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

Year Three Final Report
March 31, 1993

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
Eastern Habitat Joint Venture
Nova Scotia Department of Natural Resources
Wildlife Habitat Canada

Acadia Centre for Estuarine Research Publication No. 28

SUMMARY

The feasibility of using artificial fertilization to enhance the productivity of oligotrophic acidic freshwater wetlands was evaluated at eight sites located in the vicinity of the Tobeatic Wildlife Management Area in southwestern Nova Scotia. The study was carried out over a three-year period between 1990 and 1992. During the first year of study baseline information on the physical, chemical and biological characteristics of each site was collected. In the second year the sites were divided into control and experimental sites and the latter were fertilized with a triple-super phosphorus urea mix. The changes in physical, chemical and biological characteristics resulting from fertilization were monitored during the second and third years of the study. Although the response was variable among the experimental sites, phytoplankton biomass, periphyton growth and zooplankton numbers generally increased dramatically during the fertilization year. However, with the exception of zooplankton numbers, this increase did not persist into the following year. A large proportion of the added fertilizer was apparently lost, either by sedimentation or by flushing via surface water outflows. Estimates of the amount of added nutrients lost via the outputs suggests the latter to be most probable. The behavior of the added fertilizer, as well as the biological response produced, appears to depend largely on the physical characteristics of the site, particularly flushing rate, morphology, the presence of surface water inputs and outputs, and stratification characteristics.

CONTENTS

CONTENTS Cont.

I. INTRODUCTION

1. Background

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 soluble 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 low species diversity and low levels of both primary and secondary production (summarized by Baker and Christensen 1991). Waterfowl are indirectly affected by acidic precipitation as a result of changes in the quantity and quality of the aquatic organisms that make up their food supply (McNicol et al. 1987; Schell 1988).

The problem of wetland acidification is most prominent in industrialized regions of the world where local geomorphology, particularly the presence of igneous and metamorphic bedrock of low solubility, leads to aquatic systems having limited buffering capacity. In eastern Canada a relatively large percentage of the total land area is ranked as being highly sensitive to acid deposition (e.g., 82% in Quebec, 56% in Newfoundland and Labrador, 54% in Nova Scotia, 46% in Prince Edward Island, 34% in Ontario and 31% in New Brunswick) (Jeffries 1991). In Nova Scotia a large proportion of the freshwater wetlands have little or no buffering capacity. In a survey of 232 Nova Scotia lakes, Jeffries et al. (1986) reported that 39% had a pH less than or equal to 5.

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 can become eutrophic and support high levels of primary and secondary producer biomass (Kerekes et al. 1984; Payne 1985: Schell 1988; Schell and Kerekes 1989). This has prompted wildlife managers to suggest that artificial nutrient addition may prove to be a cost-effective management strategy in programs designed to increase the abundance of waterfowl and other species of aquatic wildlife in acidic wetlands of low productivity.

A number of studies have illustrated the general feasibility of this approach for enhancement of aquaculture fisheries (Boyd 1981), natural fisheries (Huntsman 1948; Smith 1969; LaBrasseur et al. 1978; Hyatt and Stockner 1985; Johnston et al. 1990), and waterfowl (Payne et al. 1984; Melanson and Payne 1988; Gabor et al. in press). The application of this technique as a routine management procedure, 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 Natural Resources 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.

2. 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 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 community 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 versus 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 the study was to select a number of small aquatic systems, similar to the type considered to be most appropriate for use in rehabilitation management, and to evaluate the impact of artificial fertilizer addition. The first year of the study involved obtaining pre-fertilization baseline information on each site. During the second year the sites were divided into experimental and control units and the experimental units subjected to the addition of fertilizers. Monitoring of the effects of fertilization began at this time and continued into the third year.

II. STUDY AREA

1. Choice of 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 TWMA was 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.

2. General Description of Study Area

The TWMA is located in the central part of western Nova Scotia (Fig. 1). It contains a variety of river systems, large lakes, ponds and other wetlands, most of which are typically acidic, dystrophic and of low productivity. The area is mainly forested and composed of mixed conifer-angiosperm stands characterized by red spruce (*Picea rubens*) and black spruce (*P. mariana*), with smaller amounts of eastern hemlock (*Tsuga canadensis*), white pine (*Pinus strobus*), red pine (*Pina resinous*), white birch (*Betula papyrifera*), red maple (*Acer rubum*), beech (*Fagus grandifolia*), and yellow birch (*B. allegheniensis*). There are also large areas of early successional shrub dominated communities and heath dominated barrens. Bedrock is mainly composed of Devonian granite, Halifax slates and Goldenville greywacke covered with glacial till and drumlin and moraine deposits. The soils are mainly nutrient poor acidic sandy loams and organic peats.

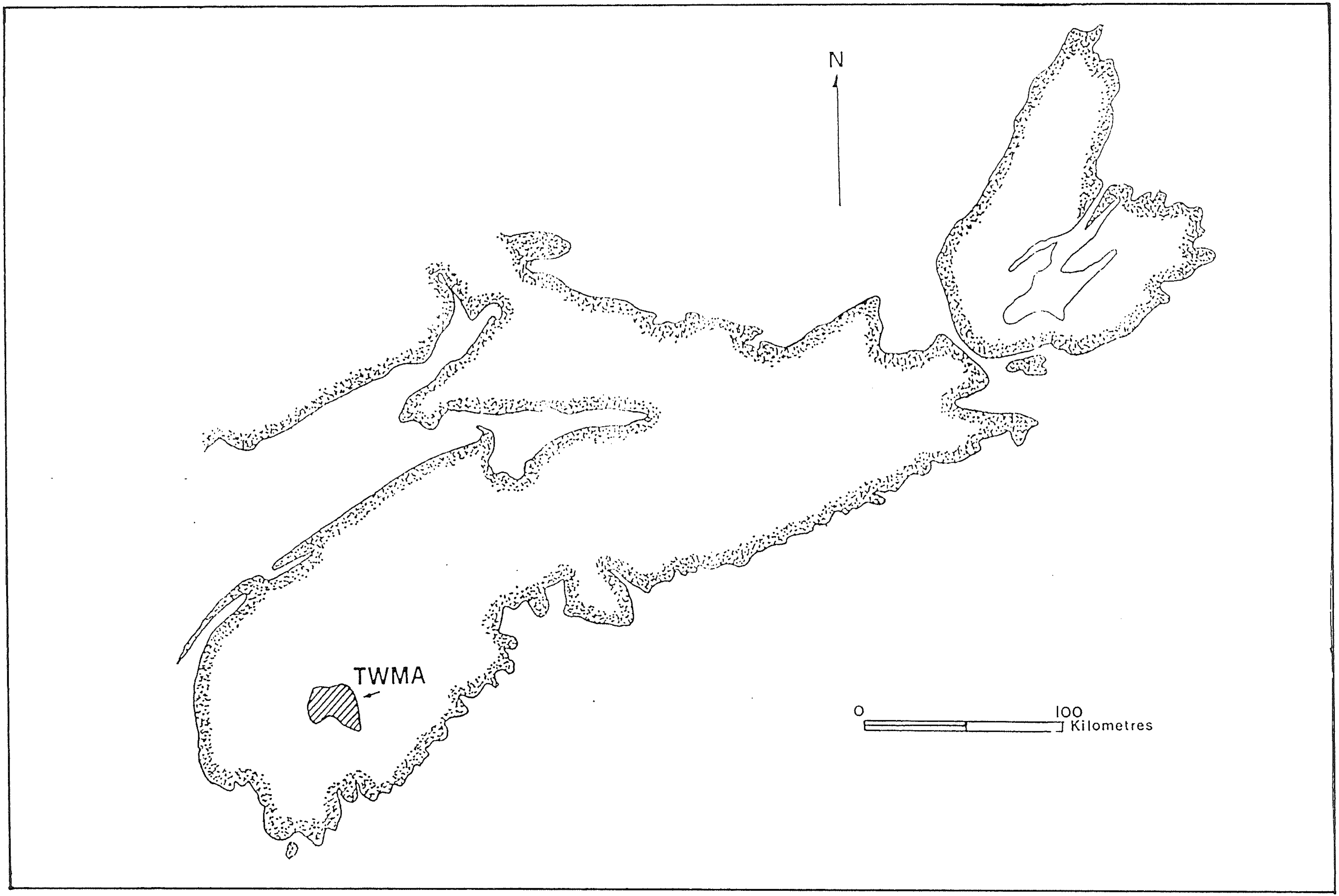


Figure 1. Map of Nova Scotia showing the location of the Tobeatic Wildlife Management Area (TWMA).

III. STUDY SITES

In early May 1990 an extensive survey was conducted to locate and evaluate potential study sites. The major criteria used in site selection 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, 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 analysis.

Figure 2 shows the location of each site. All are within a 15 km radius of the Nova Scotia Department of Natural Resources' camp at Pollard Falls where a 10 x 40 foot trailer, modified for use as a field laboratory, was established for use as a base for field work.

1. Morphological Characteristics of Study Sites

During the summer of 1990 a bathymetric survey of each site was made. Table 1 lists the general morphometric characteristics of each site. Appendix A 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 surface inflows or outflows. Jib has a well developed surface outflow but no obvious surface inflow. Oscar has a well developed surface inlet and outlet. Stump has an intermittent surface inlet and outlet both of which were dry between about mid-June and mid-August of each year. All of the sites have relatively low values of shoreline development which reflects the absence 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% and is closely correlated to mean depth.

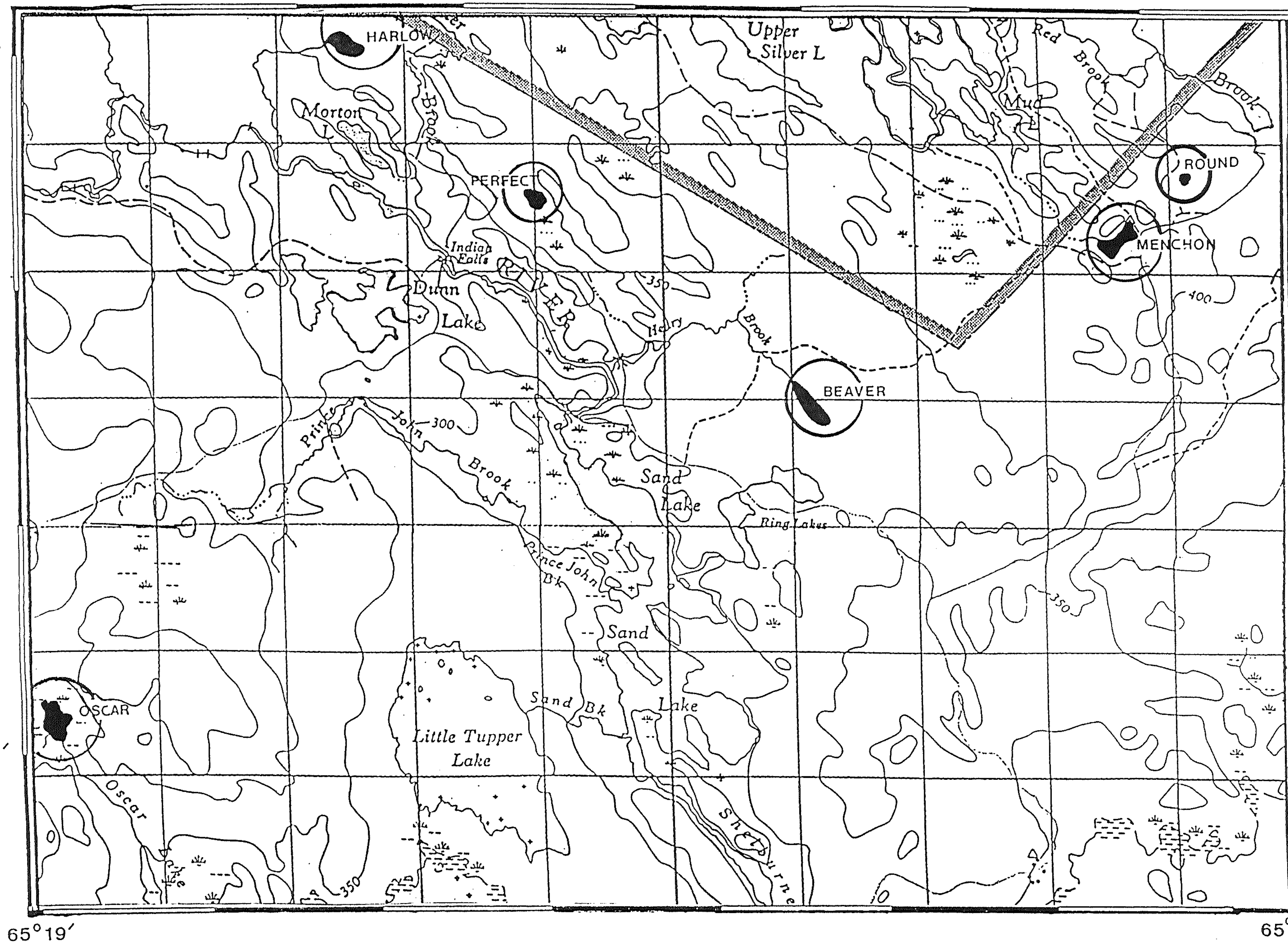


Figure 2. Location of six of the eight study lakes in the Tobeatic Wildlife Management Area.

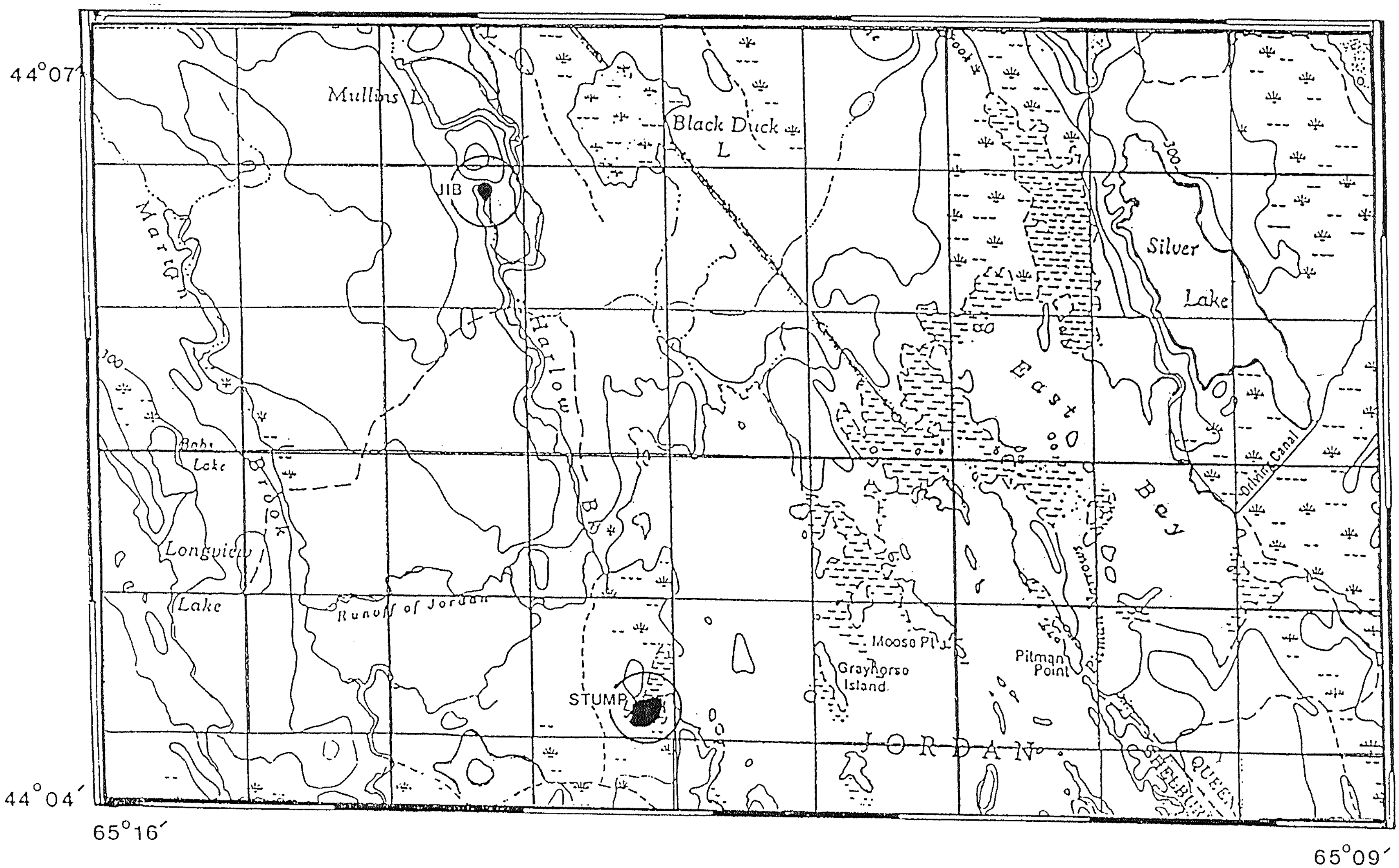


Figure 2 (cont.). Location of Stump and Jib Lakes in the Tobeatic Wildlife Management Area.

Table 1. Morphological characteristics of study sites.

SITE	Surface Area (m^2)	Volume (m^3)	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	Relative Depth	Area above 1 m (%)
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
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
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
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
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
Perfect	11904.5	19499.5	1.6	4.0	163.5	128.7	72.8	513.5	1.33	0.41	2.90	35.0
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

2. Drainage Basin Areas and Flushing Rates

Drainage basin areas, lake volumes and flushing rates are presented in Table 2.[1] Flushing rates were calculated assuming an average annual precipitation of 1436 mm yr^{-1}. Values ranged from a low of 3.0 to a high of 30.2 times yr^{-1}. The highest rate is for Oscar which is also the largest study site.

3. Sediment Types

Although an extensive survey of sediment types within each site was not carried out, sediment samples were collected in conjunction with determination of sediment phosphorus concentrations. All of the study sites contain sediments composed of a fine brown organic material of the *dy* type characteristic of brown-water dystrophic lakes. Sediment organic content is relatively high, ranging between 40 and 77%, at all sites except Menchon which had a value of only 12% (Fig. 3). Despite the high organic contents, and in some cases the presence of an anaerobic hypolimnion, there was little evidence of strong anaerobic conditions within the sediments at any of the study sites.

[1]It was not possible to calculate a flushing rate for Stump since it receives intermittent inputs, the amounts of which are difficult to estimate, from a larger lake (Jordan) during periods of high water levels.

Table 2. Drainage basin areas, volumes and flushing rates.

Site	Drainage Basin Area (m^2)	Volume (m^3)	Flushing Rate (times yr^{-1})
Beaver	588,379	26,308	17.9
Harlow	217,561	58,242	3.0
Jib	173,195	8,012	17.3
Menchon	309,486	45,588	5.4
Oscar	2,144,199	56,822	30.2
Perfect	254,316	19,450	10.5
Round	167,960	8,877	15.1
Stump	-	5,278	-

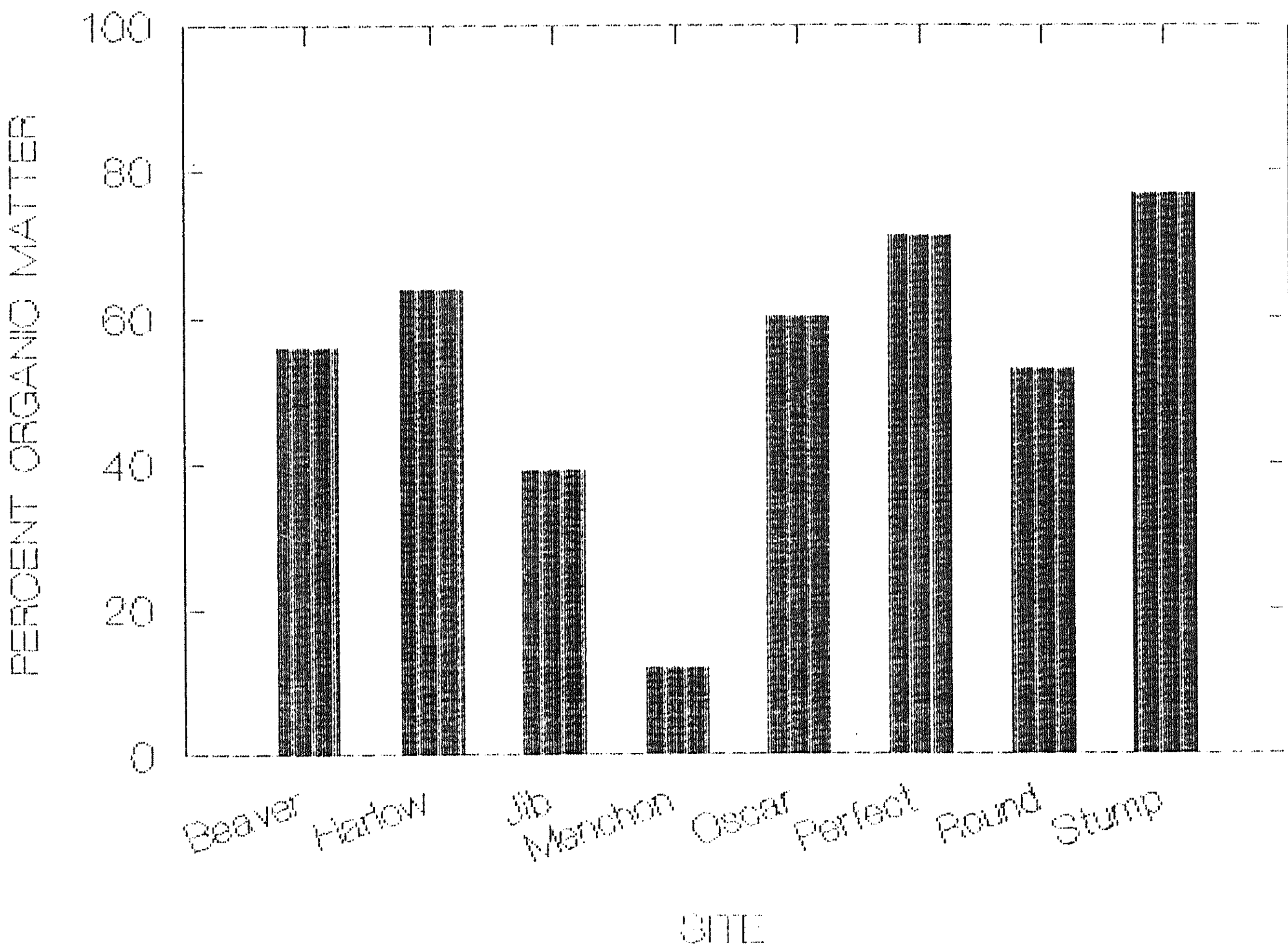


Figure 3. Percent organic matter content of sediments.

IV. METHODOLOGY

1. Experimental Design

The first year of the study (1990) was used to obtain baseline data on the physical, chemical and biological characteristics of each study site. In the second year the sites were divided into control and experimental sites and the experimental sites were fertilized in the early spring. Monitoring of the changes in physical, chemical and biological parameters was carried out at both control and fertilized sites during 1991 and 1992. Interpretation of the changes brought about by the addition of fertilizer was made on the basis of comparisons among the experimental sites between pre and post fertilization years, and comparisons between the control and experimental sites after fertilization.

2. Sampling Stations

Two distinct sampling stations were established at each site, 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. The littoral station was equipped with a water level meter, insect emergence trap, periphyton growth sampler and minnow trap. This station was also used to collect benthic invertebrate samples. At those sites having an obvious outlet an additional station was established within the outlet which was sampled for water quality parameters only. In the case of Jib, its outlet was also sampled at a station located about 0.3 km downstream from the lake proper just above where it intersects a larger brook (Harlow Brook), and an additional sample, to serve as a control, was taken from the larger brook just above where the outlet enters the brook.

3. Variables Monitored

The variables monitored at each site (Table 3) include those typically used to characterize the physical, chemical and biological aspects of aquatic systems. The biological variables emphasize groups thought to be especially important to waterfowl populations in terms of food, particularly zooplankton and aquatic insects.

4. Sample Collection and Analysis Techniques

A set of standardized procedures was developed for field sampling and laboratory analysis of samples. These are described in Appendix B. In most cases the procedures follow standard limnological techniques, but in some instances slight modifications were made to optimize sample

Table 3. 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 (Depth profiles)
2. pH
3. Alkalinity
4. Total Carbon Dioxide
5. Dissolved Oxygen (Surface and Bottom)
6. Hardness
7. Dissolved Phosphorus
8. Total Phosphorus
9. Sediment Phosphorus

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 Phosphorus

III. Biological

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

collection and processing time. Analyses of the more labile chemical parameters (pH, dissolved oxygen and alkalinity) were carried out at the field laboratory within 3 to 4 hr of collection. Other chemical analyses were 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 had been stored refrigerated.

The field sampling program was essentially the same during all three years of the study except that after the first year measurement of suspended particulate matter (SPM) concentration was discontinued and a sediment phosphorus sampling program added. SPM measurements were discontinued mainly because of the limited information they provided relative to the amount of field and laboratory work required. The addition of the sediment phosphorus sampling program was considered important for evaluation of the fate of added P.

Sample collection times were biweekly from May to about early October. Each site was also visited once in November, and once in late February-early March to make observations on winter ice conditions and measurements of dissolved oxygen concentrations under ice cover.

5. Fertilization Protocol

Four of the eight study sites, Jib, Oscar, Perfect and Stump, were chosen to serve as experimental sites and receive fertilizer. The remaining four sites, Beaver, Harlow, Menchon and Round, were selected to act as controls.

The fertilization regime employed was based on the results of work carried out at Jordan Lake by the Nova Scotia Department of Natural Resources (Melanson and Payne 1988). In that study fertilization was carried out using a mixture of triple-super phosphate and urea having an N:P ratio of ten. The study showed that, upon initial application of the fertilizer, phosphate levels immediately rose to very high levels, but then dropped quickly (within days), and in order to produce P levels appropriate to creating eutrophic conditions it was necessary to initially add on the order of 2 mg P l^{-1} of lake water.

Fertilization of the experimental sites was carried out on 27 and 28 April 1991. Perfect and Jib, which are small and reasonably accessible, were fertilized by slowly adding fertilizer by hand into the propeller swash of an outboard motor as the boat traversed the lake (Fig. 4a). Oscar, the largest

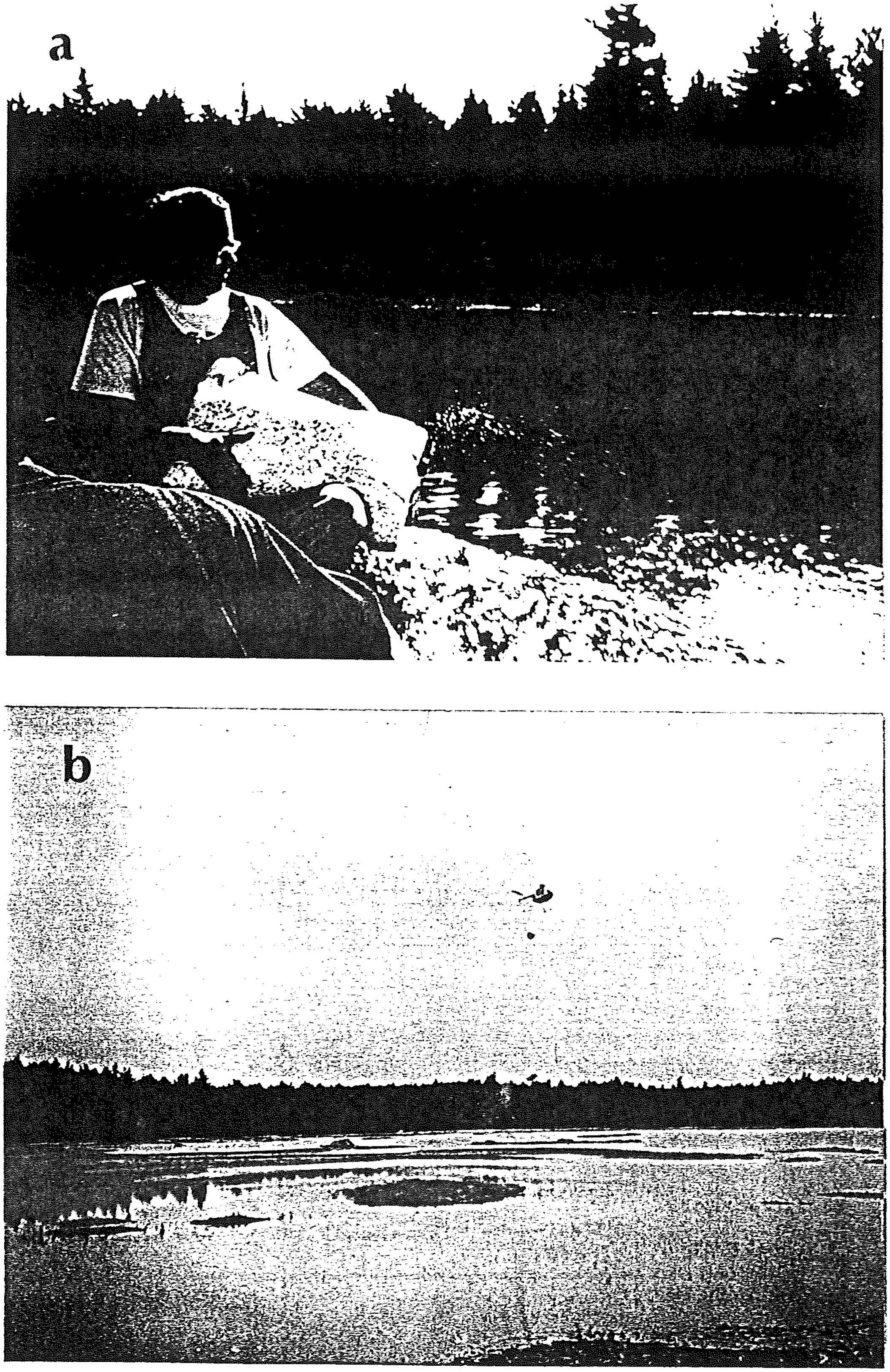


Figure 4. Method of fertilizer application. (a) Perfect and Jib were fertilized by boat; (b) helicopter and water bucket used to fertilize Oscar and Stump.

experimental site, and Stump, the least accessible experimental site, were fertilized by helicopter using a water bucket (Fig. 4b).

The following amounts of P (added as a triple-super phosphate urea mix containing a 10:1 ratio of N to P) were added to each experimental site: Oscar - 113.6 Kg; Perfect - 38.9 Kg; Jib - 16.1 Kg; Stump - 10.6 Kg. These quantities represent the amount of fertilizer required to provide 2 mg P l^{-1} of lake water.

V. RESULTS

1. Precipitation

Average annual precipitation in the TWMA amounts to about 1500 mm. During the course of the study there was considerable variation between years in the total annual precipitation (1603.7 mm in 1990, 1370.0 mm in 1991 and 1178.2 mm in 1991). The seasonal variation among years was also great (Fig. 5); 1990 was characterized by a wet spring and summer; 1991 by a wet spring and unusually dry summer; and 1992 by a dry spring and summer.

2. Physical Characteristics

2.1. Water Temperature and Thermal Stratification

Surface water temperatures exhibited the same seasonal trends at all sites (Fig. 6). Maximum temperatures occurred during late July and ranged between 25 to 30 C. Four of the eight study sites (Harlow, Perfect, Round and Jib) exhibit seasonal thermal stratification of the dimictic type typical of temperate lakes, and in all cases mixing is holomictic. Figure 7 illustrates seasonal temperature isopleths for each of these sites. All are weakly stratified at the beginning of May. The degree of stratification increases into the summer peaking at the time of maximum surface temperature (early August). Stratification then decreases until about mid-October when fall overturn occurs and the lakes become isothermal. There was very little year to year variation in this pattern during the course of the study. Surprisingly, Menchon Lake, which has considerable depth, did not show any sign of becoming stratified, probably as a result of its relatively clear water and greater exposure to wind induced mixing.

During the winters, all of the sites visited had ice cover ranging in thickness between 30 and 45 cm and exhibited inverse thermal stratification.

2.2. Water Transparency

Water transparency was monitored using Secchi disk measurements (Fig. 8). Additional information on transparency is provided by measurements of apparent color and turbidity (Figs. 9 and 10). With the exception of Menchon, all of the sites are characterized by low transparency, due primarily to light attenuation by humic based dissolved organic matter, and are characterized by the

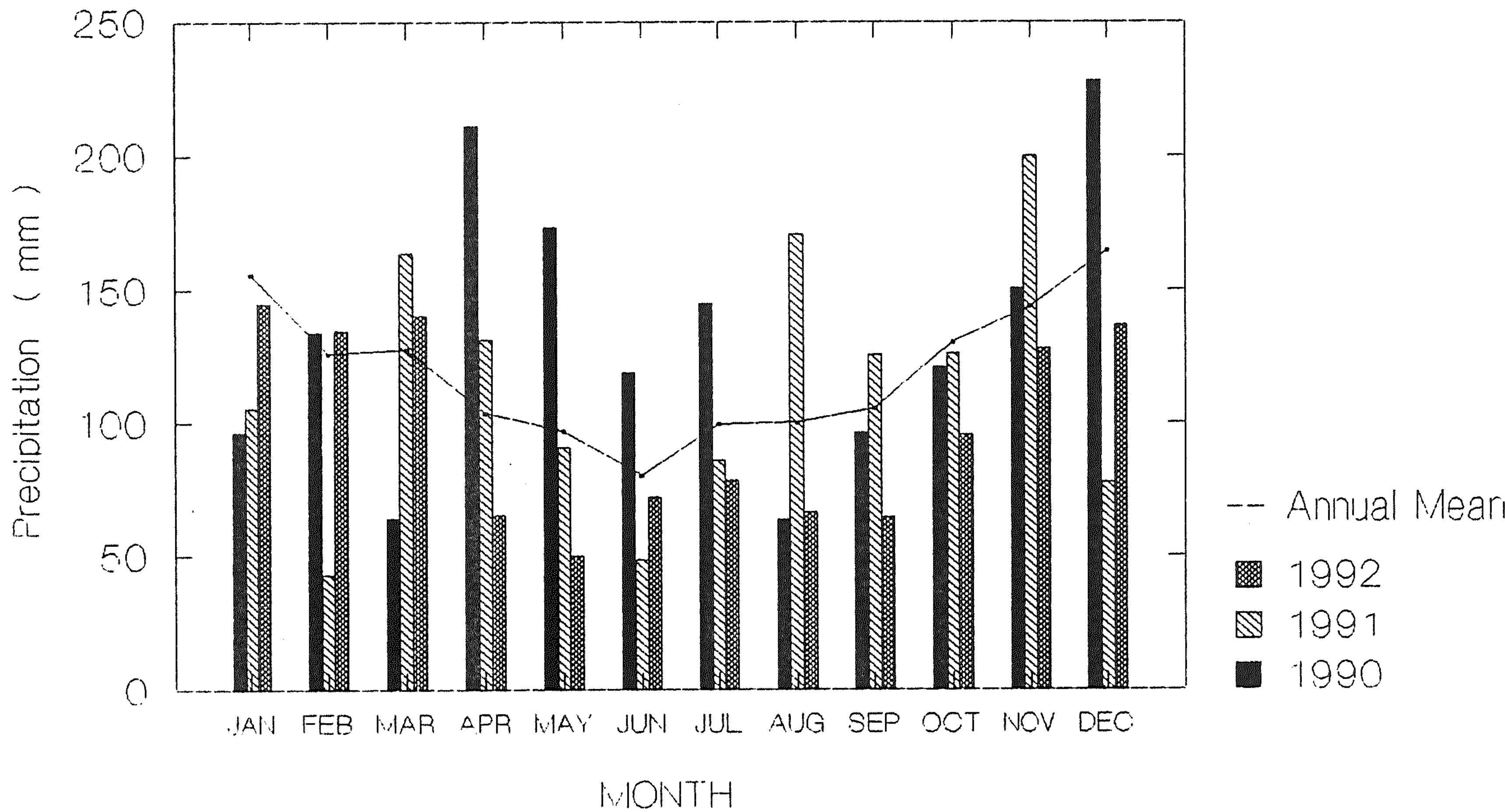


Figure 5. Seasonal variation in precipitation during the study period (based on data collected at Kejimkujik National Park).

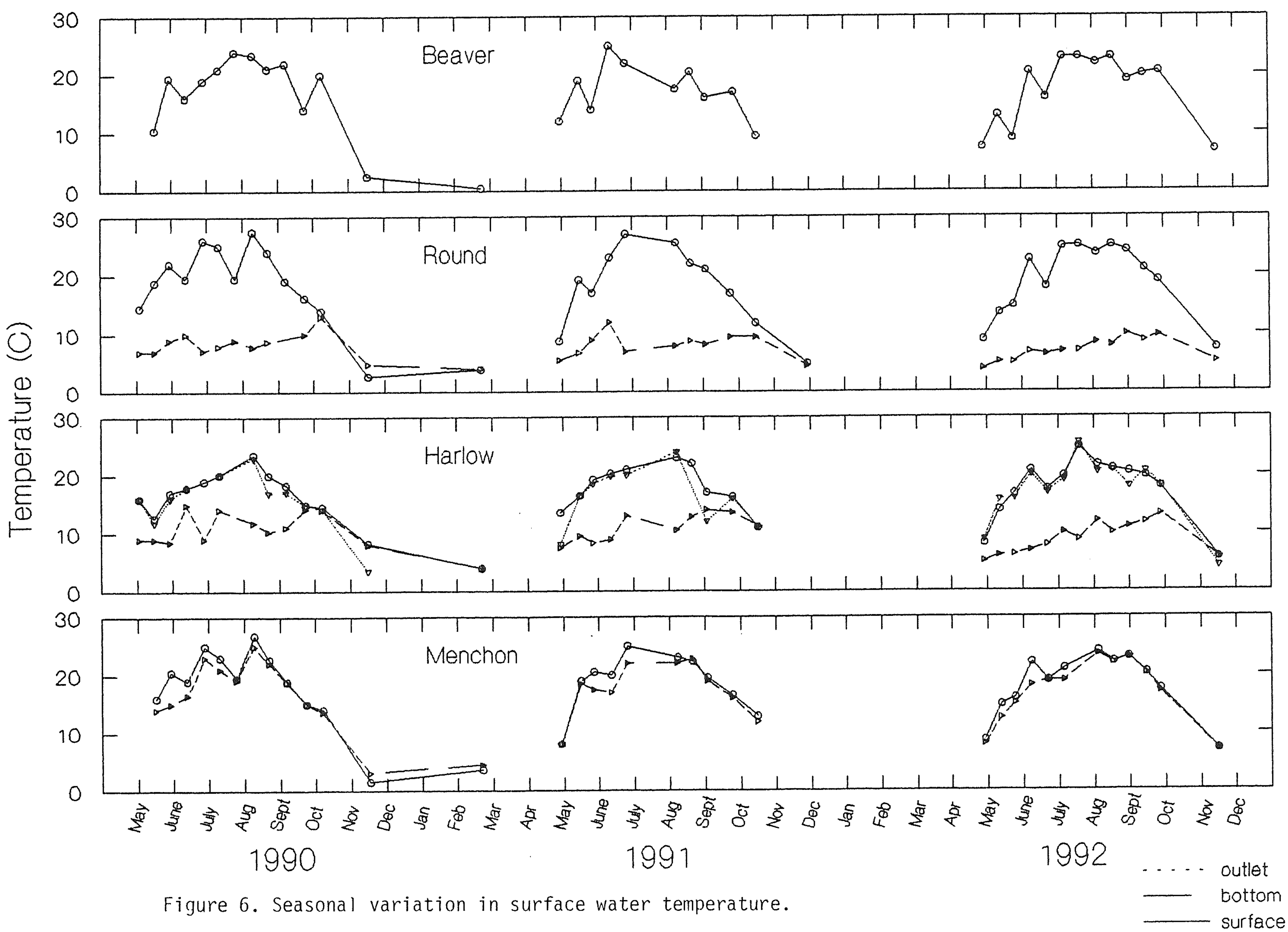


Figure 6. Seasonal variation in surface water temperature.

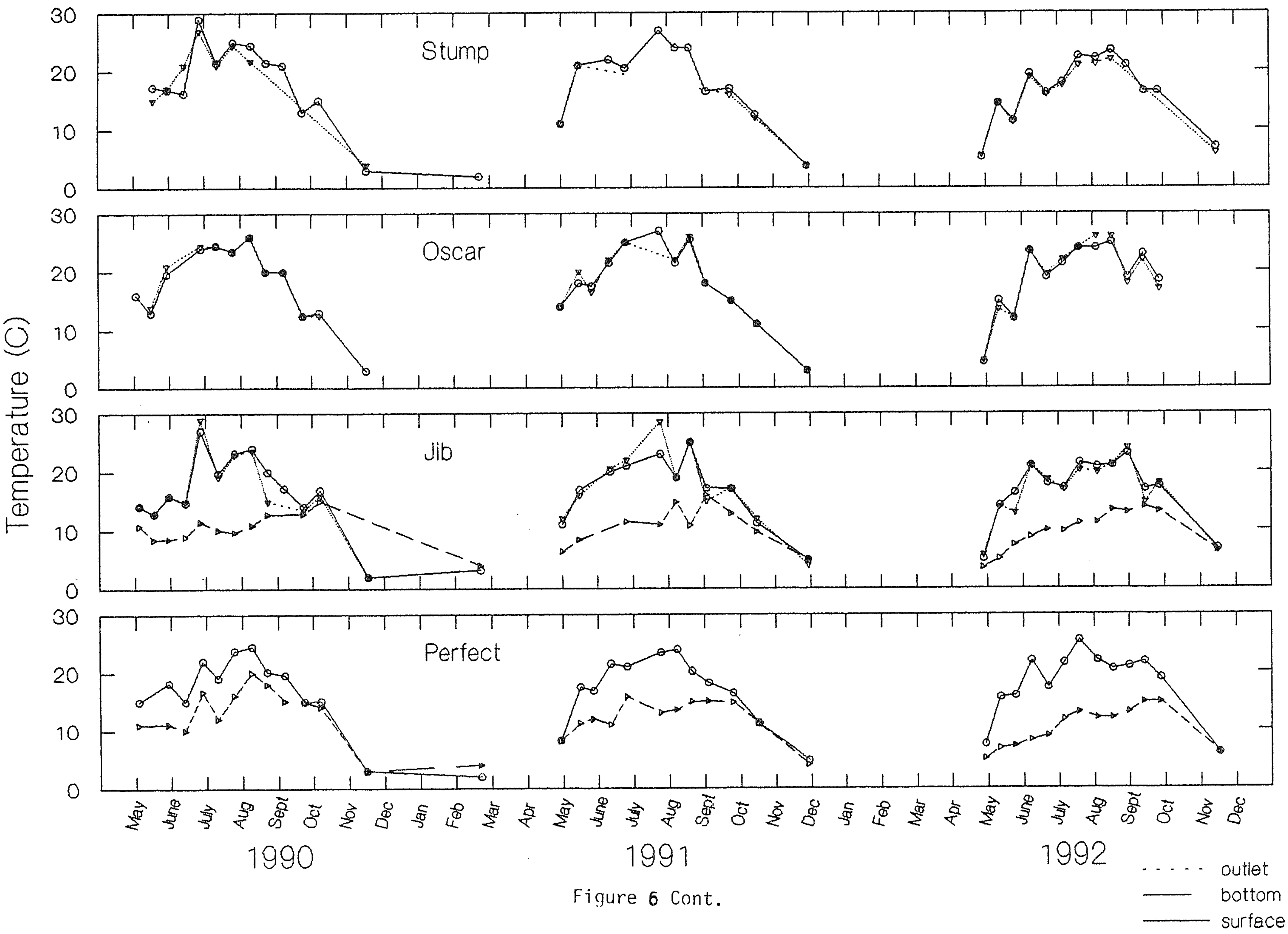


Figure 6 Cont.

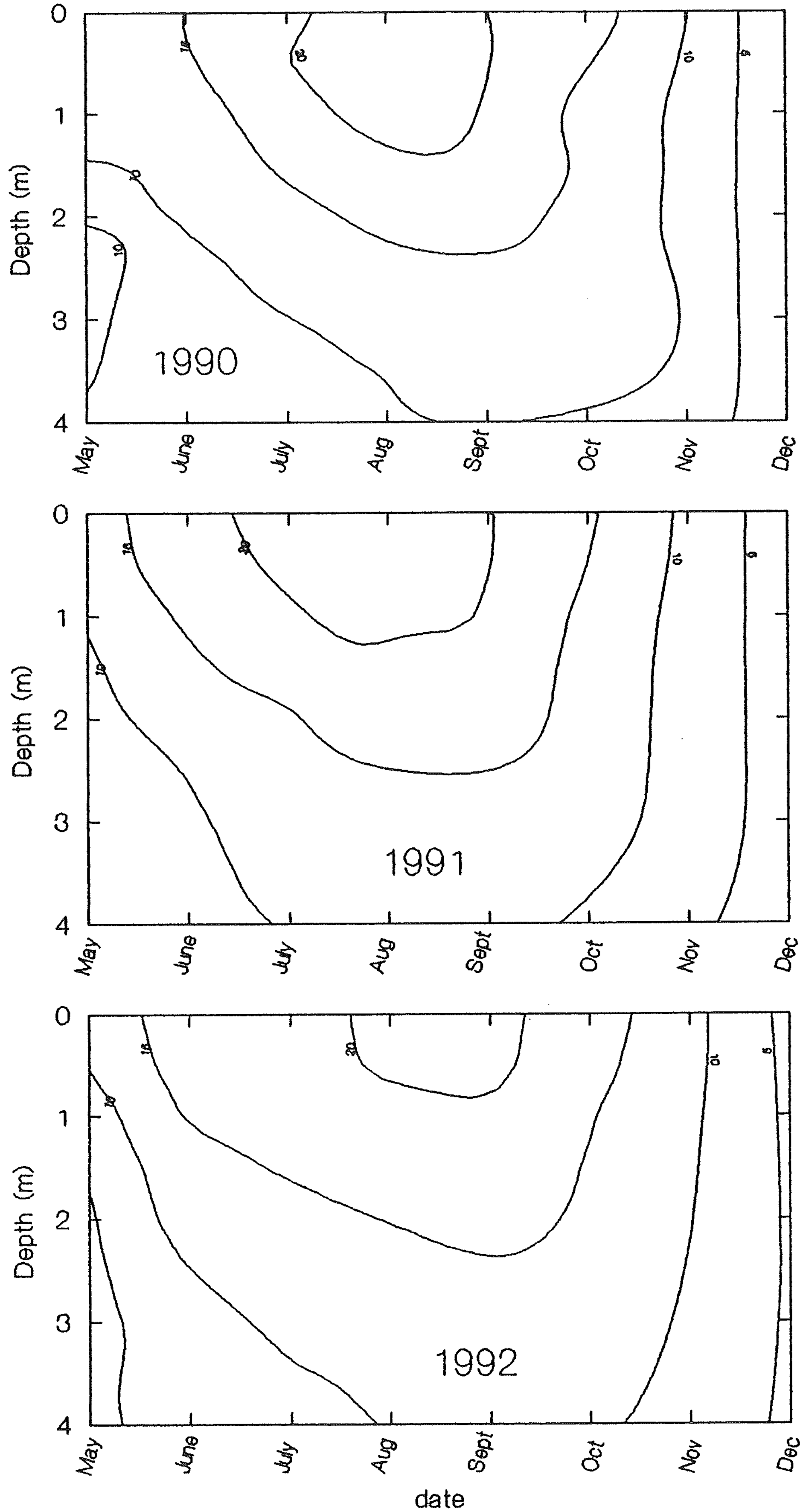


Figure 7a. Seasonal temperature isopleths for Jib.

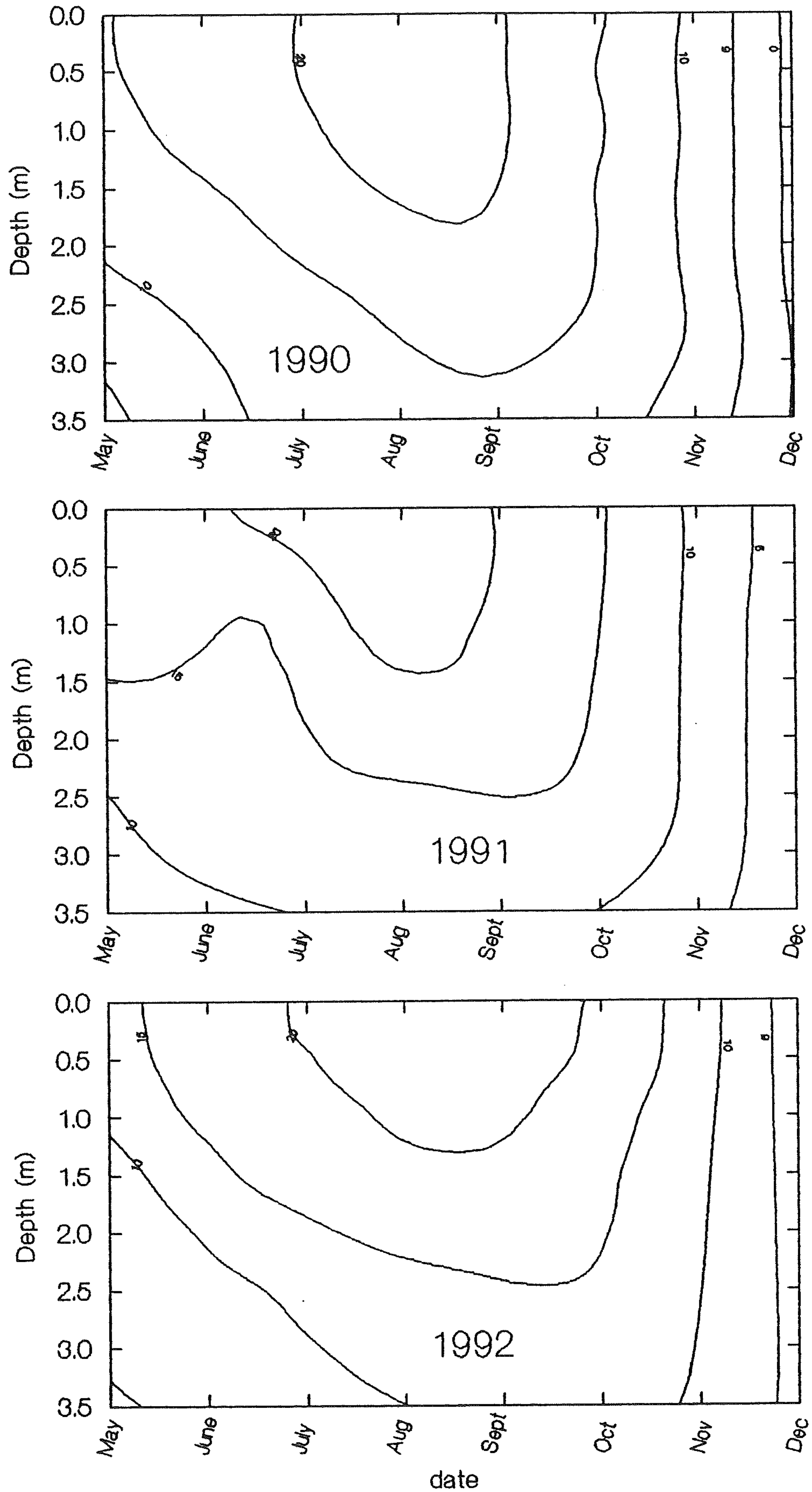


Figure 7b. Seasonal temperature isopleths for Perfect.

