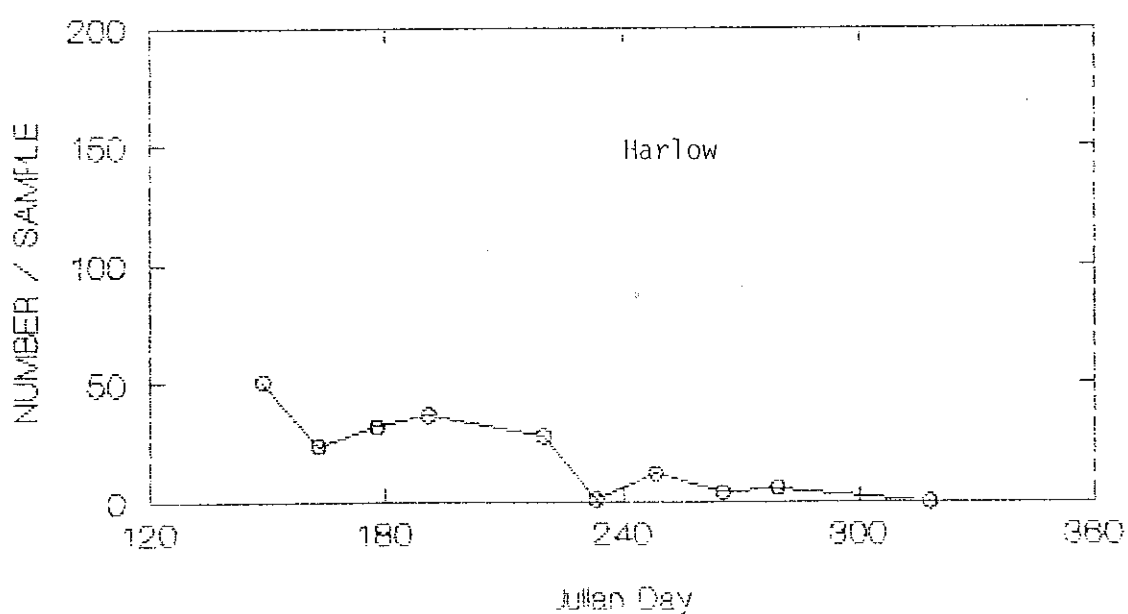


Stump(c)
Chlorophyll a (ug / l)
Julian Day

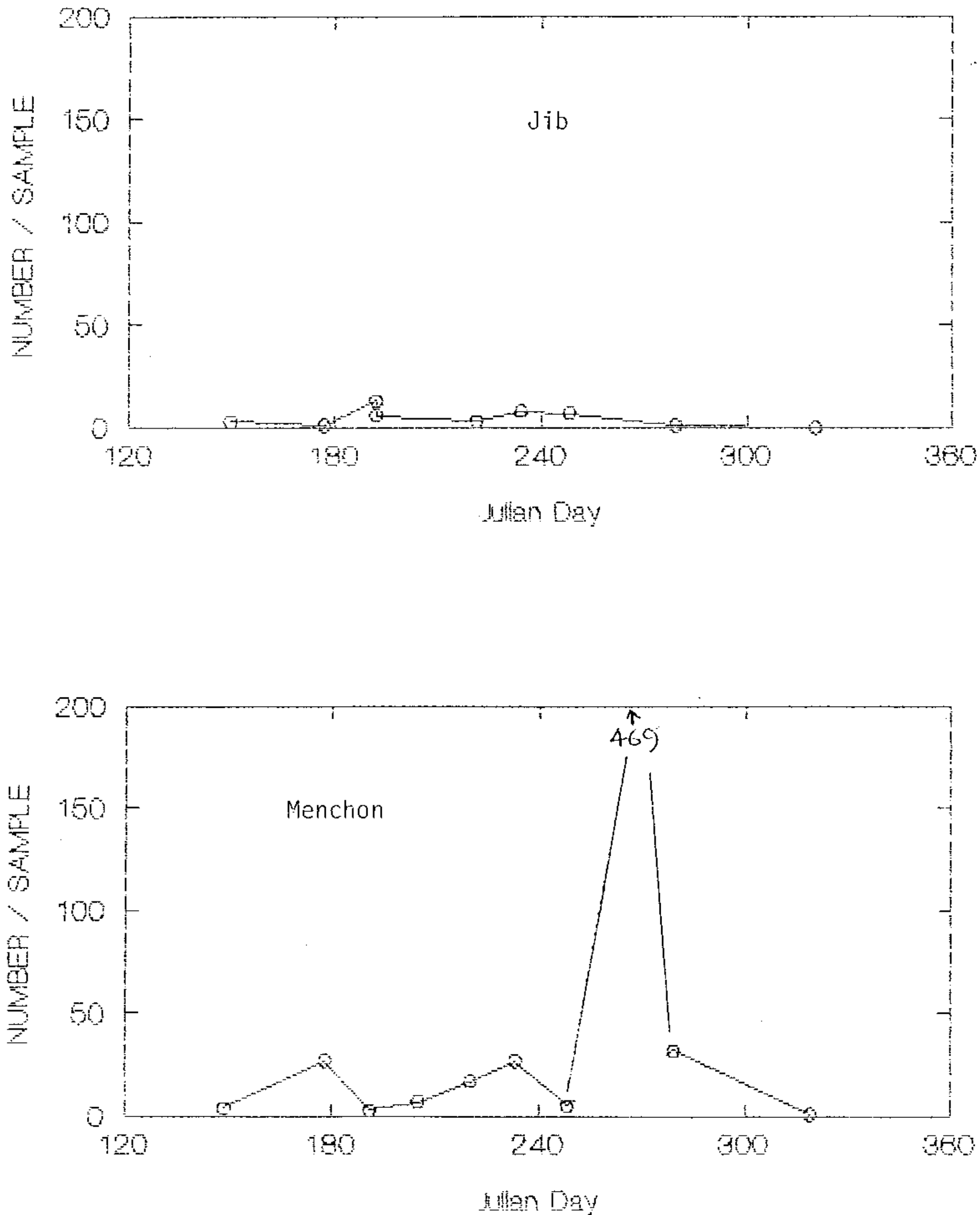
APPENDIX K

SEASONAL VARIATION IN EMERGENT INSECTS