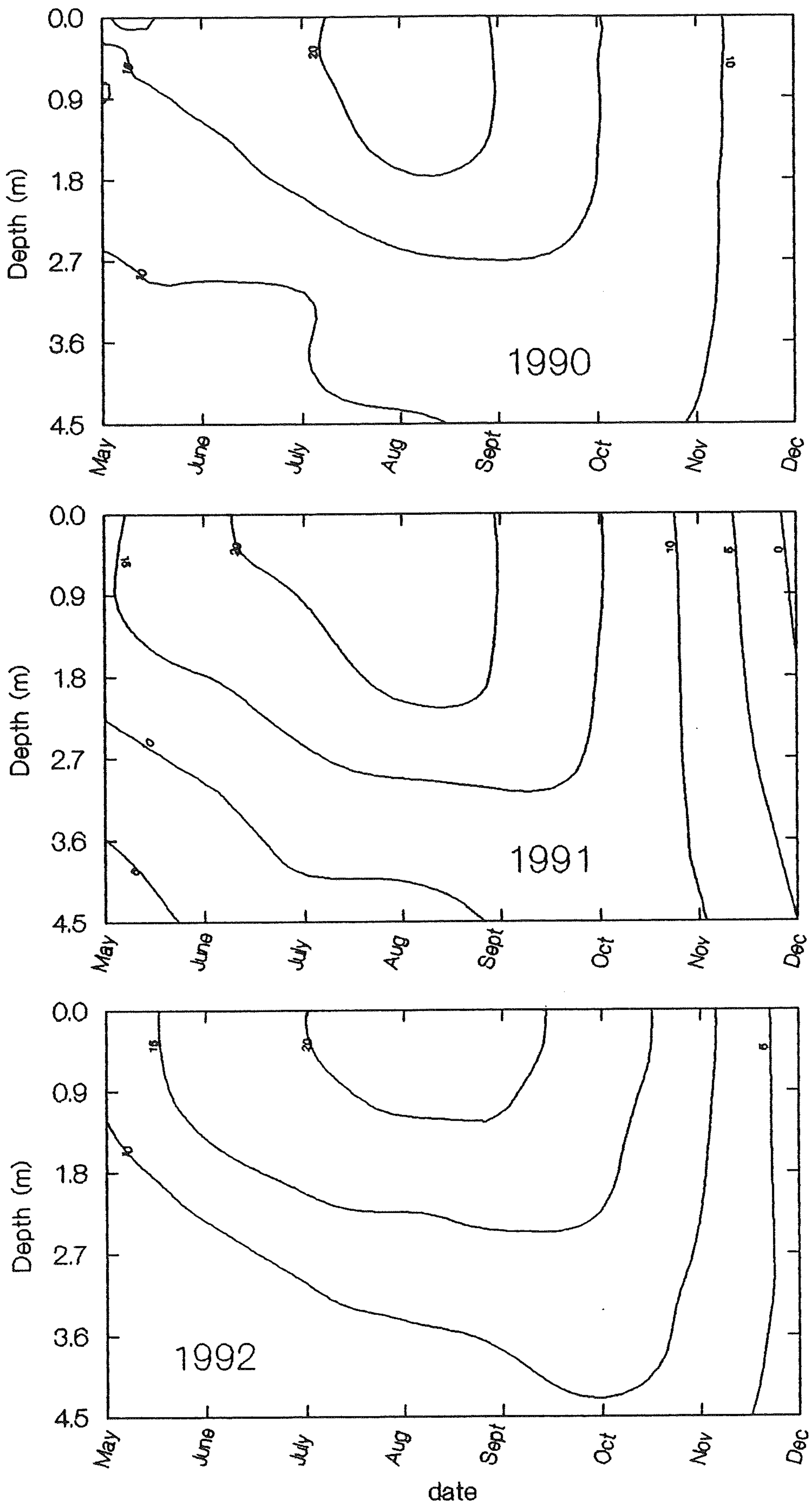


Figure 7c. Seasonal temperature isopleths for Harlow.

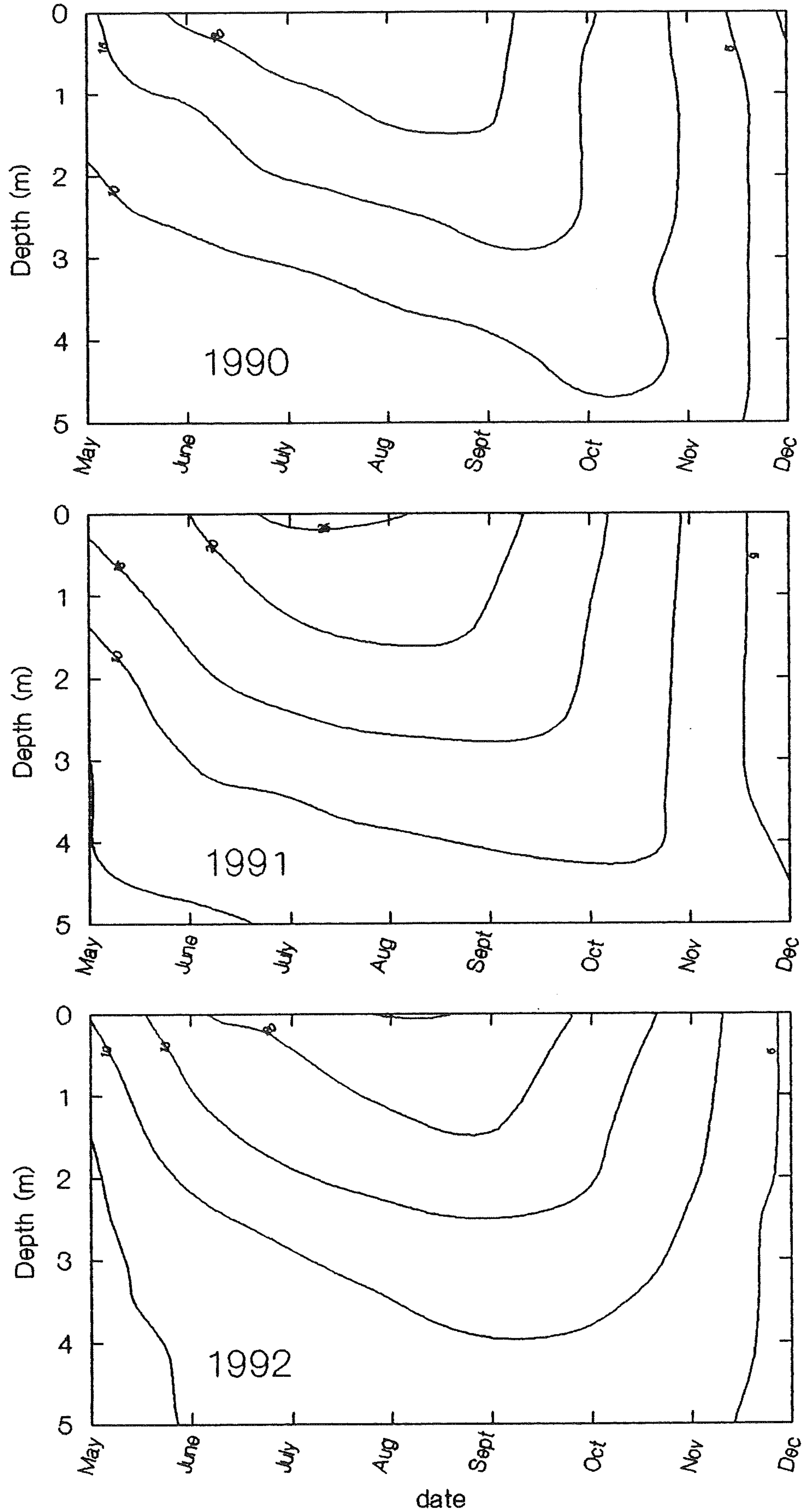


Figure 7d. Seasonal temperature isopleths for Round.

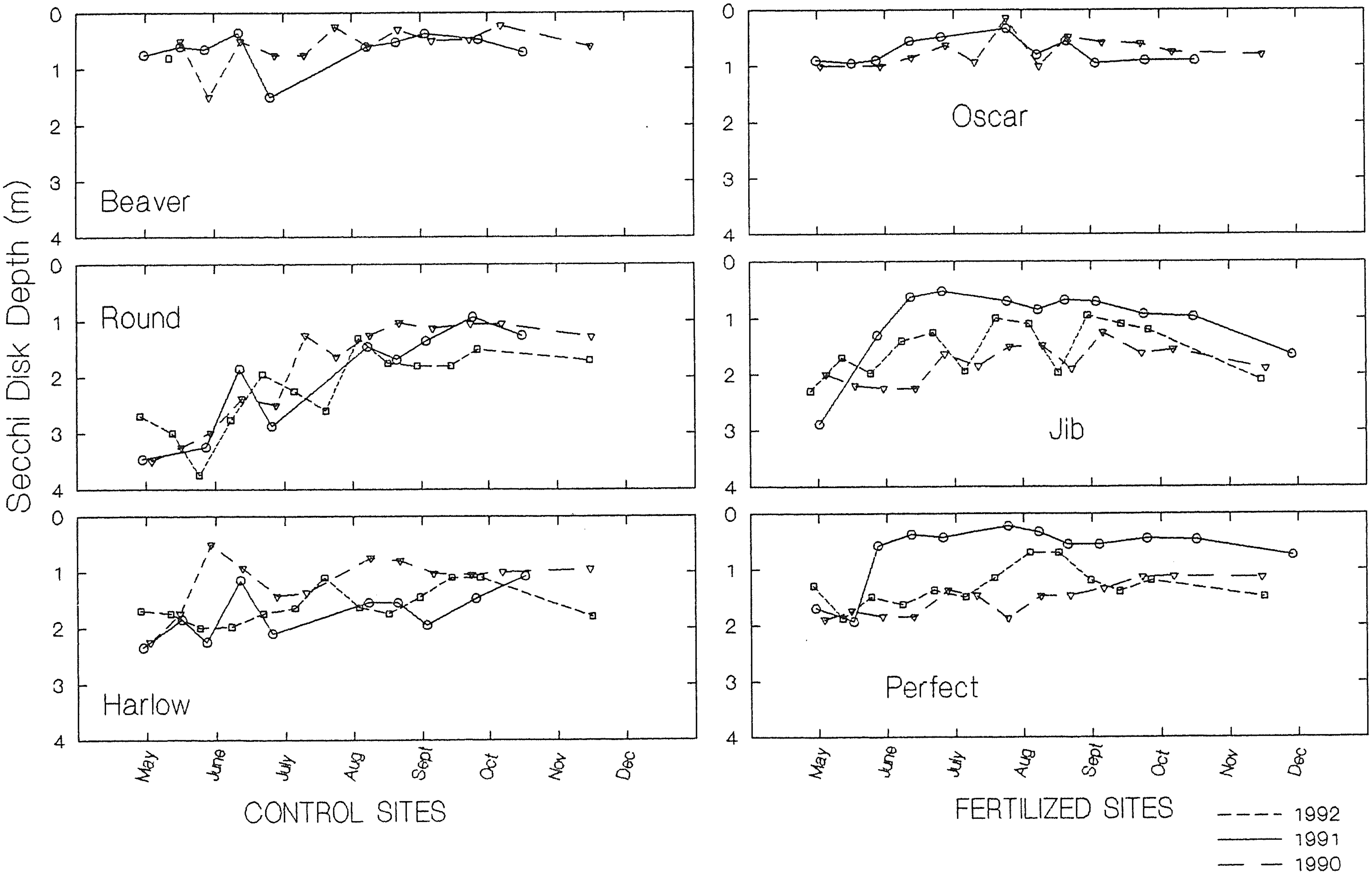


Figure 8. Seasonal variation in Secchi disk depth (the bottom was always visible at Menchon and Stump).

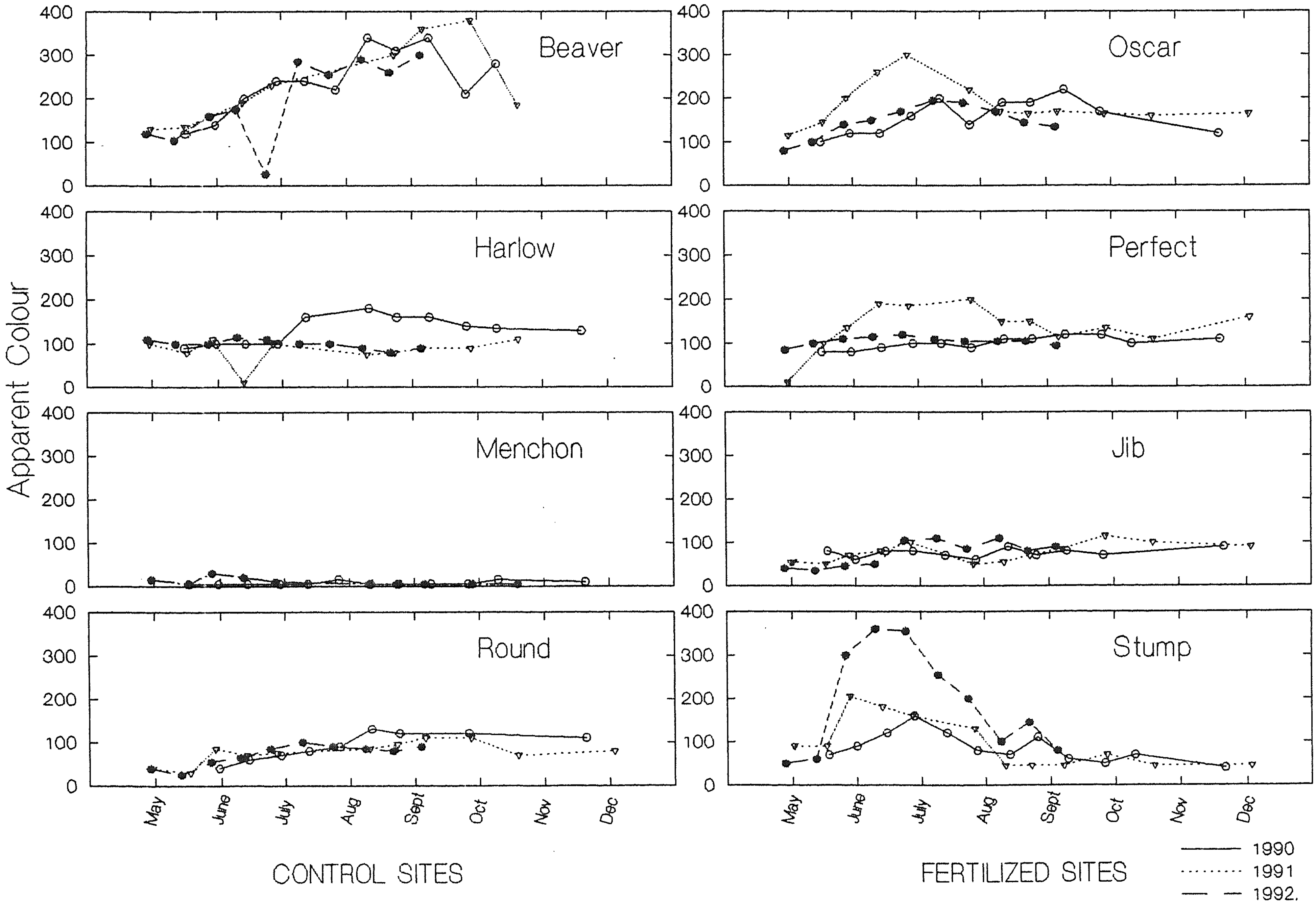


Figure 9. Seasonal variation in apparent colour.

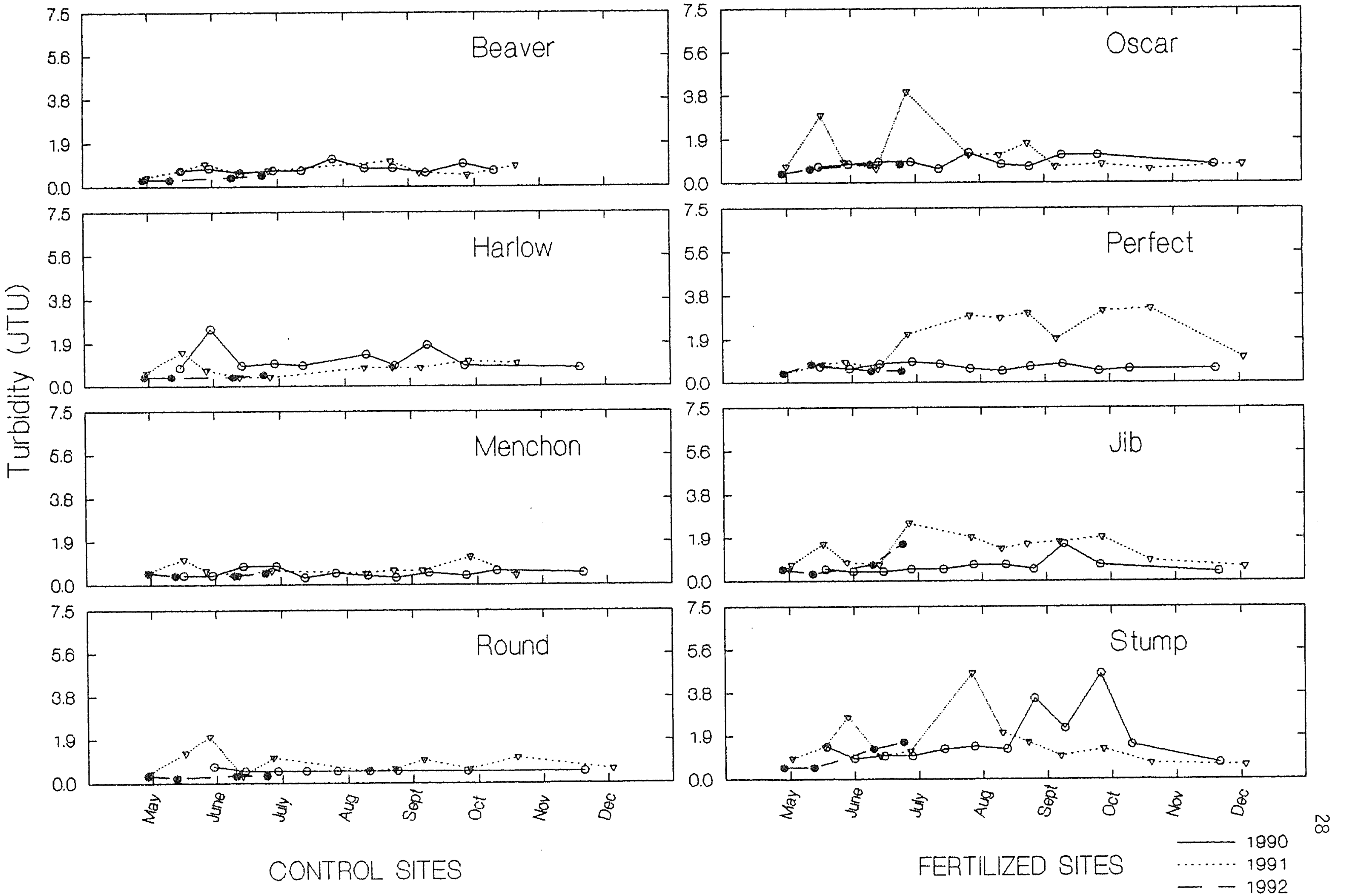


Figure 10. Seasonal variation in turbidity.

brown water typical of lakes surrounded by drainage basins containing a large proportion of coniferous vegetation. It is doubtful that the deeper sites have sufficient light to allow development of submersed benthic macrophytes within the lower parts of their basins.

Beaver and Round consistently exhibited a gradual decrease in transparency between the spring and fall of each year. All of the fertilized sites exhibited a decrease in transparency and an increase in apparent color after fertilization as a result of the increased levels of phytoplankton biomass brought about by fertilization.

3. Chemical Characteristics

3.1. Conductivity and Hardness

Conductivity values generally ranged between 20 and 60 Sie cm^{-1} and are typical of soft-water lakes. Total hardness values were also low ranging between 0.3 and 0.6 meq l^{-1}. With the exception of Beaver and Jib, which showed a gradual increase over the summer, there were no consistent seasonal trends in conductivity during the non-fertilization years (Fig. 11). During the fertilization year, however, both Perfect and Stump, but not Oscar and Jib, exhibited higher conductivities which showed a seasonal variation similar to that of total P. None of the study sites, including those that stratified, showed any evidence of variation in conductivity with depth.

At most of the study sites conductivities were slightly greater during 1991, particularly during the earlier part of the summer when rainfall was low. At the two stratified experimental sites (Jib and Perfect) fertilization appears to have increased conductivity even more. During 1992 conductivity values at all sites were very similar to those observed during 1990.

3.2. Major Cations and Anions

Figures 12 and 13 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 Menchon and Perfect. The dominance of Na^+ and Cl^- at all sites reflects the influence of maritime climatic conditions. Fertilization had no apparent effect on either total hardness or the relative amounts of cations or anions.

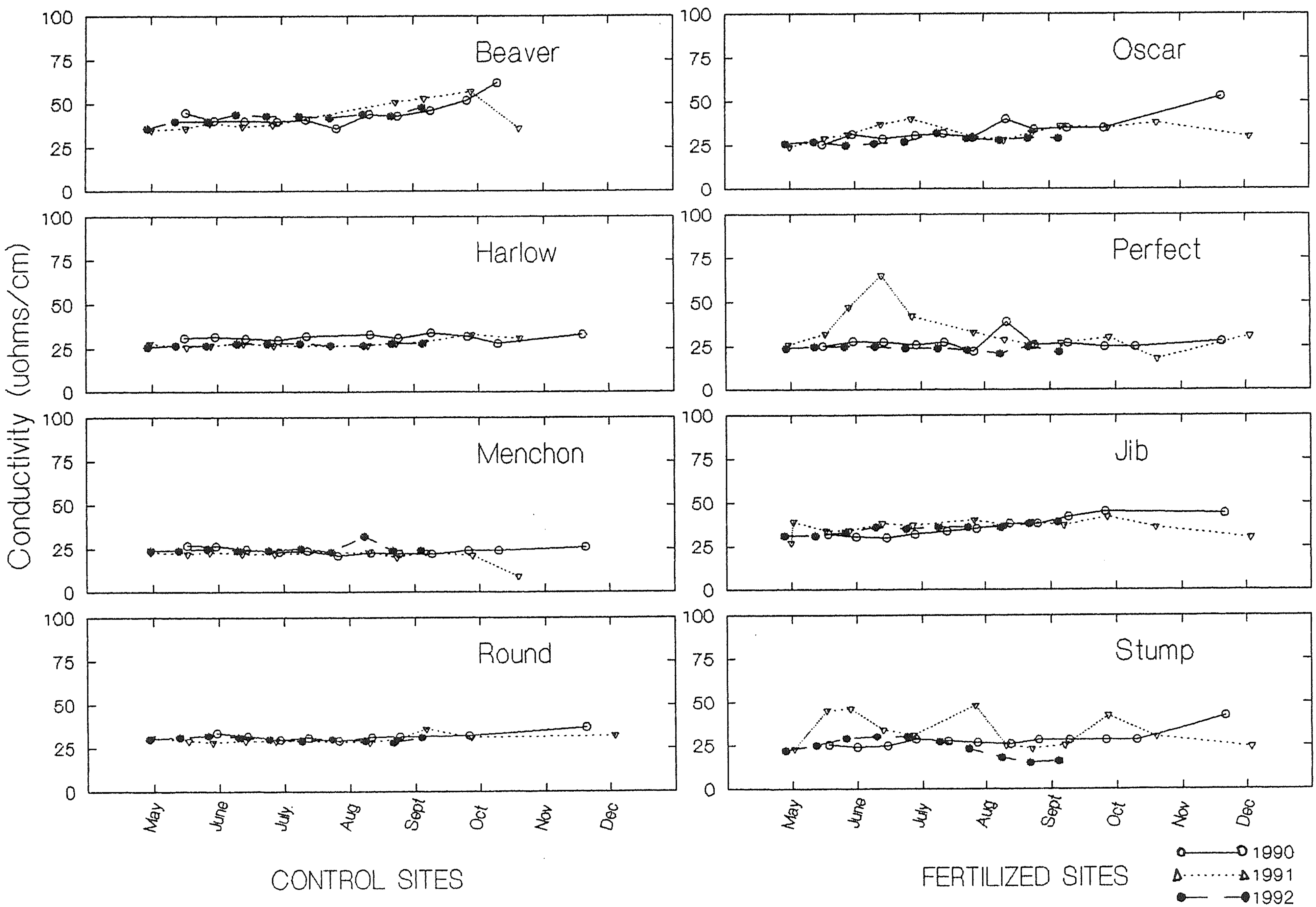


Figure 11. Seasonal variation in conductivity.

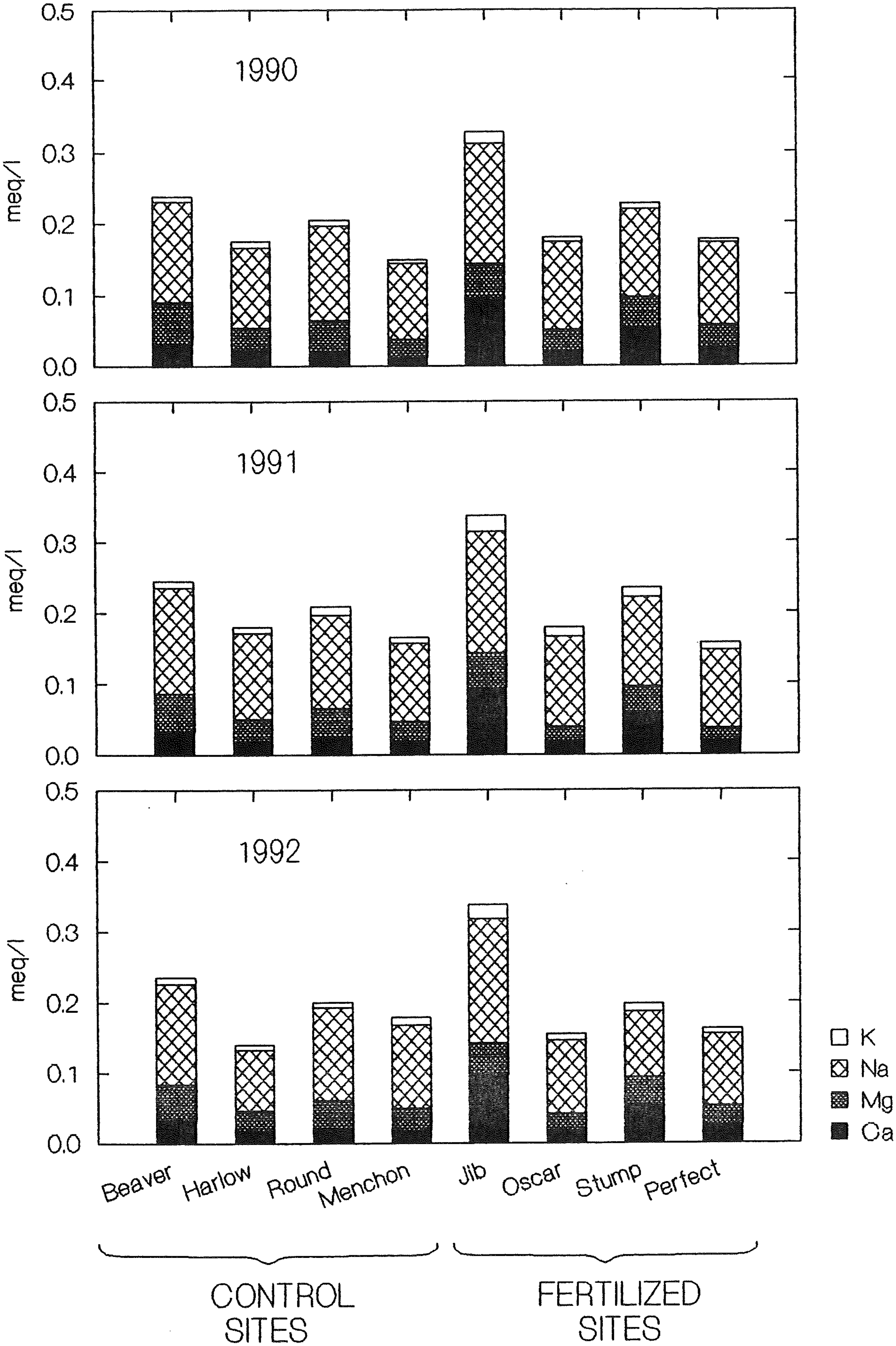


Figure 12. Major cations at each site.

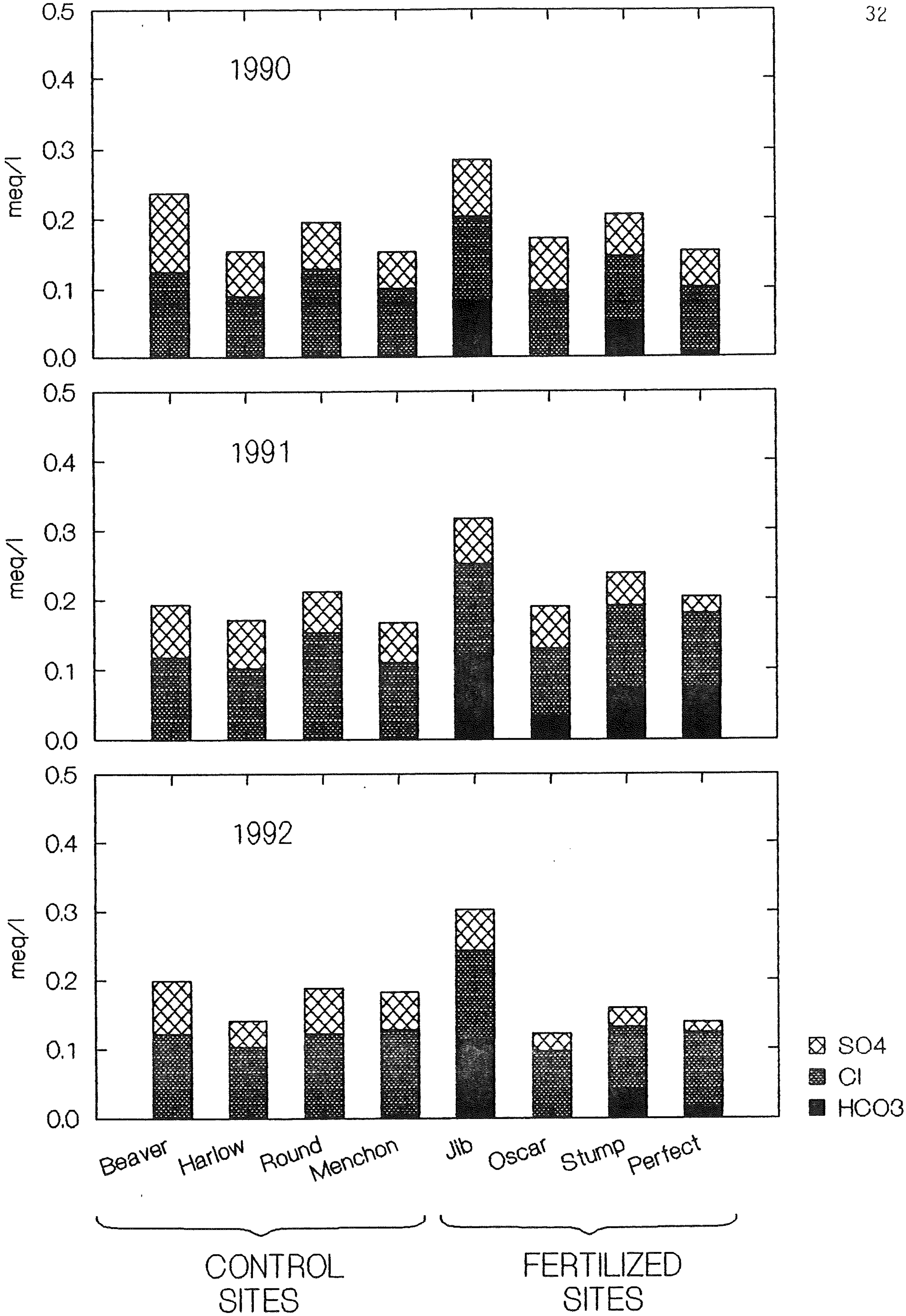


Figure 13. Major anions at each site.

3.3. pH and Alkalinity

Seasonal variations in pH and gran-alkalinity for each site are illustrated in Figures 14 and 15 respectively. Prior to fertilization, pH ranged from 4.4 to 6.3 and gran-alkalinity from -1.58 to 3.03 mg l^{-1}. There was very little seasonal variation. The highest pH and alkalinity values were observed at Jib and Stump. All sites have extremely limited buffering capacity. Based on the results of anion content, all of the alkalinity is attributable to bicarbonate as neither carbonate nor hydroxide is present.

One of the most surprising changes in chemistry resulting from fertilization was a large increase in pH at the experimental sites. This effect was evident at all of the experimental sites, but was most pronounced at Perfect and Jib where pH reached values of 7.9 and 8.7 respectively. Variations in gran alkalinity values closely followed those of pH. This increase in pH and alkalinity, which is most probably a result of the buffering capacity of super-phosphate, gradually increased beginning immediately after fertilization, peaked in early July, and then declined to near normal levels in early August. During 1992, pH and alkalinity values at all of the fertilized sites were typical of those observed prior to fertilization.

3.4. Dissolved Oxygen

Dissolved oxygen and percent saturation measurements were made for surface waters at all sites (Figs. 16 and 17) and for bottom waters at those sites exhibiting thermal stratification (Figs. 18 and 19). There was considerable variability in bottom water dissolved oxygen levels, both between sites and between years at the stratified sites. At Harlow, Jib and Perfect, bottom water oxygen concentrations decreased to very low levels during the summer of 1990. Jib became the most strongly anaerobic reaching zero percent saturation in mid-July and remaining anaerobic until late August. Perfect also became 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 site 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% saturation.

During 1991 and 1992 Harlow, a control site, exhibited essentially the same trend as in 1990. Round, however, which is also a control site, experienced short periods of anaerobic conditions during mid-August in 1991 and 1992. The reasons for this are unclear since there was no obvious difference between those years and 1990 in either the onset or degree of thermal stratification.

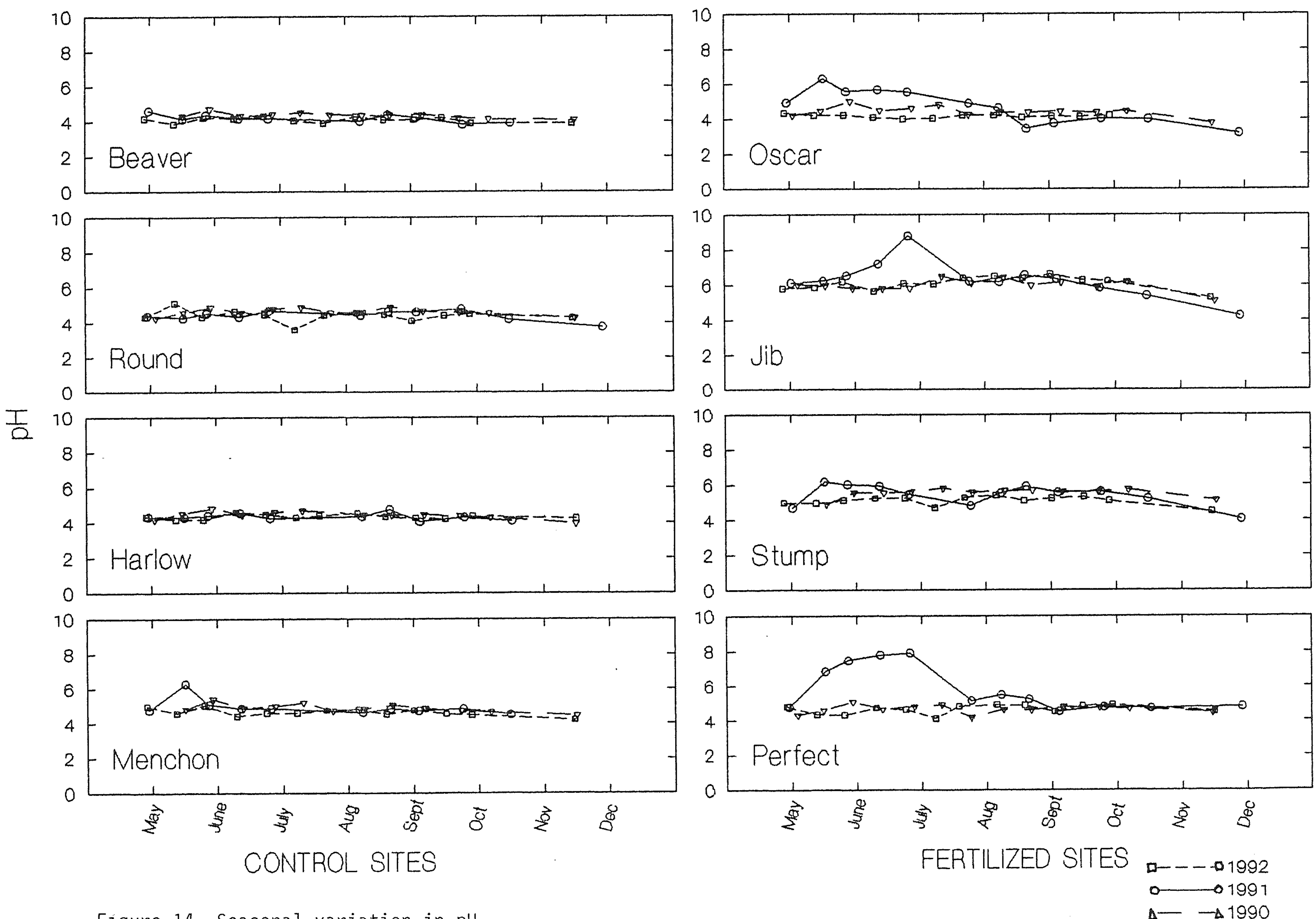


Figure 14. Seasonal variation in pH.

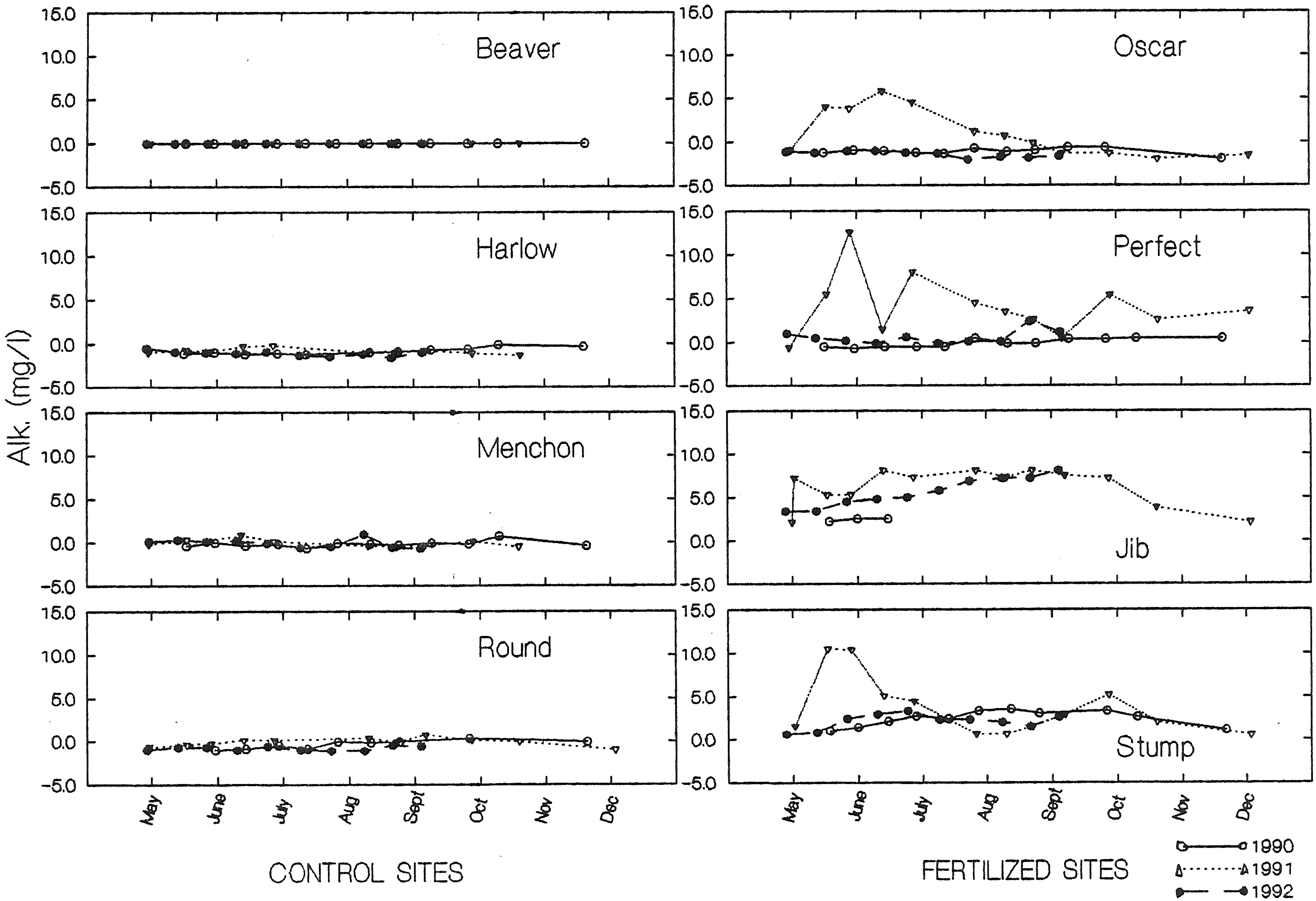


Figure 15. Seasonal variation in alkalinity.

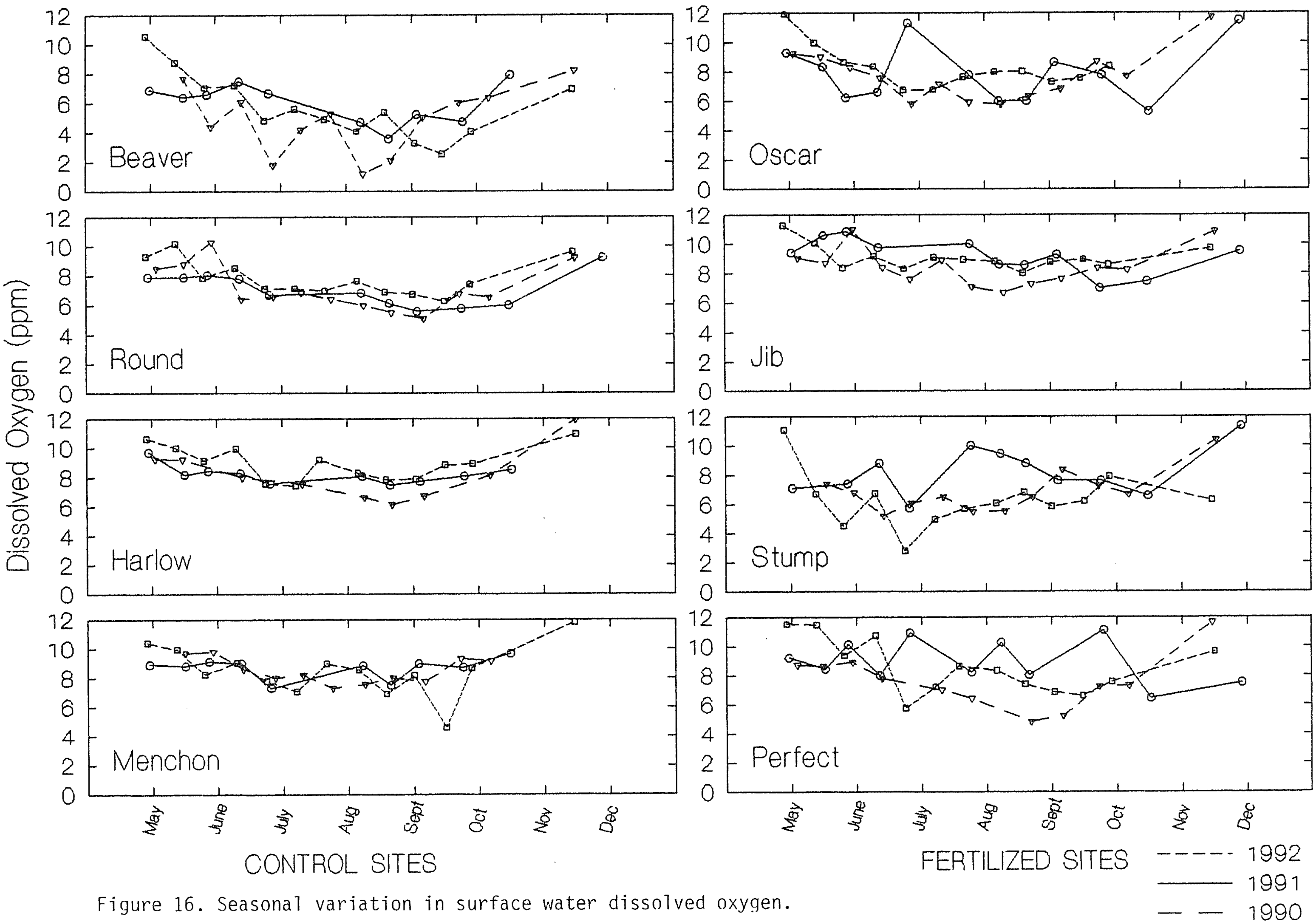


Figure 16. Seasonal variation in surface water dissolved oxygen.

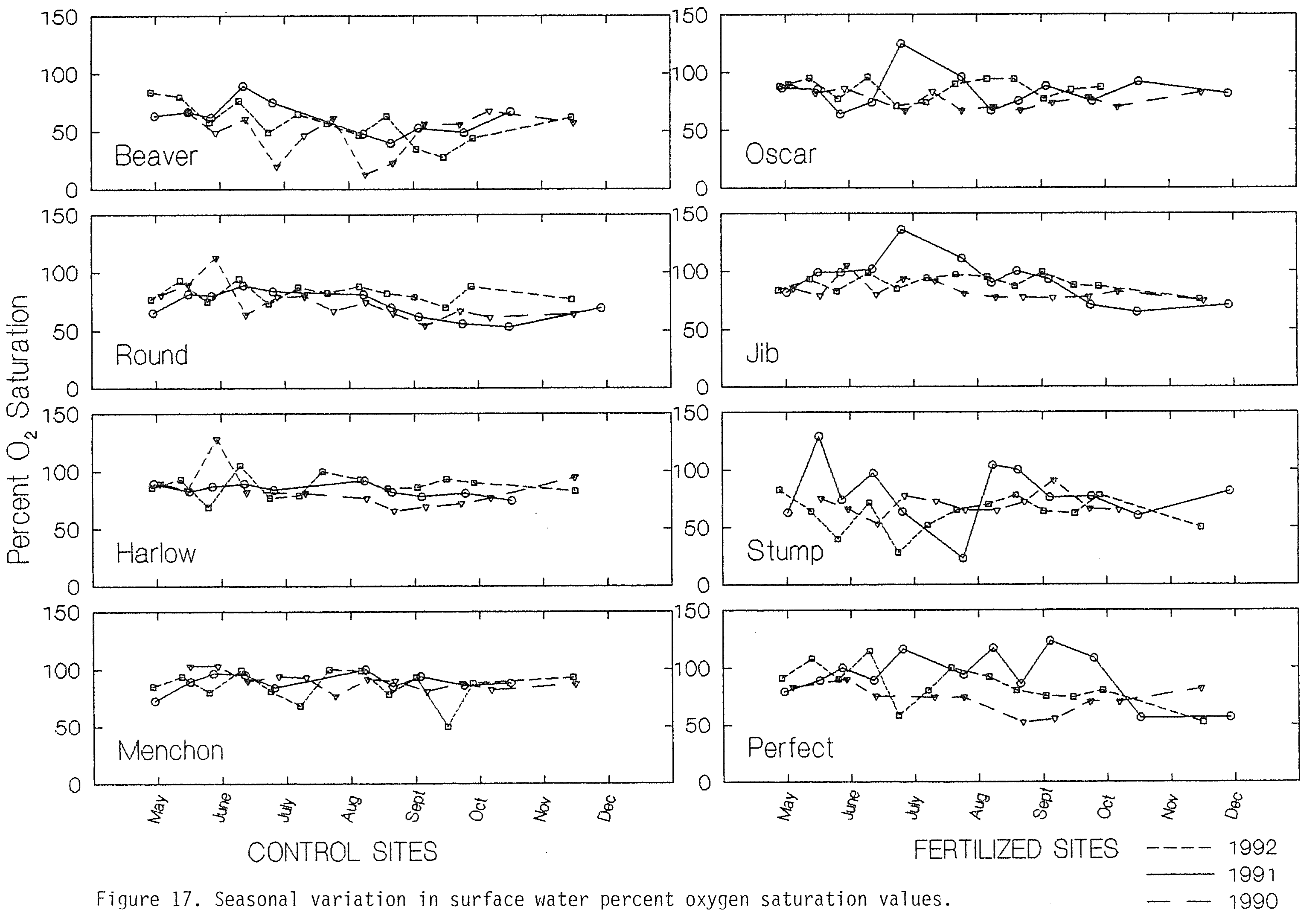


Figure 17. Seasonal variation in surface water percent oxygen saturation values.

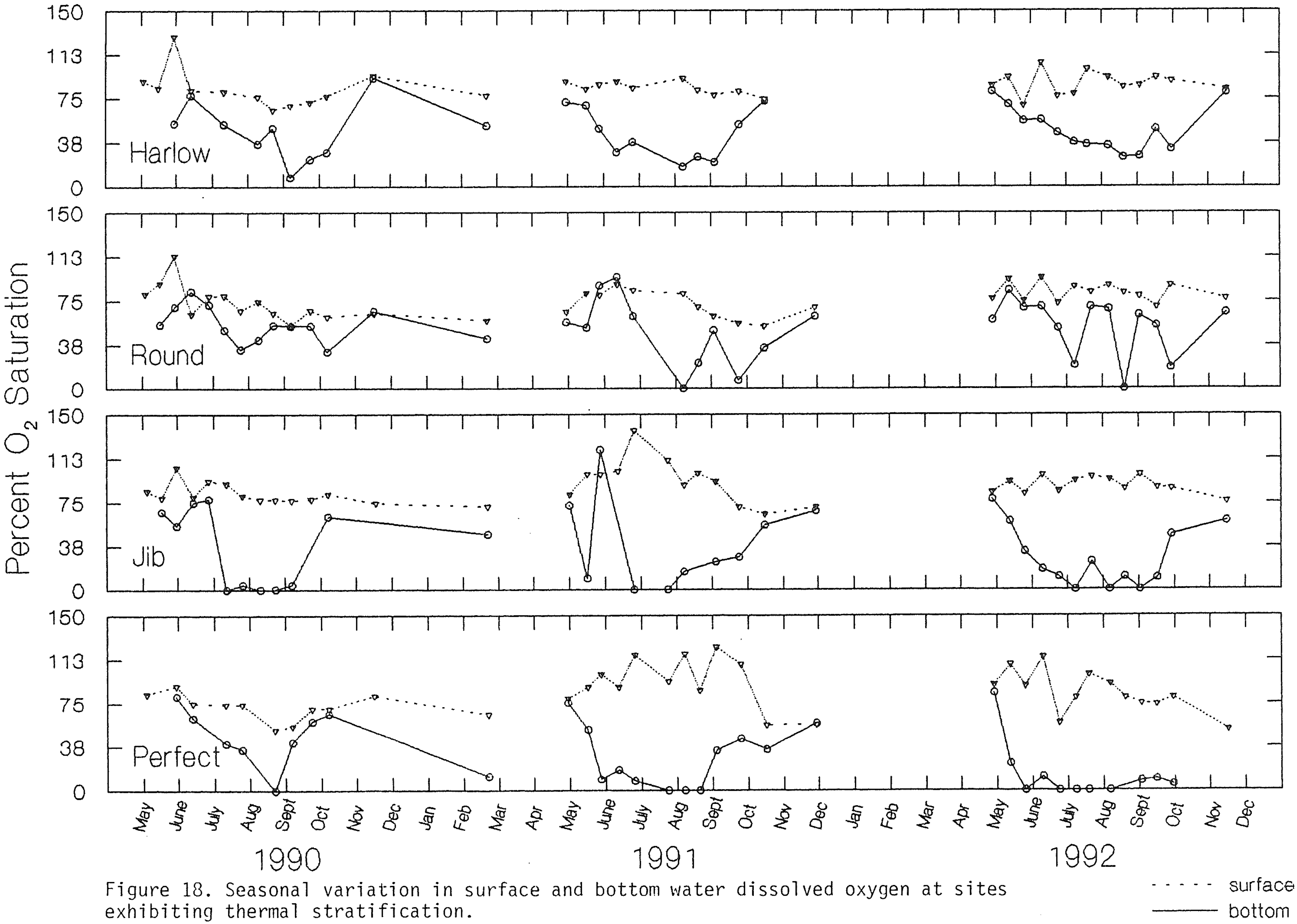


Figure 18. Seasonal variation in surface and bottom water dissolved oxygen at sites exhibiting thermal stratification.

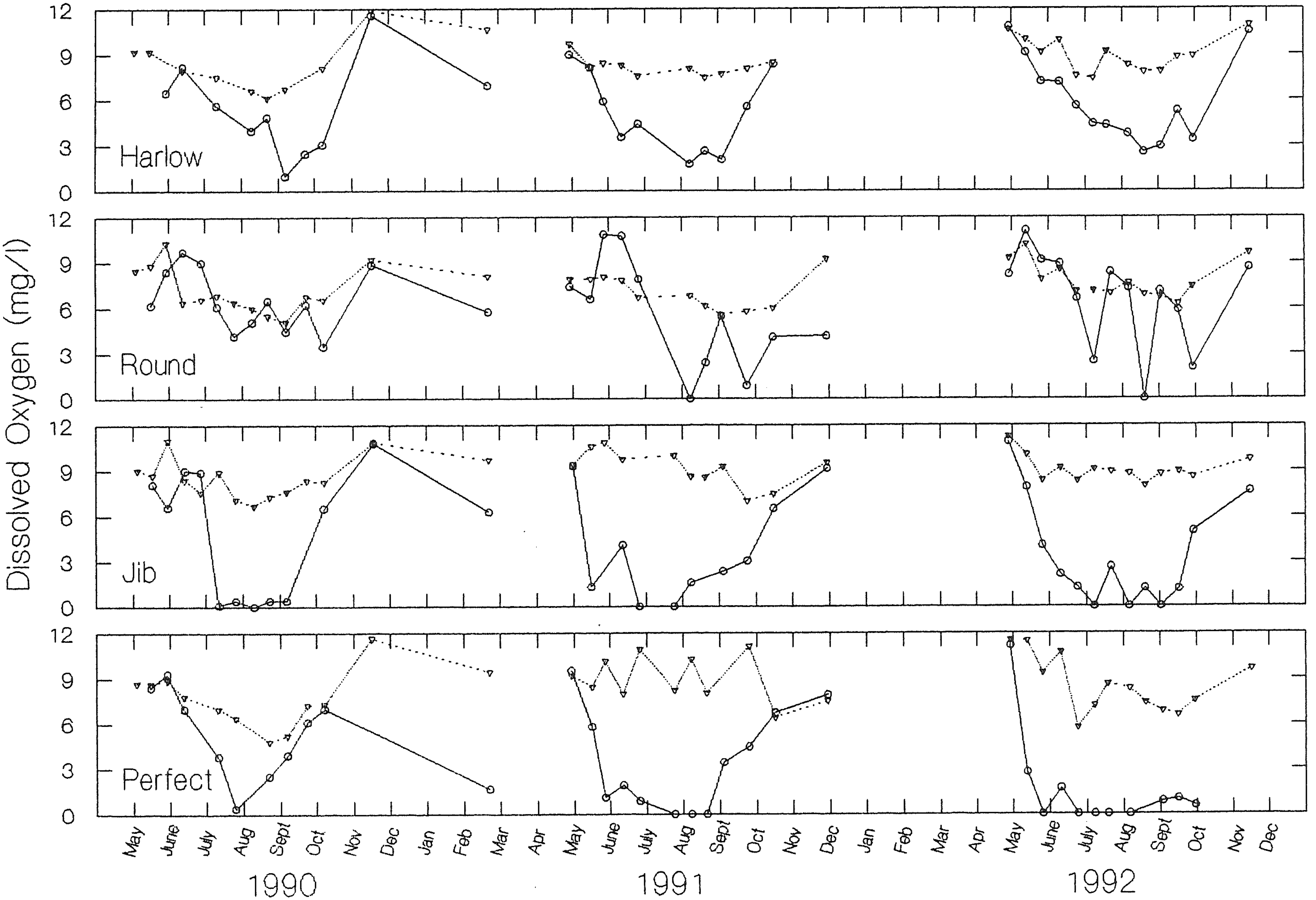


Figure 19. Seasonal variation in surface and bottom water percent oxygen saturation values at sites exhibiting thermal stratification.

Fertilization appears to have had some influence on bottom water dissolved oxygen levels at Jib and Perfect, the two experimental sites that exhibit thermal stratification. During all three years a strong thermocline developed during mid-July. Oxygen concentrations in the hypolimnion, however, decreased to minimum values approximately two weeks earlier in both years after fertilization. The decrease in time to deplete hypolimnion oxygen concentrations after stratification at the fertilized sites is probably a result of increased primary production in the water column and enhanced degradation of dissolved and particulate detritus. The increased primary productivity would result in an increase in the amount of organic matter settling into the hypolimnion, and the greater availability of nutrients resulting from fertilization would increase microbial activity. Both of these processes would cause an increase in the hypolimnetic biological oxygen demand.

Some data is available for dissolved oxygen levels and percent saturation values during winter ice cover (Figs. 20 and 21). Due to inaccessibility not all sites were sampled. Fertilization appears to have decreased winter dissolved oxygen levels at both Jib and Perfect, but not to the point where they ever became completely anaerobic.

3.5. Nutrients

Table 4 summarizes average phosphorus and nitrogen concentrations at each site over the three years of study.

3.5.1. Phosphorus

Prior to fertilization the concentration of phosphorus was low at all sites at all times. Average values for total phosphorus were generally 5 $\mu g\ l^{-1}$ and typical of oligotrophic systems. There was little indication that P levels varied seasonally.

Data on phosphorus concentration during 1991 and 1992 was collected for surface waters, hypolimnetic waters at the stratified experimental sites, outlet waters at those sites having outlets, and for sediments at both the control and experimental sites.

The control sites showed little year to year variation (Fig. 22). Following fertilization total P concentrations at all of the experimental sites increased dramatically. However, samples taken at Jib immediately (within hours) after the addition of fertilizer revealed that a relatively small proportion of the added P was present within the water column. The total P concentration was on the order of 0.3 mg l^{-1}. Although this certainly exceeds the amount required to achieve eutrophic conditions (by a

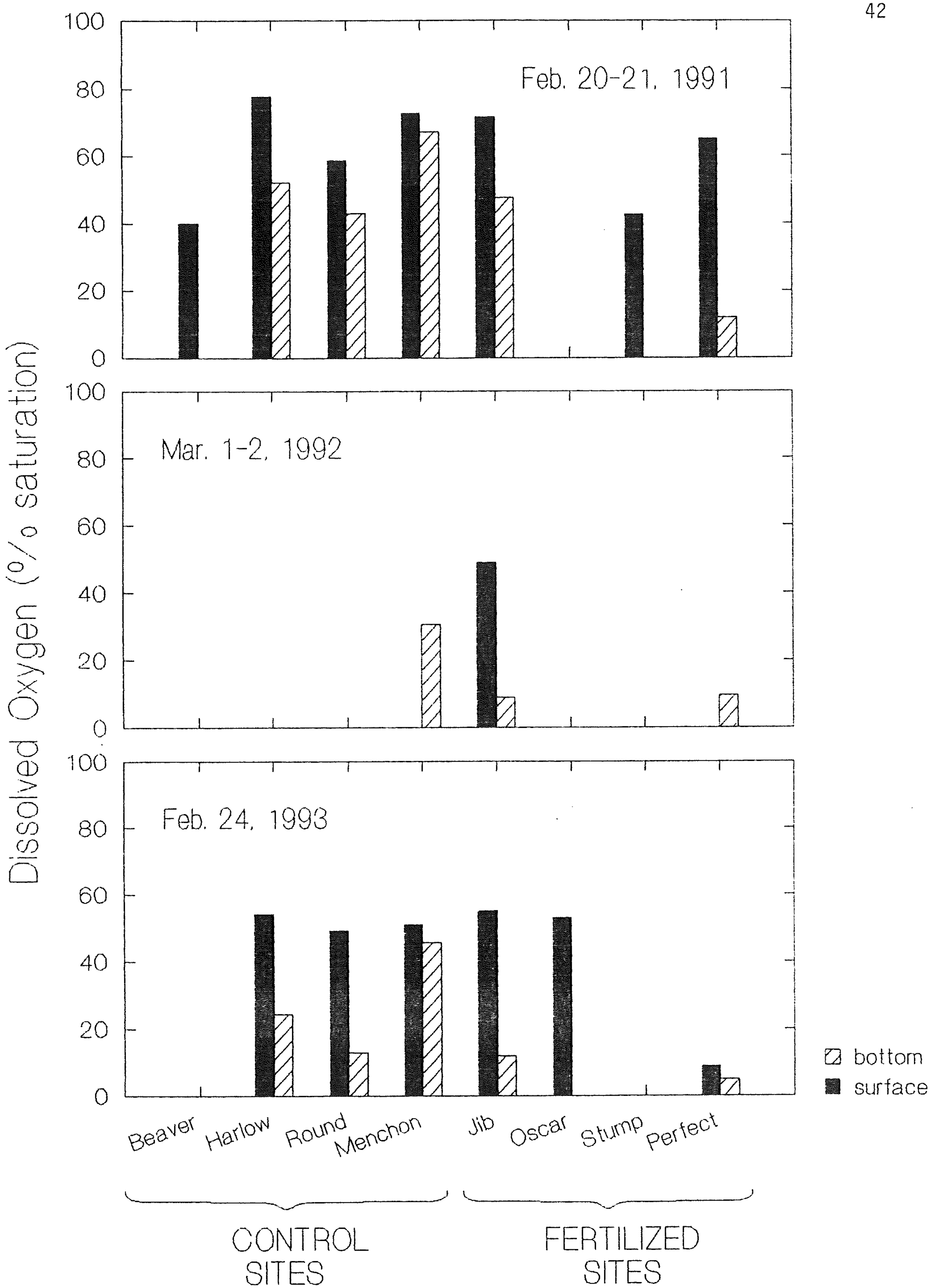


Figure 21. Percent oxygen saturation levels during winter.

Table 4. Summary of mean (sd) phosphorus and nitrogen concentrations at each site.

Site	Year	Total P Surface (mg/l)	Total P Outlet (mg/l)	Total N Surface (mg/l)	Total N Outlet (mg/l)
Beaver	1990	0.015 (0.010)	0.037 (0.041)	0.253 (0.091)	0.331 (0.153)
	1991	0.234 (0.621)	0.062 (0.123)	0.288 (0.144)	0.325 (0.094)
	1992	0.040 (0.072)	0.024 (0.014)	0.313 (0.121)	0.390 (0.077)
Harlow	1990	0.111 (0.328)	0.027 (0.058)	0.215 (0.054)	0.212 (0.040)
	1991	0.021 (0.013)	0.016 (0.006)	0.273 (0.106)	0.215 (0.038)
	1992	0.014 (0.010)	0.020 (0.024)	0.202 (0.037)	0.257 (0.112)
Menchon	1990	0.003 (0.001)		0.119 (0.021)	
	1991	0.018 (0.016)		0.134 (0.039)	
	1992	0.008 (0.007)		0.130 (0.042)	
Round	1990	0.005 (0.003)		0.149 (0.051)	
	1991	0.041 (0.085)		0.161 (0.066)	
	1992	0.011 (0.011)		0.127 (0.038)	
Jib	1990	0.008 (0.004)	0.009 (0.009)	0.181 (0.045)	0.189 (0.040)
	1991	0.096 (0.125)	0.090 (0.090)	1.448 (3.148)	1.377 (2.677)
	1992	0.021 (0.011)	0.019 (0.009)	0.239 (0.092)	0.284 (0.093)
Oscar	1990	0.010 (0.006)	0.008 (0.004)	0.313 (0.115)	0.289 (0.070)
	1991	0.100 (0.101)	0.075 (0.109)	1.236 (1.107)	1.068 (0.883)
	1992	0.024 (0.015)	0.013 (0.008)	0.377 (0.118)	0.423 (0.076)
Perfect	1990	0.010 (0.004)		0.231 (0.055)	
	1991	0.207 (0.136)		2.912 (2.397)	
	1992	0.116 (0.196)		0.476 (0.153)	
Stump	1990	0.015 (0.009)	0.036 (0.048)	0.416 (0.143)	0.394 (0.237)
	1991	0.150 (0.138)	0.086 (0.101)	1.428 (1.282)	1.661 (1.816)
	1992	0.034 (0.022)	0.041 (0.033)	0.542 (0.142)	0.890 (0.471)

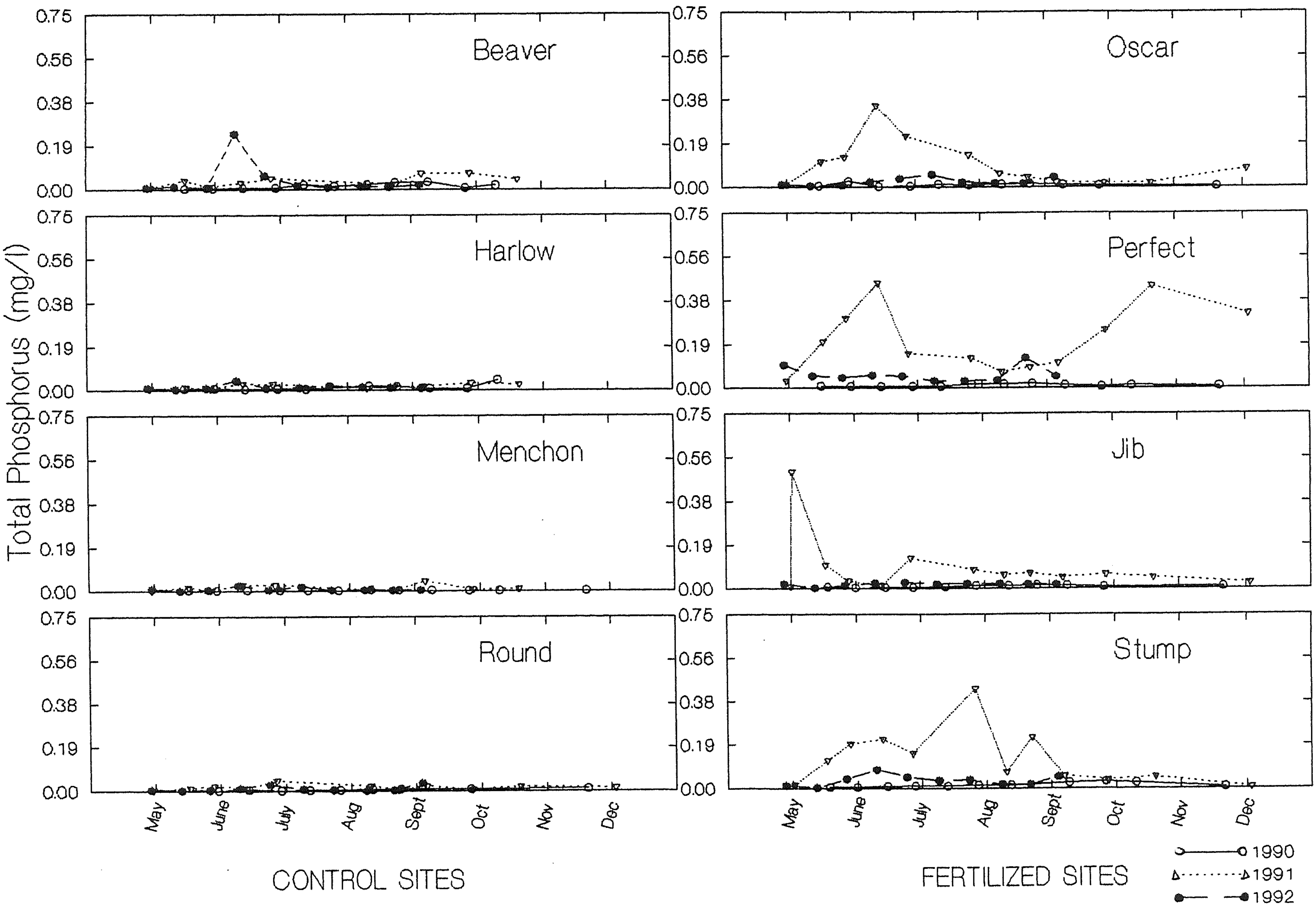


Figure 22. Seasonal variation in total P.

factor of about 10), it represents 15% of the P contained in the fertilizer. Apparently a large portion of the added fertilizer did not dissolve and settled as particulate material. Unfortunately, total P samples were not collected at the other experimental sites immediately after fertilizer application, but it is likely that a large proportion of the added fertilizer settled out as particulate material at all of the fertilized sites, particularly those fertilized by helicopter.

The total P value at Jib two weeks after fertilization decreased to about 0.05 mg l^{-1} indicating that P continued to be lost from the water column, probably as a result of continued settling of small particles of fertilizer. The other experimental sites had similar total P values. From this point on total P concentrations at all of the experimental sites began to increase. At Oscar and Perfect, peak total P concentrations of about 0.2 mg l^{-1}, which represents about 10% of the added P, occurred in early June. At Stump the peak total P concentration was also about 0.2 mg l^{-1}, but this did not occur until mid-July. At Jib, the total P concentration tended to stabilize after the initial decline at about 0.07 mg l^{-1}, a value considerably below the other sites.

The seasonal trend in total P during 1991 differed greatly among sites. At Jib, total P in the surface waters increased to very high levels (0.20 mg l^{-1}) immediately after fertilization, then declined rapidly over a two-week period after which it stabilized at about 0.07 mg l^{-1}. At Perfect, surface water P increased relatively slowly over a period of about six weeks after fertilization, then declined for two weeks, stabilized at about 0.1 mg l^{-1} for the following two months and then peaked again. This latter peak coincided with the beginning of the fall overturn. Oscar behaved very much like Perfect with two peaks, one in mid-July and one in mid-September. At Stump surface water P levels increased gradually for four months after fertilization and then declined.

Based on the average water column total P concentration during 1991, an estimate was made of the proportion of P added that remained available within the water column during the growing season. This amounted to 3.6% for Jib, 3.5% for Oscar, 6.1% for Perfect and 3.4% for Stump. The higher value for Perfect is most likely due to the fact that this site, in contrast to the others, has no surface outflow and, consequently, less opportunity for nutrients to be flushed out of the system.

During 1992 total P concentrations at all of the fertilized sites were very much less than during 1991, and at all except Oscar, were only slightly higher than the levels measured during 1990, the pre-fertilization year. At Oscar, total P concentrations during 1992 were actually less than during 1990.

During the fertilization year Jib and Perfect, the two experimental sites that stratify, exhibited hypolimnion P levels that were always much greater than those in the surface waters (Figs. 23 and 24). Apparently a great deal of the added fertilizer became entrained in the hypolimnion once the sites became stratified. There was considerable seasonal variation in the hypolimnion total P levels, especially at Jib, which is difficult to explain, particularly since the seasonal trend does not appear to exhibit a clear relationship to the onset or breakdown of thermal stratification. During 1992 hypolimnion P levels at Jib were very similar to surface P levels. At Perfect, however, hypolimnion P values were much greater than surface P levels. This difference in behavior is probably related to the fact that Jib has an intermittent surface inlet and a permanent outlet, whereas Perfect lacks either. The presence of a surface inlet and outlet at Jib would tend to flush the epilimnion to a greater degree than it would the hypolimnion.

The seasonal variation in total P concentration at the outlets of the fertilized sites was generally similar to that at the lake center (Fig. 25), but the level of total P was always slightly lower. The lower concentration is most likely a reflection of incomplete mixing of surface inflows with the standing lake water. At Jib total P samples were also collected at a station (Jib Brook) located about 0.3 km below the lake. This station exhibited the same seasonal trends as the lake center but the values were always lower by a factor of about four (Fig. 26). Apparently P leaving the lake via the output is quickly depleted either through sedimentation or uptake by macrophytes or periphyton.

Based on the average concentration of P at the outlets, together with an estimate of flushing rate, it is possible to make a very rough estimate of the amount of P lost via the outputs during the period beginning two weeks after the fertilizer was applied and ending on the last sampling date in 1991 (28 November). This represents a period of 198 days during which total precipitation amounted to 757 mm. Expressed relative to the total amount of P added, this amounted to 73% at Jib and 107% at Oscar. These values are probably somewhat overestimated since no allowance was made for evaporation or transpiration of precipitation. (It was not possible to make similar calculations for Stump or Perfect since it was not possible to estimate the flushing rate of Stump, and Perfect has no surface outlet). The lower value for Jib is probably related to the fact that this site stratifies and, as suggested previously, the hypolimnion is flushed to a lesser extent than the epilimnion. In either case, however, it is apparent that the added P is relatively quickly flushed from these systems.

Data on sediment P concentrations are available for 1991 and 1992 (Fig. 27). At all sites most of the phosphorus in sediments is present in the organic as opposed to the inorganic form. With the exception of Stump, which exhibited sediment P concentrations about twice as high as the other sites, there was little difference between the control and experimental sites in the amount P contained in the

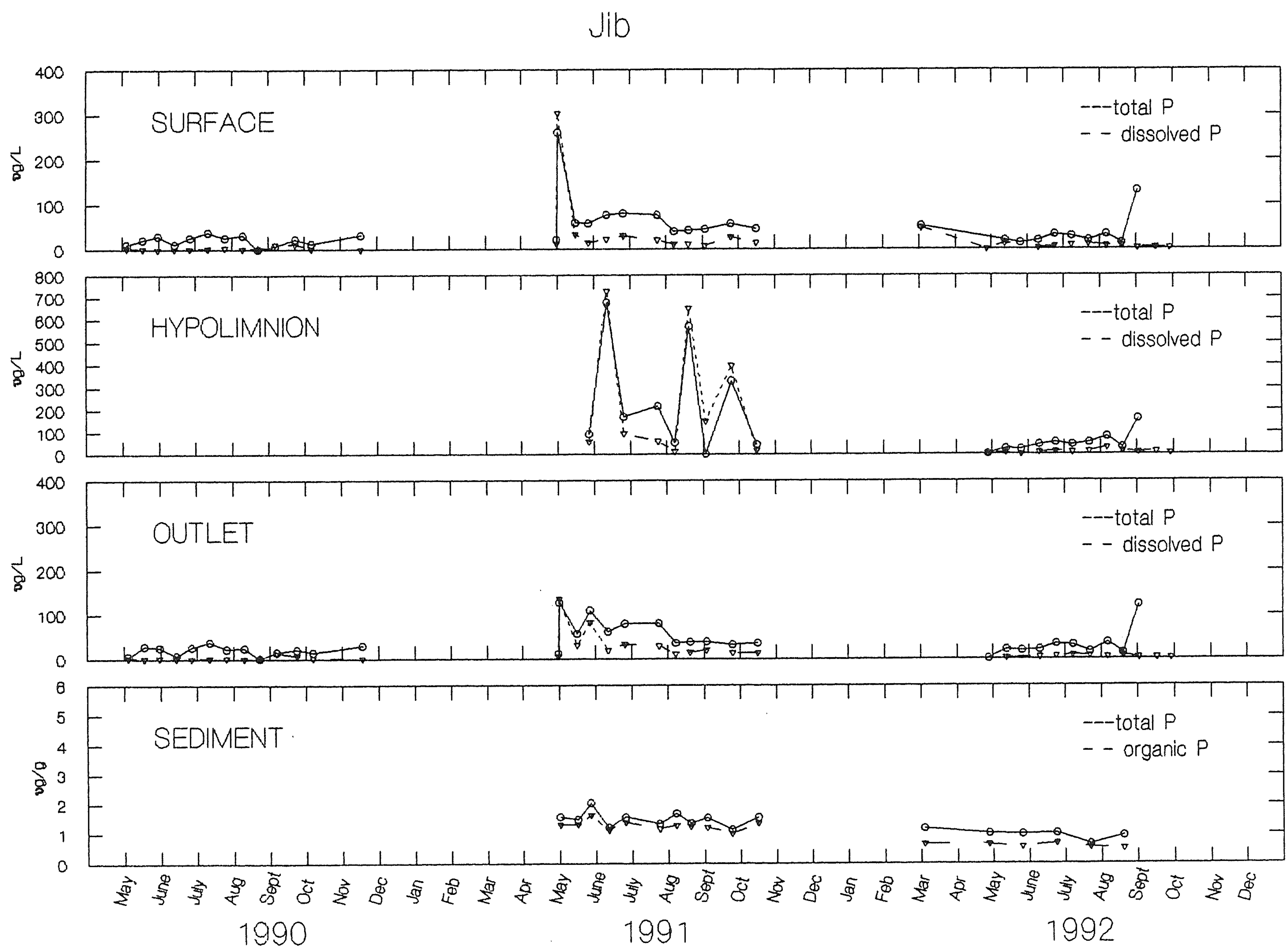


Figure 23. Seasonal variation in P at Jib.

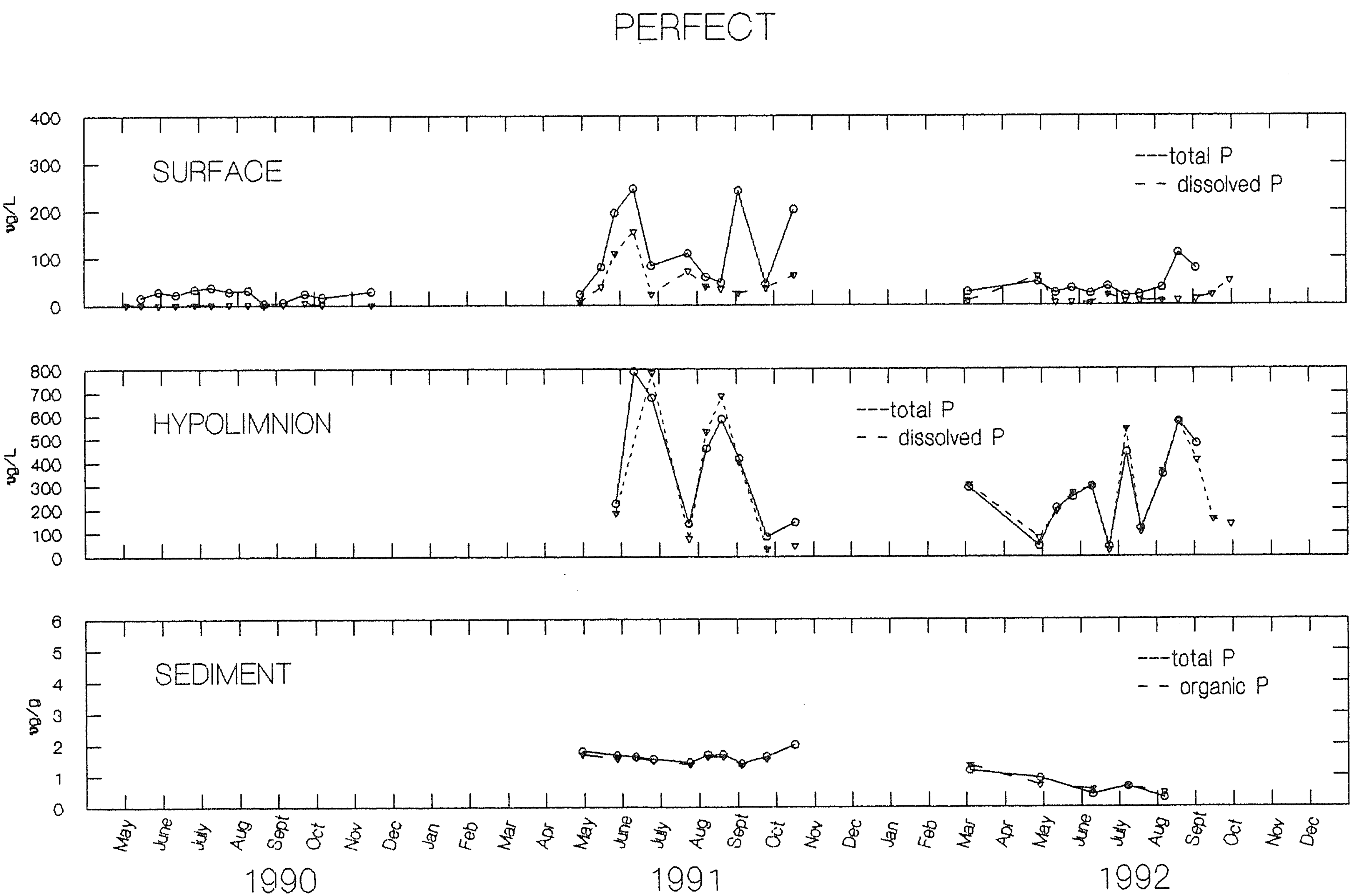


Figure 24. Seasonal variation in P at Perfect.

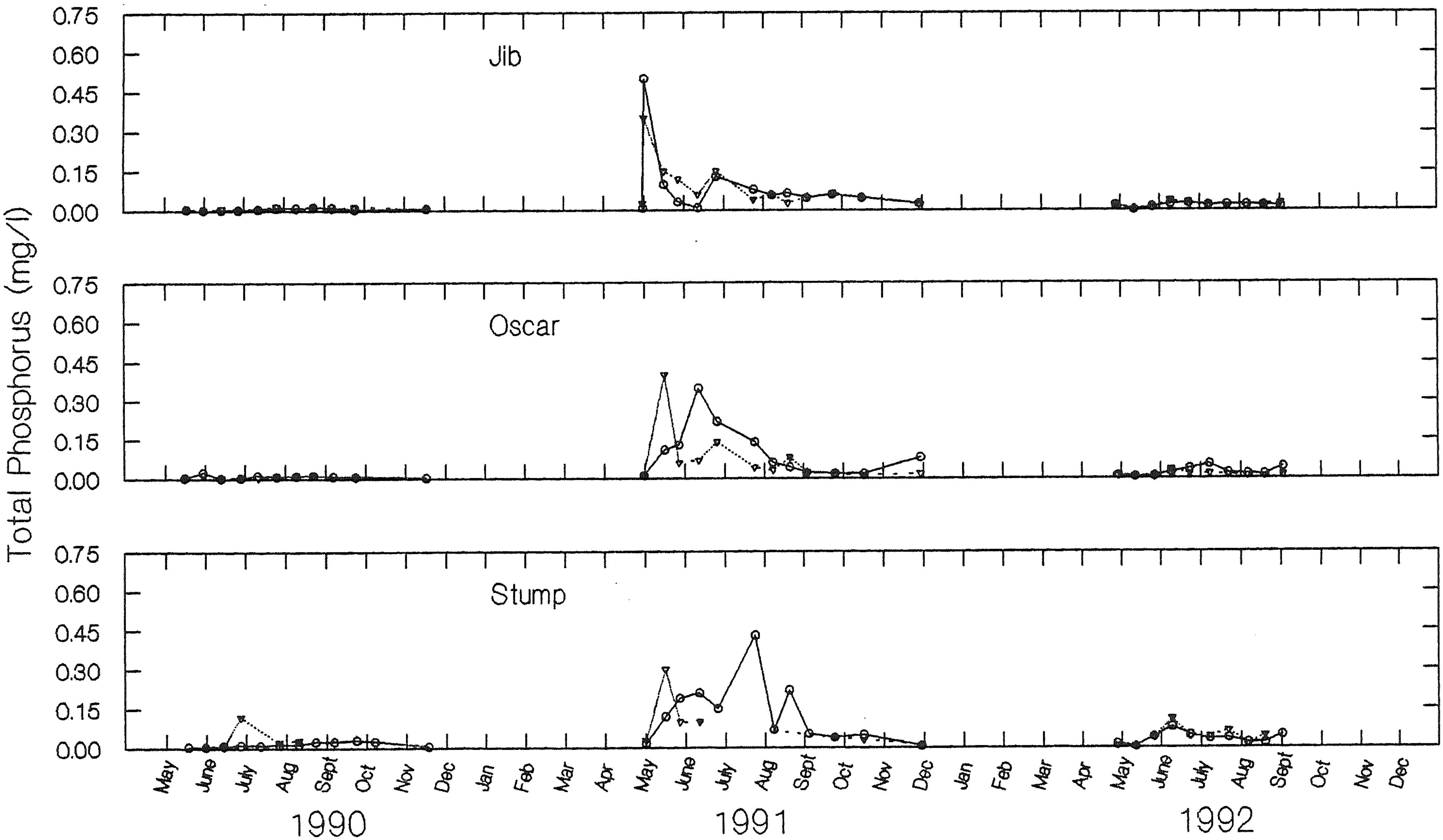


Figure 25. Comparison of total P values at lake center and outlet for those experimental sites having outlets.

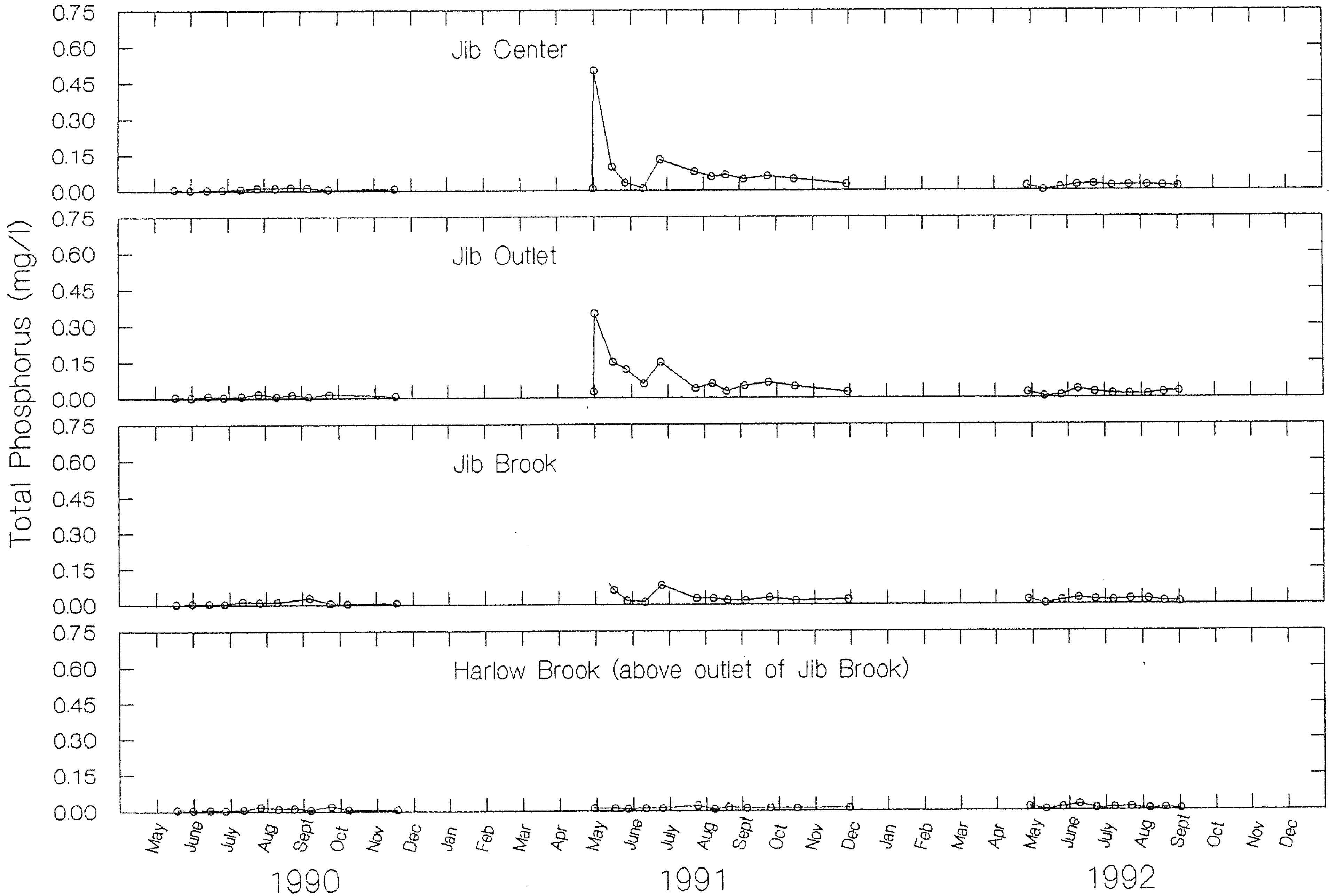


Figure 26. Comparison of total P values at Jib center, outlet, brook below outlet and Harlow Brook.

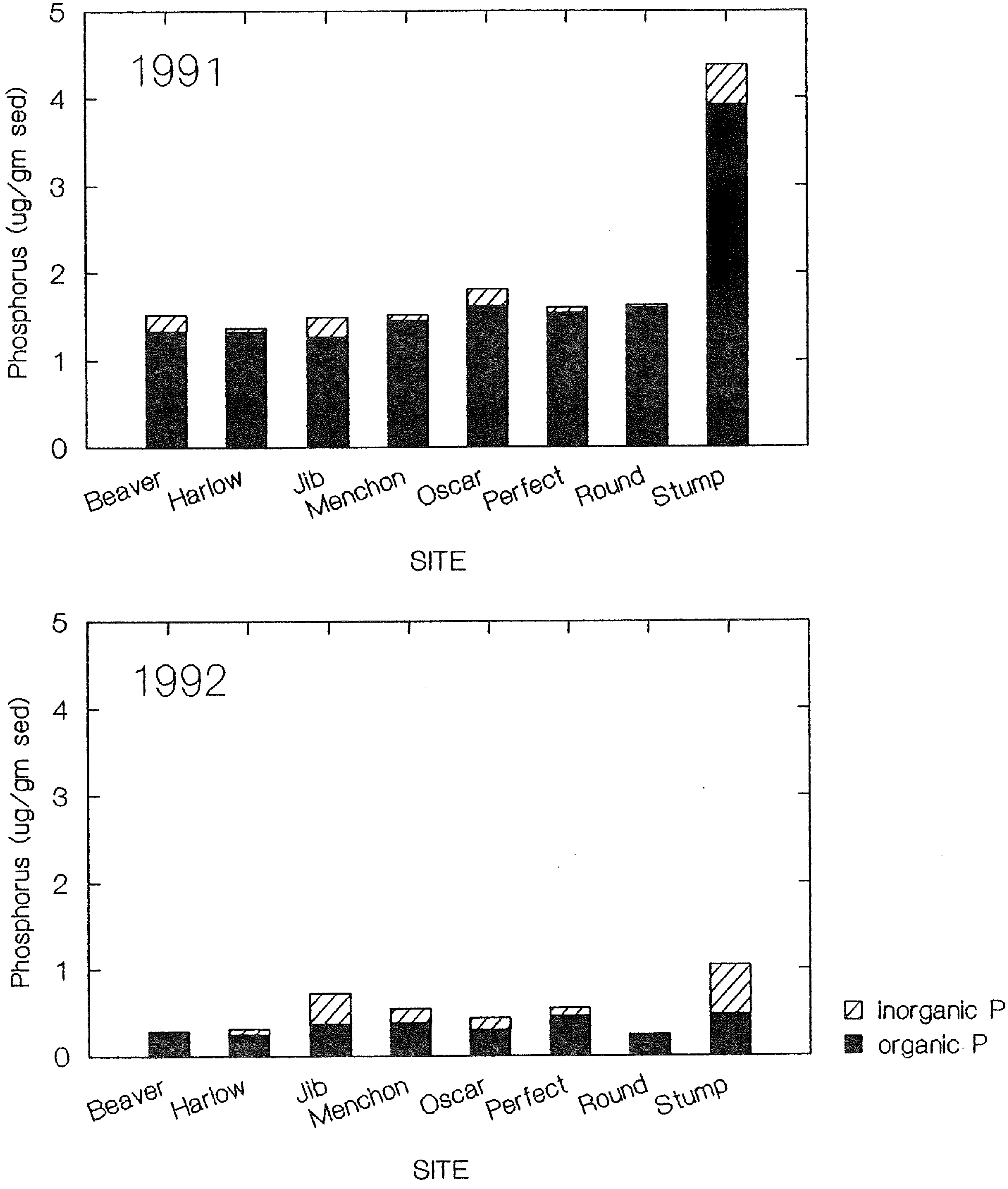


Figure 27. Comparison of mean sediment P concentrations.

sediments during either year. This is somewhat surprising since it would be expected that considerable P would have settled out into the sediments at the fertilized sites. The lack of any clear difference in sediment P between the control and fertilized sites suggests that the amount of added P that settled out into the sediments at the fertilized sites is small relative to the amount contained in the sediments prior to fertilization. The fact that most of the sediment P is in the organic form suggests that it is derived biologically and may have accumulated over a long time period. If this is true background P concentrations may be much higher than the amount of P settling out making the latter difficult to detect. A better approach to determining the amount of P lost to the sediments would have been measurement of pore water P rather than sediment P concentrations.

3.5.2. Nitrogen

Prior to fertilization both total and dissolved nitrogen concentrations were very low (0.5 mg l^{-1}) at all of the study sites (Fig. 28). The control sites exhibited low nitrogen values throughout the study. Following fertilization nitrogen levels at the experimental sites increased to values on the order of 3 to 8 mg l^{-1}. During the second year after fertilization N levels decreased to pre-fertilization values at all of the experimental sites.

The results for Jib, which was sampled immediately prior to and after fertilization, indicate that N behaved very similar to P. Total N levels increased dramatically immediately after the application of fertilizer, and then declined markedly over the following two-week period. Immediately after application total N values within the water column amounted to about 12 mg l^{-1}. This represents 60% of the N contained in the fertilizer and indicates that N dissolved to a much greater extent during application than did the P.

The seasonal variations in total N at the fertilized sites during the fertilization year were much less variable than for total P, and generally tended to show a gradual and continuous decrease over the growing season. Average total N concentrations in surface waters over the growing season, relative to the amount of N added, were 7.2% at Jib, 6.0% at Oscar, 14.5% at Perfect and 7.0% at Stump. These values are about twice that calculated for total P, but since a much greater proportion of the added N was originally dissolved, indicates that N was lost from the water column to a much higher degree than was P. This suggests that the added N was more susceptible to being flushed from the systems than was the P, probably as a result of its greater dissolution.

As was the case with P, the seasonal variations in N levels at the outlets were very similar to those at the lake center (Fig. 29). Unlike total P, however, the concentrations at the outlet were always

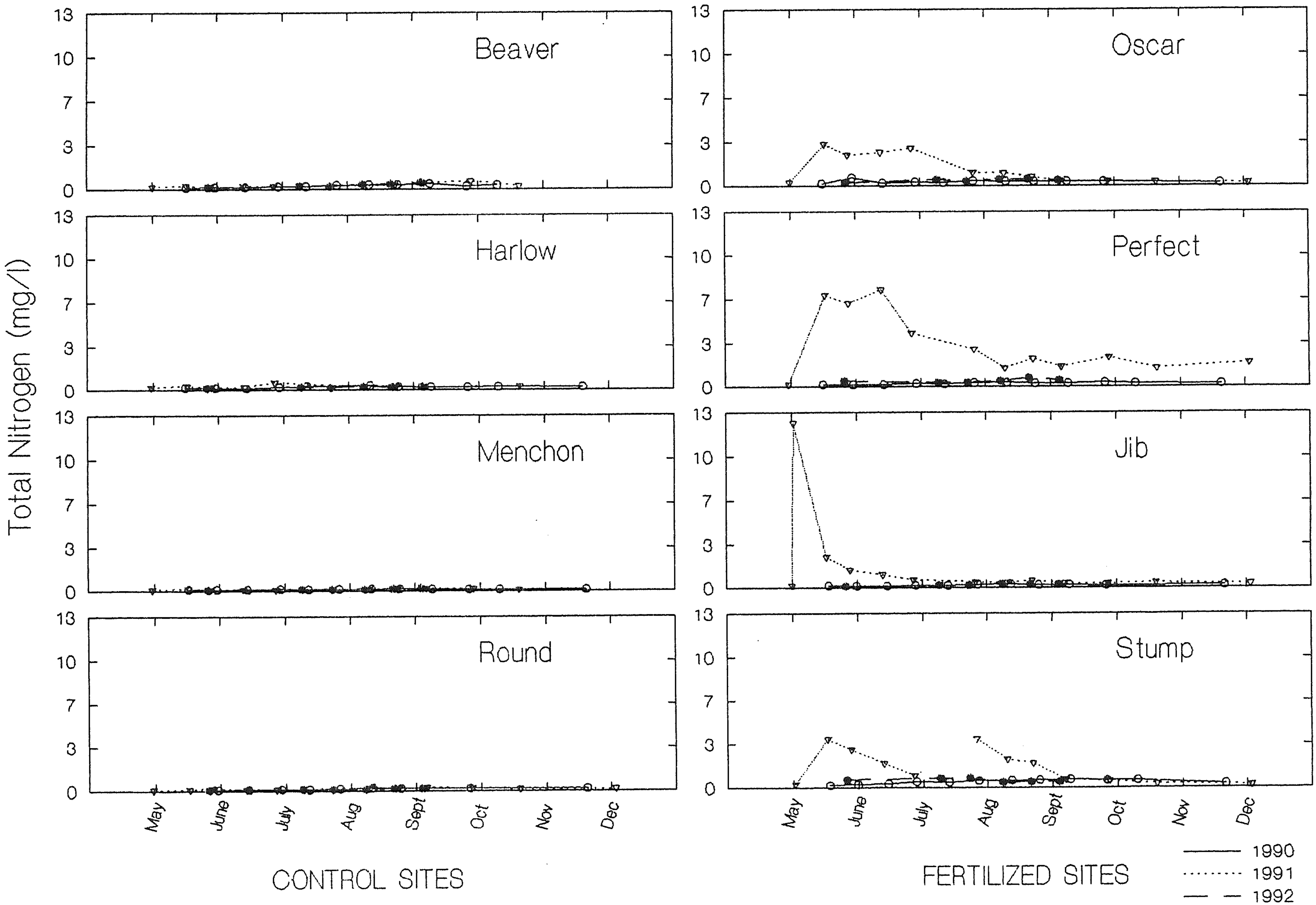


Figure 28. Seasonal variation in total N.

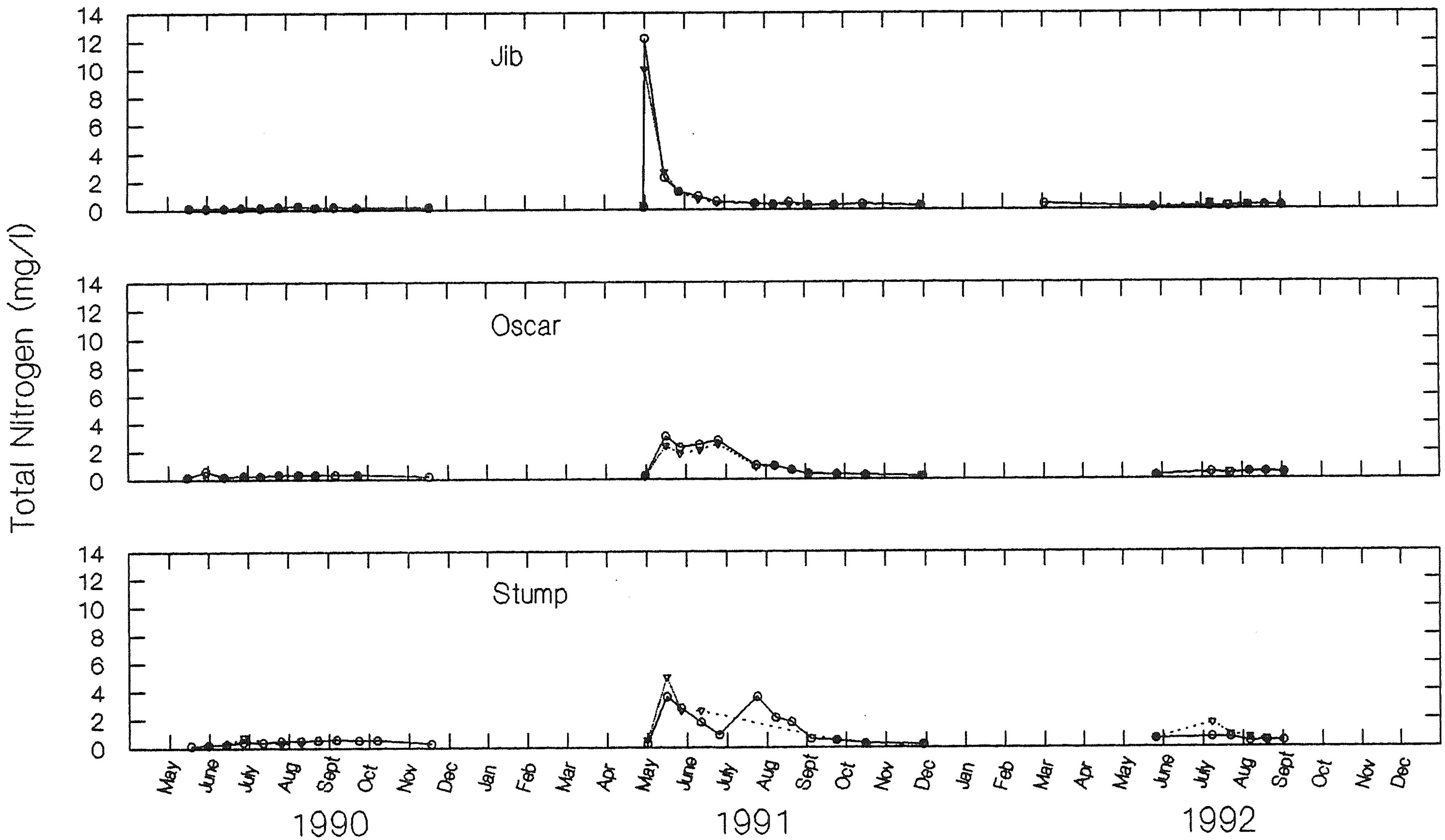


Figure 29. Comparison of total N values at lake center and outlet for those experimental sites having outlets.

about equal to those at the lake center. This difference in behavior is also probably related to the greater solubility of urea compared to triple-super phosphate. The amount of N lost via the outlets during 1991, calculated in the same manner as for P, amounted to 84% at Jib and 116% at Oscar indicating that most of the added N was flushed from the sites during the fertilization year.

3.5.3. Silica

Silicate concentrations ranged from 0.2 to 8.1 mg l^{-1} (Fig. 30) and were generally above levels that would be considered limiting. Two of the control sites (Beaver and Round) consistently exhibited high silicate concentrations with little year to year variation. The remaining control sites (Harlow and Menchon), and two of the experimental sites (Oscar and Stump), were characterized by lower silicate concentrations. Perfect and Jib showed a consistent seasonal trend of increasing silicate concentration over the spring and summer of each year. There is a strong positive relationship among the study sites between water transparency and silicate concentration. This suggests that the variation in silicate concentration between sites is influenced primarily by the concentration of dissolved organic humic materials. Humic acids have been reported to enhance the solubility of silicon (Wetzel 1983). Fertilization had no obvious effect on silicate levels.

3.6. Biology

Table 5 summarizes average values for a number of selected biological parameters at each site over the three years of study.

3.6.1. Macrophytes

During early September 1990 a survey to determine the species composition and relative abundance of the major macrophytes at each study site was carried out. The results are presented as a series of maps (Appendix C).

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.

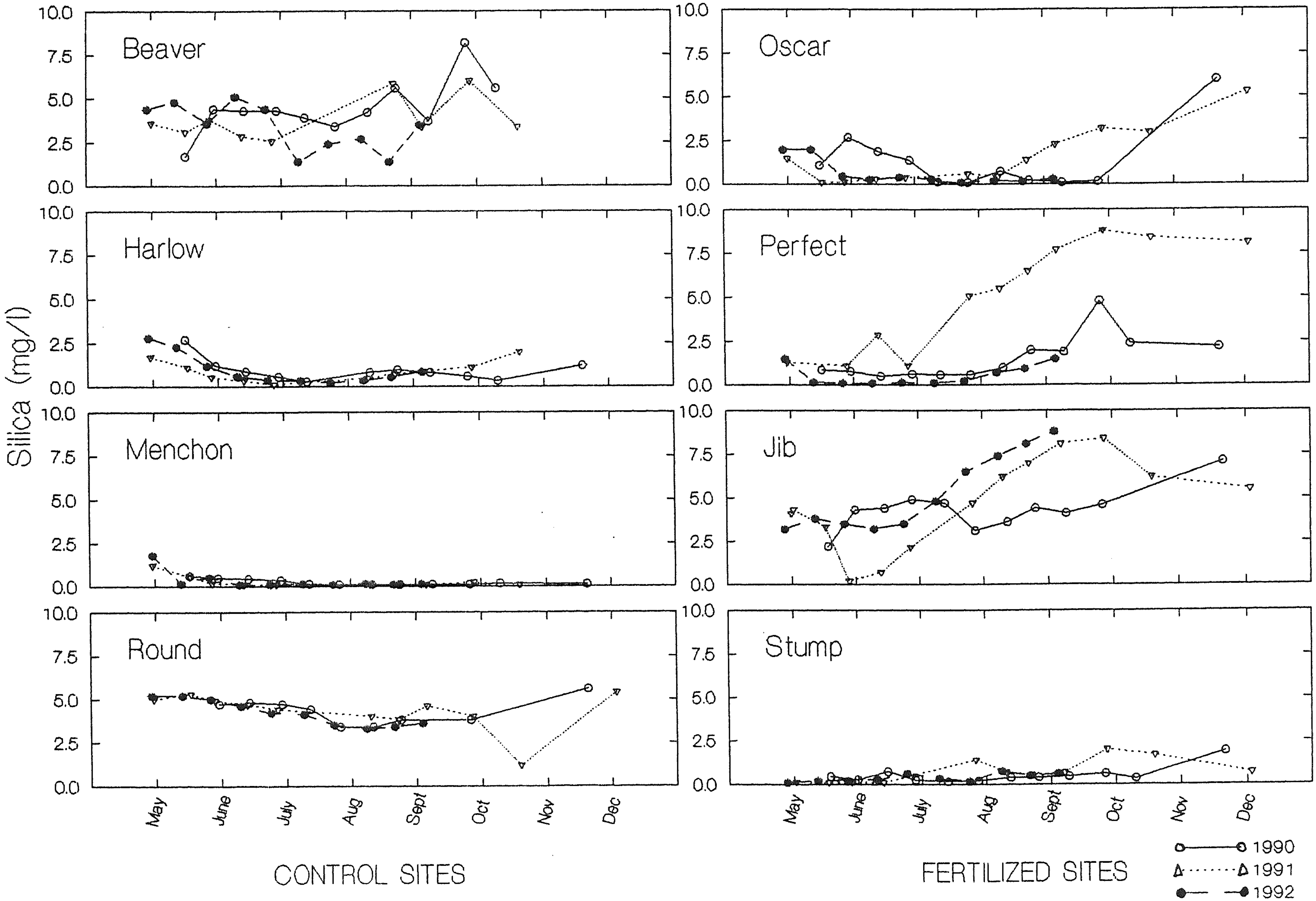


Figure 30. Seasonal variation in Silica.