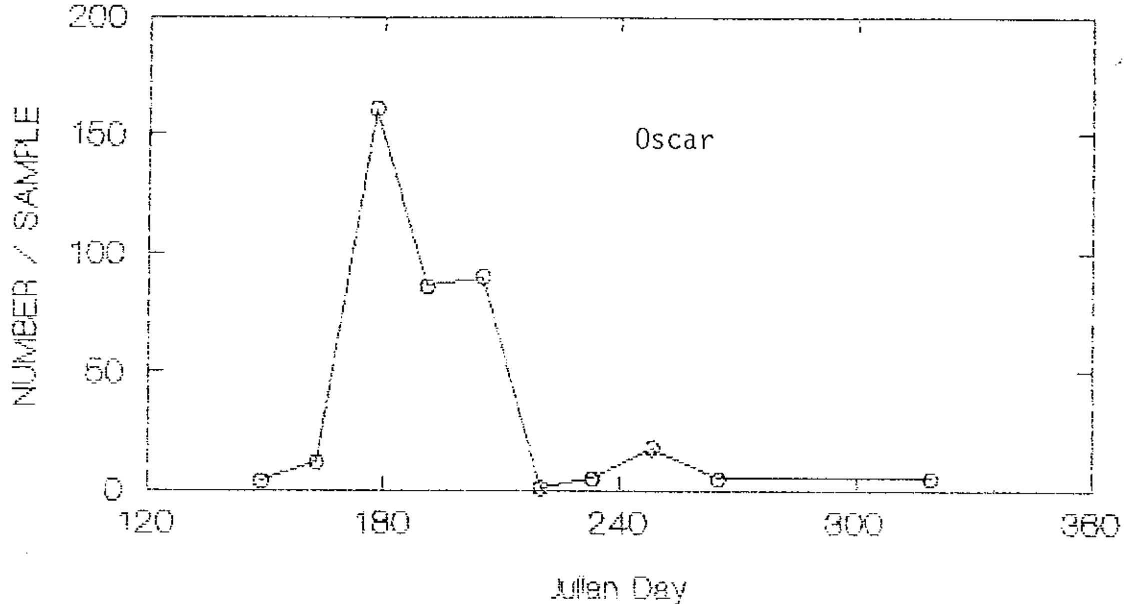


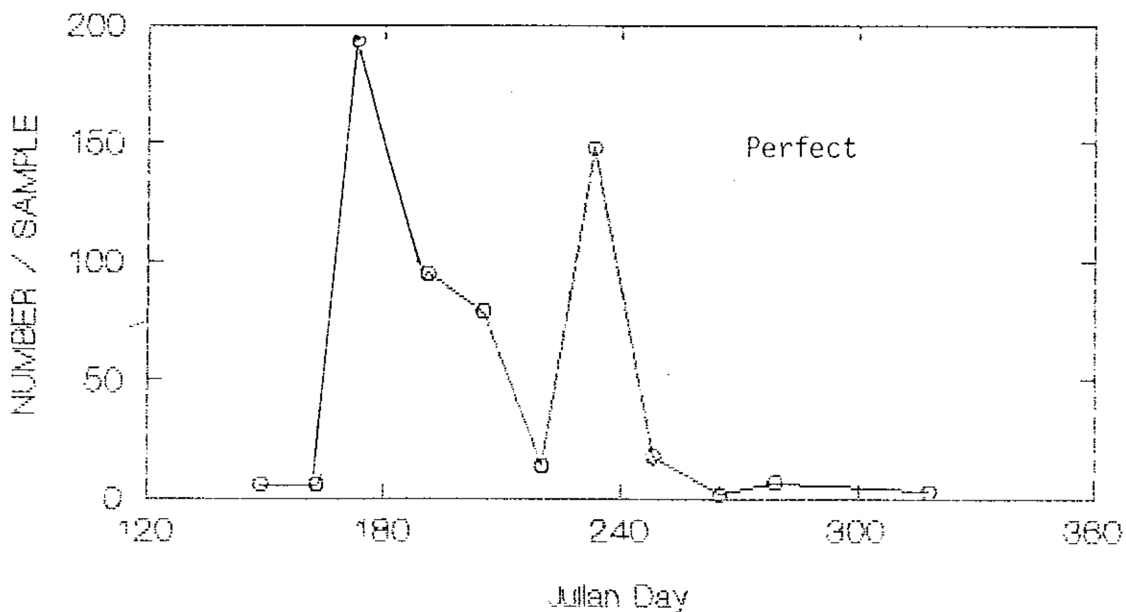


Seasonal variation in number of emergent insects.

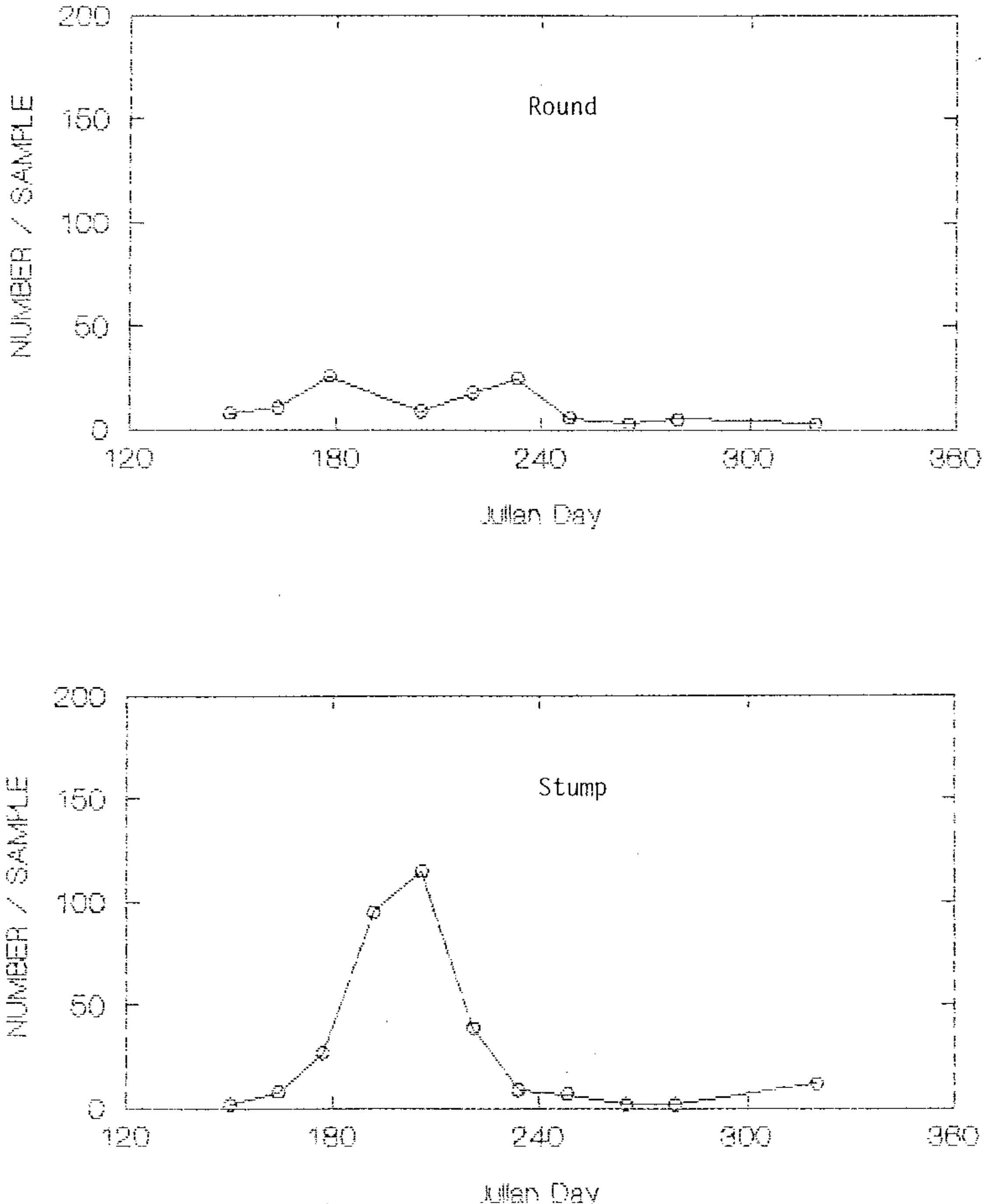


Seasonal variation in number of emergent insects.





Seasonal variation in number of emergent insects.



Seasonal variation in number of emergent insects.