Table 5. Summary of mean values (sd) of selected biological parameters at each site.

Site	Year	Phyto. Chl *a* (µm/l)	Periphyton Chl *a* (µm/mo)	Zoo-plankton (No./l)	Emergent Insects (No./Sample)	Benthic Invertebrates (No./Sample)	Minnow Trap (No./Sample)
Beaver	1990	1.18 (0.76)	0.47 (0.42)	6.93 (10.75)	6.78 (8.94)	49.44 (38.54)	4.14 (4.10)
	1991	0.77 (1.24)	2.78 (2.46)	6.53 (6.04)	115.37(163.10)	80.14 (80.02)	4.22 (4.79)
	1992	1.87 (2.89)	0.94 (1.03)	46.72 (83.32)	11.73 (13.69)	148.64(192.73)	9.33(13.00)
Harlow	1990	2.54 (1.38)	0.49 (0.41)	24.53 (21.40)	21.67 (17.05)	61.57 (47.40)	4.10 (5.47)
	1991	1.69 (1.53)	0.61 (0.67)	13.77 (10.85)	57.63 (35.39)	43.13 (45.33)	1.56 (1.33)
	1992	2.61 (2.22)	0.79 (0.84)	121.50(110.82)	126.30 (56.64)	95.53 (93.62)	6.60 (3.69)
Menchon	1990	0.65 (0.44)	0.40 (0.47)	5.05 (5.42)	12.33 (8.60)	79.89 (52.19)	9.27(11.12)
	1991	0.50 (0.72)	0.26 (0.52)	52.53(114.10)	112.75(225.32)	58.50 (67.99)	8.67(18.13)
	1992	0.41 (0.26)	0.58 (0.65)	42.33 (34.01)	135.36 (91.31)	140.09(189.01)	12.82(20.36)
Round	1990	1.46 (2.43)	1.03 (2.43)	8.59 (10.22)	64.56(148.34)	95.56 (32.64)	21.33(18.17)
	1991	0.91 (0.74)	0.44 (0.55)	13.38 (22.98)	79.13(110.84)	89.14(121.90)	11.22(13.53)
	1992	0.86 (0.39)	0.60 (0.46)	36.30 (23.32)	100.18 (65.79)	70.73 (39.21)	13.27 (8.17)
Jib	1990	2.09 (0.95)	1.40 (1.32)	23.34 (19.16)	5.25 (4.10)	94.44 (72.46)	5.60 (4.60)
	1991	17.65 (16.56)	2.78 (3.10)	196.05(532.90)	117.63(133.39)	97.11 (60.67)	4.33 (2.78)
	1992	3.09 (2.13)	2.78 (4.20)	317.72(350.16)	129.09(121.55)	167.64(115.21)	1.82 (3.13)
Oscar	1990	2.23 (1.88)	0.17 (0.14)	32.39 (65.29)	42.44 (56.72)	88.75 84.26	1.78 (1.20)
	1991	4.01 (6.16)	5.20 (5.61)	70.44 (15.43)	212.33(194.55)	60.20 (32.39)	4.30 (4.19)
	1992	2.05 (1.03)	0.53 (0.47)	66.59 (82.53)	169.10(179.27)	84.55 (70.26)	7.09 (6.41)
Perfect	1990	3.42 (3.88)	0.27 (0.40)	14.24 (15.30)	30.60 (41.29)	158.67(156.85)	6.60 (3.34)
	1991	105.20(107.41)	0.85 (1.03)	167.16(280.82)	73.56(110.18)	74.60 (63.76)	36.50(22.03)
	1992	12.80 (10.90)	3.63 (4.41)	378.23(529.62)	135.36 (77.10)	103.36(101.08)	38.33(16.41)
Stump	1990	3.47 (2.30)	1.57 (2.11)	9.20 (11.13)	57.90 (71.42)	78.78 (94.52)	8.50(16.10)
	1991	24.14 (32.68)	14.83(15.46)	52.59(103.45)	92.00(141.13)	145.44(104.94)	9.67(12.50)
	1992	5.26 (6.24)	2.41 (1.81)	73.86 (71.60)	141.64(145.07)	87.09 (76.18)	8.55(11.31)

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 31 presents the abundance, in terms of percent 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. Submersed macrophytes are greatest in abundance at Beaver and Menchon. Beaver, as mentioned previously, is heavily colonized by *Sphagnum*. The high abundance of submersed 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 submersed macrophytes.

During mid-August of 1991 and 1992 the macrophyte survey was repeated and the results compared to those of the 1990 survey. Because nutrients were obviously being lost via the outputs of the experimental sites, particular effort was made to document any changes in macrophyte growth within the outlet streams. Comparison of species composition and abundance between the three surveys showed little difference in either the distribution or abundance of macrophytes within the lakes or at their outlets. The only obvious difference between years was that some macrophytes, particularly pickerelweed (*Pontederia cordata*), at the fertilized sites appeared more robust and healthier as evidenced by their large size and dark green color.

3.6.2. Rare/Endangered 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 during the first year of the study a survey were conducted 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 sites appear to contain species that are typical of the more rare coastal plain flora. This is not surprising 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.

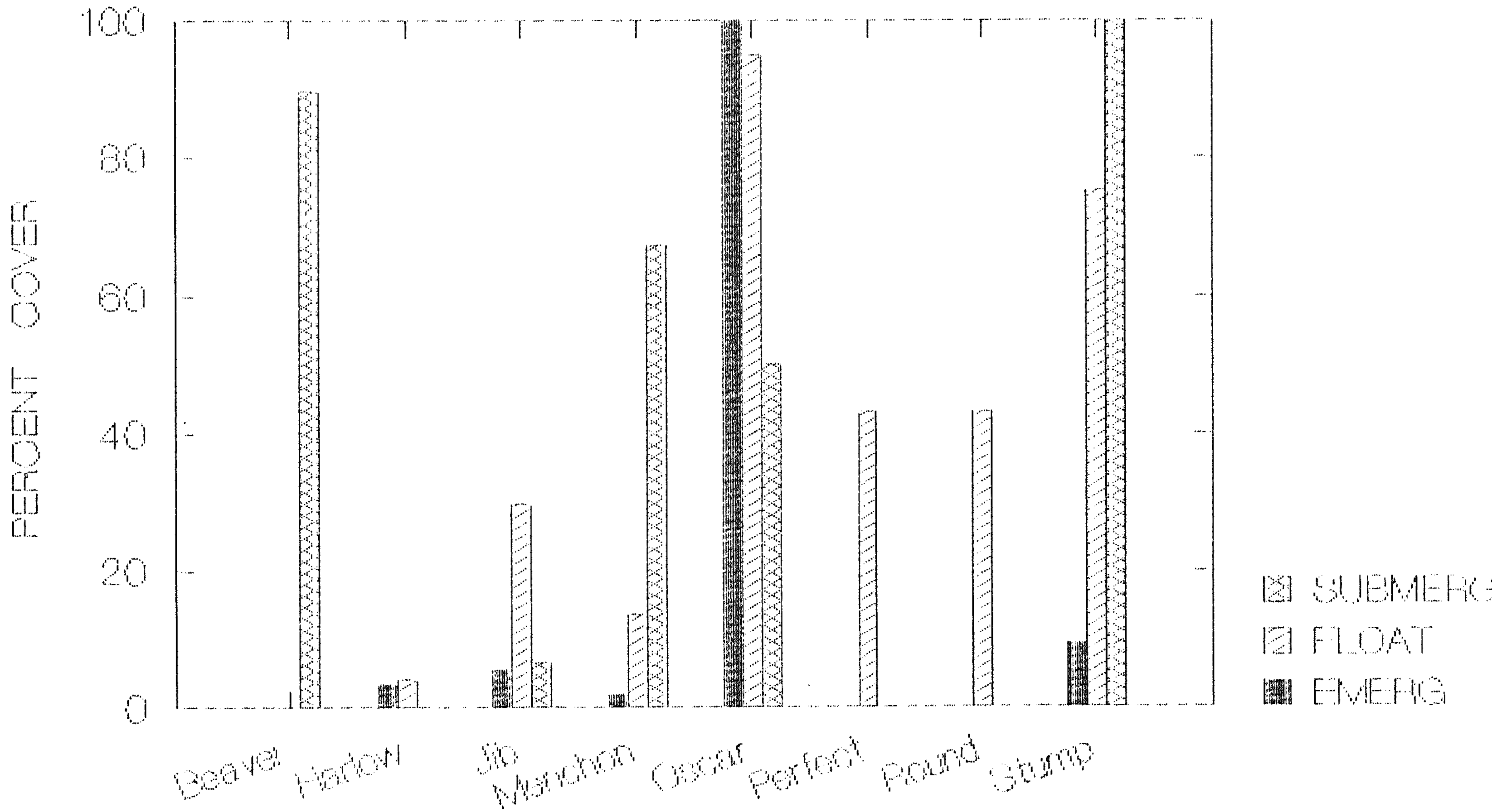


Figure 31. Percent cover of major macrophyte groups.

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					

3.6.3. Phytoplankton

Prior to fertilization mean chlorophyll *a* concentrations 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 at Beaver and Menchon and the highest at Perfect and Stump. Although most of the study sites exhibited seasonal peaks in chlorophyll *a* levels, the trends were not consistent. The most common seasonal trend was a mid-summer peak (Fig. 32).

The response of phytoplankton to fertilization was immediate and dramatic at all of the experimental sites except Oscar. Chlorophyll *a* levels increased by more than an order of magnitude and were well above levels that would classify these sites as eutrophic. The highest levels attained were on the order of 300 $\mu g\ l^{-1}$ at Perfect. At Stump and Jib, levels of 50 and 90 $\mu g\ l^{-1}$ respectively were reached. At Oscar the maximum chlorophyll *a* level attained was about 20 $\mu g\ l^{-1}$. The control sites, in contrast, exhibited slightly lower chlorophyll *a* levels than during 1991. The seasonal variation in phytoplankton chlorophyll *a* varied considerably among the different experimental sites. At Jib and Stump chlorophyll *a* levels remained high throughout most of the summer and early fall. At Perfect, there was an initial increase in chlorophyll *a* immediately after fertilization, followed by a decline during the summer, and then a very large and rapid increase during fall. The latter increase corresponded to the fall overturn which began in early September. At Oscar, phytoplankton chlorophyll *a* levels did not substantially increase until late July, nearly two months after the addition of fertilizer, and, as noted earlier, the highest level reached was only on the order of 20 $\mu g\ l^{-1}$.

The high levels of phytoplankton chlorophyll *a* observed for the experimental sites during the fertilization year did not persist into the following year. Average phytoplankton chlorophyll *a* values for 1993 were only about 1 to 3 times greater than those prior to fertilization. Only at Perfect were chlorophyll *a* values within the range characteristic of eutrophic conditions.

Phytoplankton chlorophyll *a* levels at the outlets of Jib and Stump (Fig. 33) showed the same seasonal trend as at the lake center. At Stump the levels at the outlet were about equal to those at the center. At Jib and Oscar, however, they were only about half as great which probably reflects incomplete mixing of water inputs. At Oscar, the seasonal trend at the lake center and outlet differed, the peak at the outlet occurring about one month earlier than at the center. As was the case for nutrients, a considerable proportion of the phytoplankton at Jib, Oscar and Stump was obviously being flushed via the surface outlets, and the high chlorophyll *a* values at Perfect are probably related to the fact that this site has no surface outlet which allows for greater retention of phytoplankton within the system.

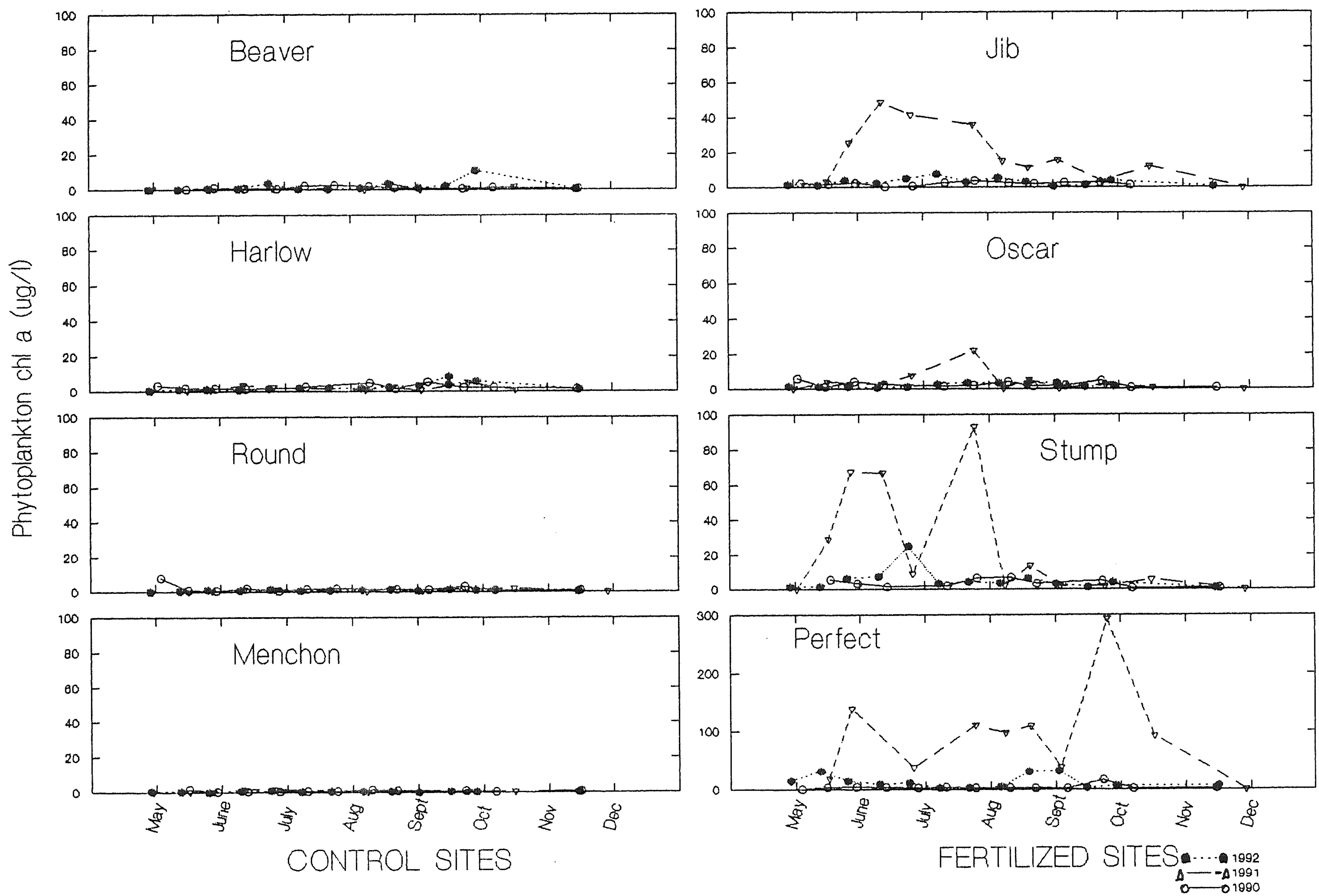


Figure 32. Seasonal variation in phytoplankton chlorophyll a.

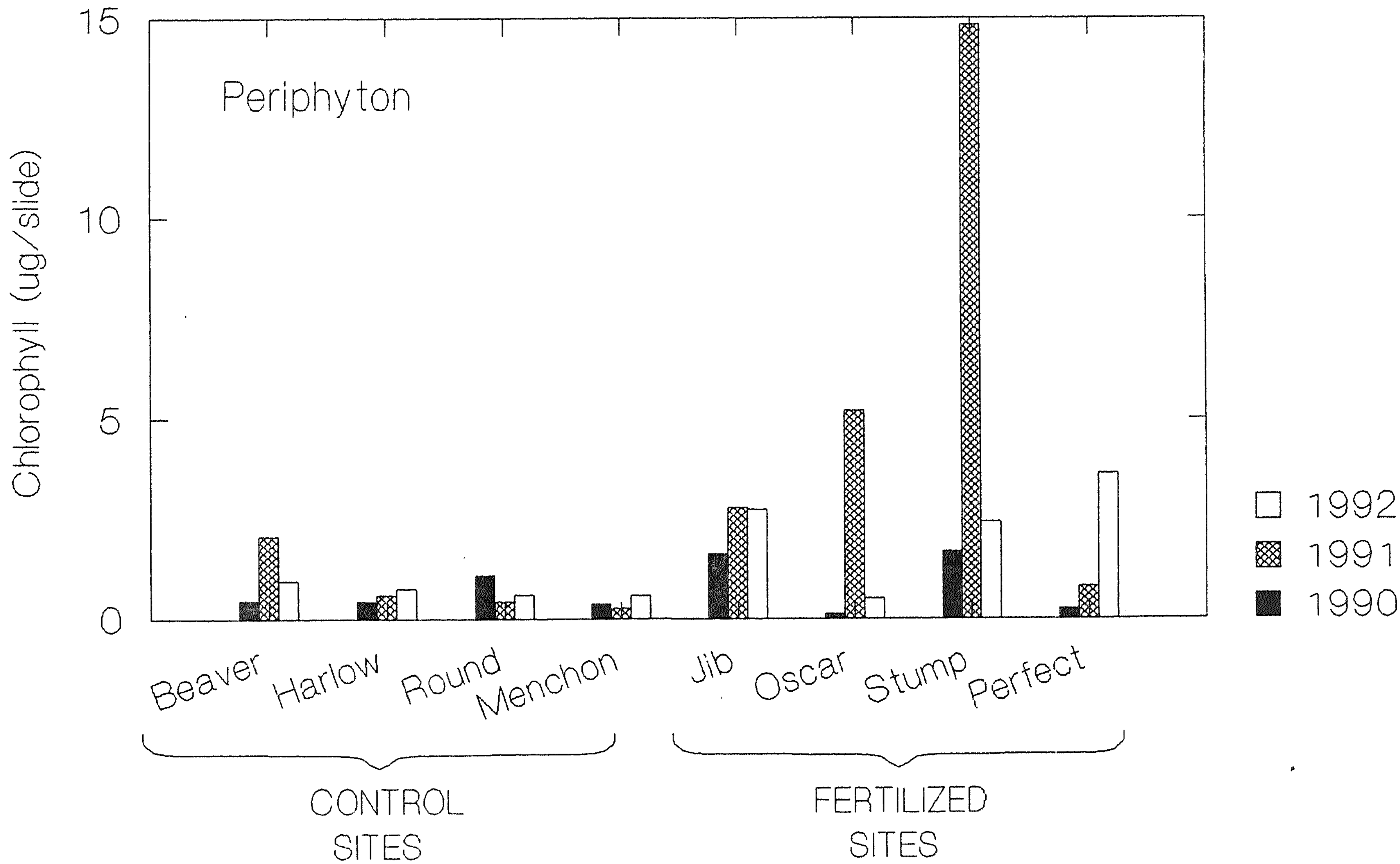


Figure 33. Mean periphyton growth.

3.6.4. Periphyton

Estimates of periphyton growth were obtained by measuring the rate of colonization of periphyton (as chlorophyll *a*) on glass microscope slides suspended in the water column just beneath the water surface within the littoral zone.

Prior to fertilization there was considerable variation between sites (Fig. 33). Periphyton growth at Jib, Round and Stump were about one order of magnitude greater than at the other sites. During the fertilization year most of the experimental sites showed a dramatic increase in periphyton growth. The greatest increase was at Stump, and the least was at Jib. In the second year after fertilization periphyton growth at all of the experimental sites, except Perfect, was much less than during the fertilization year, but still greater than during the pre-fertilization year. Periphyton growth at Perfect was greatest during 1992, the second year after fertilization.

The fertilized sites exhibited an inverse relationship between phytoplankton and periphyton growth. Perfect, which attained the highest phytoplankton chlorophyll *a* levels, had the lowest periphyton growth, and Oscar, which had the lowest phytoplankton chlorophyll *a* levels, had the second highest periphyton growth. This same inverse trend also occurred on a seasonal basis and was particularly obvious at Jib and Stump where the period of greatest periphyton growth coincided with the lowest phytoplankton chlorophyll *a* levels (Fig. 34). An inverse relationship between periphyton and phytoplankton biomass is often observed in freshwater systems and is attributed to competition for light between the two groups (Wetzel 1983). However, other factors are probably also important. Bothwell (1989) suggested that water movements have a positive influence on periphyton growth by increasing the rate at which nutrients diffuse into the algal matrix. This may be a factor in this study since the two fertilized sites exhibiting the highest and lowest periphyton growth rates (Oscar and Perfect respectively) are also those with the highest and lowest flushing rates. Another factor that may be equally important is that, unlike phytoplankton which are suspended in the water column, periphyton grow attached to a substrate and are less susceptible to being flushed out of the system by water movements.

3.6.5. Zooplankton

Mean zooplankton numbers during 1990 ranged between about 5 and 35 individuals per litre (Fig. 35). Zooplankton were most abundant at Oscar and least abundant at Menchon. Copepods were generally the most abundant group at all sites except Oscar where rotifers and cladocerans dominated the zooplankton.

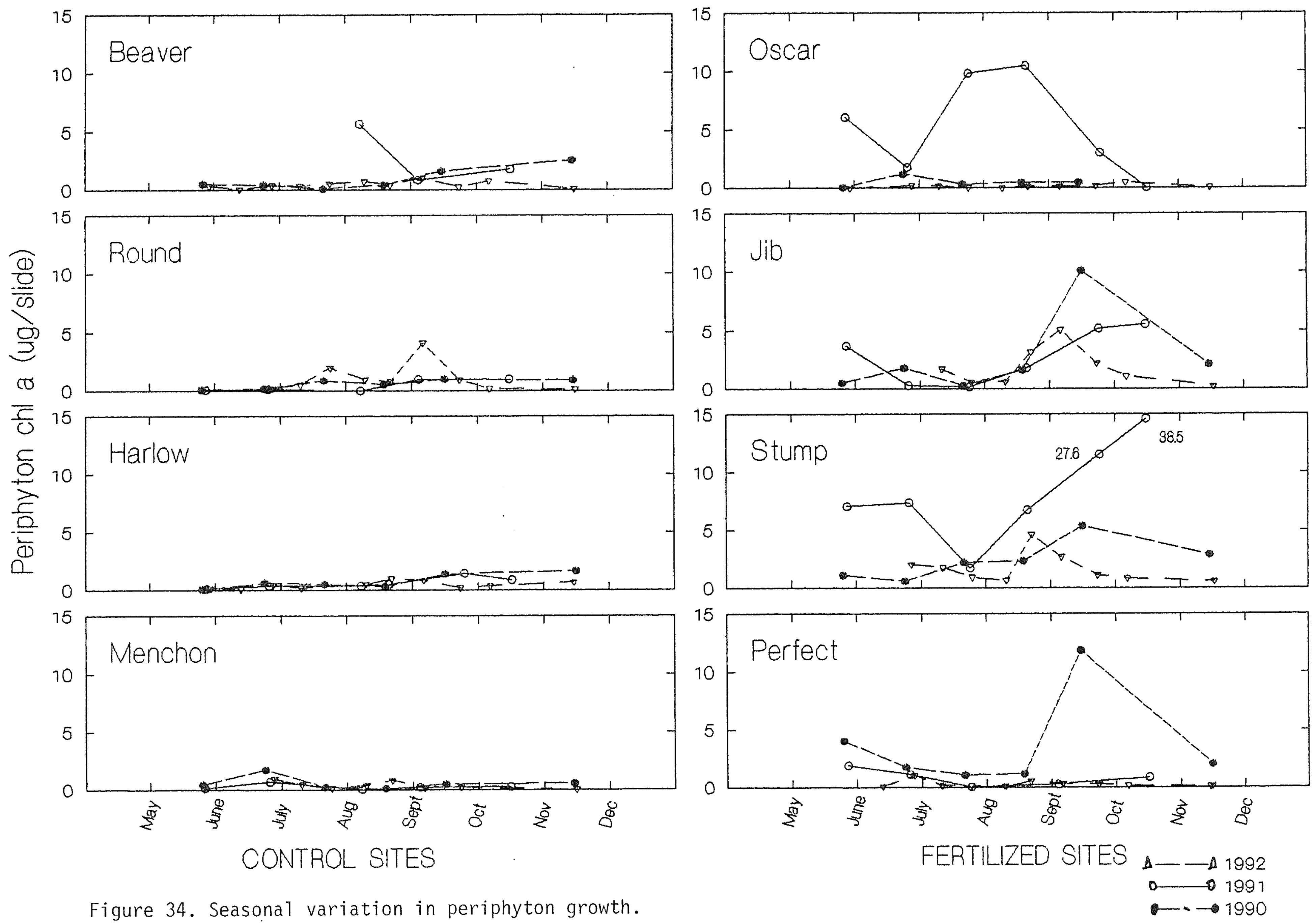


Figure 34. Seasonal variation in periphyton growth.

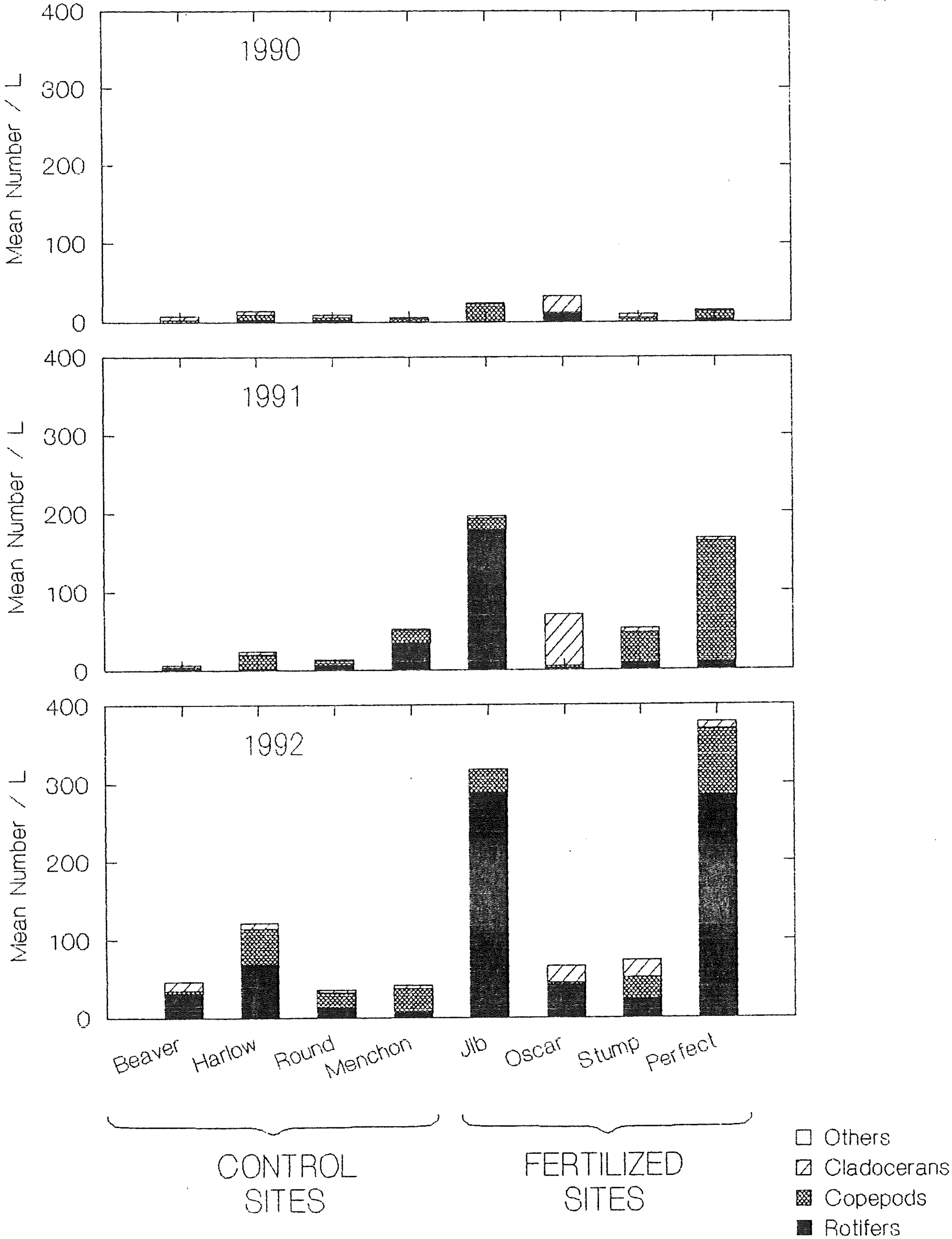


Figure 35. Mean zooplankton numbers.

At all sites except Beaver, mean zooplankton numbers were greater during 1991. Most of the experimental sites, however, showed considerably larger increases than did the control sites. The amount of increase was generally correlated with the increase in phytoplankton chlorophyll *a* and was greatest at Jib and Perfect. During 1992 zooplankton numbers at Jib and Perfect continued to increase, but Oscar and Stump remained at about 1991 levels. The influence of fertilization appears to be more persistent for zooplankton than for phytoplankton.

There was some variation in the relative proportion of zooplankton groups following fertilization. At most of the experimental sites rotifers tended to increase more than other groups. At Perfect, however, copepods showed the greatest increase during 1991, but in 1992 the increase was primarily due to rotifers.

3.6.6. Emergent Insects

Emergent insect samples were generally dominated by dipterans (Fig. 36). Most other insect groups were present in only small numbers. Of the dipterans, most were chironomids, although at Menchon and Stump significant numbers of ceratopognids and chaoborids, respectively, were recorded.

The number of emergent insects collected was considerably greater in 1991 and 1992 than in 1990 at all sites except Beaver. The relative increase in numbers, however, was about the same at both control and experimental sites and there is little indication that fertilization had a significant influence on emergent insect numbers.

3.6.7. Benthic Invertebrates

The major groups of benthic invertebrates collected in benthic sweep samples included insects, crustaceans, mollusks and mites (Fig. 37). At all sites except Jib the samples were dominated by insects. At Jib, crustaceans were the most abundant group. Significant numbers of molluscs were collected only at Jib and Stump.

Benthic crustacean numbers and species composition varied considerably among sites. 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.

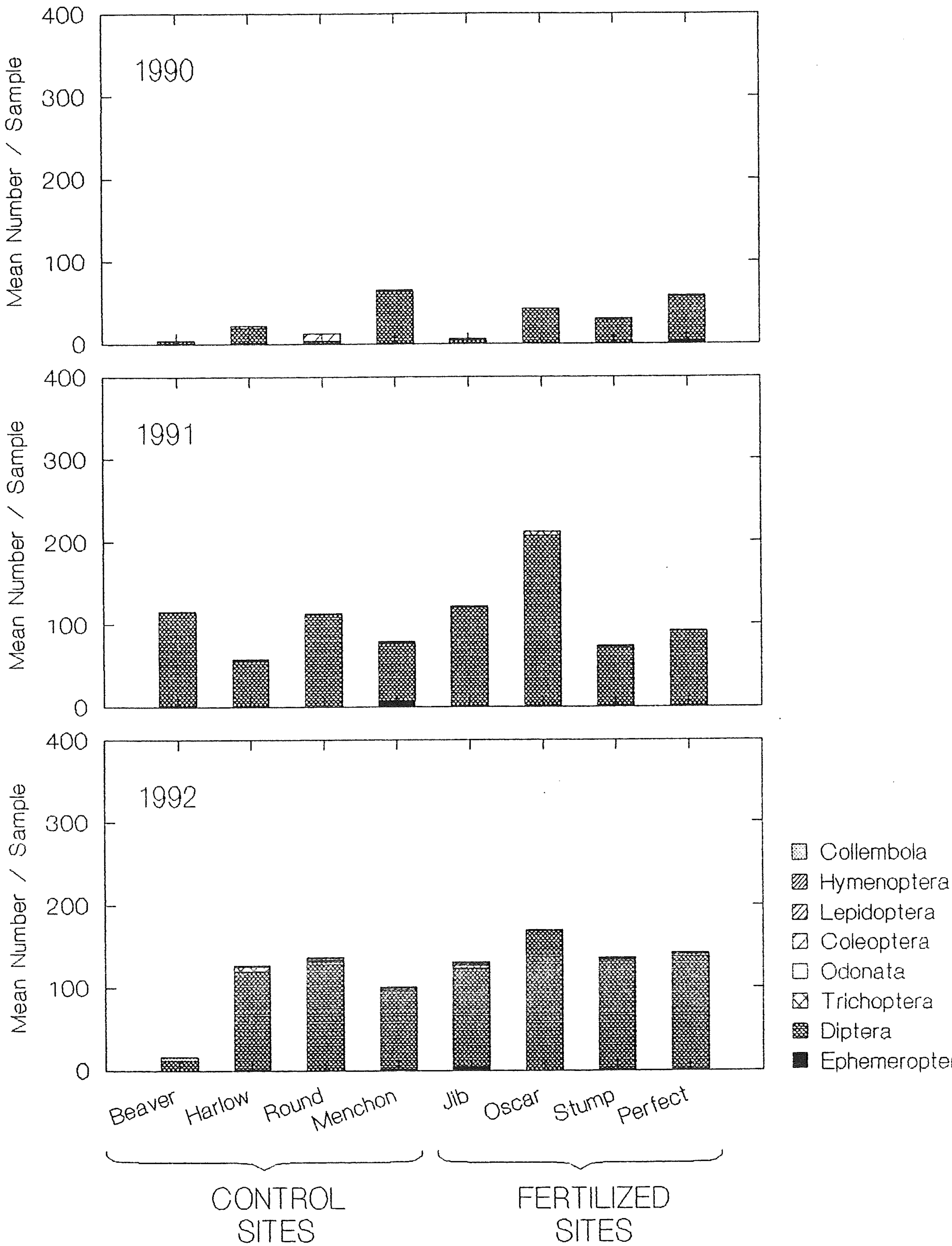


Figure 36. Mean emergent insect numbers.

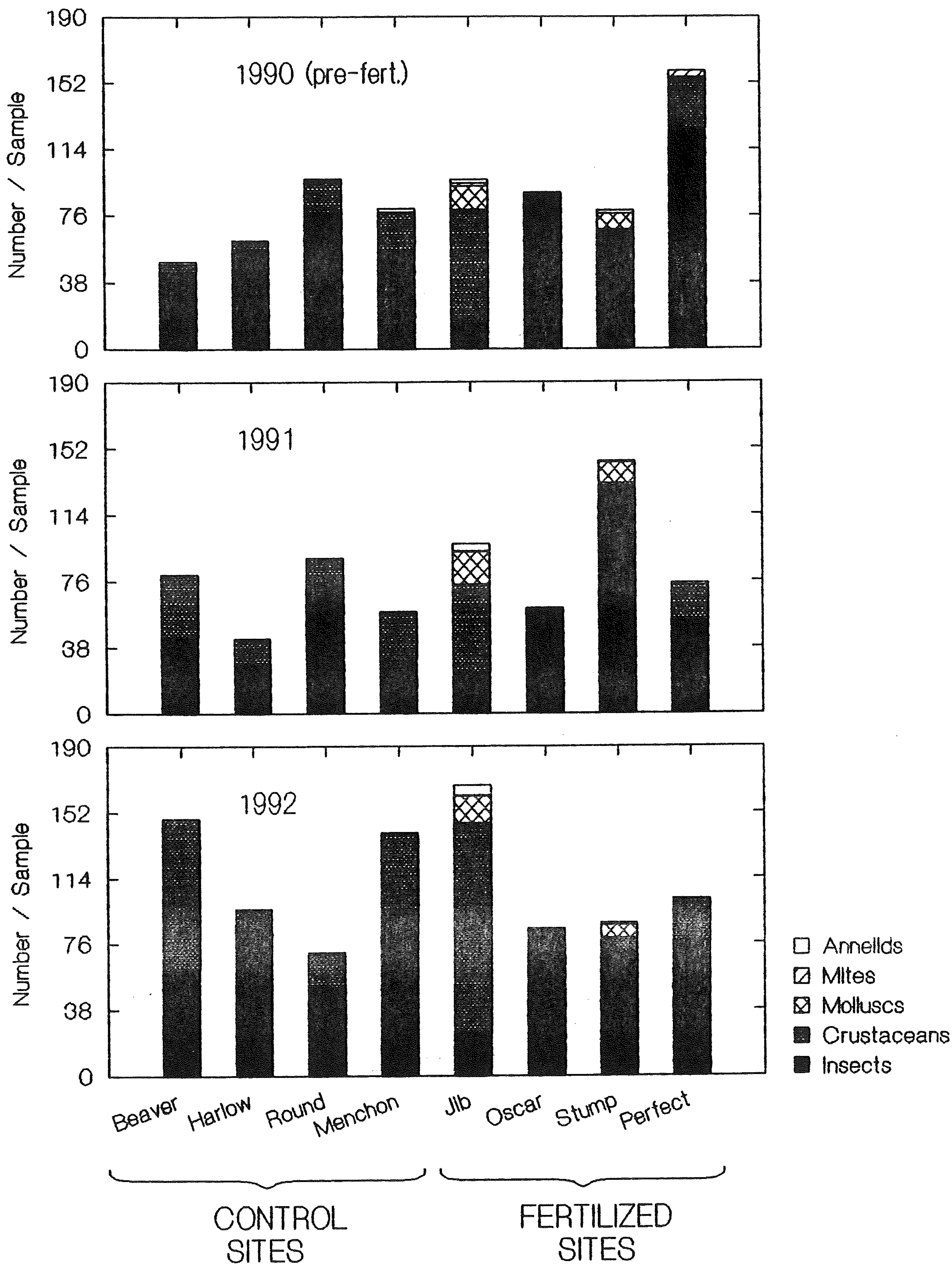


Figure 37. Mean benthic invertebrate numbers.

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. 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. Chironomids were the most abundant group at all sites (Fig. 38). 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.

Although the relative proportion of each major taxonomic group remained about the same between years, benthic invertebrate numbers varied considerably at both the control and experimental sites. The differences observed are probably a result of normal year to year variation. Fertilization did not appear to have any effect on either abundance or species composition of benthic invertebrates.

3.6.8. Minnow Trap Collections

The minnow traps collected a diversity of organisms. In addition to small fish, amphibians and some of the larger aquatic insects were also collected.

Fish were recorded from minnow trap collections at all sites except Beaver, Menchon and Oscar. 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.

The major amphibians collected in the minnow traps included tadpoles and newts. 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. The collections from Round had the greatest numbers for all groups of insects. Significant numbers of insects were

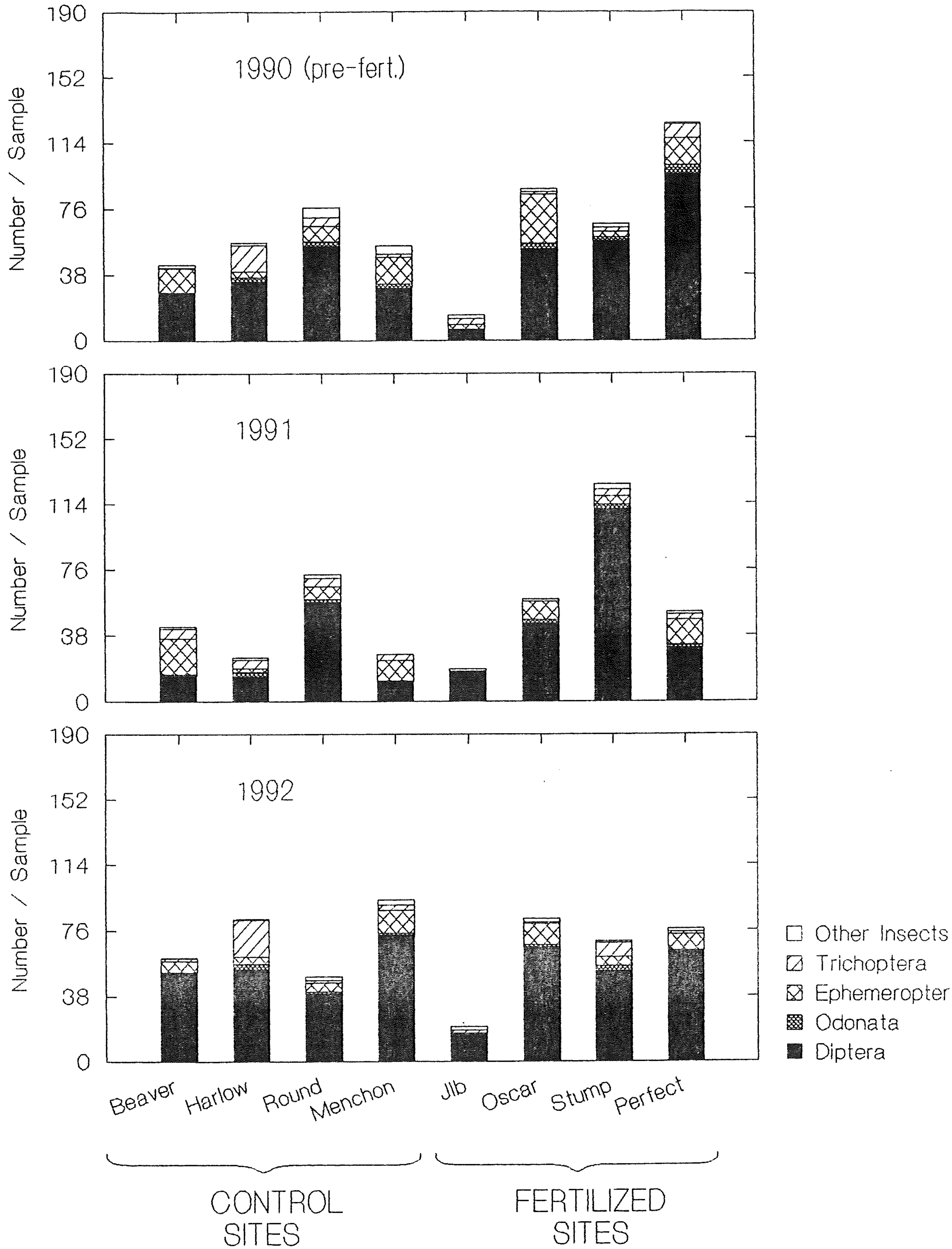


Figure 38. Insect groups collected in benthic invertebrate samples.

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.

A comparison of between year variation in minnow trap collections is shown in Figure 39. Although the sampling is limited and the number of organisms collected is low, in most cases the difference between years is minor and there is no obvious influence of fertilization. The largest difference occurred at Perfect where a greater number of fish were trapped during 1991 and 1992. This increase was largely due to the golden shiner (*Notemigonus crysoleucas*), a species which, for some reason, was not recorded at all at any site during 1990.

3.6.9. Fish

During the fall, (13-14 November) of 1990 and spring (28 April-1 May) of 1991, fish surveys were 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 center of each site and allowed to remain overnight. Fish were captured at only four of the eight study sites. The greatest numbers were captured at Jib and Harlow. Salmonids were captured only at Jib.

In 1990 the greatest number of fish were collected at Jib and included 16 white suckers (*Catastomus commeron*; 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 (average size 11.8 cm) were caught.

In 1991, 18 brown bullheads (*Ictalurus nebulosus*; average size 14.6 cm), 23 yellow perch (average size 13.8 cm) and 13 white suckers (average size 20.5 cm) were caught at Jib. At Harlow 64 white perch (*Perca fontinalis*; average size 10.2 cm) were caught, and at Perfect five brown bullheads (average size 12.4 cm) and 22 golden shiners (*Notemigonius crysolucas*; average size 10.0 cm) were caught.

3.6.10. Waterfowl

Throughout the course of the study observations were made on the occurrence of ducks at each site. Although some ducks (mainly black and ring necks) were observed at all sites over the three years of study, significant numbers were observed only at Beaver, Menchon, Oscar and Stump, and the variation between years was great (Fig. 40). Except at Oscar, there was no obvious influence of

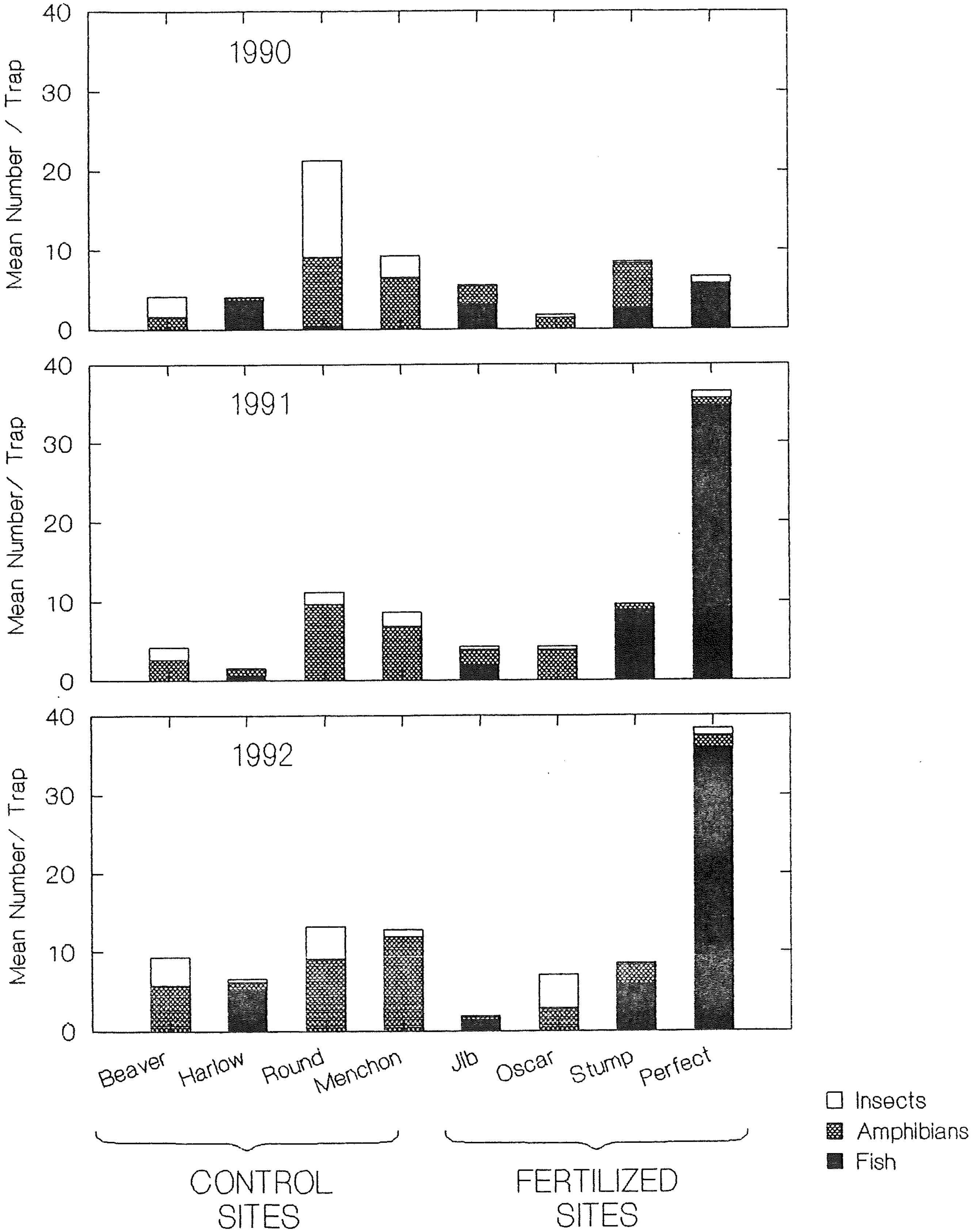


Figure 39. Mean numbers of organisms collected in minnow traps.

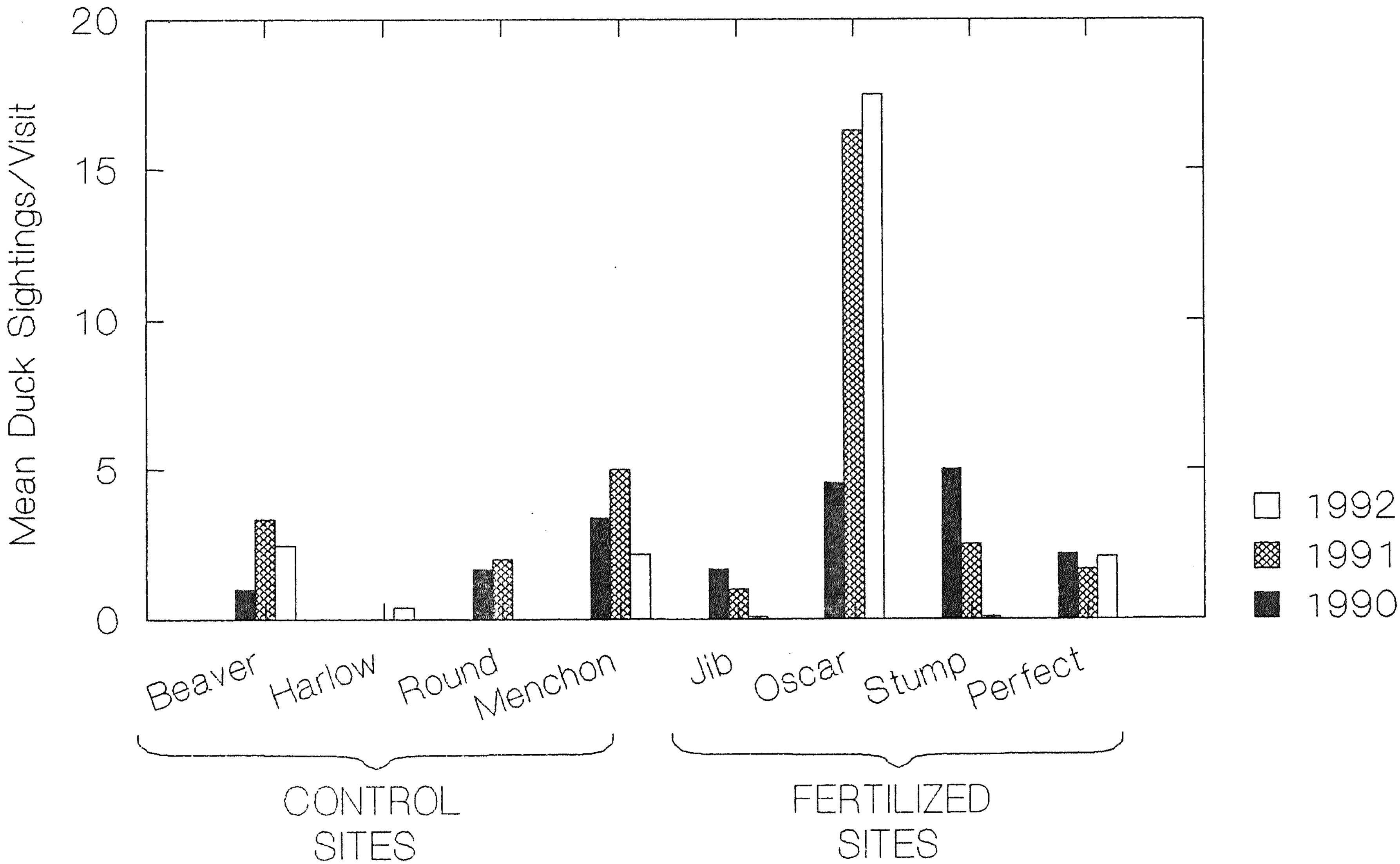


Figure 40. Number of duck sightings at each site.

fertilization on the number of ducks observed. At Oscar a greater number of ducks were observed during the second and third years of study. This could be interpreted as an indication that fertilization had a significant impact on use of this site. To further evaluate this possibility, data collected on the number of ducks observed during breeding pair surveys at Oscar between 1986 and 1992 by the Nova Scotia Department of Natural Resources was tabulated (Fig. 41). These data indicate that considerably more ducks were present at Oscar during 1992, and may be a indication that fertilization has had an influence on the use of this site by waterfowl.

3.6.11. Species Diversity

In an effort to compare sites with respect to the diversity of species present in each community sampled, and to detect any changes that may have occurred over the three years of study, Shannon-Wiener diversity indices were calculated for zooplankton, emergence trap, benthic sweep and minnow trap collections for each year. 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 the different community types, but they are useful for comparing the diversity of each community between sites and between each of the three years of study.

The greatest between year difference in diversity occurred in the zooplankton communities (Fig. 42). All of the experimental sites exhibited a decrease in zooplankton diversity during the year of fertilization. At Jib and Perfect this persisted into the following year, but at Oscar and Stump zooplankton diversity in the third year returned to about the same levels as observed in the pre-fertilization year. Emergent insect diversity varied greatly between years at both the control and experimental sites (Fig. 43). Only at Stump and Perfect did there appear to be a consistent trend showing a decrease in diversity in the second and third years of the study. There were no consistent trends in the diversity of benthic invertebrates (Fig. 44) or minnow trap collections (Fig. 45) between years at either the experimental or control sites.

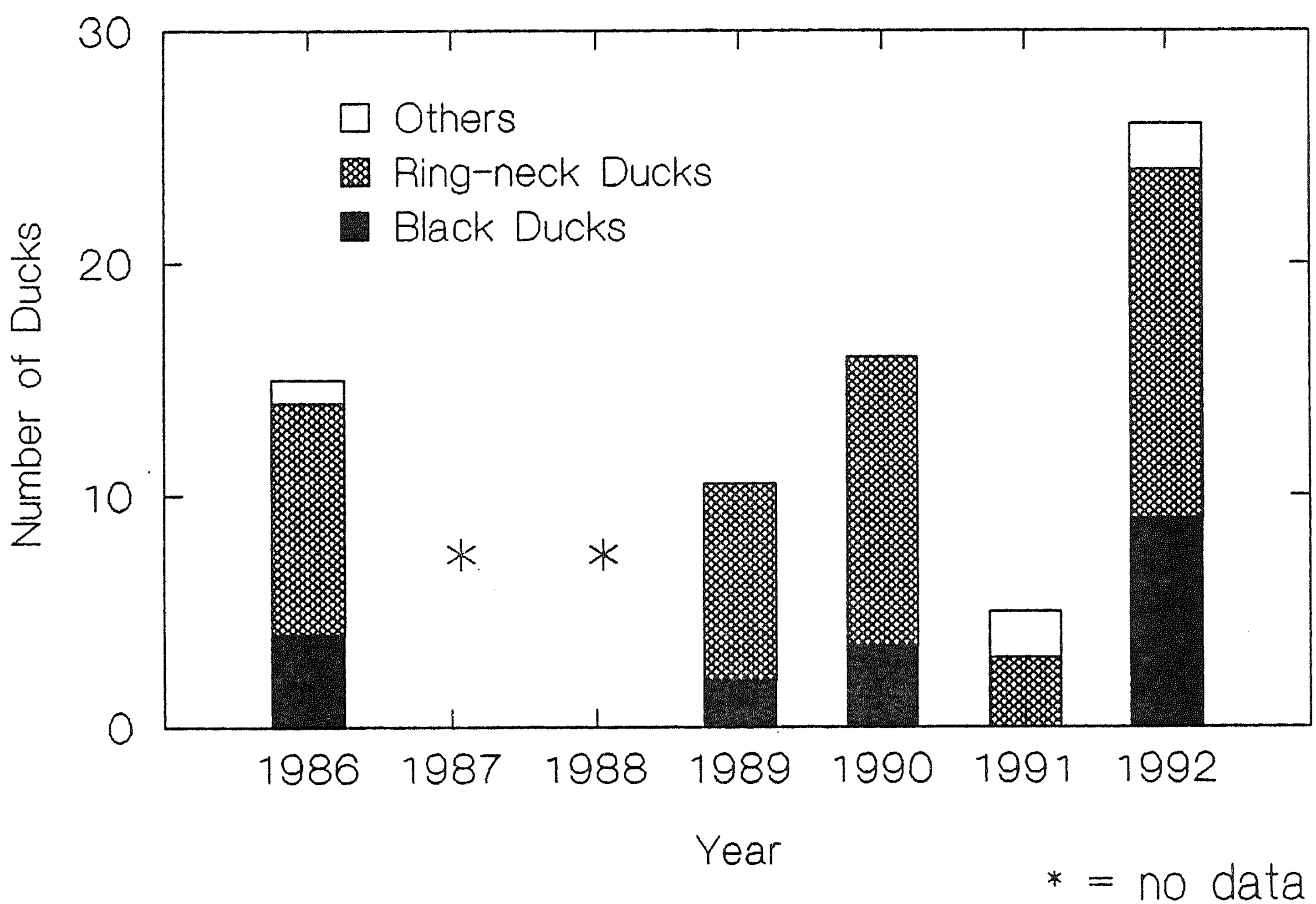


Figure 41. Number of ducks observed at Oscar during breeding pair surveys conducted by the Nova Scotia Department of Natural Resources.

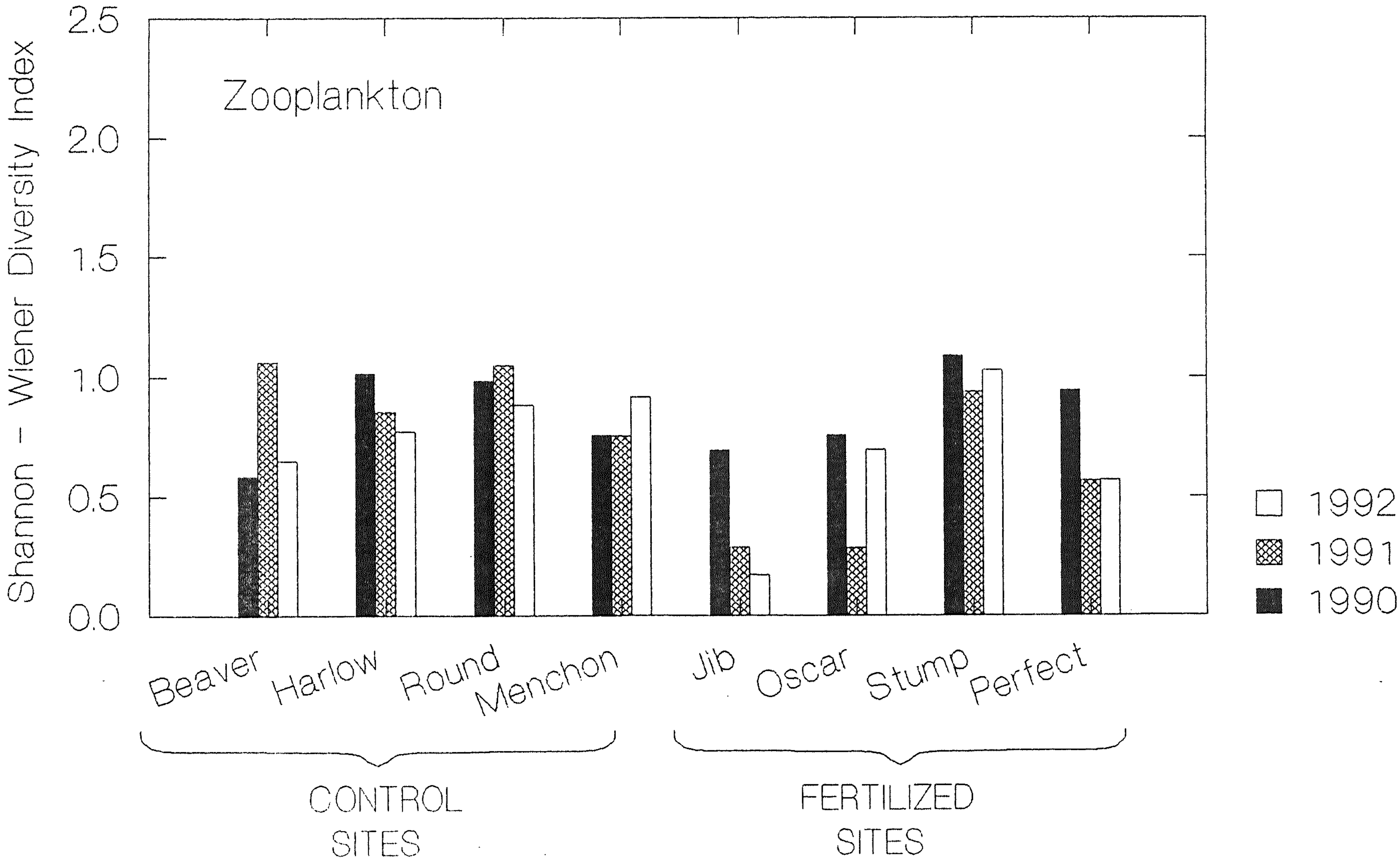


Figure 42. Variations in zooplankton diversity.

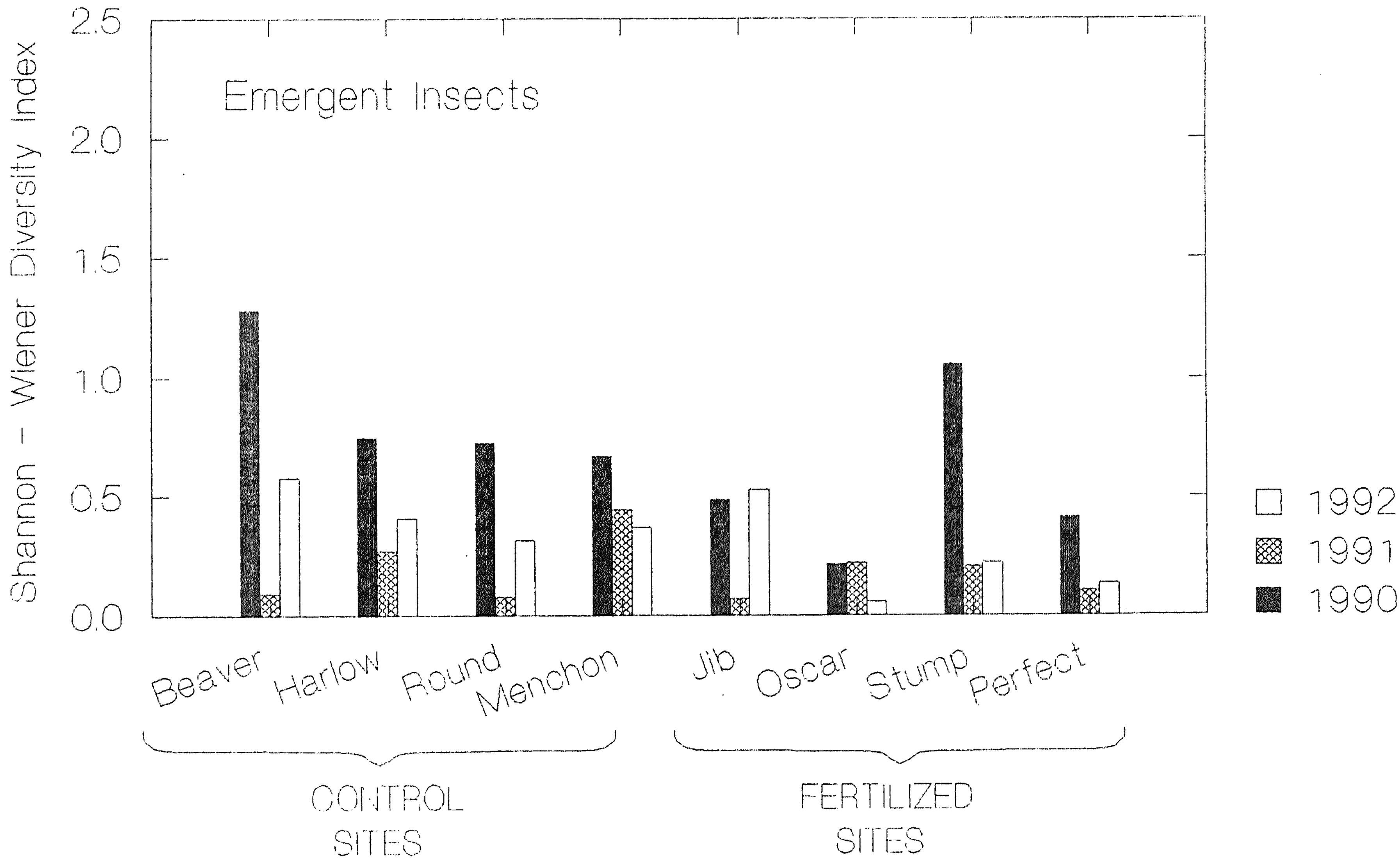


Figure 43. Variations in emergent insect diversity.

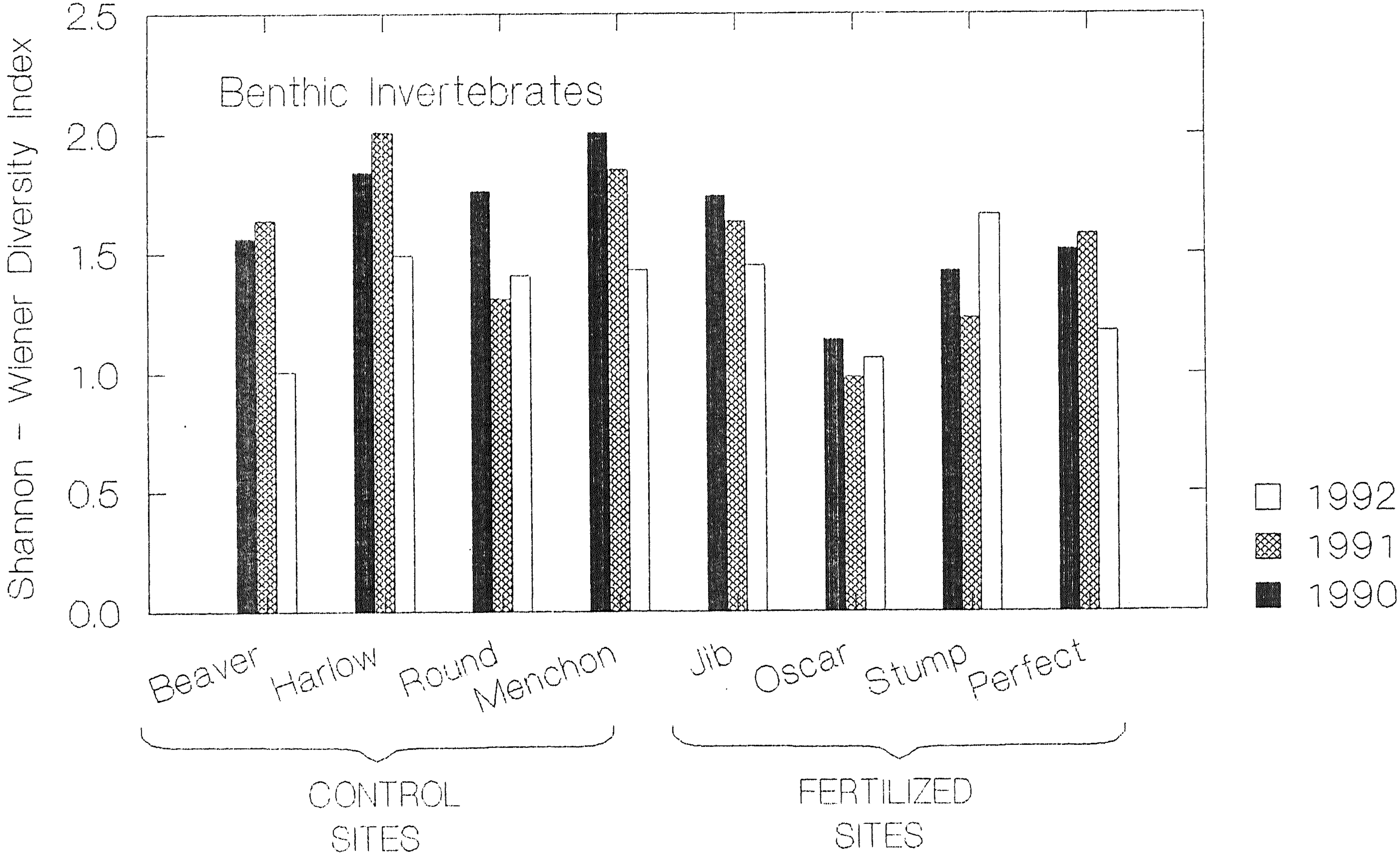


Figure 44. Variations in benthic invertebrate diversity.

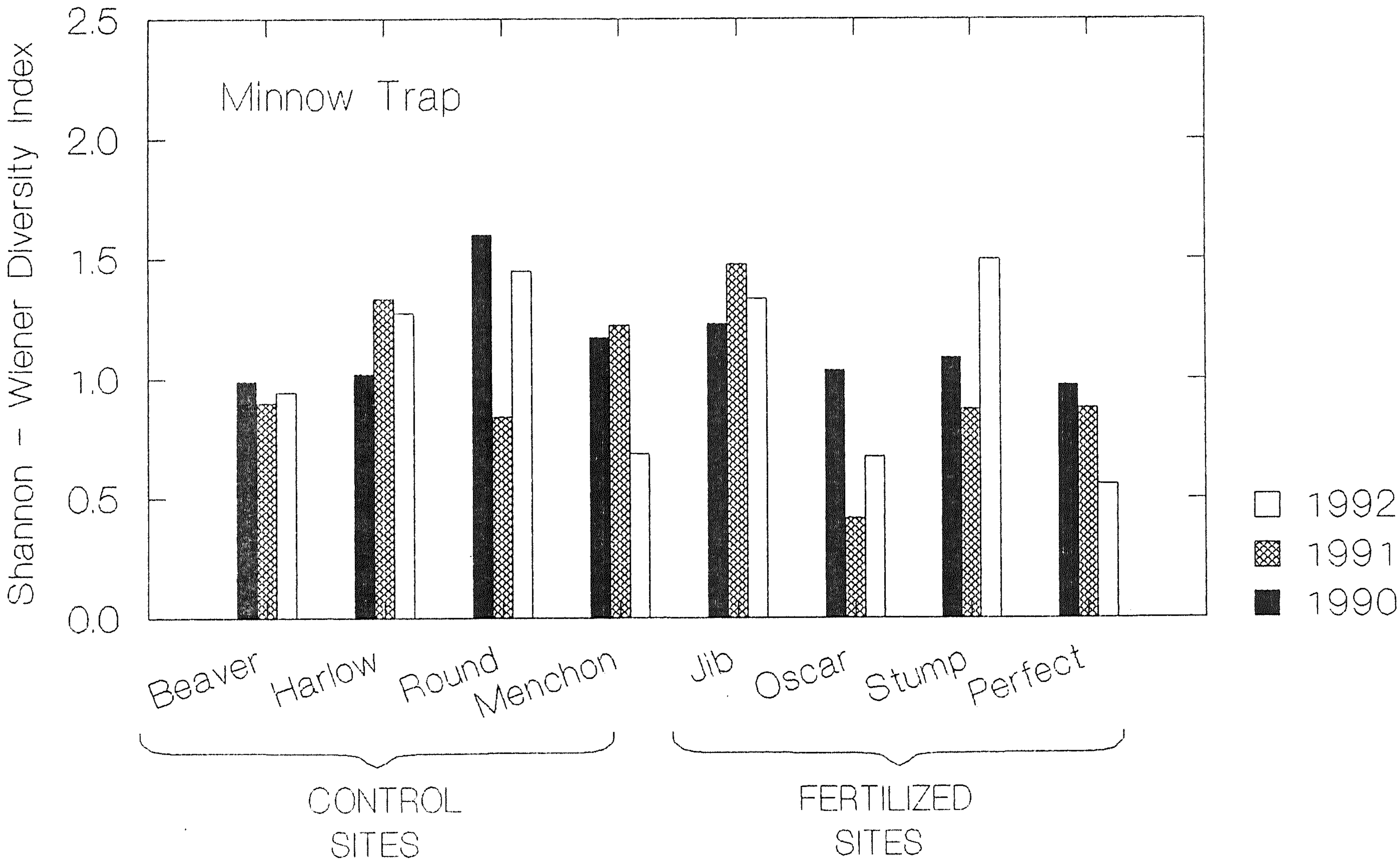


Figure 45. Variations in minnow trap collection diversity.

VI. DISCUSSION

The results of this study clearly illustrate that it is possible to enhance the productivity of acidic freshwater systems through the addition of artificial fertilizers. The response of the experimental sites to the addition of nitrogen and phosphorus fertilizer, particularly in terms of increased phytoplankton biomass, was impressive . This was also true with respect to periphyton growth and, although to a somewhat lesser extent, zooplankton biomass. Those organisms having longer generation times, such as emergent insects and benthic invertebrates, showed little response to fertilization during this first two years, but will probably also show an increase in biomass during subsequent years and there is little doubt that fertilization has the potential to increase the overall productivity of these systems. However, the response to a single addition of fertilizer appears to be relatively short lived. The second year after fertilization, both phytoplankton biomass and periphyton growth was much reduced indicating that much of the fertilizer added to the system in the previous year had either been lost from the system or became biologically unavailable.

A similar response to artificial fertilization has been reported in numerous other studies (Smith 1969; Edmondson 1970; Schindler 1974; Gabor et al. in press), and it appears that freshwater systems are unable to maintain high productivity if not provided with a continuous supply of nutrients. It was hoped that the relatively large amounts of fertilizer used in this study would load the systems to such an extent that production would be enhanced for a period of at least 3 to 4 years. This did not appear to be the case. A substantial portion of the added nutrients were either quickly flushed from the system or became entrained and unavailable within the sediments. Rough calculations of the amount of added nutrients lost via the outputs at Jib and Oscar suggest that the former is most likely the major loss.

The variation in response among the fertilized sites, particularly with regard to the nutrient levels attained, is not surprising considering the diversity in physical factors, particularly flushing rates, morphology and mixing characteristics, among the experimental sites. The results suggest that future fertilization protocols should consider factors other than lake volume alone. Predicting the level of P that would be attained for a particular system is complex but appears to depend largely on flushing rate, stratification characteristics and the nature of water inlets and outlets.

Flushing rate is perhaps the most important factor determining the response to fertilizer addition. The relationship between flushing rate, phosphorus loading and eutrophication is well established (Ketchum 1969; Dillon 1975; Vollenweider and Kerekes 1982). The relationships observed in this study between flushing rate and phytoplankton biomass indicate that flushing rate is an important determinant of the effectiveness of the added fertilizers in enhancing the productivity of the sites used in this study. Future studies should incorporate estimates of flushing rate in determining the amount of fertilizer required. In addition, only systems with low flushing rates should be considered appropriate for fertilization. Unfortunately, maritime climates are characterized by high levels of precipitation and the number of freshwater systems having low flushing rates is limited. One way of potentially dealing with this constraint is to limit fertilization to portions of larger systems, such as coves or other natural embayments, that tend to be at least partially isolated from the influence of major water inputs.

The influence of water column stratification on nutrient retention is indirectly related to flushing rate. Surface water inputs entering stratified systems generally tend to be confined to the epilimnion with the result that hypolimnion water is flushed to a much lesser extent than surface water. As a result, the hypolimnion tends to serve as a store for nutrients that eventually become available during periods of destratification. This is most likely why the two stratified experimental sites, Jib and Perfect, continued to exhibit relatively high phytoplankton biomass, as opposed to Oscar and Stump (which do not stratify) during the second year after fertilization. In addition, stratified systems which become anaerobic create conditions in which phosphorus is made more soluble and biologically available during periods of overturn. In contrast, phosphorus tends to become chemically bound in an insoluble and biologically unavailable form in unstratified systems that do not experience anaerobic conditions.

Surprisingly, the different procedures used to fertilize the sites did not appear to have much influence on the behavior of the added nutrients. Jib and Perfect were fertilized by slowly adding fertilizer into the swash of an outboard motor. This procedure would seem to greatly increase the rate at which the fertilizer would dissolve, relative to dumping by helicopter as was done at Stump and Oscar, and total P levels within the water column at Jib and Stump would be expected to be higher, and sediment P lower, than at Stump and Oscar. This was not the case and it appears that there is little difference between the two application techniques with respect to the dissolution of the fertilizer. The only suggestion that there was a difference in the behavior of the added nutrients was that the time required to reach maximum water column total P levels at Oscar and Stump was greater than at Jib and Perfect. This may be related to the fertilizer having been largely undissolved immediately after application when applied by helicopter and thus having settled into the sediments to be released slowly over time.

Another factor that should be considered in future fertilization studies concerns the type of fertilizer most appropriate for insuring continued nutrient availability. Very soluble forms of phosphorus and nitrogen, such as the triple-super phosphate and urea combination used in this study, have the advantage of becoming biologically available quickly, but tend to initially provide extremely high loading rates that surpass the systems ability to use them effectively. As a result, a large portion of the nutrients are flushed out of the system without ever being incorporated into the biological components. The use of a slow release fertilizer may provide an alternative that would tend to supply nutrients at a lower but more constant rate. The main disadvantage of using slow release fertilizers is that they are relatively more expensive (on the order of ten times), but, theoretically, a much smaller amount could be used and, in the long term, a slow release fertilizer may prove to be more cost effective than the less expensive highly soluble fertilizers.

Based on the results obtained thus far, the negative impacts of artificial fertilization appear to be minor. No obnoxious algal blooms were created and the downstream effects of nutrient export were unnoticeable. The only potentially negative impact identified was that fertilized sites that stratify may become anaerobic a short time sooner, both during summer and winter stratification, than if they were not fertilized. This will have to be considered if this approach to increasing productivity is used at sites considered to be important as feeding or breeding habitat for fish species that require high oxygen levels (e.g., salmonids).

Future monitoring to determine the response of a system to fertilization could probably be limited to measurement of phytoplankton chlorophyll *a* levels. Phytoplankton chlorophyll *a* is relatively easy and inexpensive to measure compared to nutrients or other biomass indices, and numerous studies have shown that phytoplankton biomass correlates strongly with total P concentration (Dillon and Rigler 1974). Alternatively, periphyton growth rates may be just as useful an indicator, and perhaps may be even better since periphyton tends not to be flushed out of the system as are phytoplankton.

Based on the results of this investigation, it appears unlikely that the fertilization approach adopted in this study will prove to be an effective management technique for enhancing waterfowl production in the type of freshwater systems utilized in this study. This is not to imply, however, that artificial fertilization is not a potentially viable management technique when applied to an appropriate system. The results of this study provide considerable information with respect to determining the probable conditions under which fertilization may prove to be a viable management technique, and provide important information concerning the factors that should be considered in future studies.

VII. ACKNOWLEDGEMENTS

This report was prepared with the help of Jamie Gibson. The field crews consisted of Nancy House and Don Sam as field supervisors, and Michelle Walters, Kuflom Kuflu, Mike Parrish, Sarah Richard, Fiona Clarke, and Shelly Porter as field assistants. Reg Melanson, Fred Payne and Randy Milton of the Nova Scotia Department of Natural Resources provided valuable logistic support throughout the project. 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, New Brunswick. Numerous discussions with Henry Murkin, Bruce Pollard and Andrew MacInnes of Ducks Unlimited Canada throughout the course of the study aided in experimental design and interpretation of results. Special thanks are due Jamie Gibson who assisted in the field and laboratory and did an exceptional job of managing the extensive data base developed over the course of the study.

VIII. REFERENCES

Baker, J.P. and S.G. Christensen. 1991. Effects of acidification on biological communities in aquatic ecosystems, p. 83-106. *In* D.F. Charles [ed.] Acidic deposition and aquatic ecosystems, Springer-Verlag, New York, N.Y.

Bothwell, M.L. 1989. Phosphorus-limited growth dynamics of lotic periphytic diatom communities: areal biomass and cellular growth rate responses. Can. J. Fish. Aquat. Sci. 46: 1293-1301.

Boyd, C.E. 1981. Comparison of five fertilization programs for fish ponds. Trans. Am. Fish. Soc. 110: 541-545.

Dillon, P.J. 1975. The phosphorus budget of Cameron Lake, Ontario: the importance of flushing rate to the degree or eutrophy of lakes. Limnol. Oceanog. 20: 28-39.

Dillon, P.J. and F.M. Rigler. 1974. A test of a simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Bd. Can. 32: 1519-1531.

Edmondson, W.T. 1970. Phosphorus, nitrogen and algae in Lake Washington after diversion of sewage. Science. 169: 690-691.

Gabor, T.S., H.R. Murkin, M.P. Stainton, J.A. Boughton and R.D. Titman. In press. Nutrient additions to wetlands in the interlake region of Manitoba, Canada: effects of a single pulse addition in spring. Hydrobiologia.

Huntsman, A.G. 1948. Fertility and fertilization of streams. J. Fish. Res. Bd. Can. 7(5): 248-253.

Hyatt, K.D. and J.G. Stockner. 1985. Responses of sockeye salmon (*Oncorhynchus nerka*) to fertilization of British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42: 320-331.

Jeffries, D.S. 1991. Southeastern Canada: An overview of the effect of acidic deposition on aquatic resources, p. 273-289. *In* D.F. Charles [ed.] Acidic deposition and aquatic ecosystems, Springer-Verlag, New York, N.Y.

Jeffries, D.S., D.L. Wales, J.R.M. Kelso and R.A. Lindhurst. 1986. Regional chemical characteristics of lakes in North America: Part I - Eastern Canada. Water, Air and Soil Poll. 31: 551-567.

Johnston, N.T., C.J. Perrin, P.A. Slaney and B.R. Ward. 1990. Increased juvenile salmonid growth by whole river fertilization. Can. J. Fish. Aquat. Sci. 47: 862-872.

Kerekes, J., J.B. Freeman, G. Howell and P. Clifford. 1984. Comparison of the characteristics of an acidic eutrophic and an acidic oligotrophic lake near Halifax, Nova Scotia. Water Poll. Res. J. Can. 19(1): 1-10.

Ketchum, B.H. 1969. Eutrophication of estuaries. *In*: Eutrophication: causes, consequences, correctives, p. 197-209. National Academy Press, Washington.

LeBrasseur, R.J., C.D. McAllister, W.E. Barraclough, O.D. Kennedy, J. Manzer, D. Robinson and K. Stephens. 1978. Enhancement of sockeye salmon (*Oncorhynchus nerka*) by lake fertilization in Great Central Lake, summary report. J. Fish. Res. Board Can. 35: 1580-1596.

McNicol, D.K., B.E. Bendell and R.K. Ross. 1987. Studies of the effects of acidification on aquatic wildlife in Canada: waterfowl and trophic relationships in small lakes in northern Ontario. Occasional Paper No. 62, Canadian Wildlife Service, Ottawa, Ont. 76 p.

Melanson, R.J. and F.G. Payne. 1988. Wetlands habitat management through nutrient enrichment. Occasional Paper No. 1, Nova Scotia Department of Lands and Forests, Kentville, N.S. 115 p.

Payne, F.J. 1985. Notes on high density brood staging areas in Nova Scotia. Unpub. Ms. Nova Scotia Department of Lands and Forests, Kentville, N.S. 6 p.

Payne, F.J., R.J. Melanson and G.R. Boyd. 1984. A summary of a preliminary study in whole lake fertilization. Wildlife Division, N.S. Department of Lands and Forests, Kentville, N.S. 15 p.

Schell, V.A. 1988. Distribution, abundance and biomass of benthic macroinvertebrates relative to pH and nutrients in nine lakes of Nova Scotia. MSc. thesis, Dalhousie University, Halifax, N.S. 129 p.

Schell, V.A. and J.J. Kerekes. 1989. Distribution, abundance and biomass of benthic macroinvertebrates relative to pH and nutrients in eight lakes of Nova Scotia, Canada. Water, Air, and Soil. Poll. 56: 359-374.

Schindler, D.W. 1974. Eutrophication and recovery in experimental lakes: implications for lake management. Science. 184: 897-899.

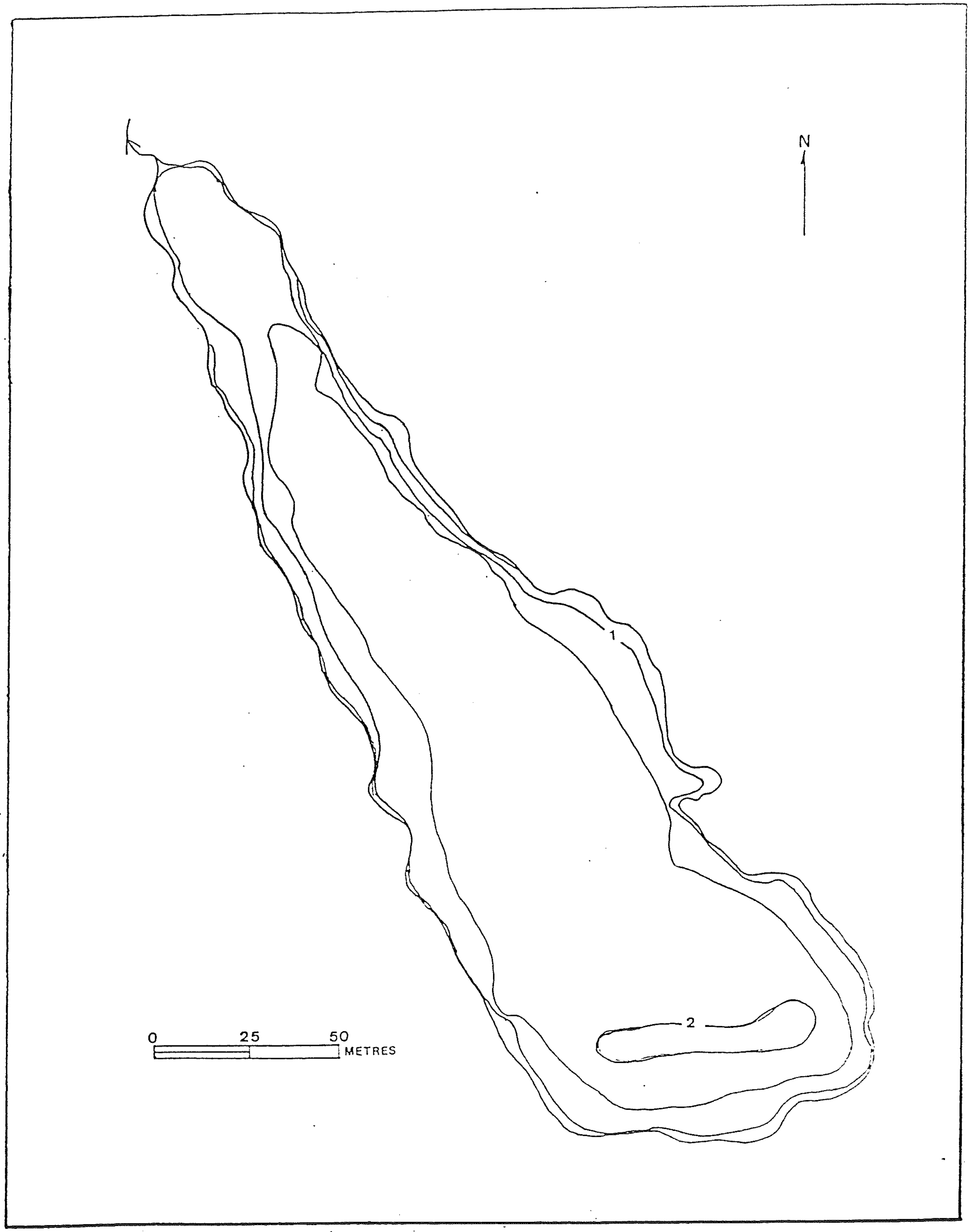
Smith, M.W. 1969. Changes in the environment and biota of a natural lake after fertilization. J. Fish. Res. Bd. Can. 26: 3101-3132.

Vollenweider, R.A. and J.J. Kerekes. 1982. Eutrophication of waters. Monitoring, assessment and control. OECD, Paris. 154 p.

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

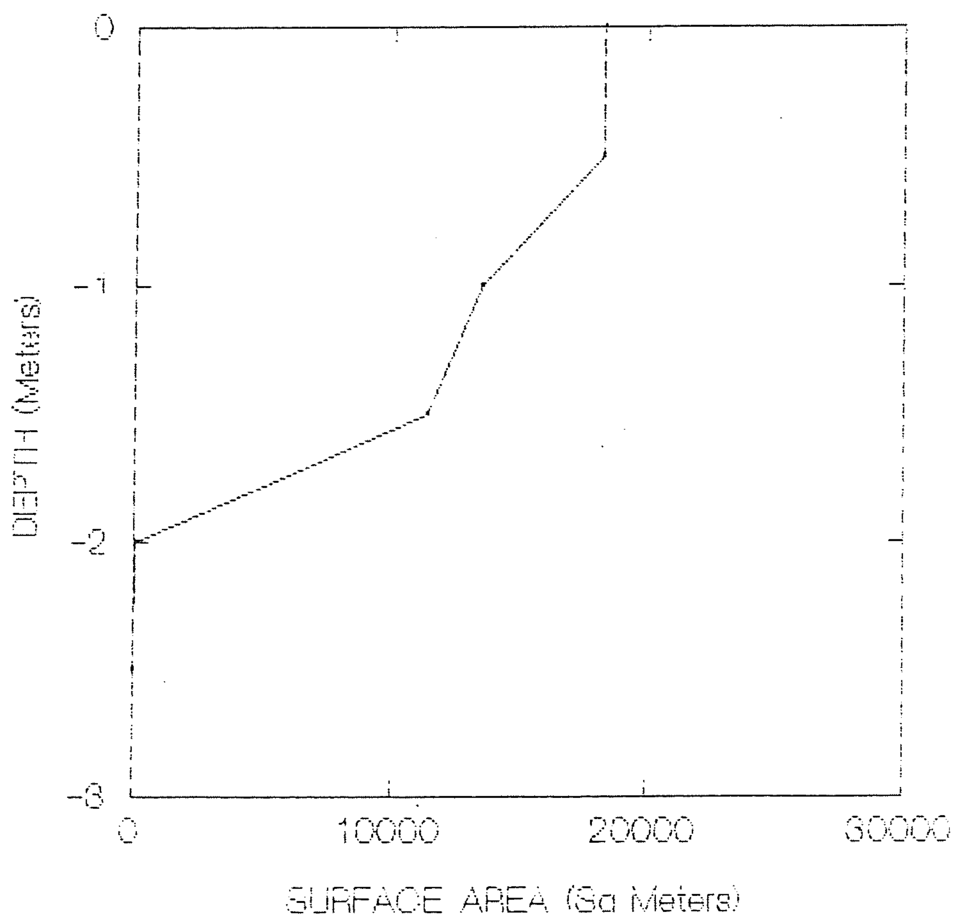
IX. APPENDICES

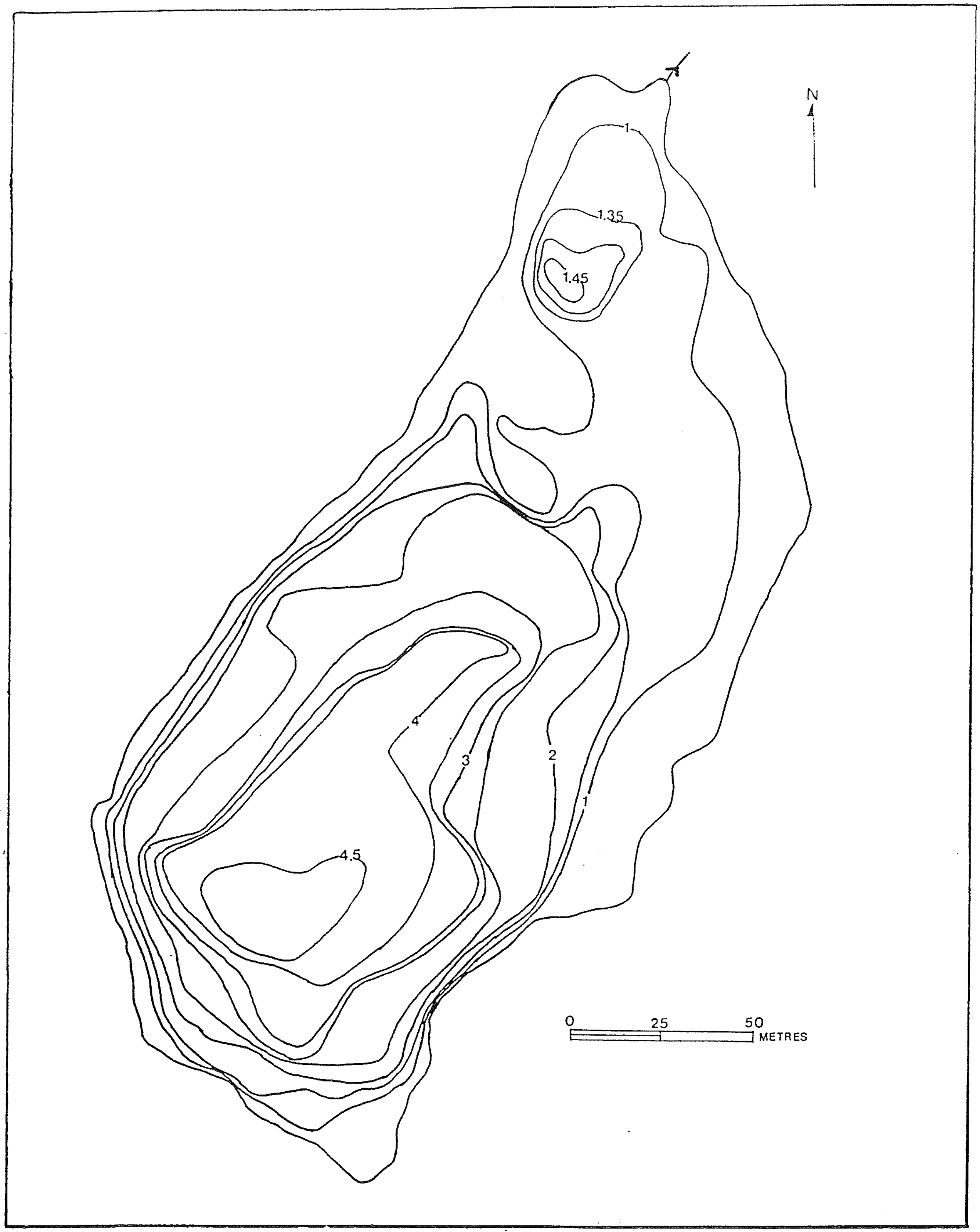
Appendix A. Bathymetric maps and hypsographic curves for each study site



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

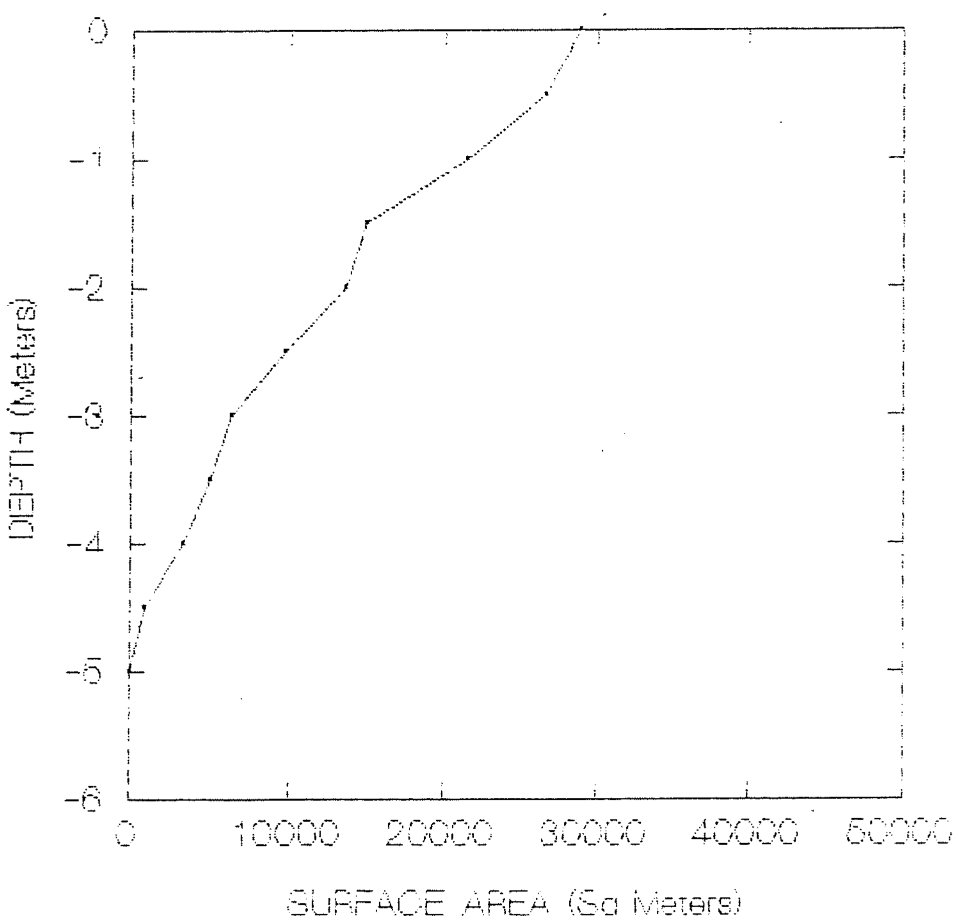
Hypsographic Curve of Beaver Lake

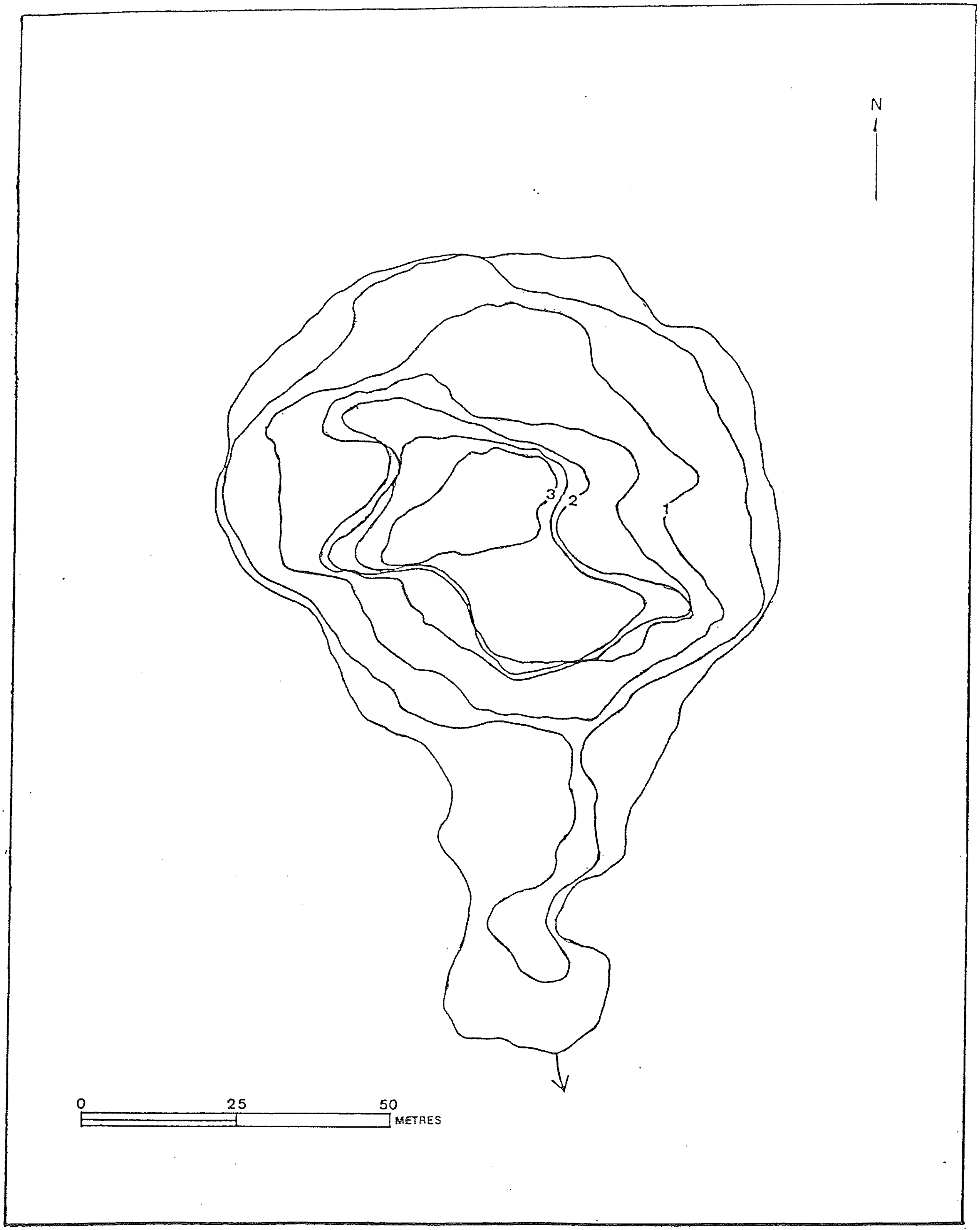




Bathymetric map of Harlow Lake. Depth contours are in 0.5 m intervals.

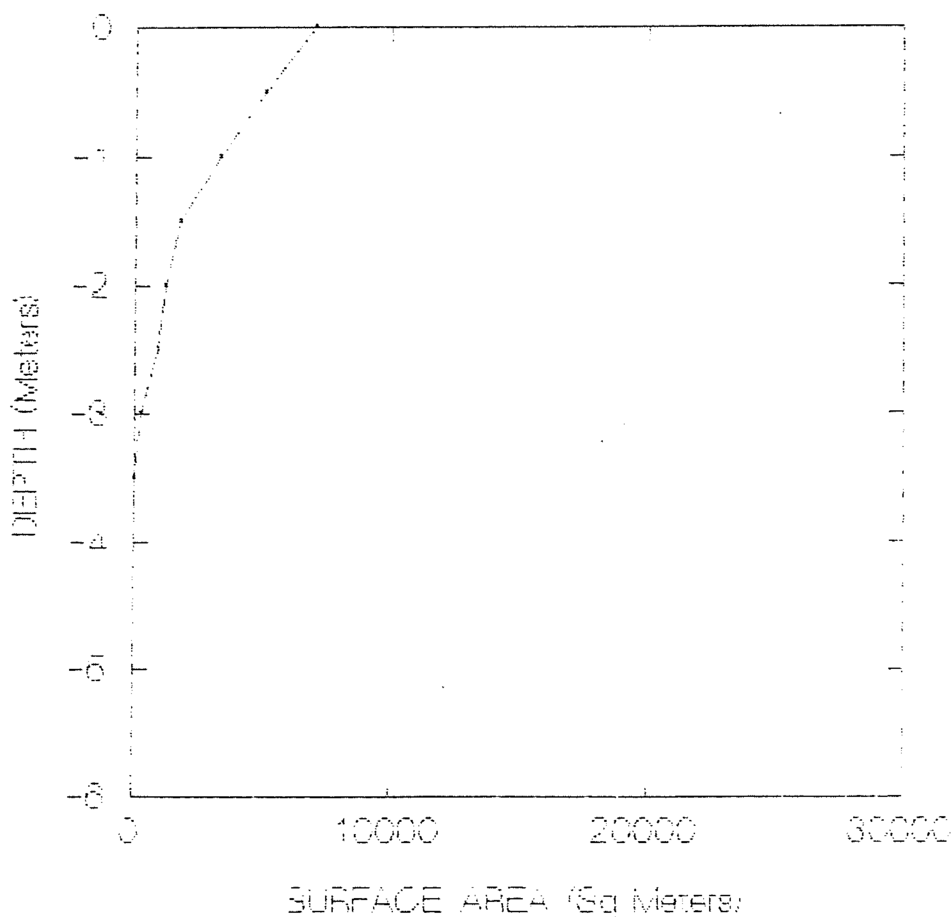
Hypsographic Curve of Harlow Lake

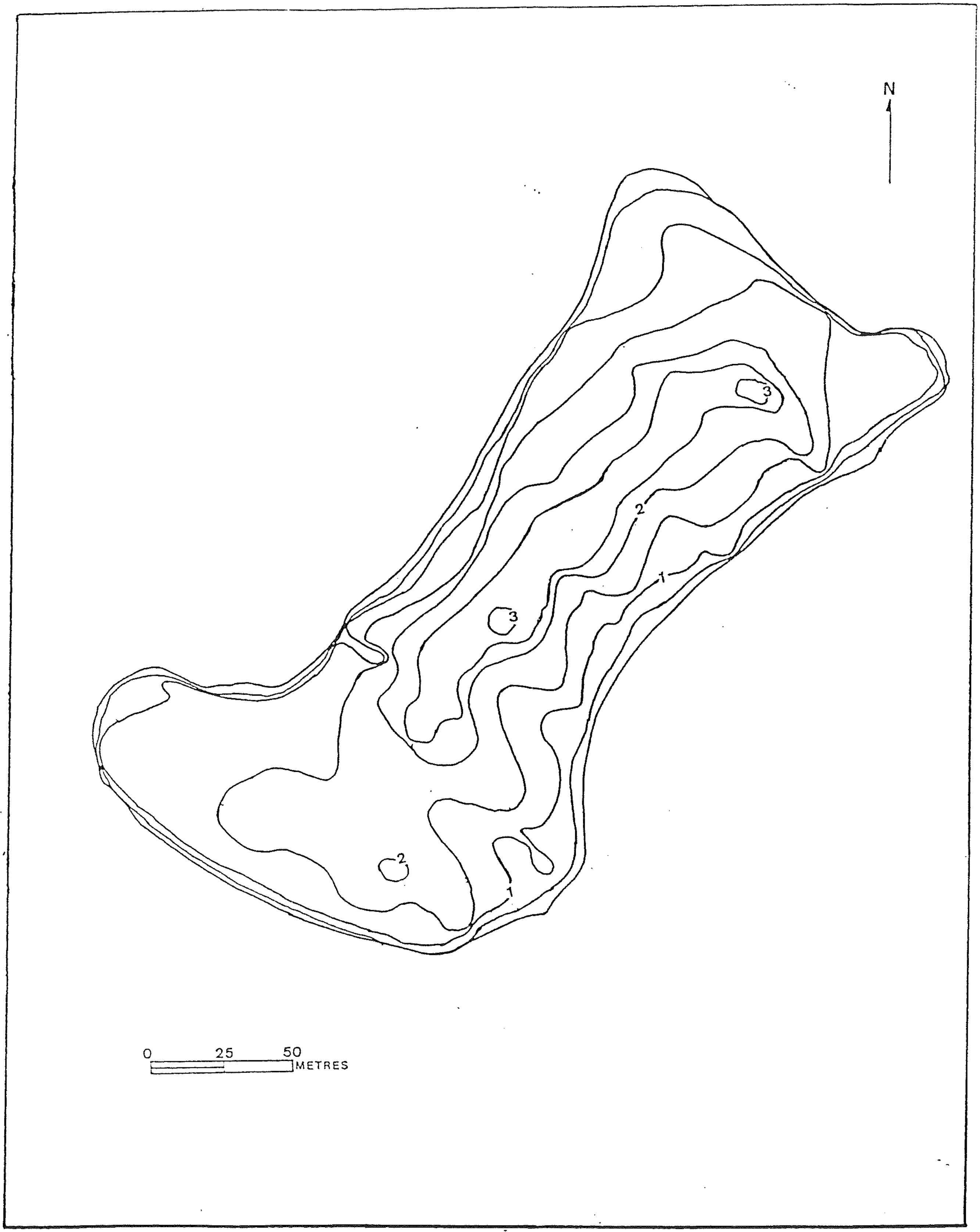




Bathymetric map of Jib Lake. Depth contours are in 0.5 m intervals.

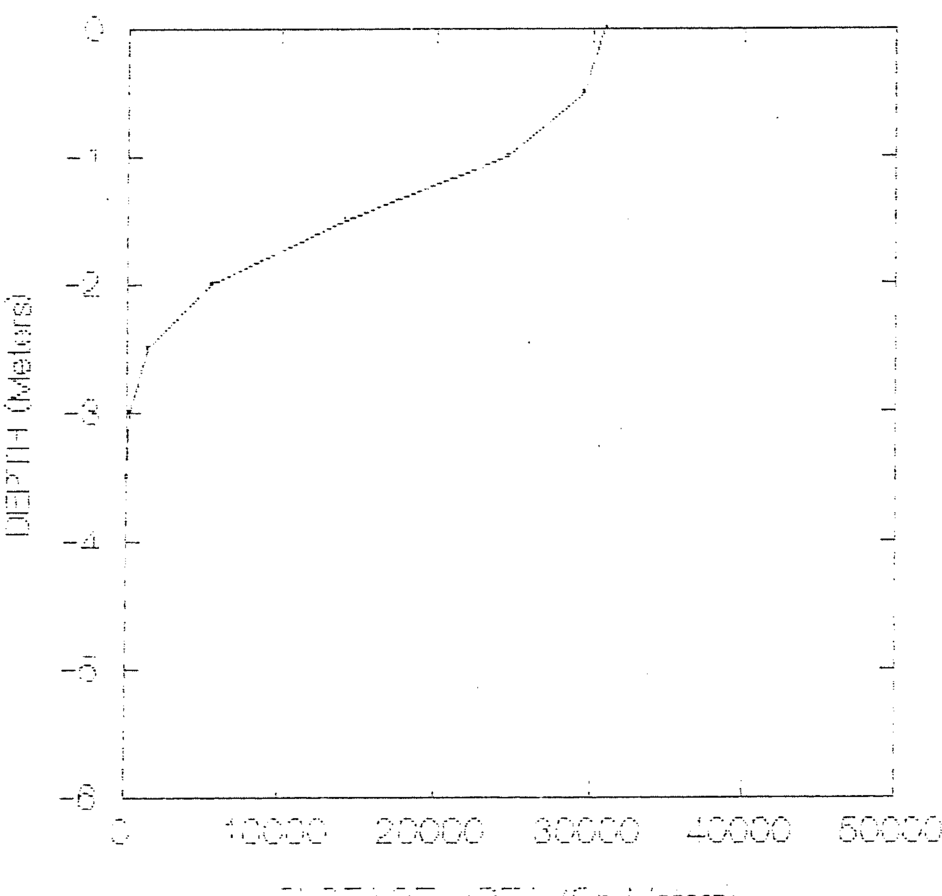
Hypsographic Curve of Jib Lake

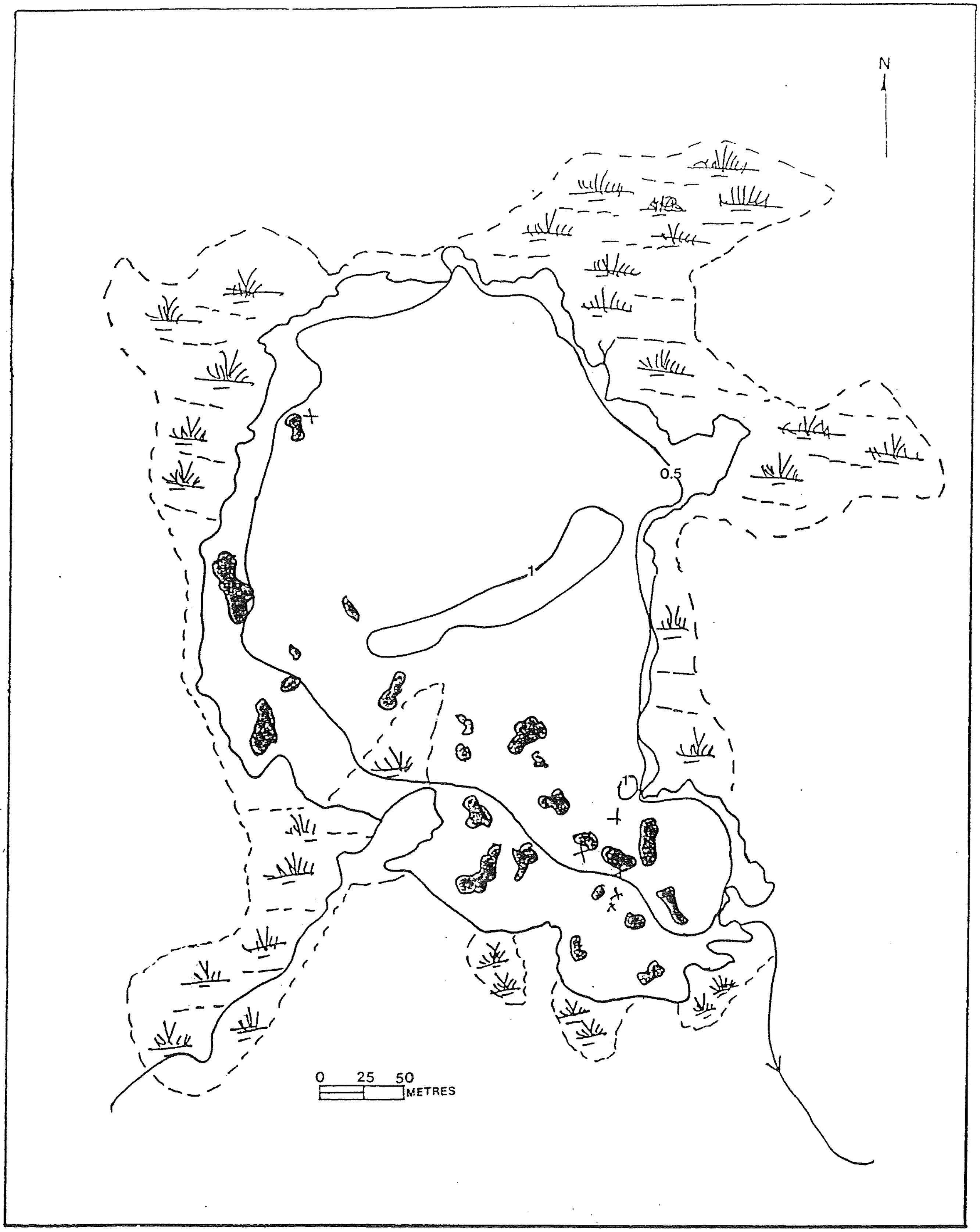




Bathymetric map of Menchon Lake. Depth contours are in 0.5 m intervals.

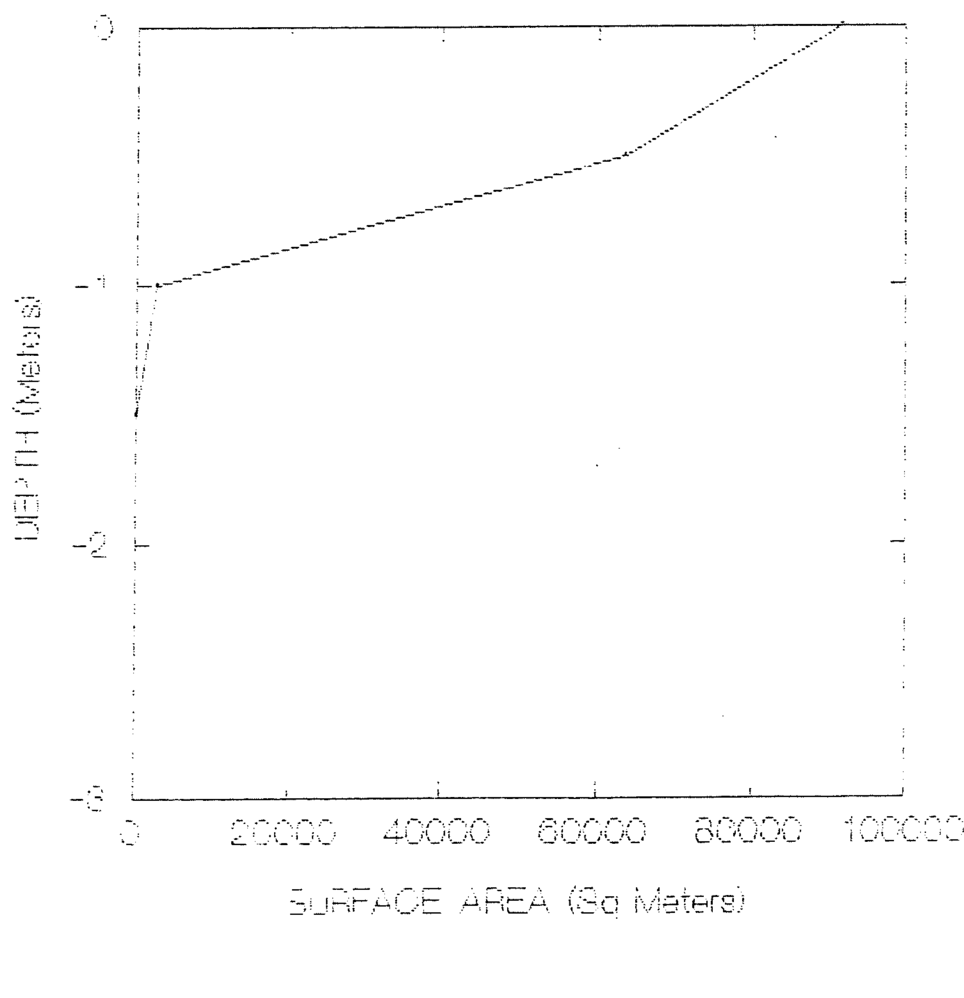
Hypsographic Curve of Menchon Lake

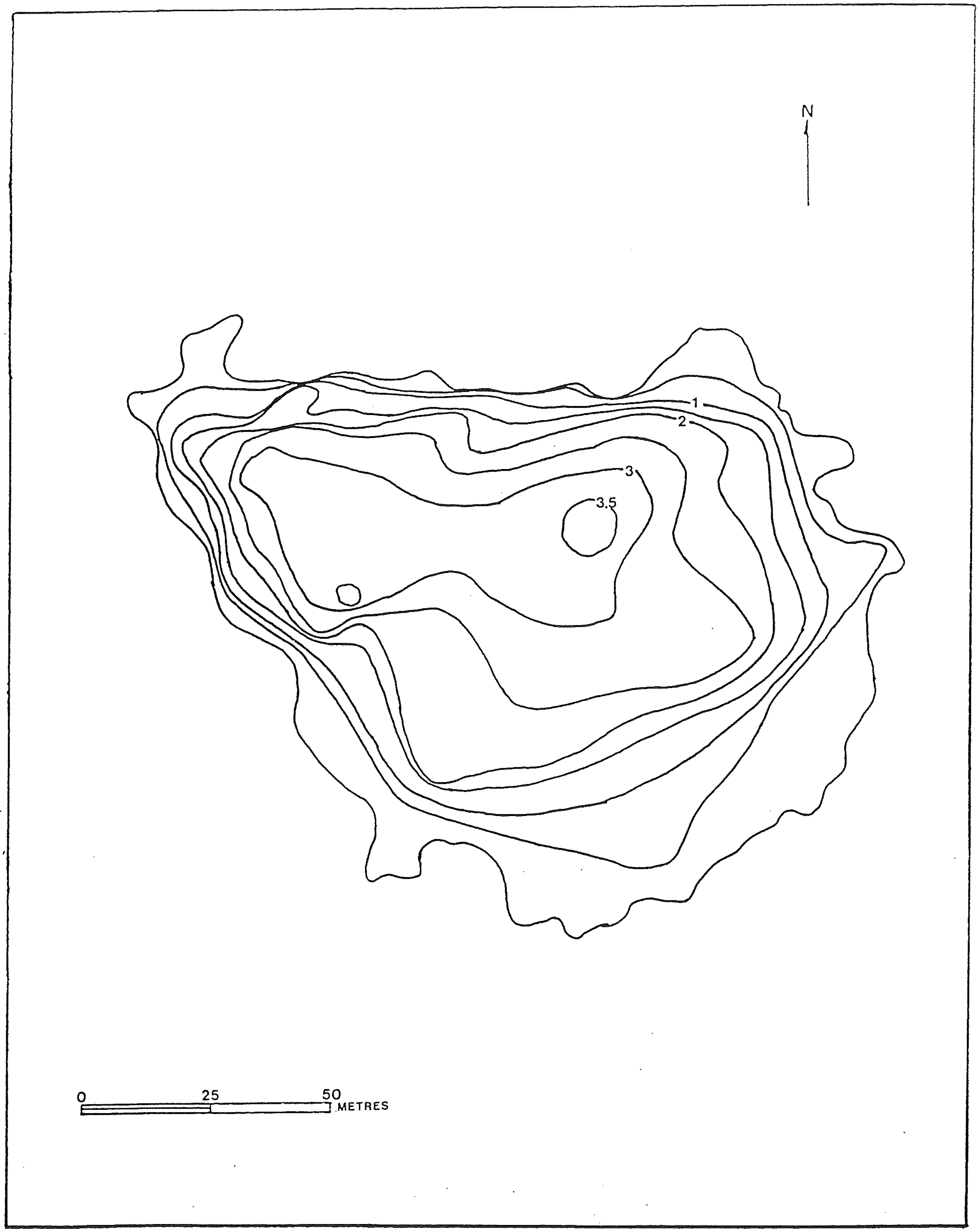




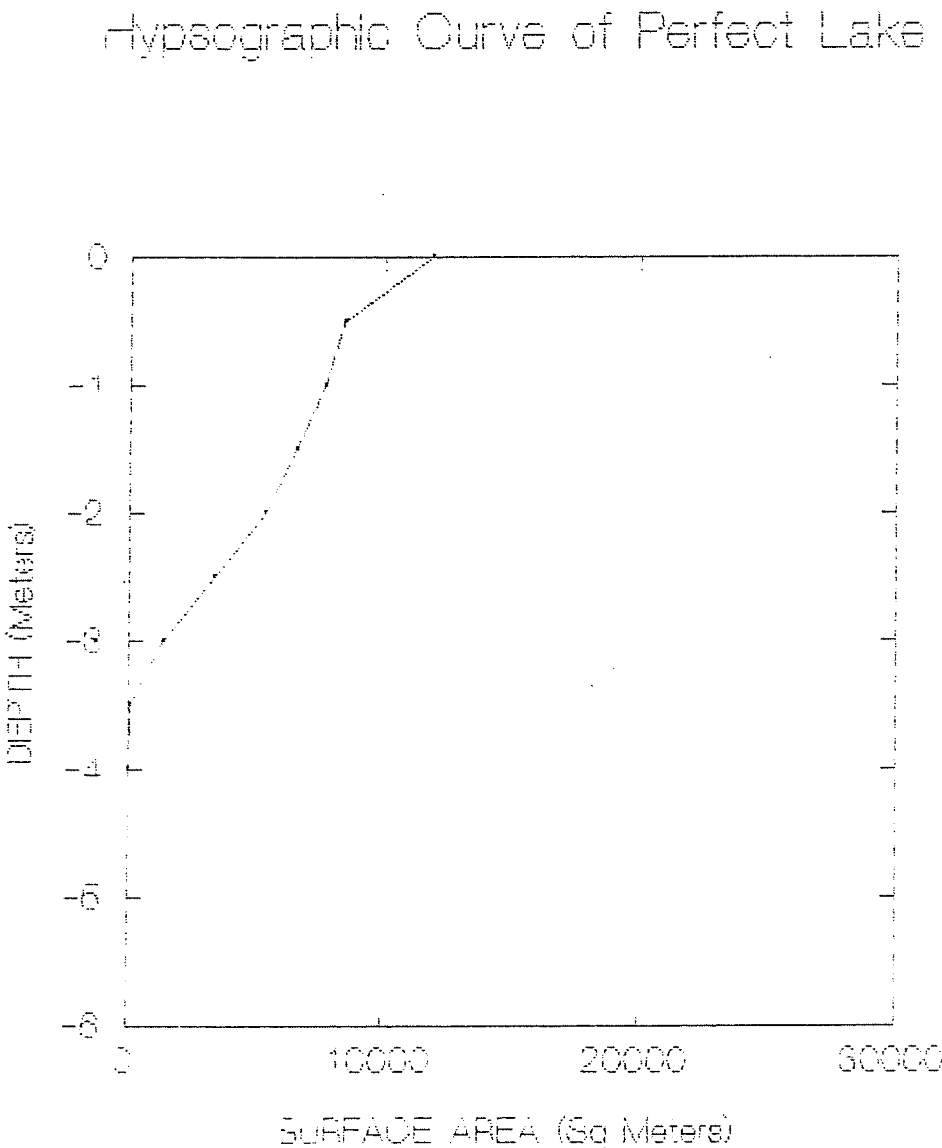
Bathymetric map of Oscar Lake. Depth contours are in 0.5 m intervals.

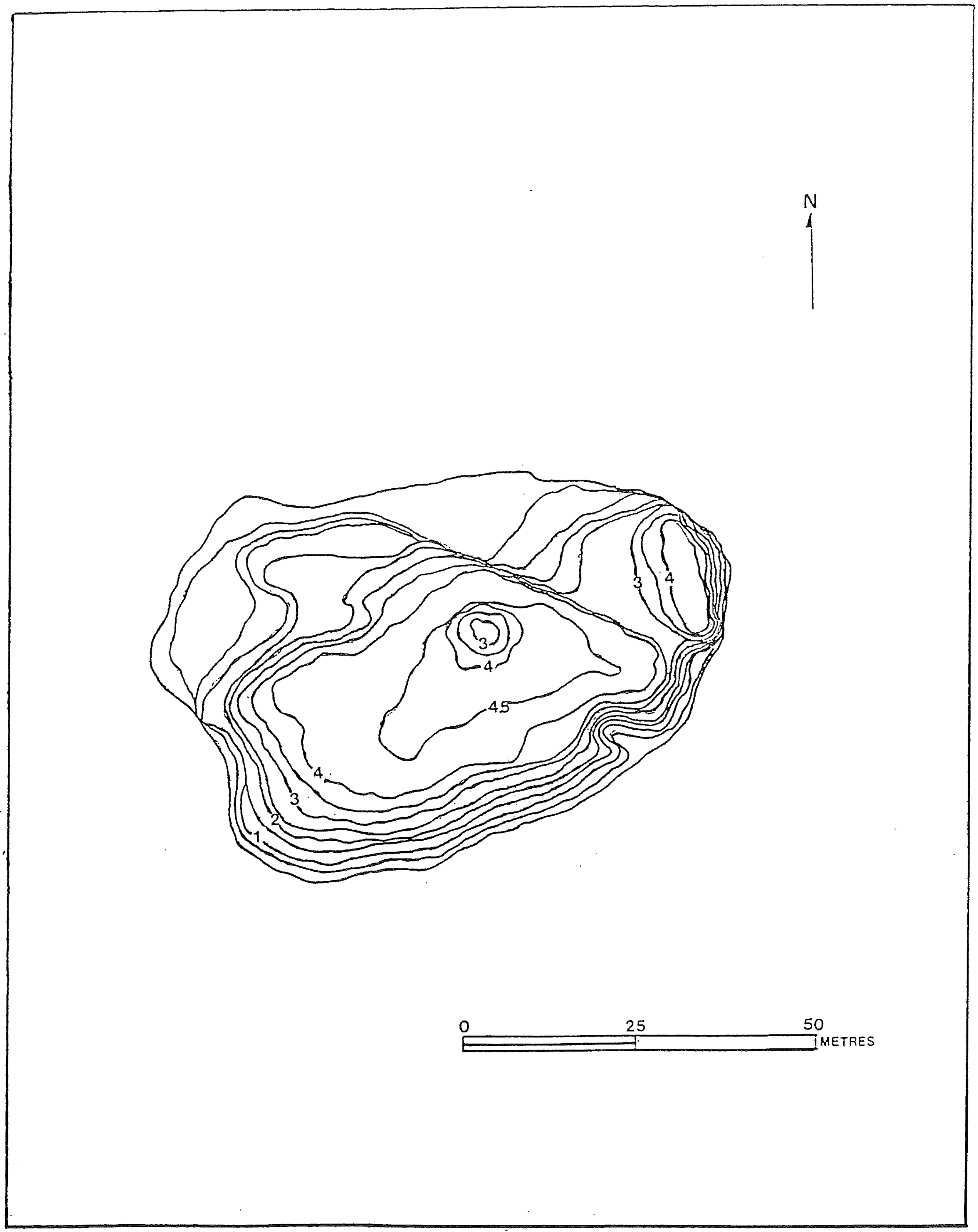
Hyposographic Curve of Oscar Lake



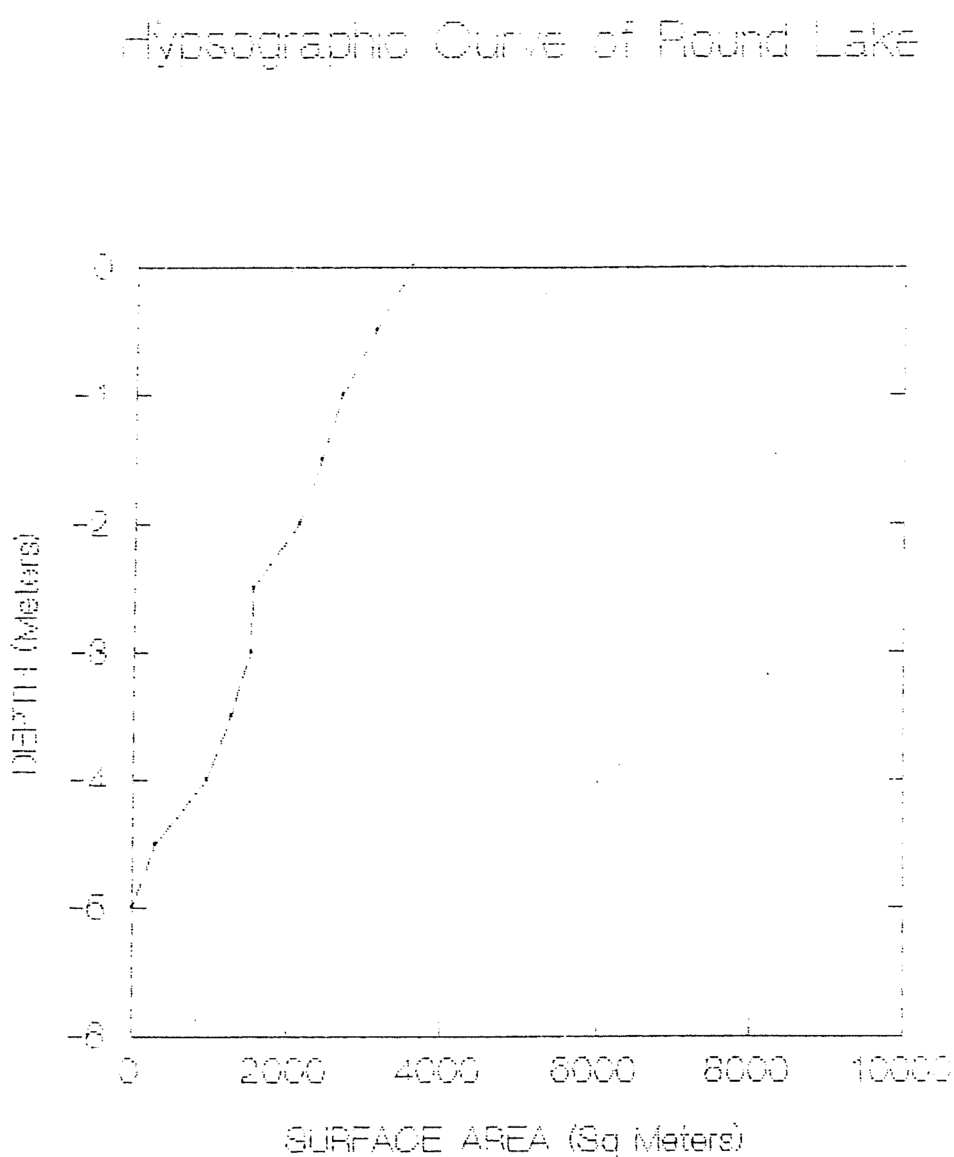


Bathymetric map of Perfect Lake. Depth contours are in 0.5 m intervals.

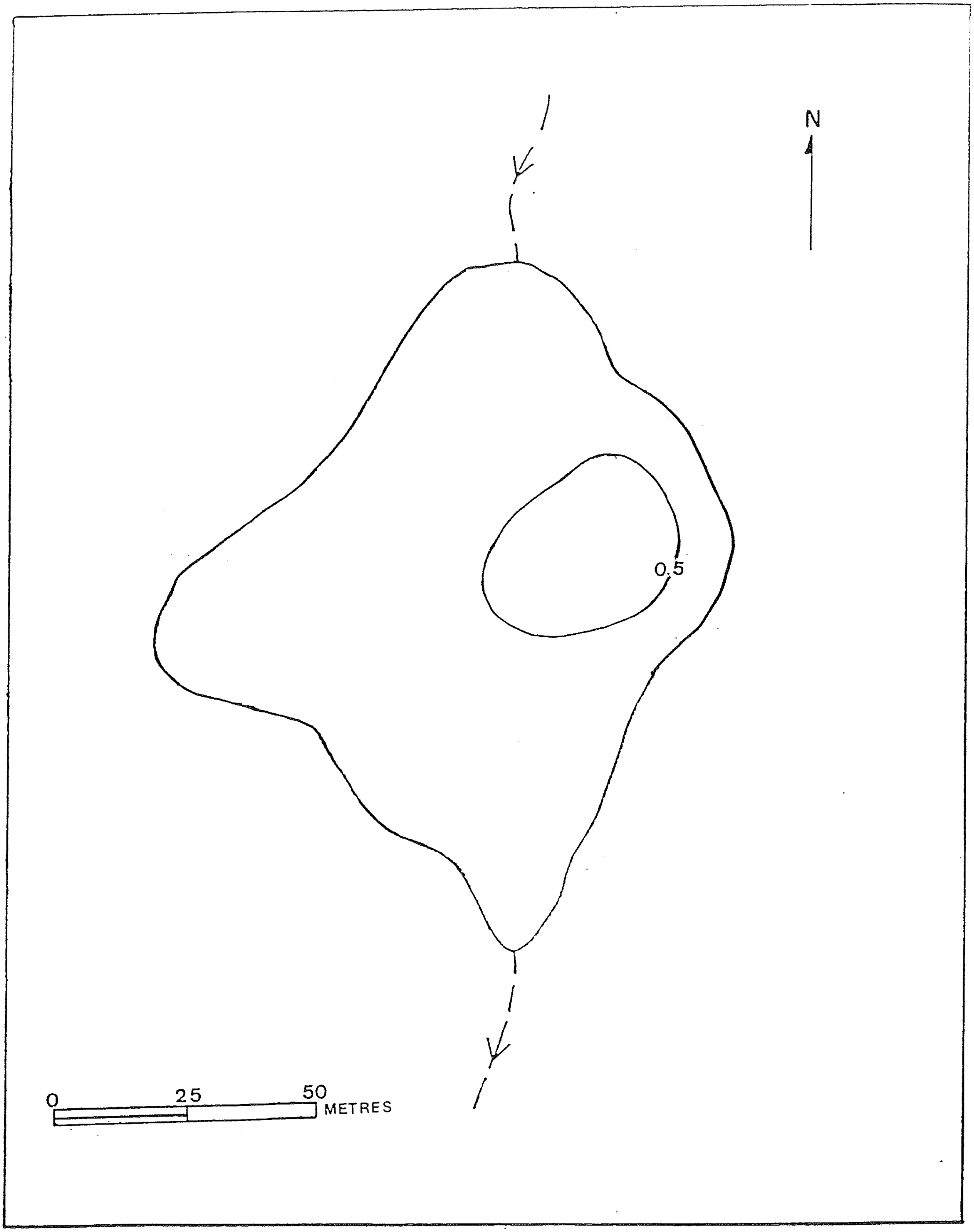

Hypsographic Curve of Perfect Lake
0
-1
-2
-3
-4
-5
-6
DEPTH (Meters)
0
10000
20000
30000
SURFACE AREA (Sq Meters)



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

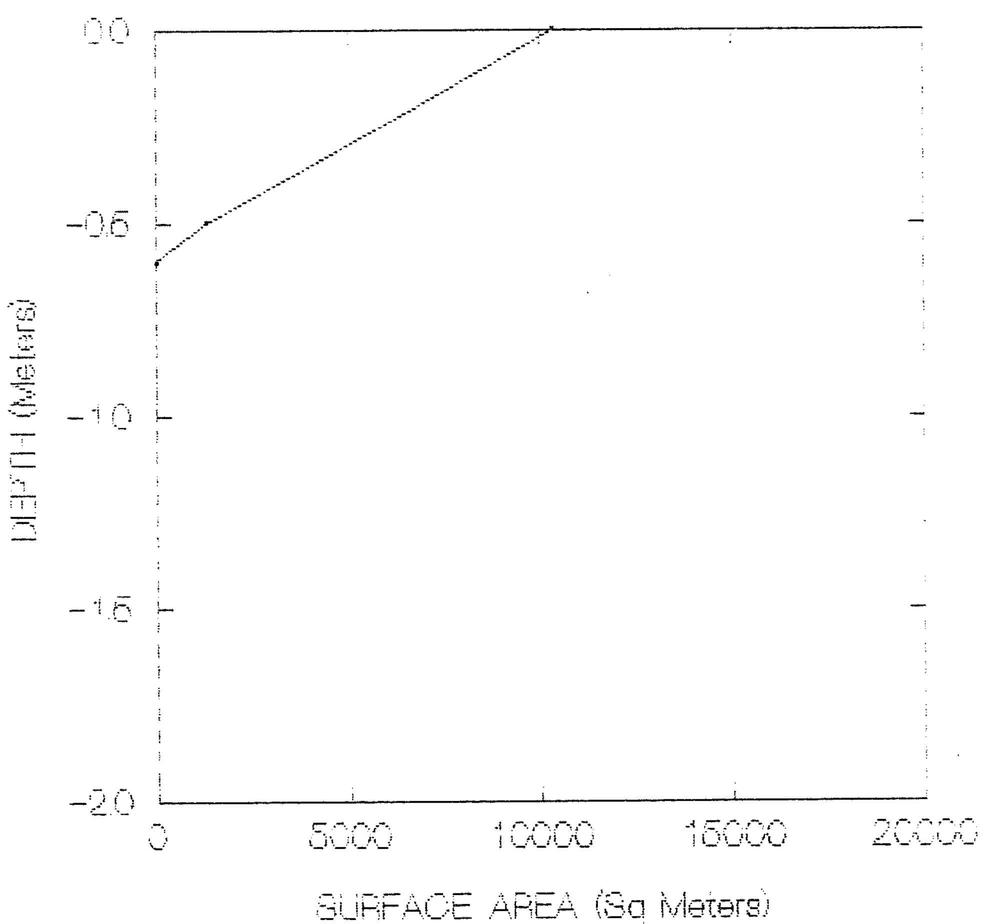


Hypsographic Curve of Round Lake
0
-1
-2
-3
-4
-5
-6
DEPTH (Meters)
0
2000
4000
6000
8000
10000
SURFACE AREA (Sq Meters)



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

Hypsographic Curve of Stump Lake



Appendix B. Field and laboratory procedures

I. FIELD PROCEDURES

1. **Water Level:** Each site was provided with a marked stake. Changes in water level were recorded as the difference between present water level and the water level at the time the stake was installed.

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

3. **Secchi Disk Depth:** A 30 cm dia Secchi disk was used. Secchi disk depth was calculated as the average of the depth at which the Secchi disk disappeared and reappeared as it was lowered into the water and then retrieved. All readings were made from the shady side of the boat.

4. **Conductivity:** Conductivity depth-profiles were measured at half meter intervals using a YSI-SCT meter.

5. **Dissolved Oxygen:** Dissolved oxygen was measured in surface water samples at all sites and in bottom water samples at those sites exhibiting thermal stratification. Water samples were collected using a 2 litre Van Dorn water sampler and transferred to 300 ml BOD bottles. Samples were immediately fixed and upon return to the field laboratory were analyzed using the Winkler procedure.

6. **CWS Water Chemistry Samples:** Water samples for analysis by CWS were collected from the surface in acid washed 1 litre polypropylene bottles and stored refrigerated.

7. **ACER Water Chemistry Samples:** Water samples for analysis by ACER were collected from the surface in acid washed 1 litre polyethylene bottles. At the field laboratory 50 ml was removed and used to measure pH using a Fisher model 910 pH meter. The remaining sample was stored refrigerated until analysis for phosphorus at the ACER laboratory.

8. **Sediment Phosphorus:** During 1991 samples for sediment phosphorus analysis were collected with an Ekman dredge. The upper surface (to ca. 3 cm depth) of the sample was subsampled, placed in a plastic bag and stored frozen until analysis. During 1992, samples

were obtained using a 5 cm dia plastic coring device and the subsample consisted of the upper 3 cm of the core sample.

9. **Phytoplankton Chlorophyll *a*:** A 1 litre water sample was collected from the surface. At the field laboratory the sample was filtered through a Watman GF/C filter under low vacuum. The samples were stored frozen in petri dishes until further analysis at the ACER laboratory.

10. **Periphyton Growth:** Periphyton growth was monitored by determing growth (as chlorophyll *a*) on glass microscope slides contained in trays that were set to float ca. 10 cm below the water's surface. The slides were left in place for four weeks at which time they were collected and stored in a dessicator for later analysis of chlorophyll *a* at ACER.

11. **Zooplankton:** Zooplankton samples were collected by pouring 100 litres of surface water through a 200 μm mesh plankton net. Samples were stored preserved in 10% formalin.

12. **Emergent Insects:** One insect emergence trap was located in the littoral zone at each site. The trap was constructed of fiberglass door screening and was cone shaped and had a 50 cm dia bottom end. The apex lead into an open ended bottle having a plastic funnel attached to the lower end. The bottle was filled with 10 ml of conc formalin. During each sampling the trapped insects were transferred to a collection jar and preserved in Kahle's solution.

13. **Benthic Invertebrates:** Benthic invertebrate samples were collected using a sweep net. Each sample consisted of three figure-eight sweeps. Samples were immediately preserved in 70% alcohol.

14. **Minnow Trap Collections:** Small fishes, amphibians and larger invertebrates were collected in minnow traps set within the littoral zone of each site. The organisms collected were enumerated and identified in the field.

II. LABORATORY PROCEDURES

1. **Phytoplankton Chlorophyll *a*:** Phytoplankton chlorophyll *a* was extracted by placing the filters in 15 ml of 90% acetone for 24 hr. Extraction was carried out under refrigeration and in the dark. The concentration of chlorophyll *a* was measured spectrophotometrically using a 5 cm pathlength cuvette. Absorption measurements were made at 665 and 750 µm before and after acidification with 0.1 ml of 10% HCl. Chlorophyll *a* concentration was calculated using the equations presented by Lorenzen (1967).

2. **Periphyton Chlorophyll *a*:** Periphyton chlorophyll *a* was extracted and measured in the same manner as for phytoplankton using scrapings from the microscope slides.

3. **Water Column Phosphorus:** Total and dissolved phosphorus was measured using the calorimetric ammonium molybdate method (Murphy and Riley 1962). Digestions for total phosphorus were carried out using potassium persulfate acid and autoclaving at 15 psi and 120 C for 30 min.

4. **Sediment Phosphorus:** Sediment phosphorus was determined according to the procedure described in the analytical methods manual of the Inlands Waters Directorate of Environment Canada (1979).

5. **Zooplankton Numbers:** Zooplankton samples were enumerated using a stero microscope. If required, 2 to 10 ml subsamples were drawn using a Hansen-Stempel volumetric pipette.

6. **Emergent Insects:** Emergent insects were enumerated using a stereo microscope.

7. **Benthic Invertebrates:** Benthic invertebrate samples were sorted and enumerated using a stero microscope.

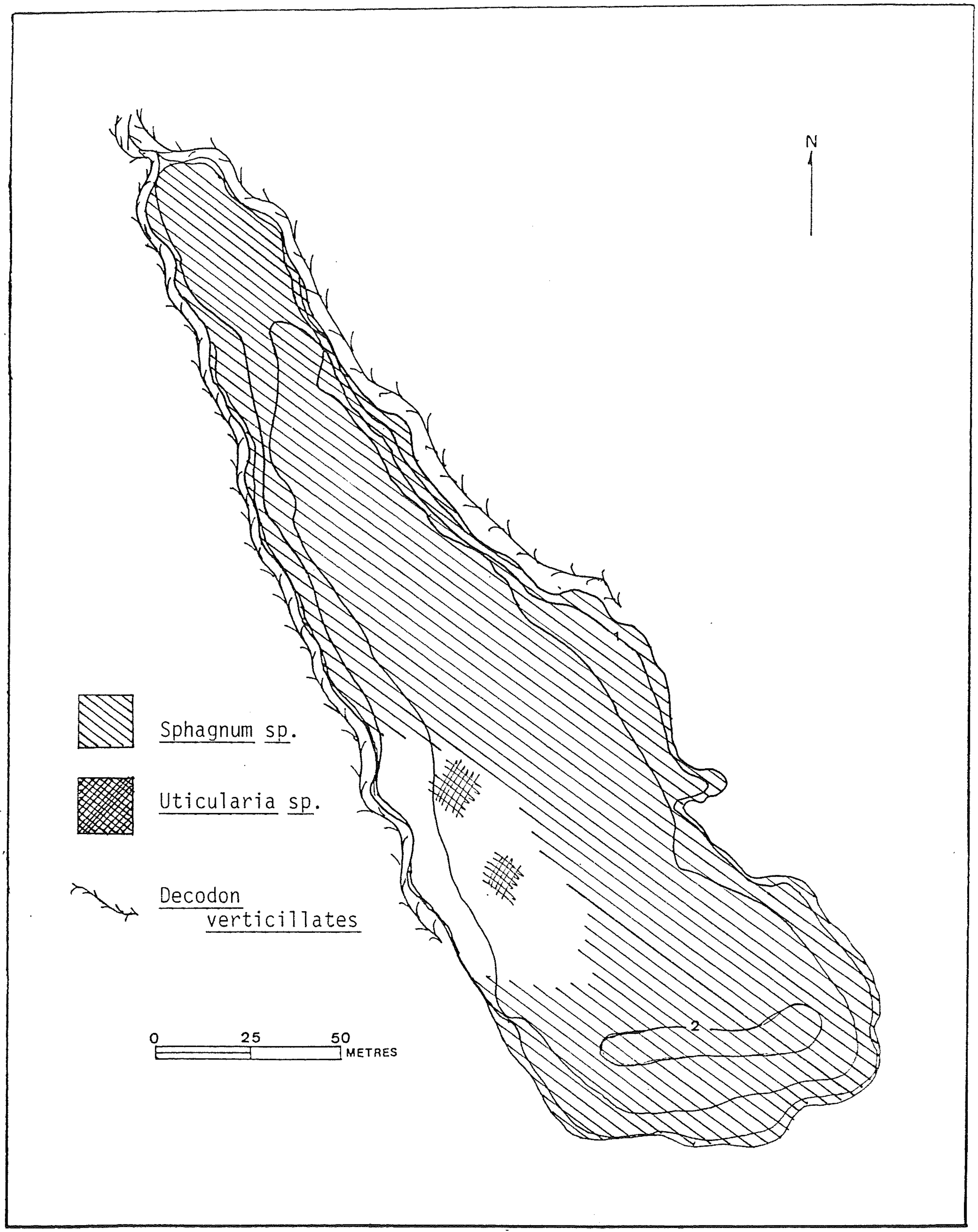
REFERENCES:

Environment Canada, Inlands Water Directorate, Water Quality Branch. 1975. Analytical methods manual.

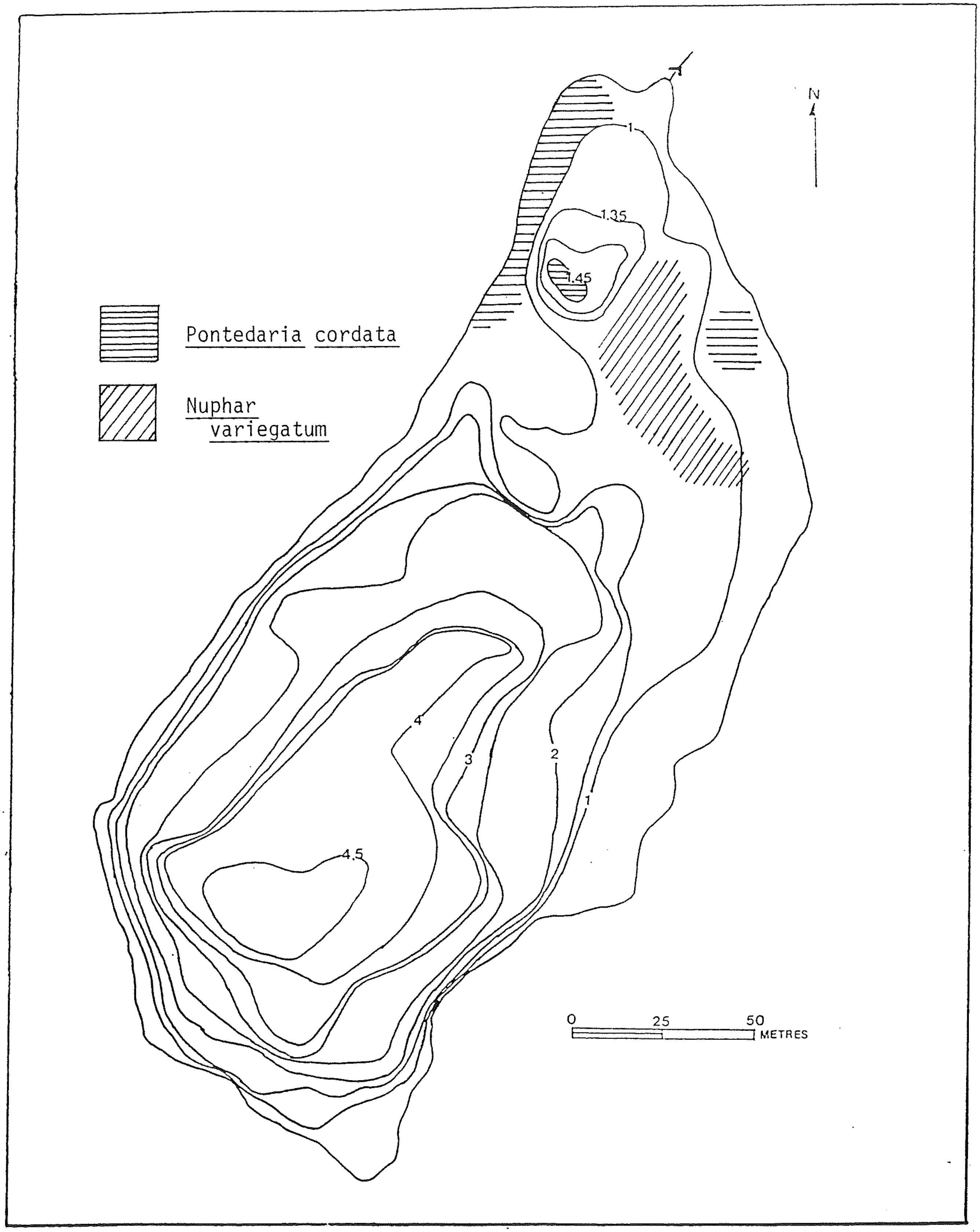
Lorenzen, C.J. 1967. Determination of chlorophyll and phaeo-pigments: spectrophotometric equations. Limnol. Oceanogr. 12: 343-346.

Murphy, J. and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chem. Acta. 27: 31-36.

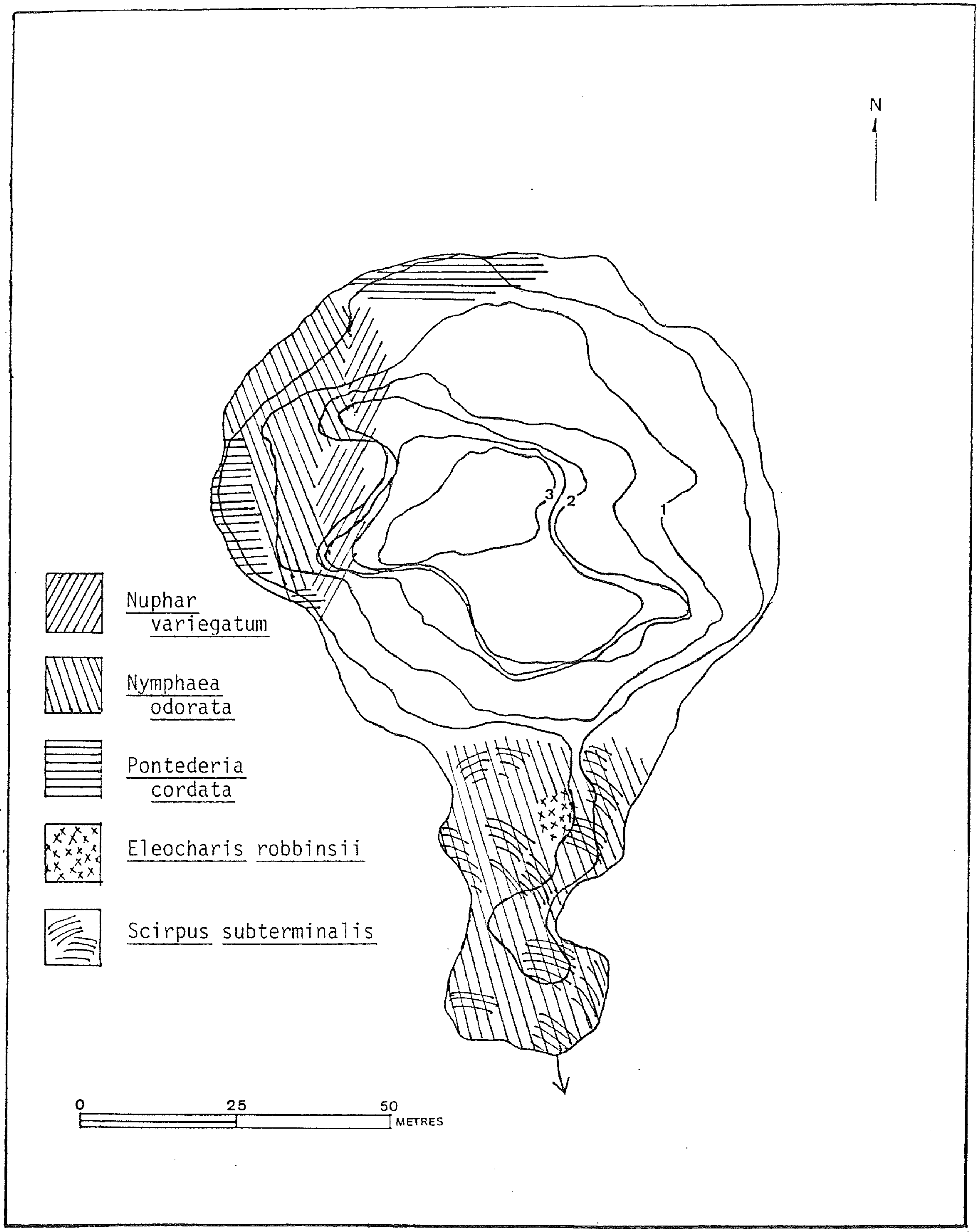
Appendix C. Distribution and species composition of major macrophytes



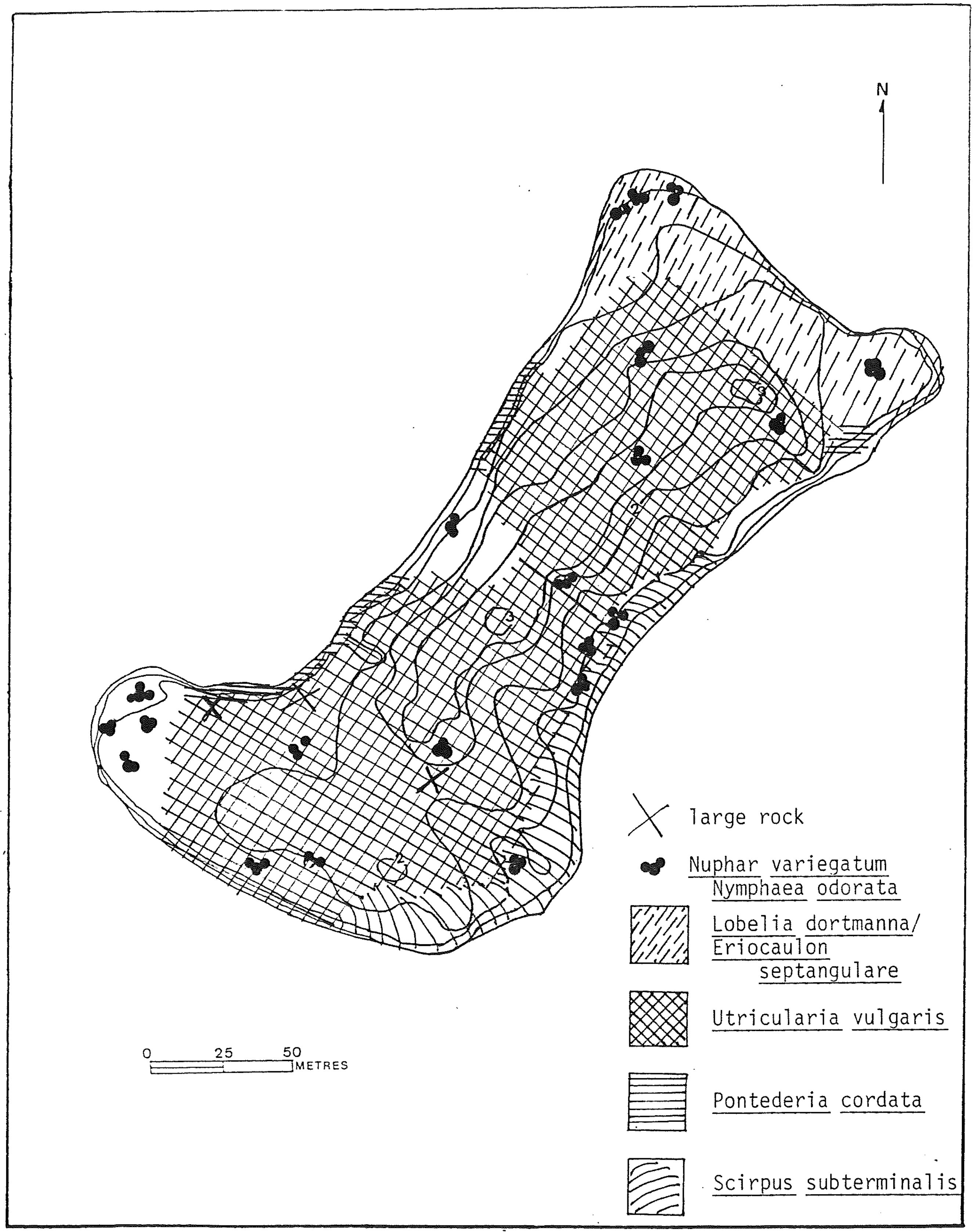
The distribution of the dominant submerged and emergent macrophytes in Beaver Lake.



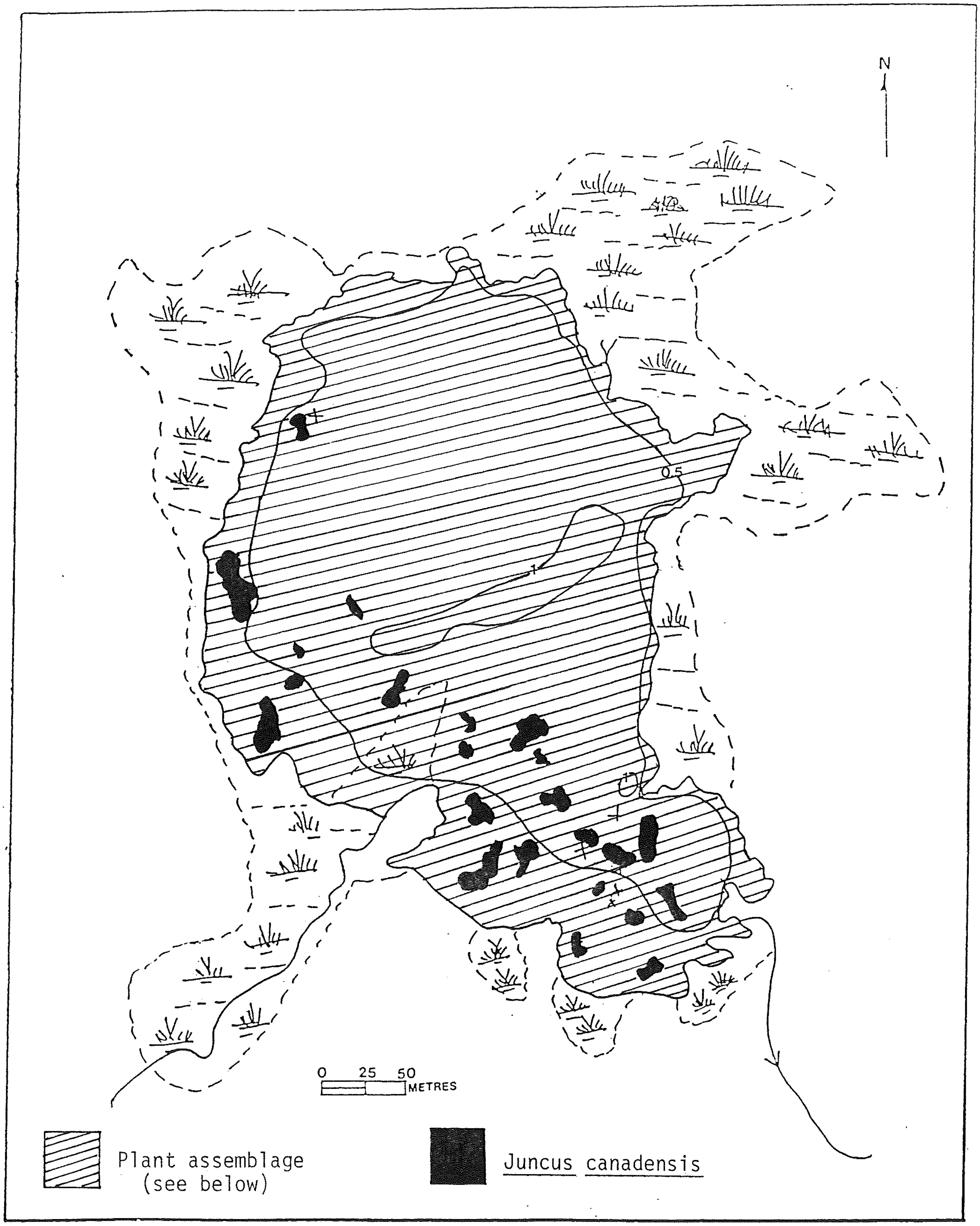
The distribution of the dominant submerged and emergent macrophytes in Harlow Lake.



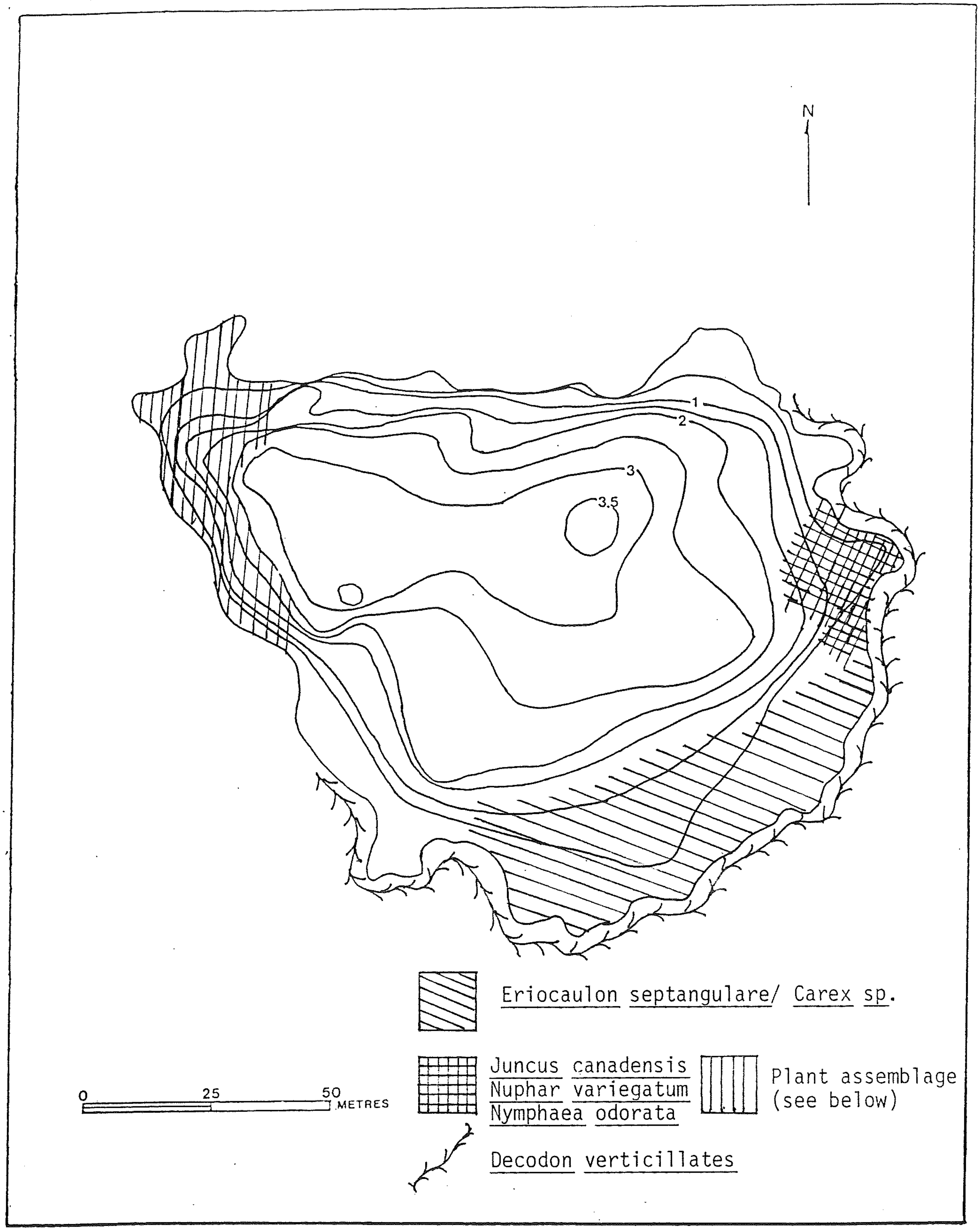
The distribution of the dominant submerged and emergent macrophytes in Jib Lake.



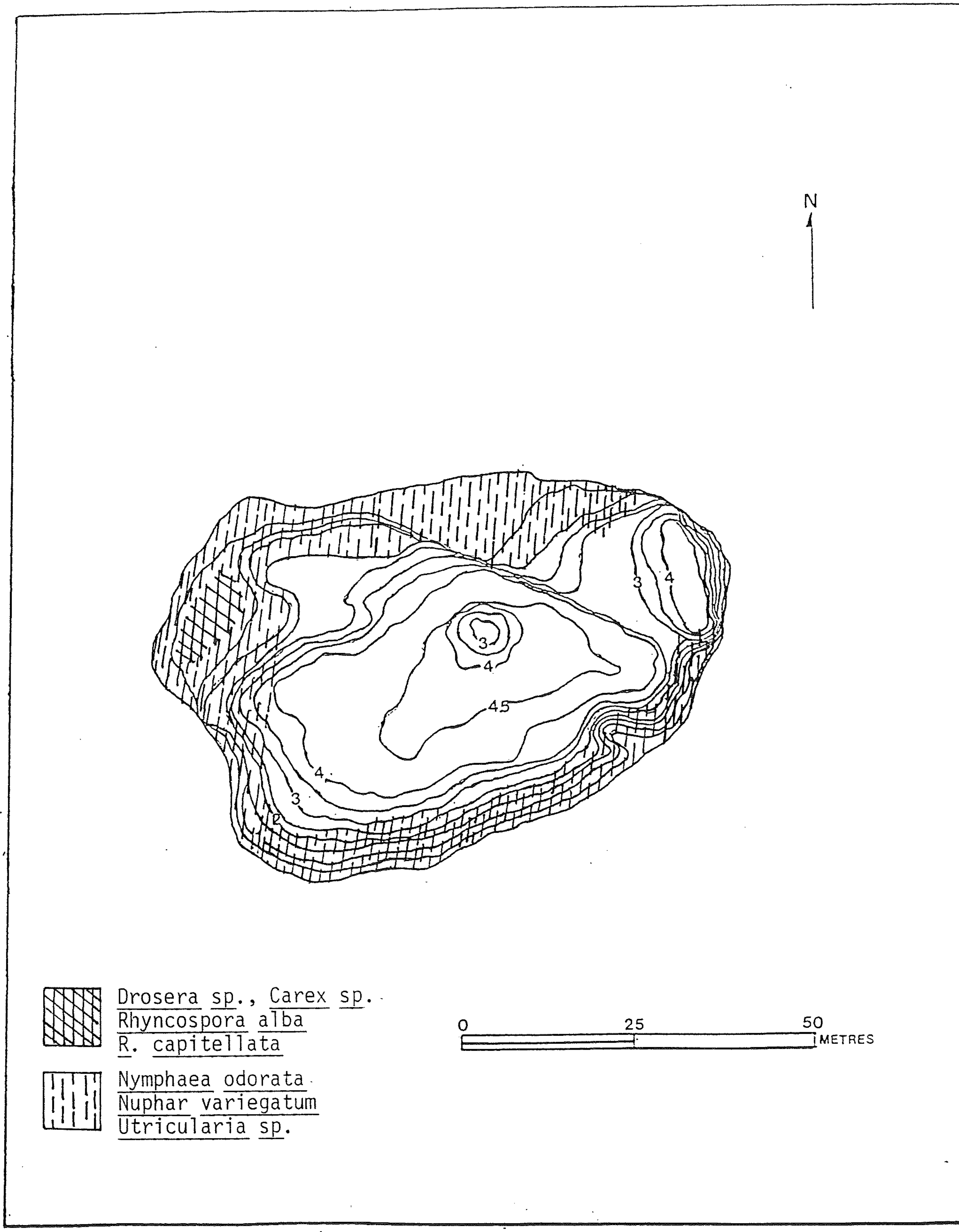
· The distribution of the dominant submerged and emergent macrophytes in Menchon Lake.



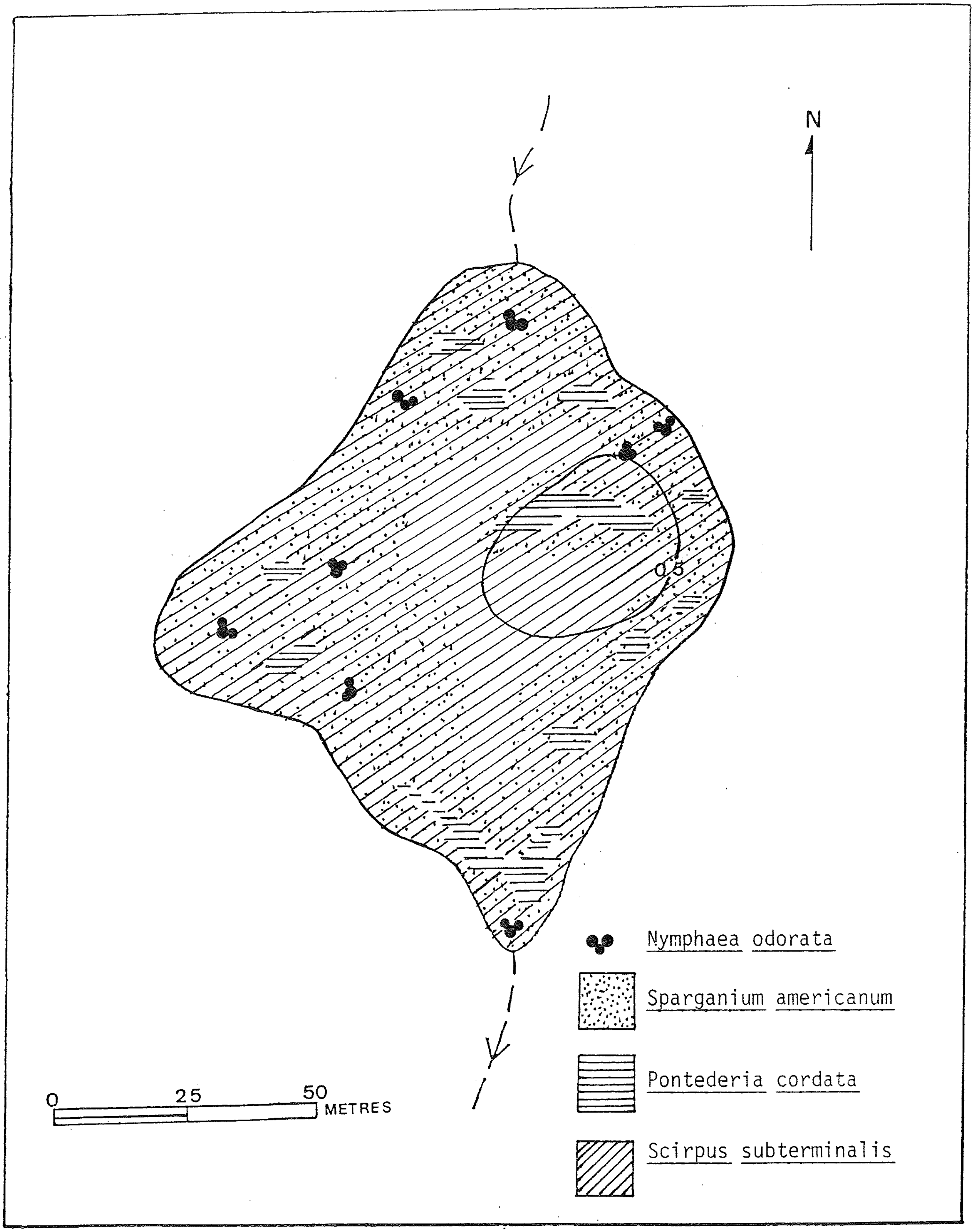
The distribution of the dominant submerged and emergent macrophytes In Oscar Lake. Plant assemblage: Juncus militaris, Brasenia schreberi, Nymphaea odorata, Nuphar variegatum, and Scirpus subterminalis.



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

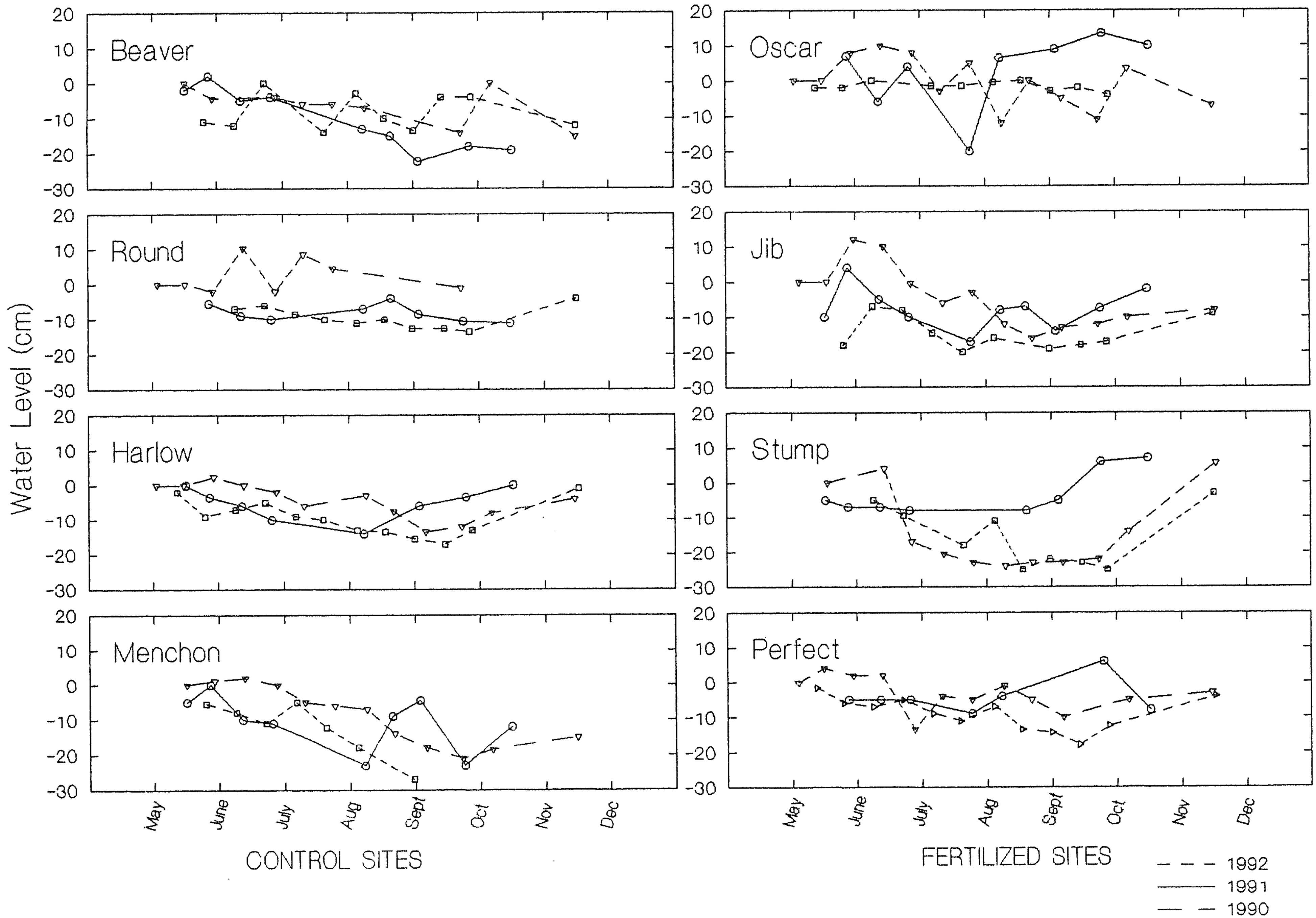


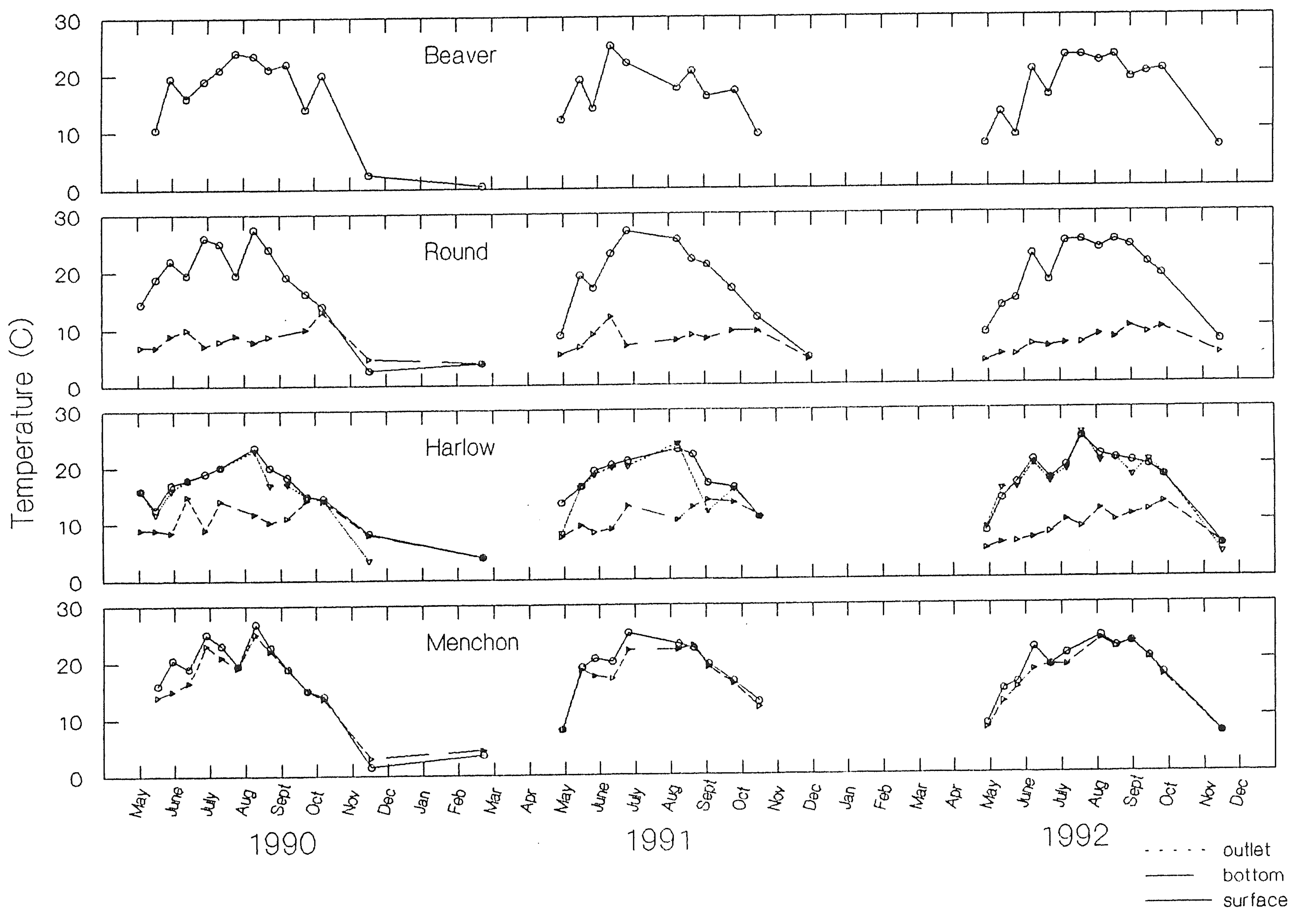
The distribution of the dominant submerged and emergent macrophytes in Round Lake.

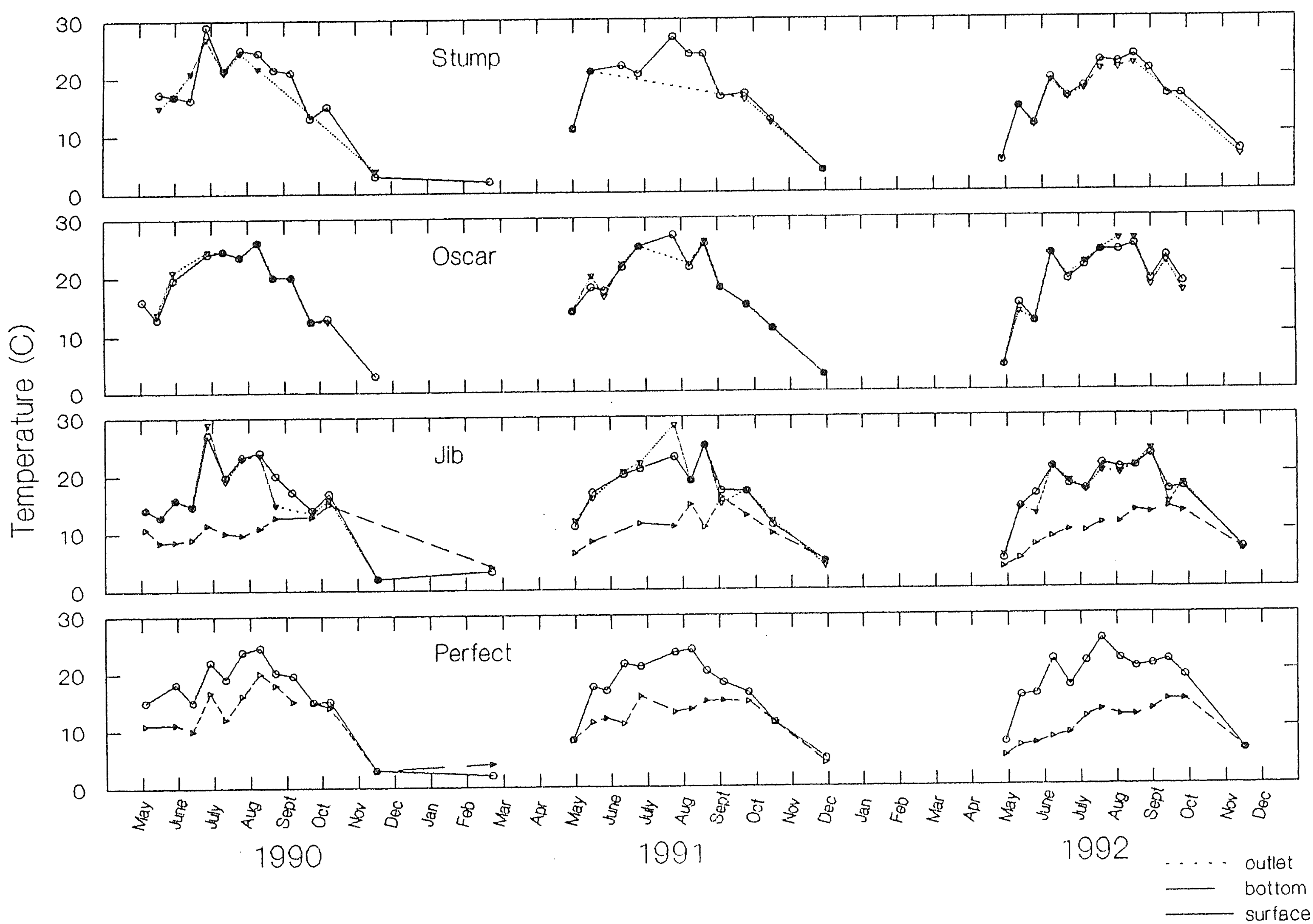


The distribution of the dominant submerged and emergent macrophytes in Stump Lake. Note: tree stumps are abundant throughout the lake.

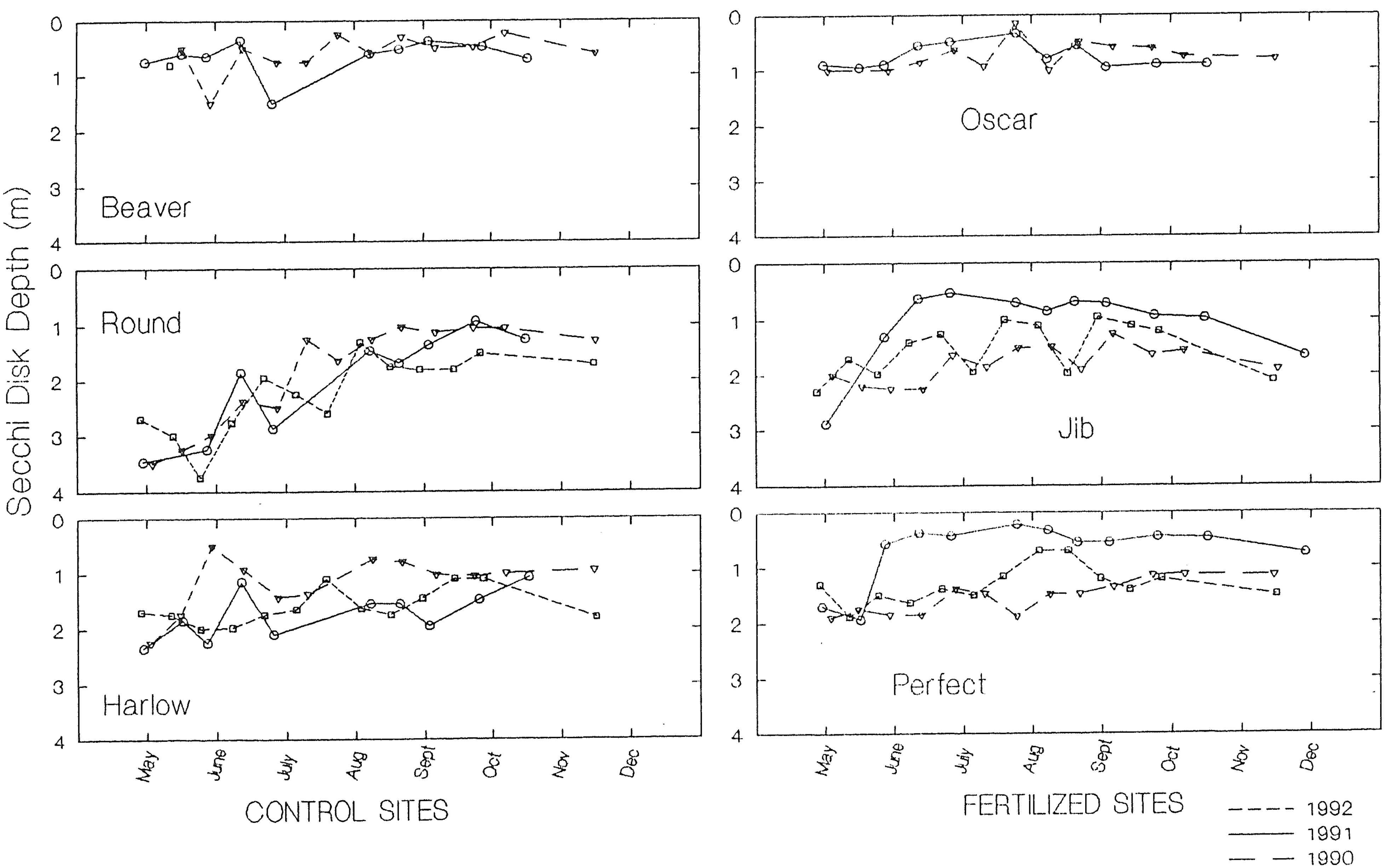
Appendix D. Graphical summaries of physical data

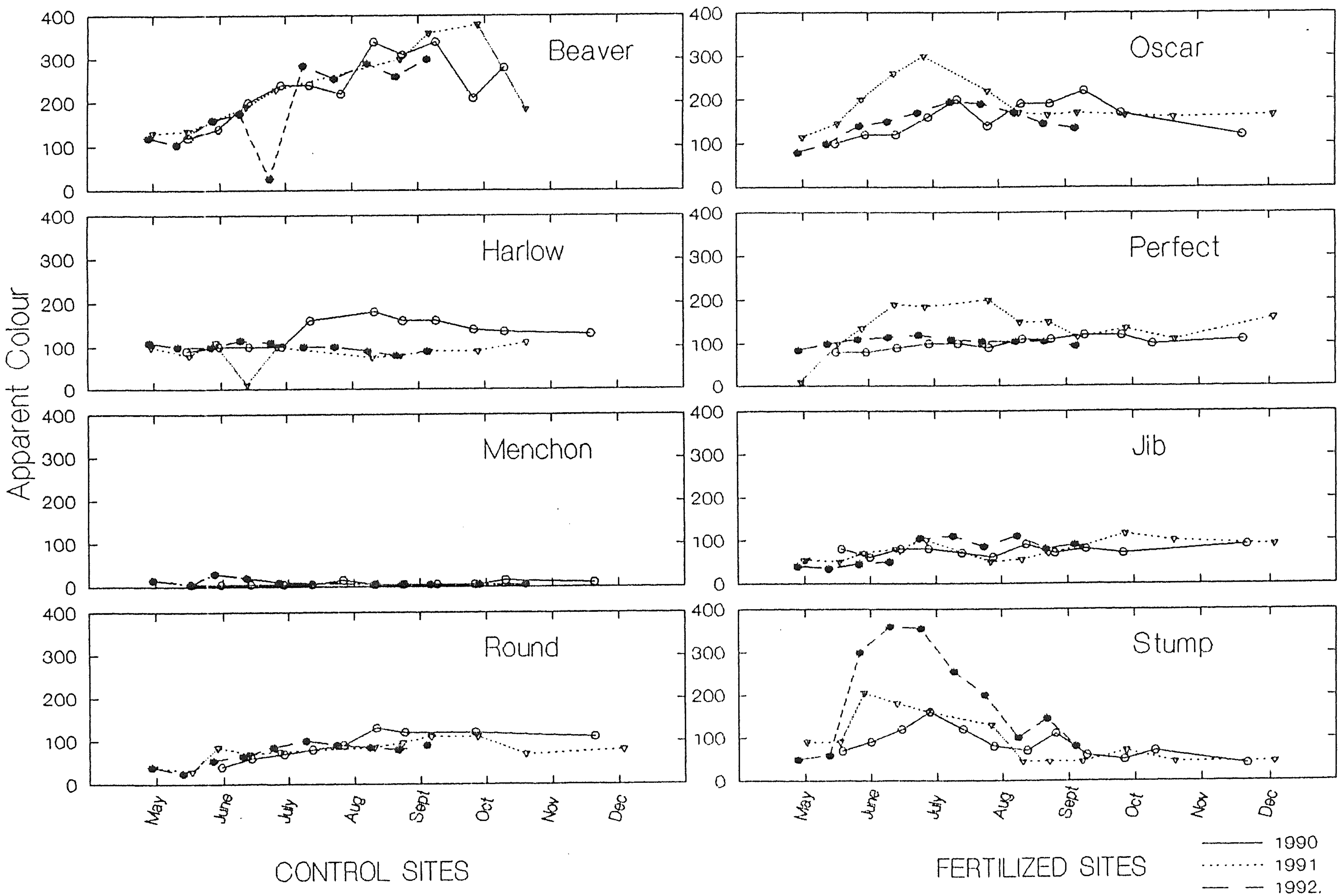

Water Level (cm)
Beaver
Round
Harlow
Menchon
Oscar
Jib
Stump
Perfect
20
10
0
-10
-20
-30
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990

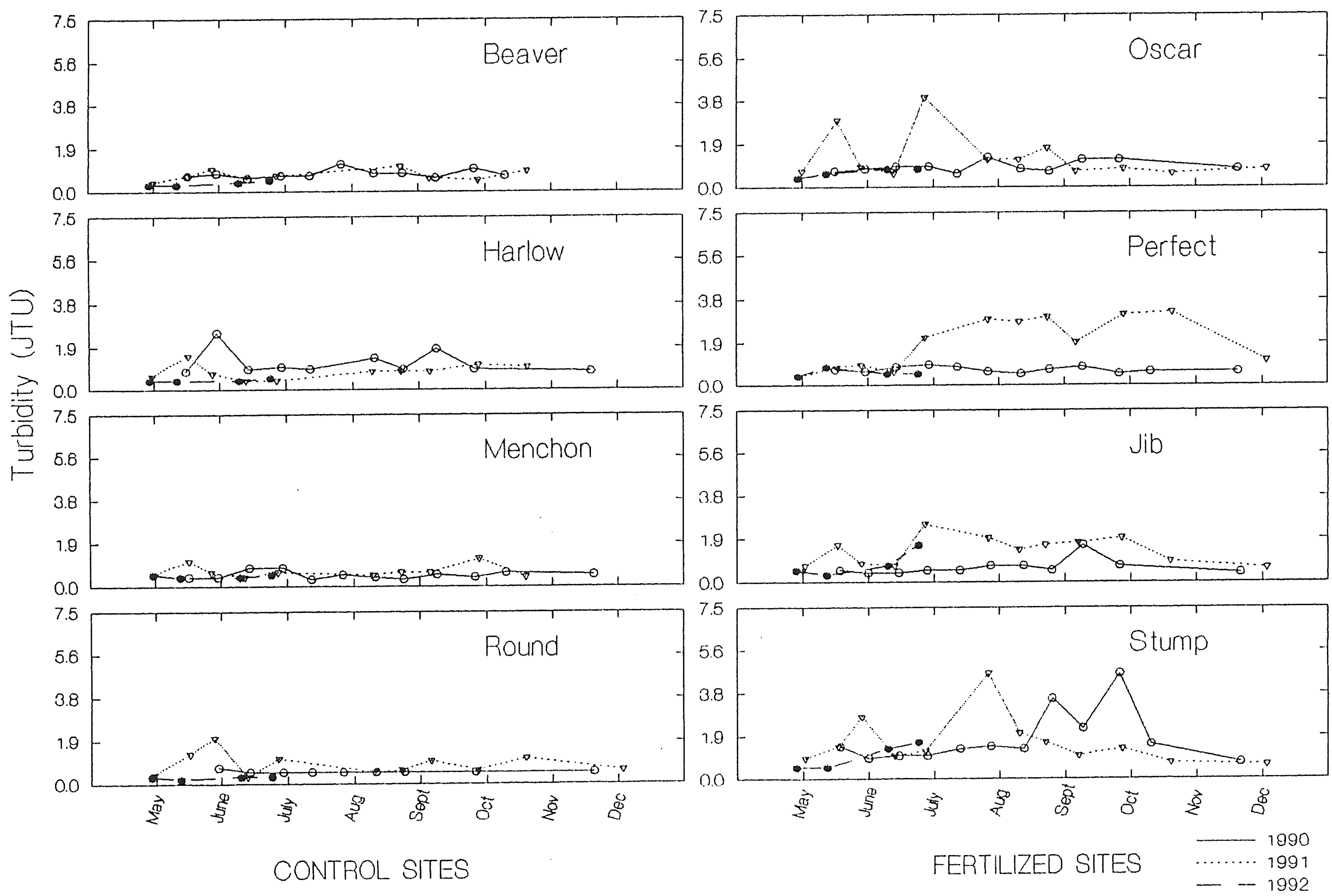

Beaver
Round
Harlow
Menchon
Temperature (C)
30
20
10
0
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992
outlet
bottom
surface



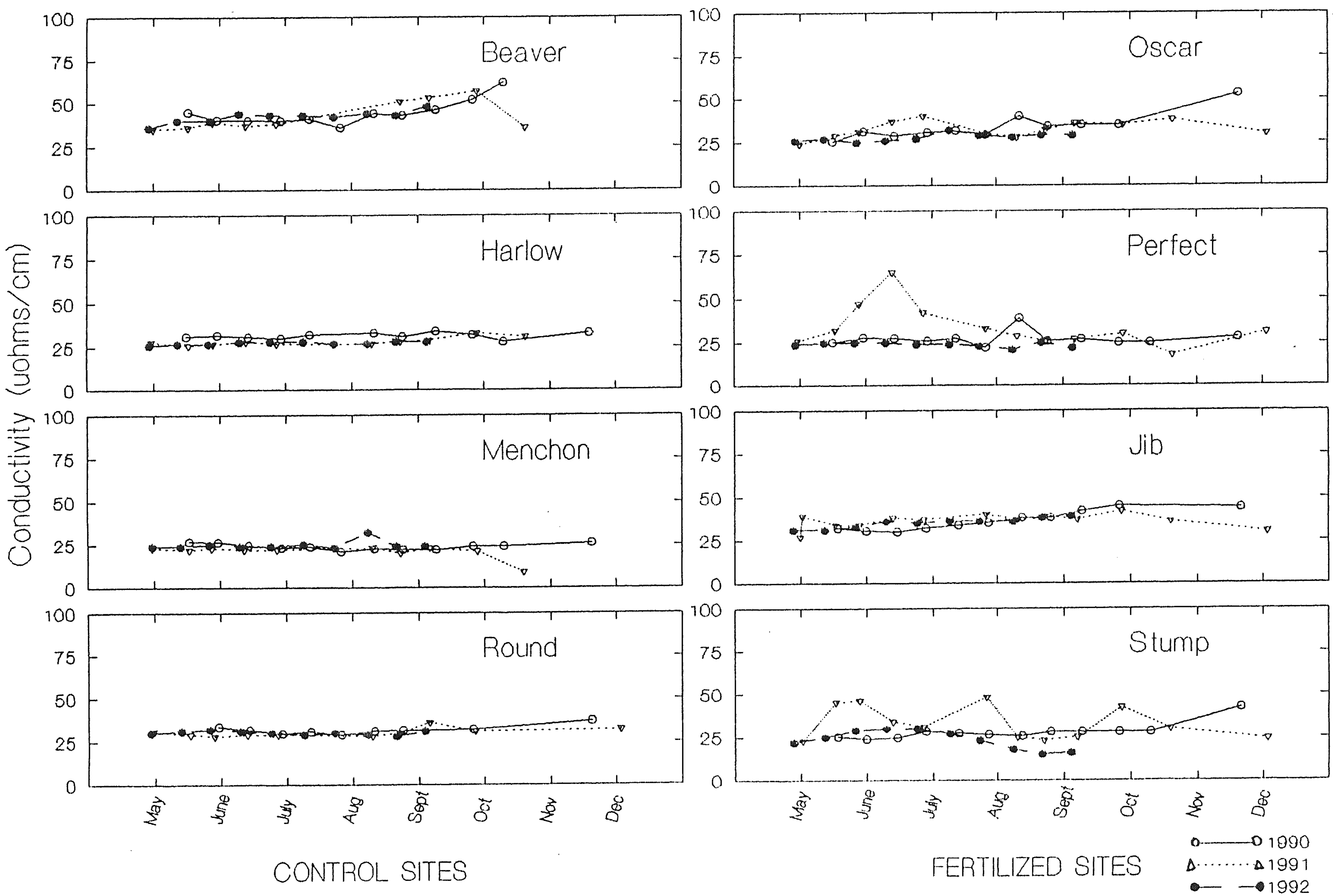
Temperature (C)
30
20
10
0
Stump
Oscar
Jib
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992
outlet
bottom
surface

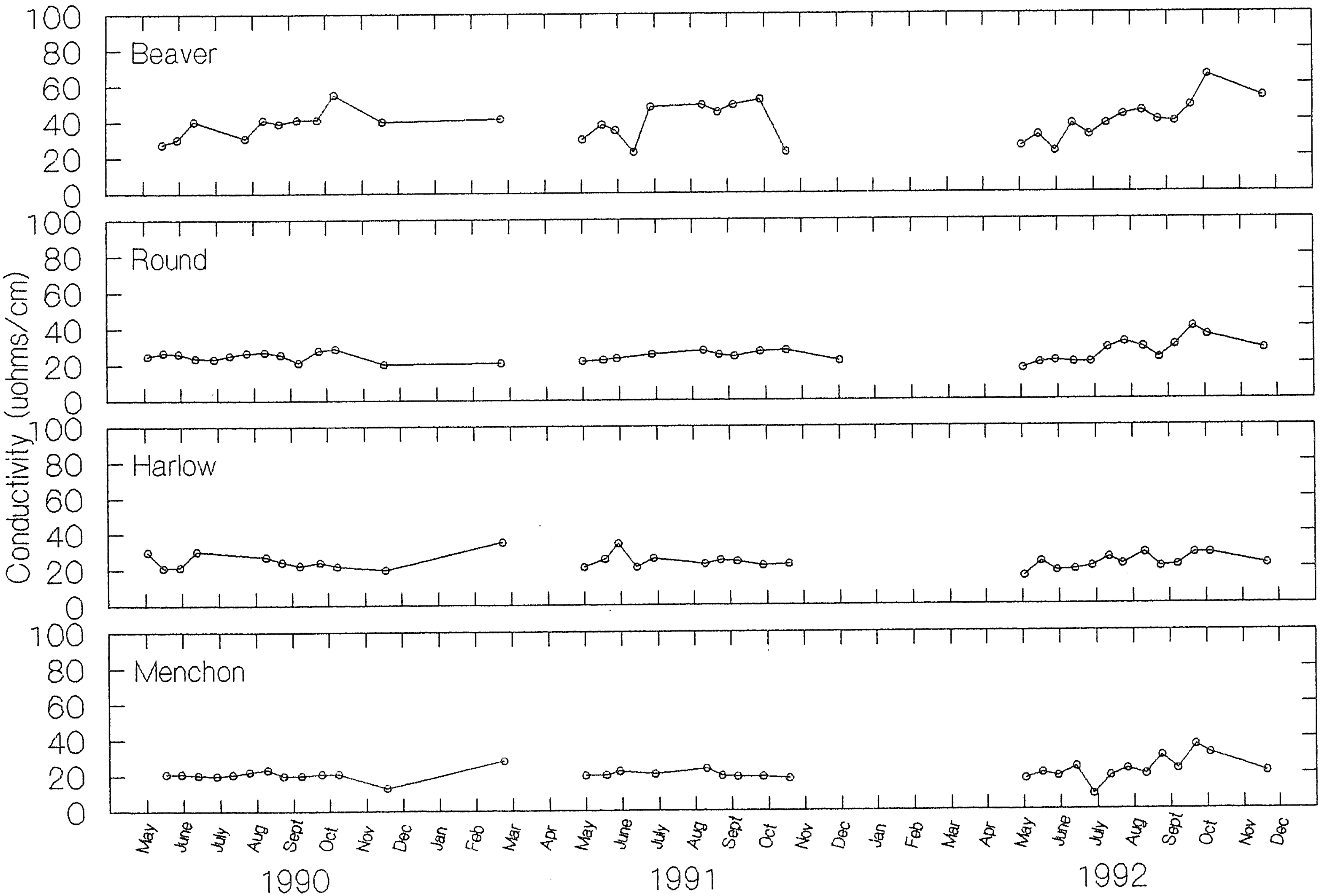

Secchi Disk Depth (m)
Beaver
Round
Harlow
Oscar
Jib
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990

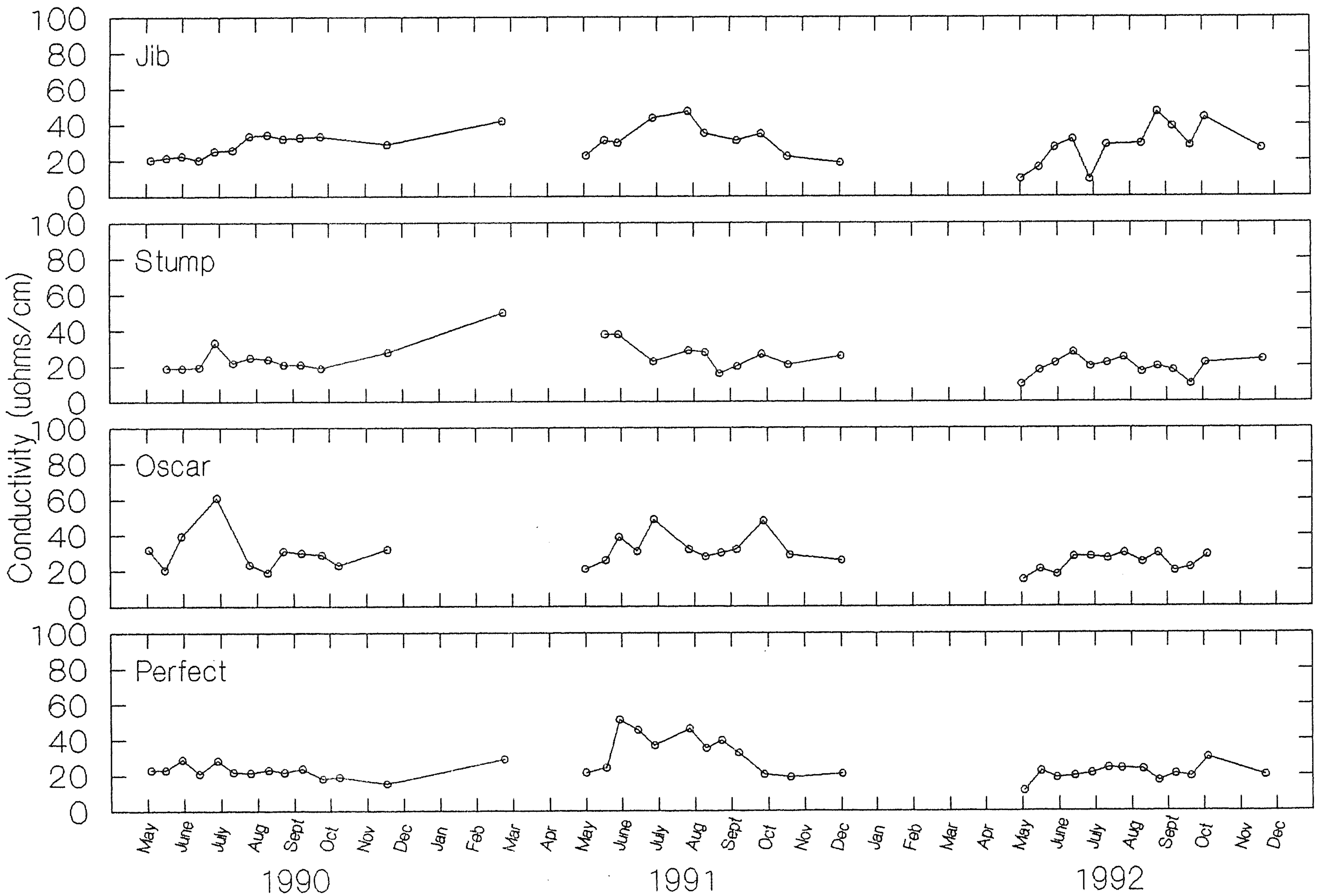

Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
Apparent Colour
0
100
200
300
400
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992.

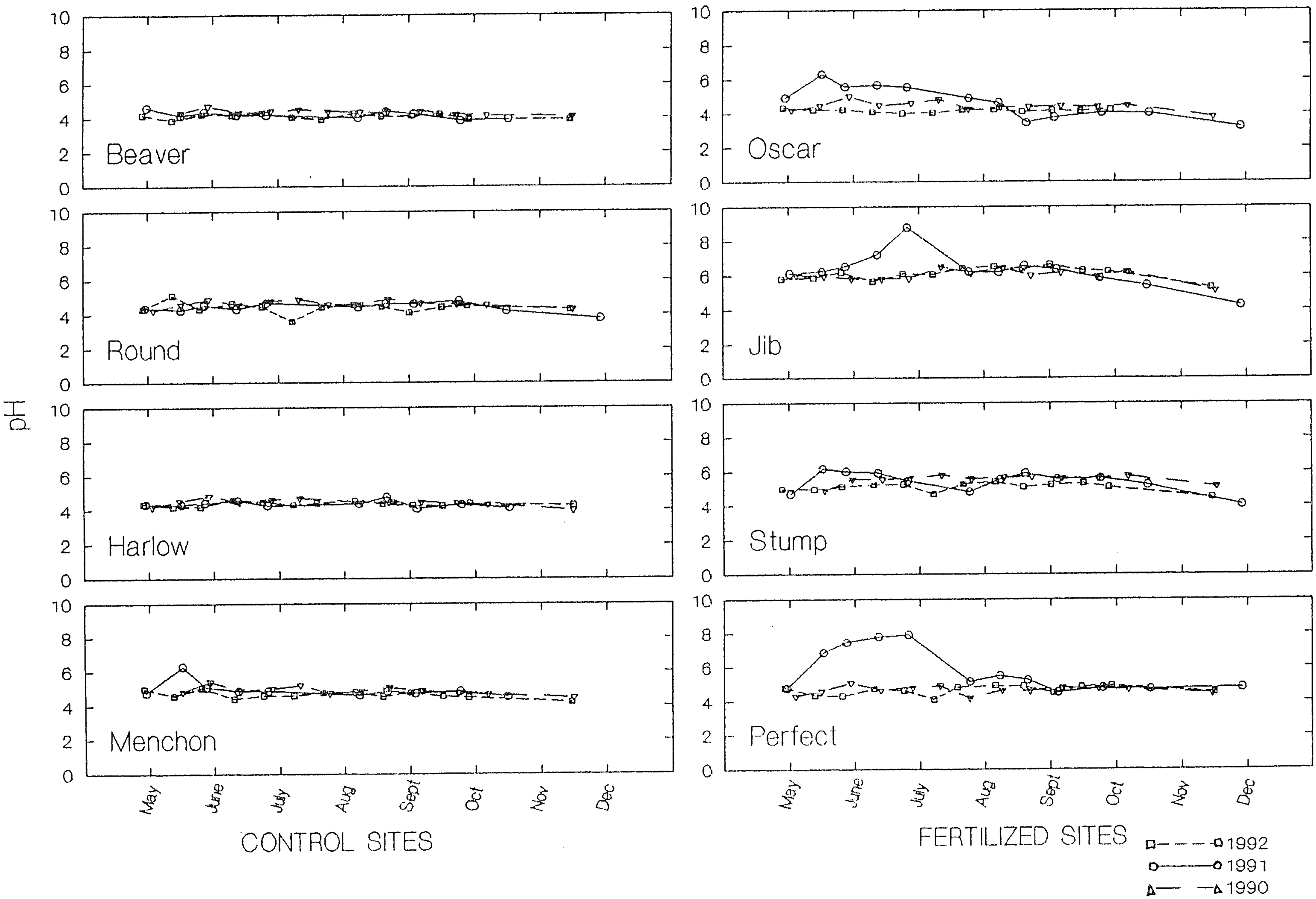

Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
Turbidity (JTU)
7.5
5.6
3.8
1.9
0.0
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992

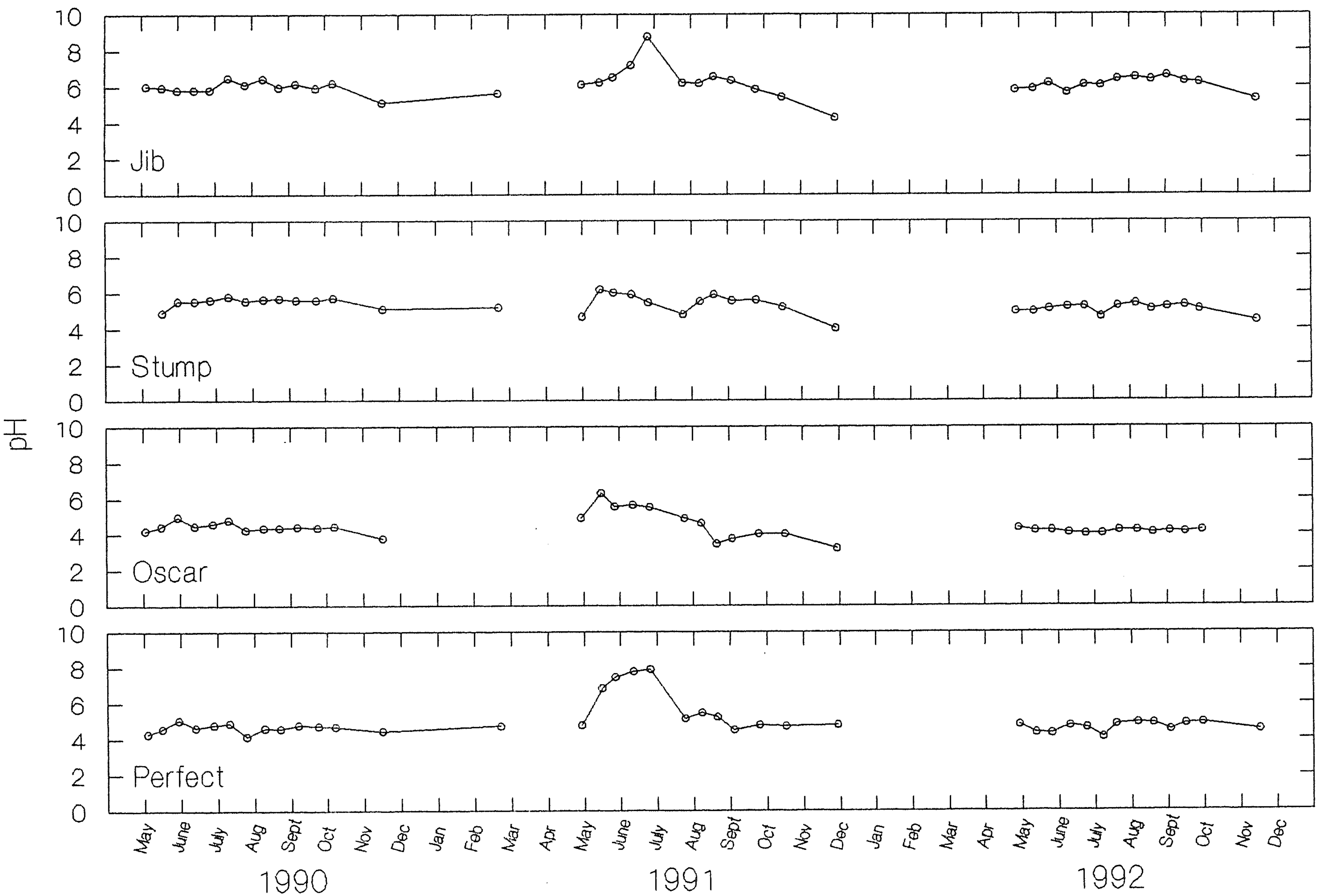
Appendix E. Graphical summaries of chemical data

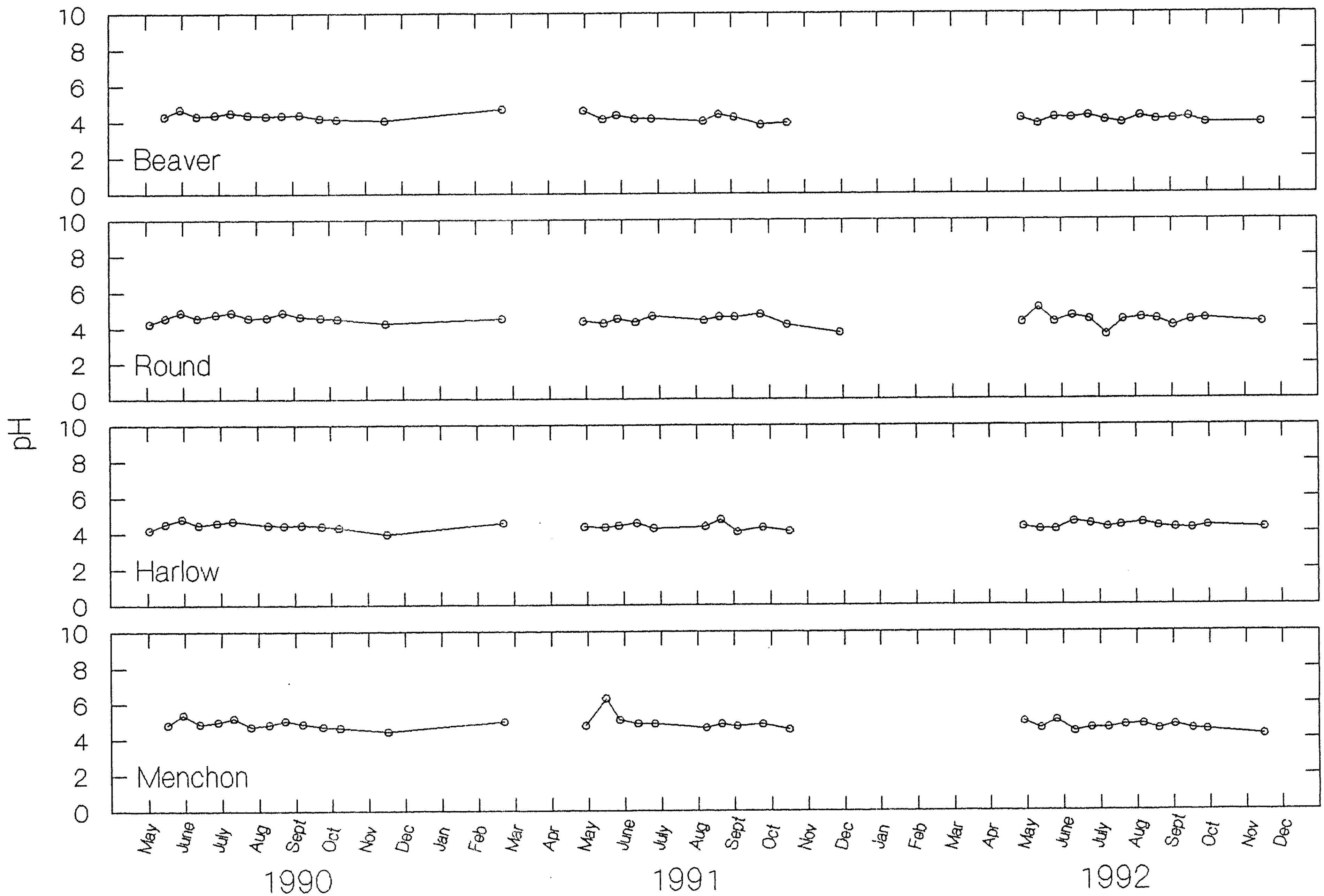

Conductivity (uohms/cm)
Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992

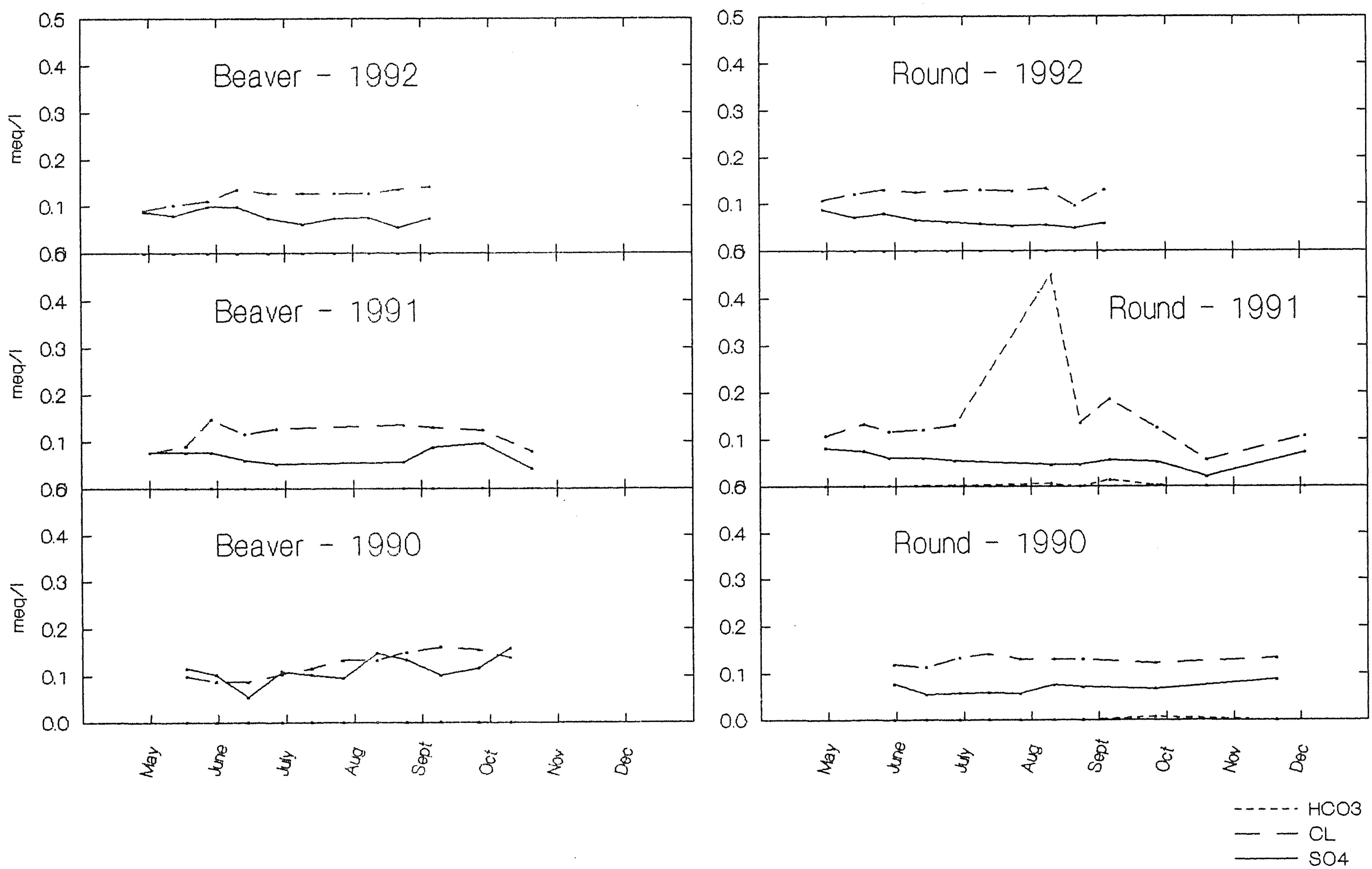

Beaver
Round
Harlow
Menchon
Conductivity_(uohms/cm)
100
80
60
40
20
0
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992

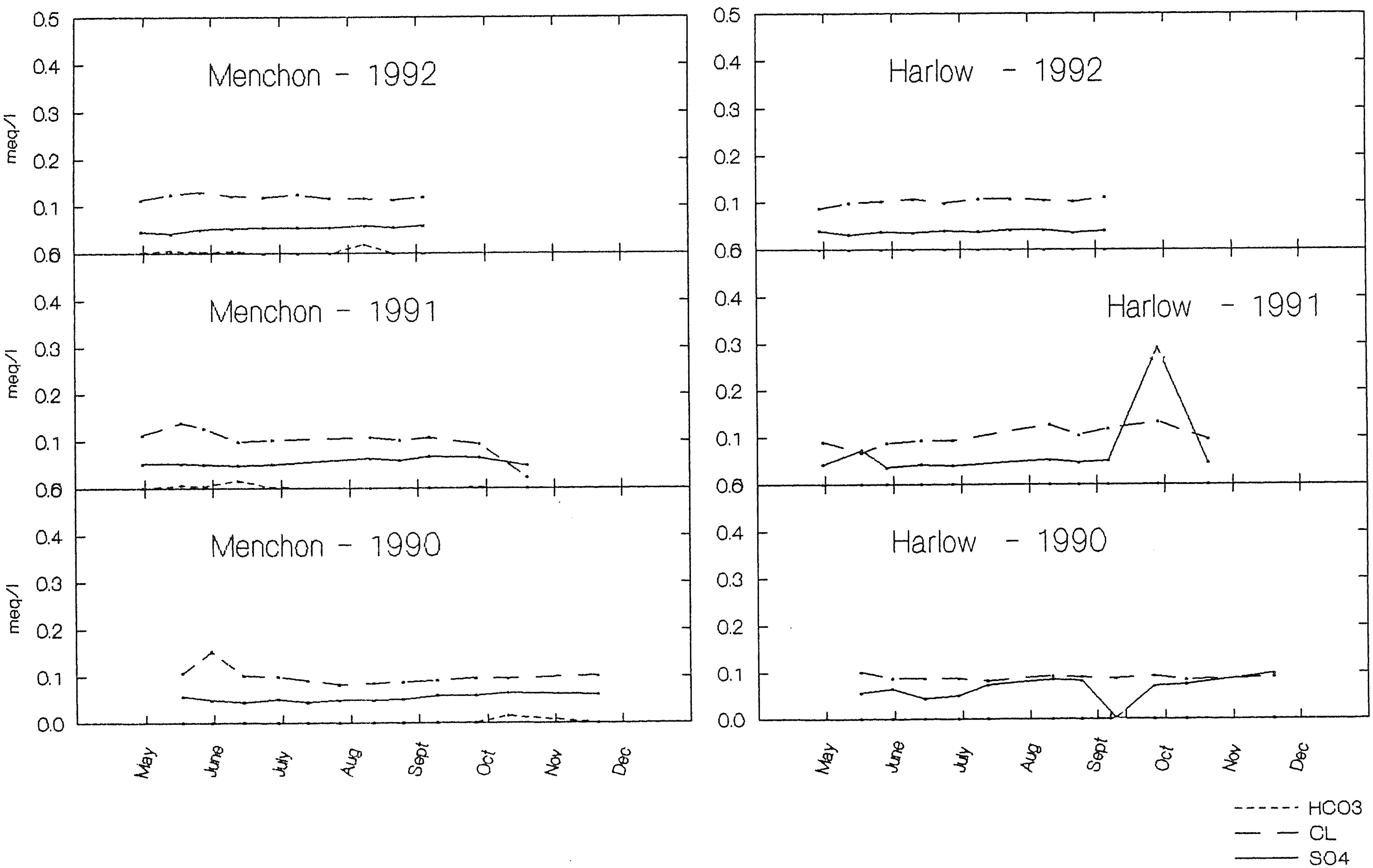

Jib
Stump
Oscar
Perfect
Conductivity_(uohms/cm)
100
80
60
40
20
0
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992

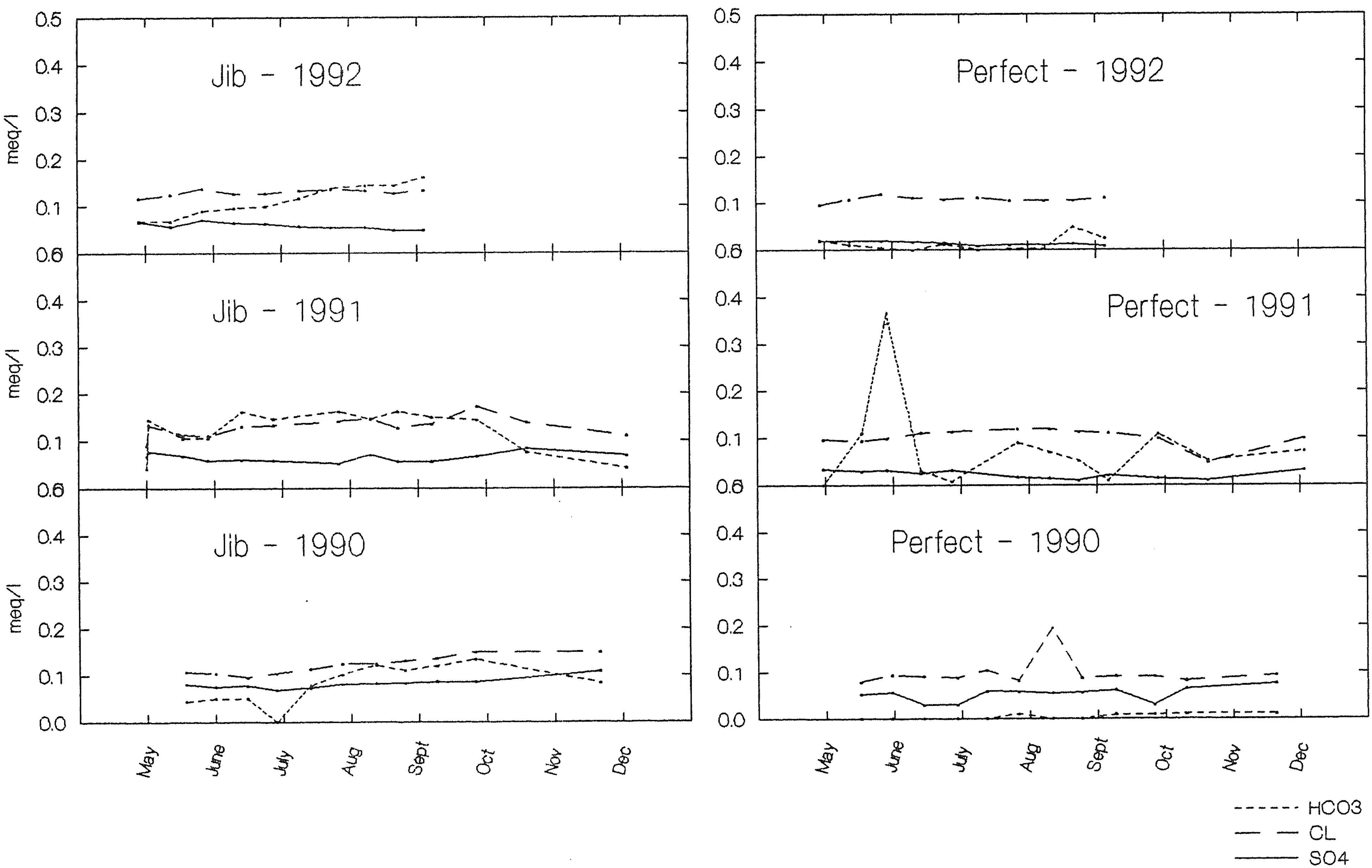

pH
Beaver
Round
Harlow
Menchon
Oscar
Jib
Stump
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990

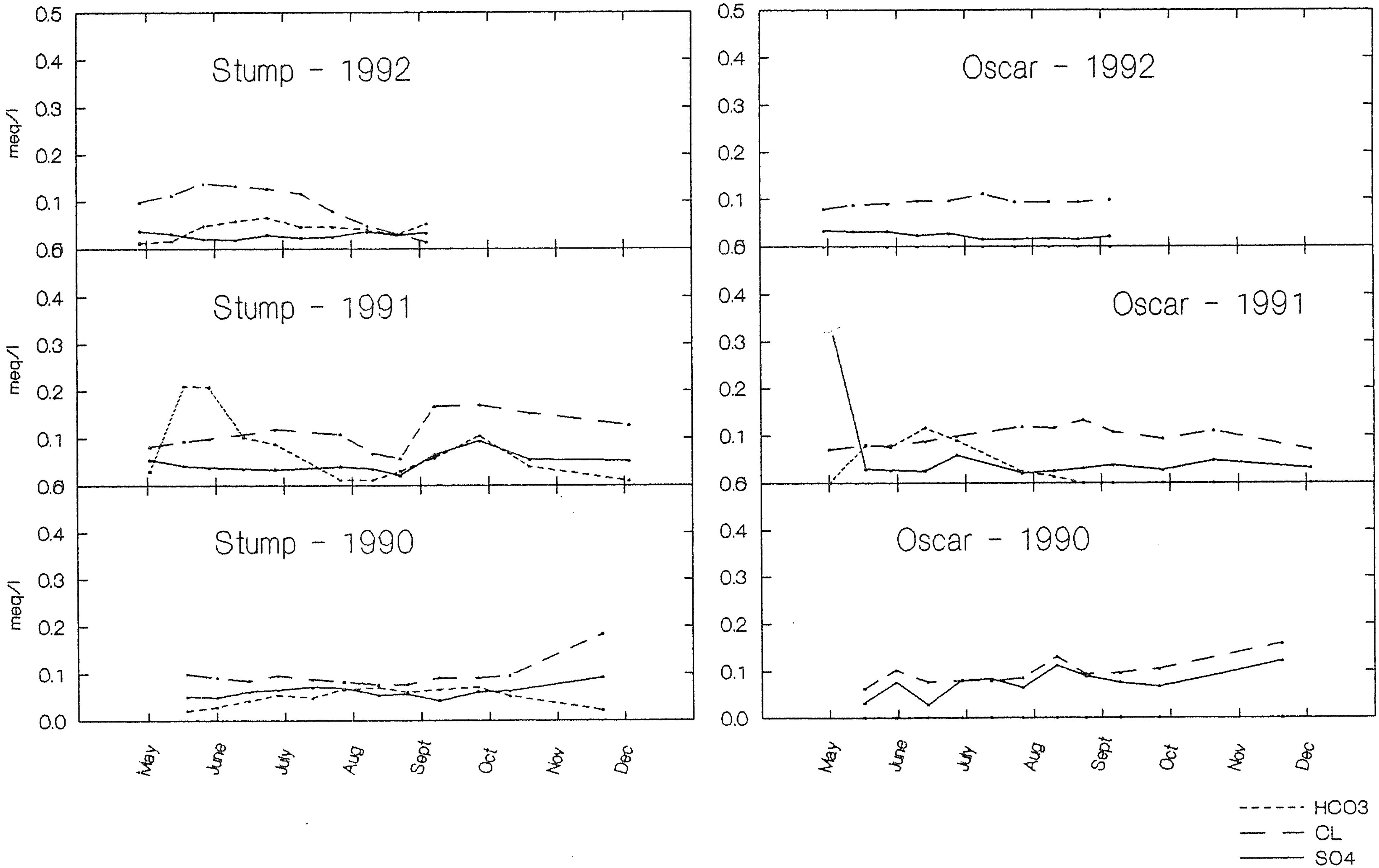

pH
Jib
Stump
Oscar
Perfect
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
1990
1991
1992

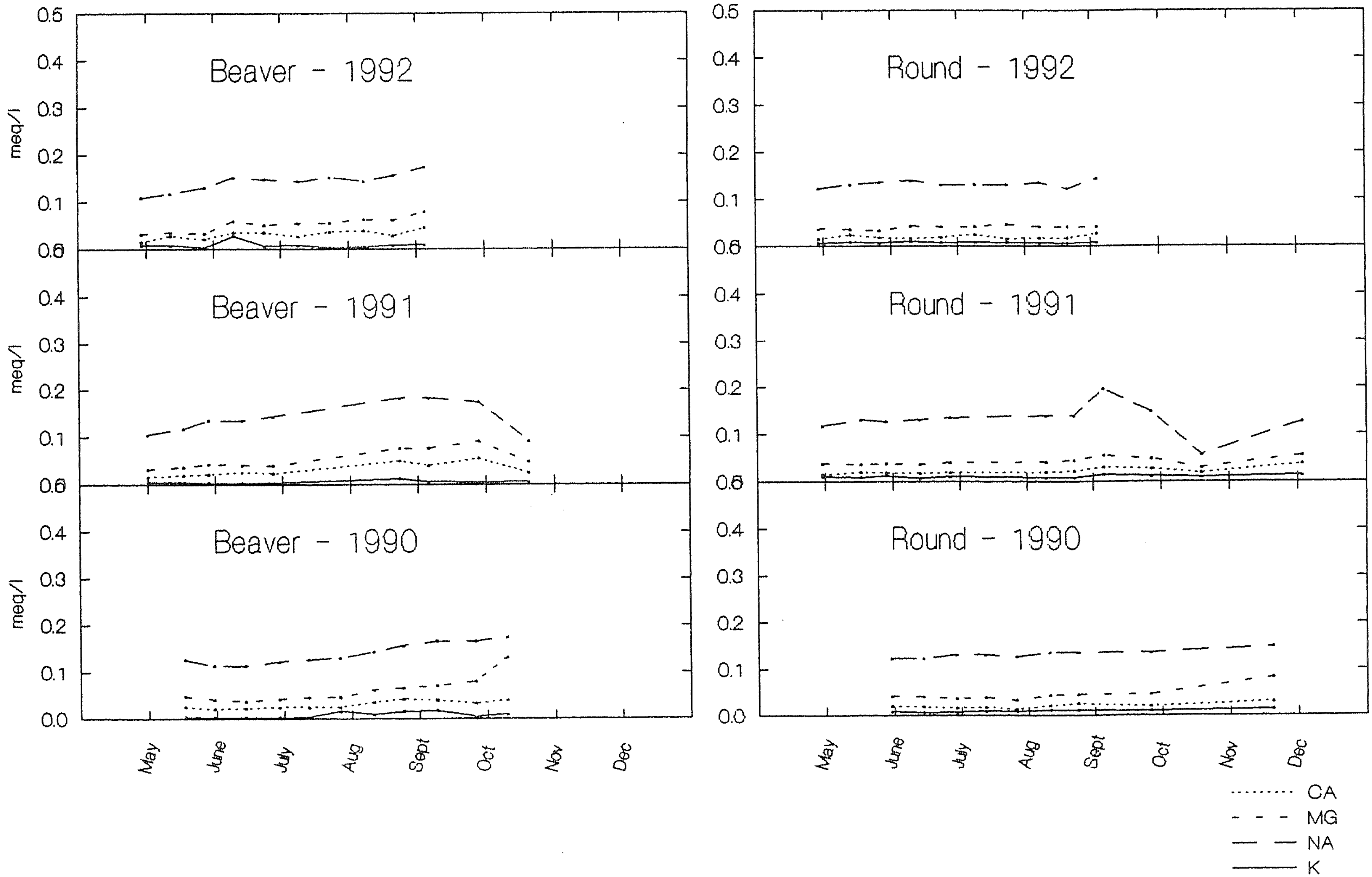

pH
10
8
6
4
2
0
Beaver
Round
Harlow
Menchon
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992


Beaver - 1992
Beaver - 1991
Beaver - 1990
Round - 1992
Round - 1991
Round - 1990
meq/l
0.5
0.4
0.3
0.2
0.1
0.0
May
June
July
Aug
Sept
Oct
Nov
Dec
HCO3
CL
SO4

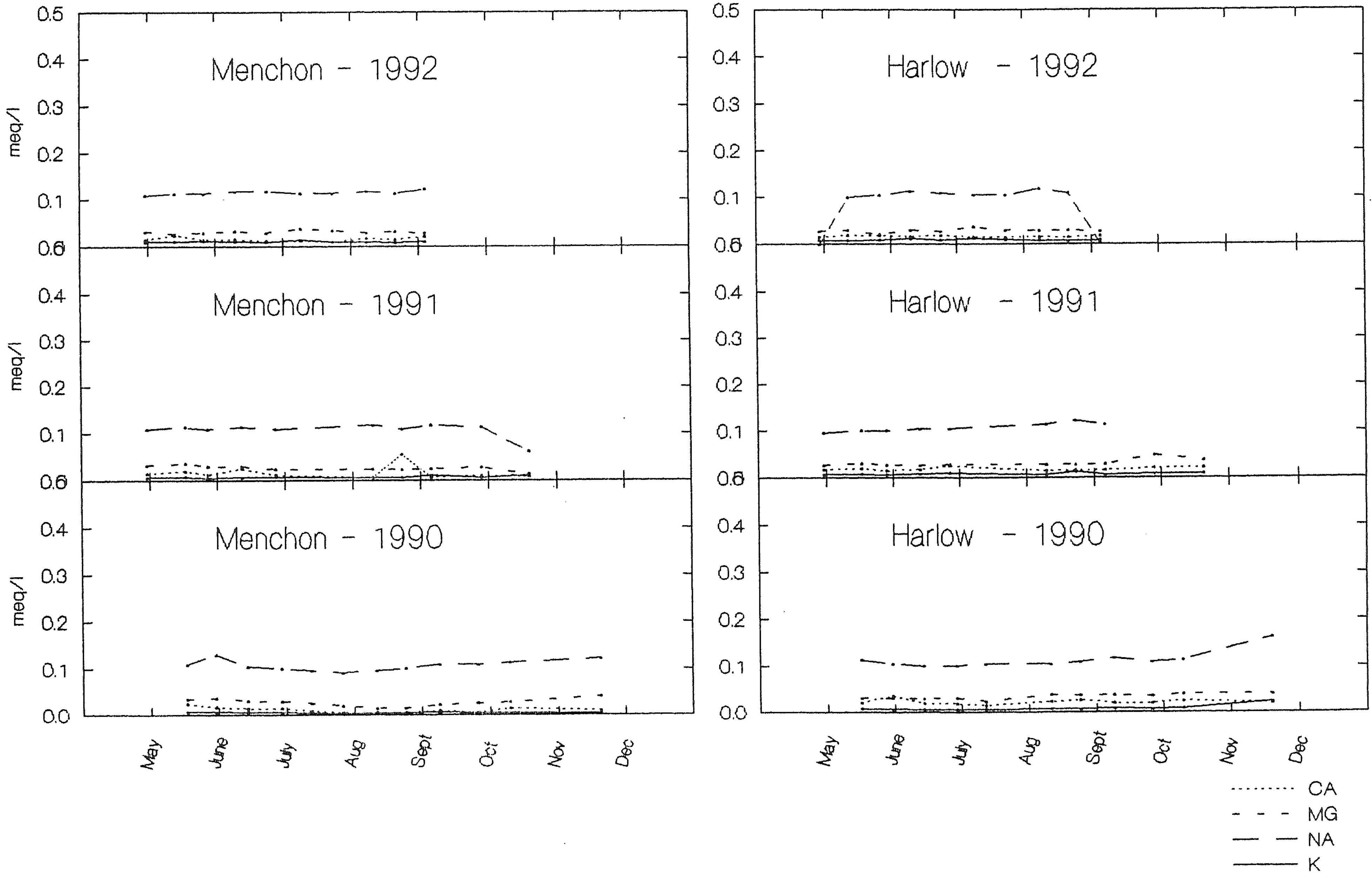

Menchon - 1992
Menchon - 1991
Menchon - 1990
Harlow - 1992
Harlow - 1991
Harlow - 1990
meq/l
0.0
0.1
0.2
0.3
0.4
0.5
0.6
May
June
July
Aug
Sept
Oct
Nov
Dec
HCO3
CL
SO4

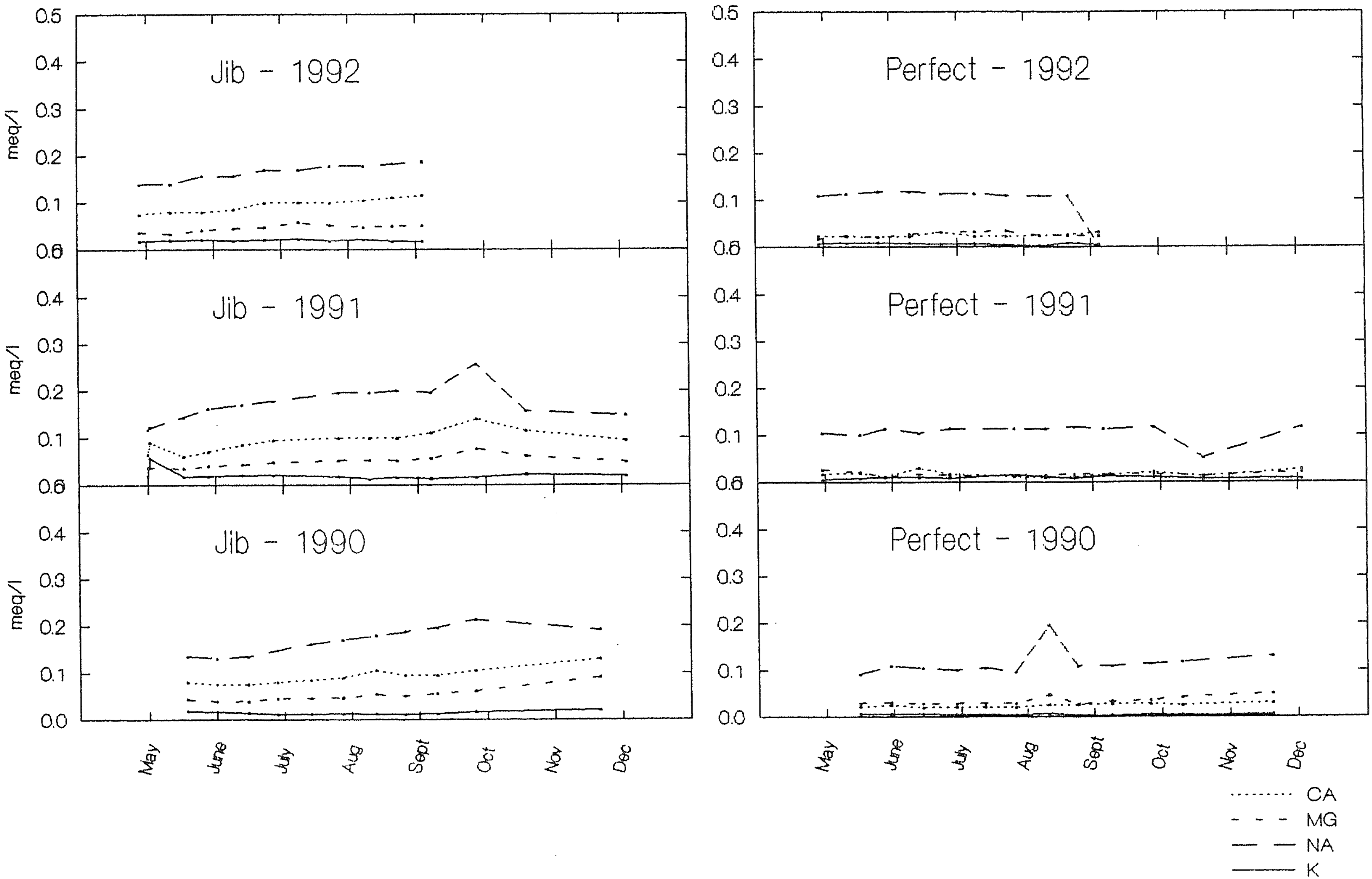

Jib - 1992
Jib - 1991
Jib - 1990
Perfect - 1992
Perfect - 1991
Perfect - 1990
meq/l
May
June
July
Aug
Sept
Oct
Nov
Dec
HCO3
CL
SO4

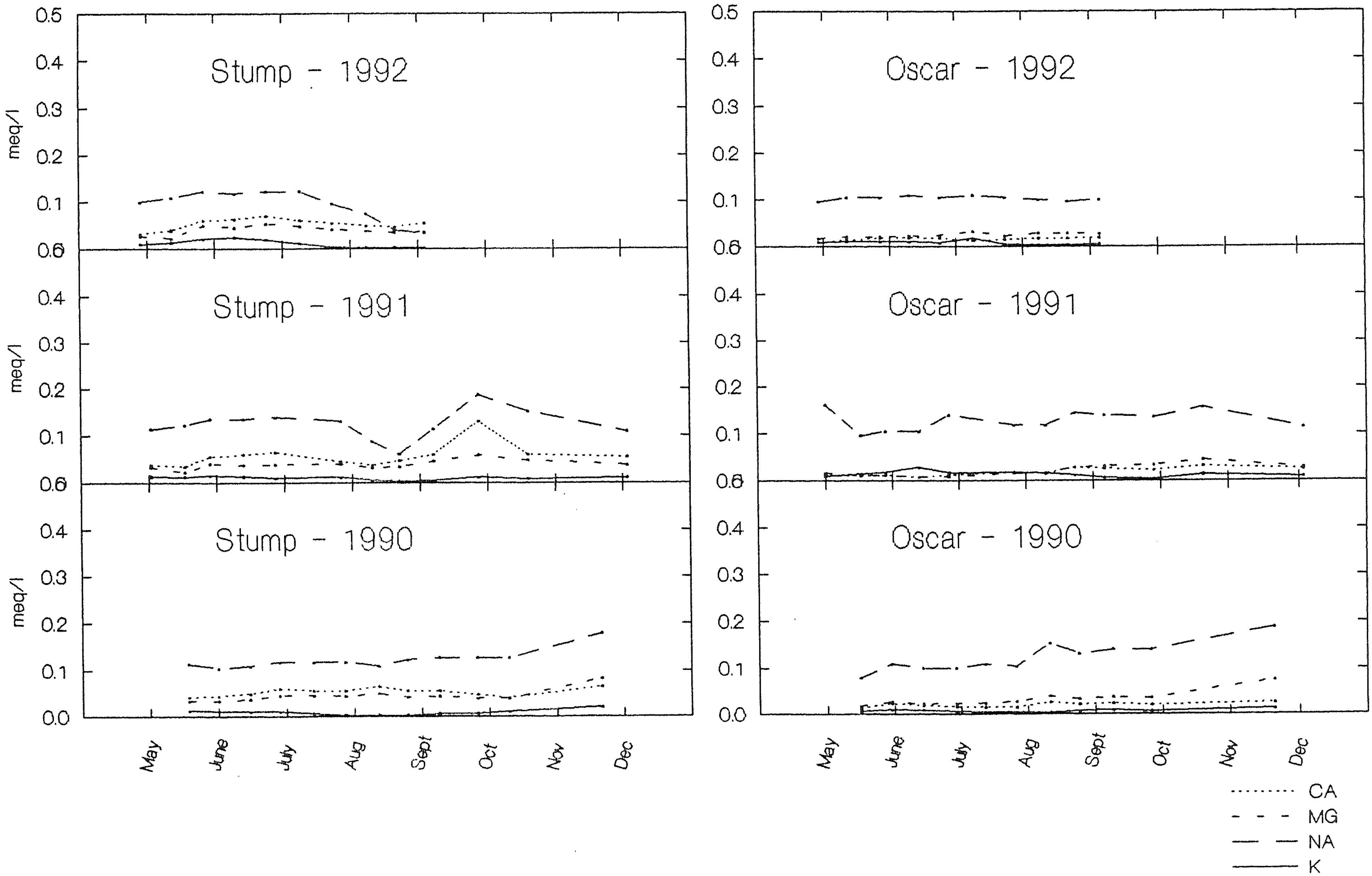

Stump - 1992
Stump - 1991
Stump - 1990
Oscar - 1992
Oscar - 1991
Oscar - 1990
meq/l
0.0
0.1
0.2
0.3
0.4
0.5
May
June
July
Aug
Sept
Oct
Nov
Dec
HCO3
CL
SO4



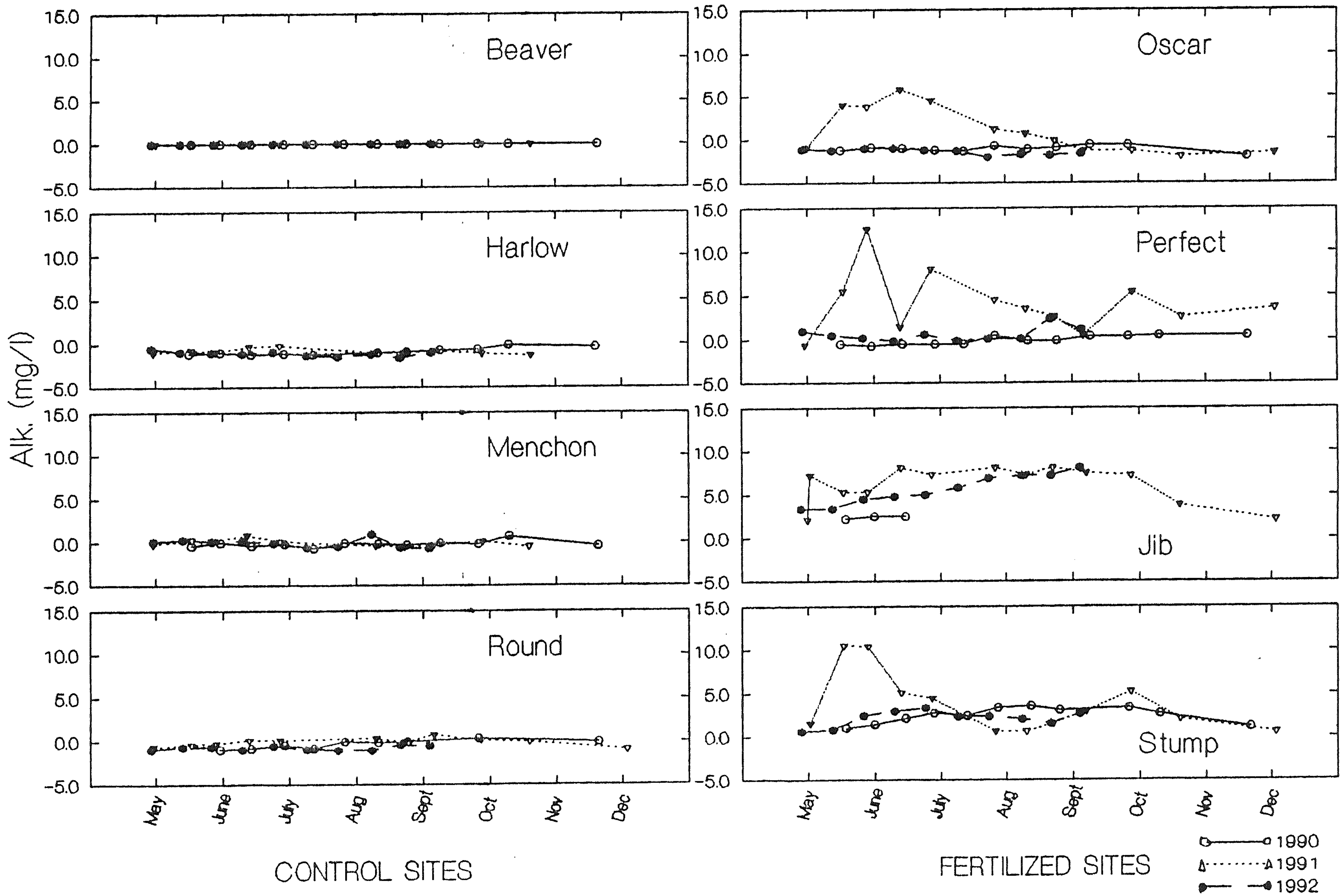
Beaver - 1992
Beaver - 1991
Beaver - 1990
Round - 1992
Round - 1991
Round - 1990
meq/l
0.0
0.1
0.2
0.3
0.4
0.5
May
June
July
Aug
Sept
Oct
Nov
Dec
CA
MG
NA
K


Menchon - 1992
Menchon - 1991
Menchon - 1990
Harlow - 1992
Harlow - 1991
Harlow - 1990
meq/l
0.5
0.4
0.3
0.2
0.1
0.0
May
June
July
Aug
Sept
Oct
Nov
Dec
CA
MG
NA
K

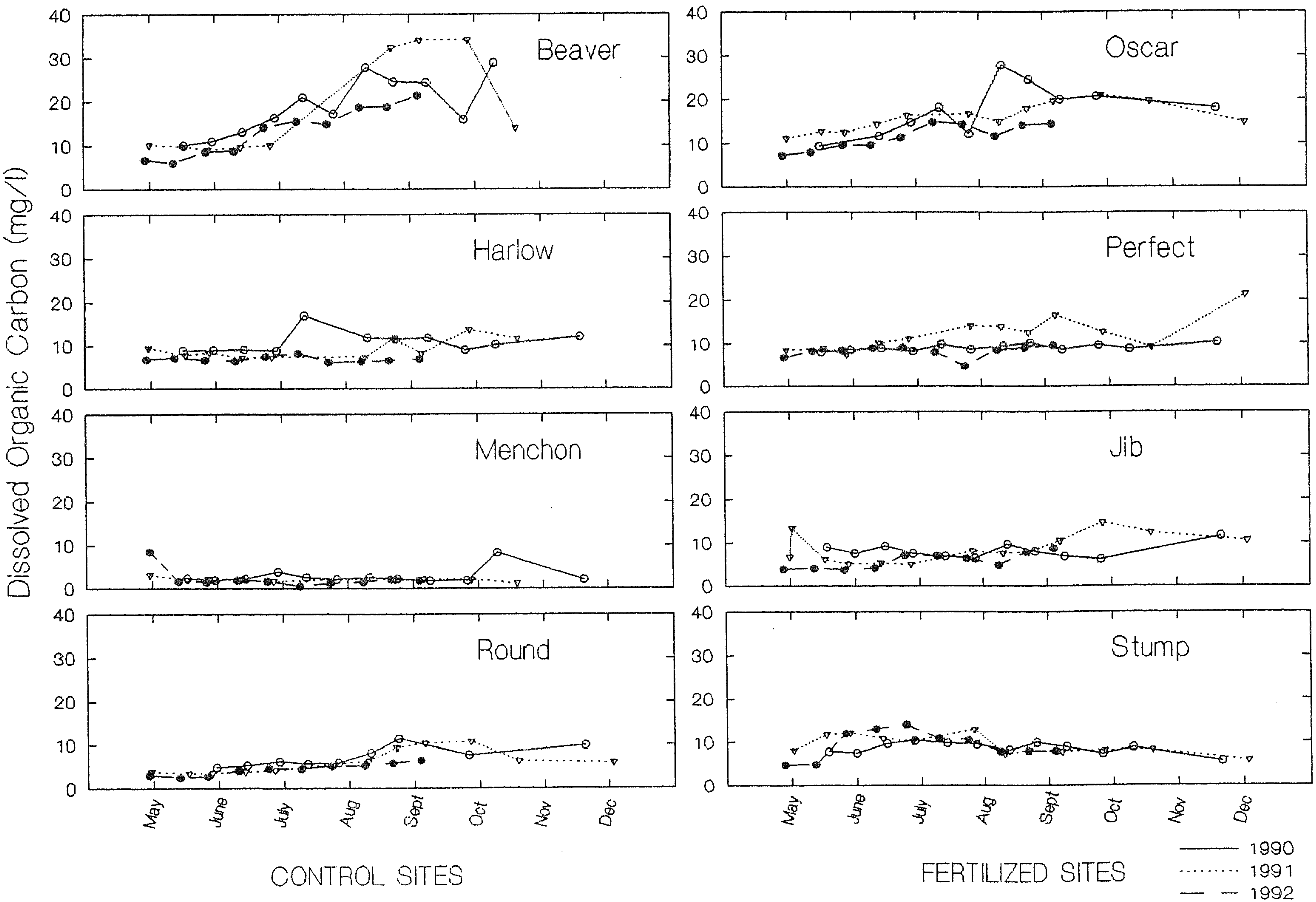

Jib - 1992
Jib - 1991
Jib - 1990
Perfect - 1992
Perfect - 1991
Perfect - 1990
meq/l
0.5
0.4
0.3
0.2
0.1
0.0
May
June
July
Aug
Sept
Oct
Nov
Dec
CA
MG
NA
K

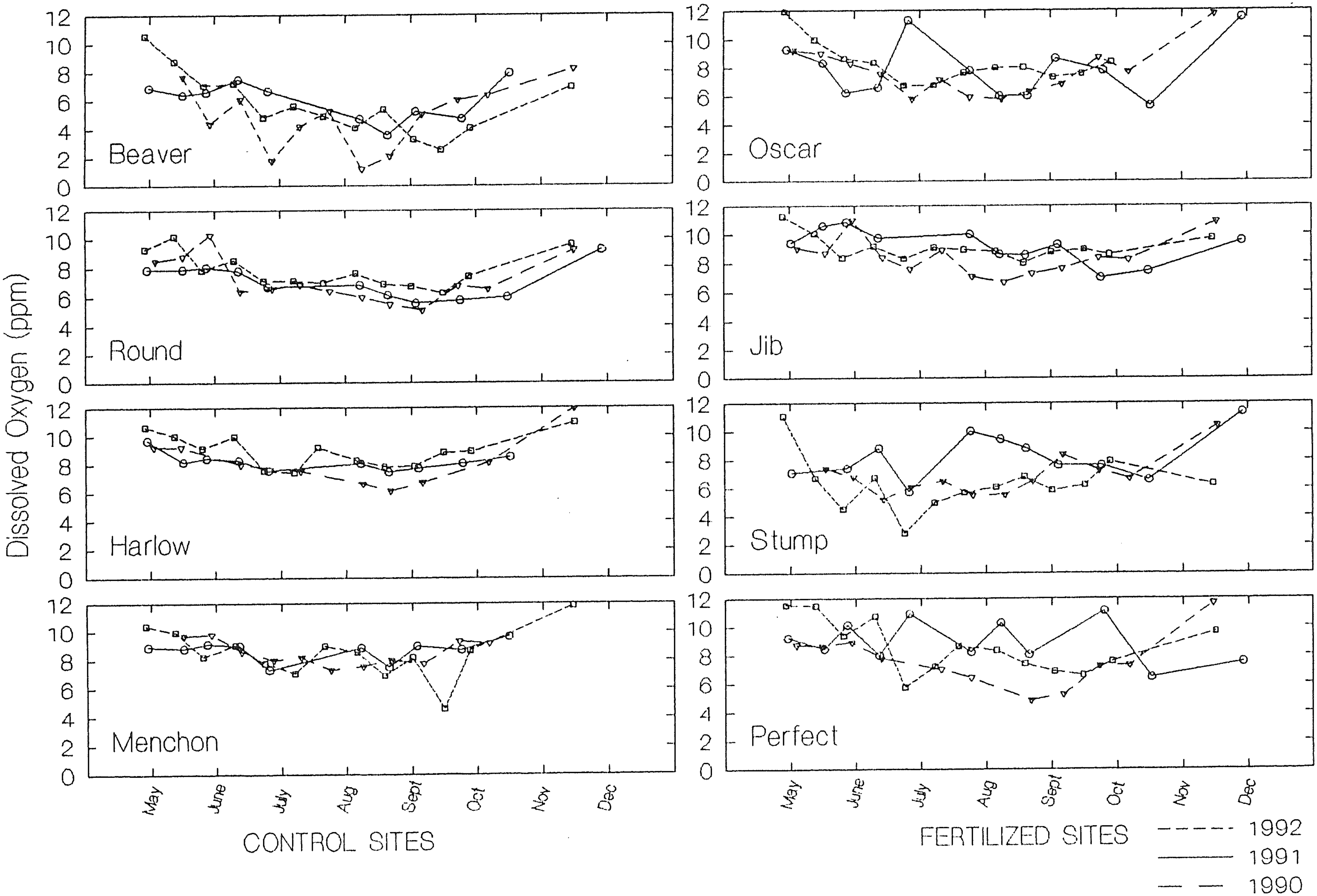


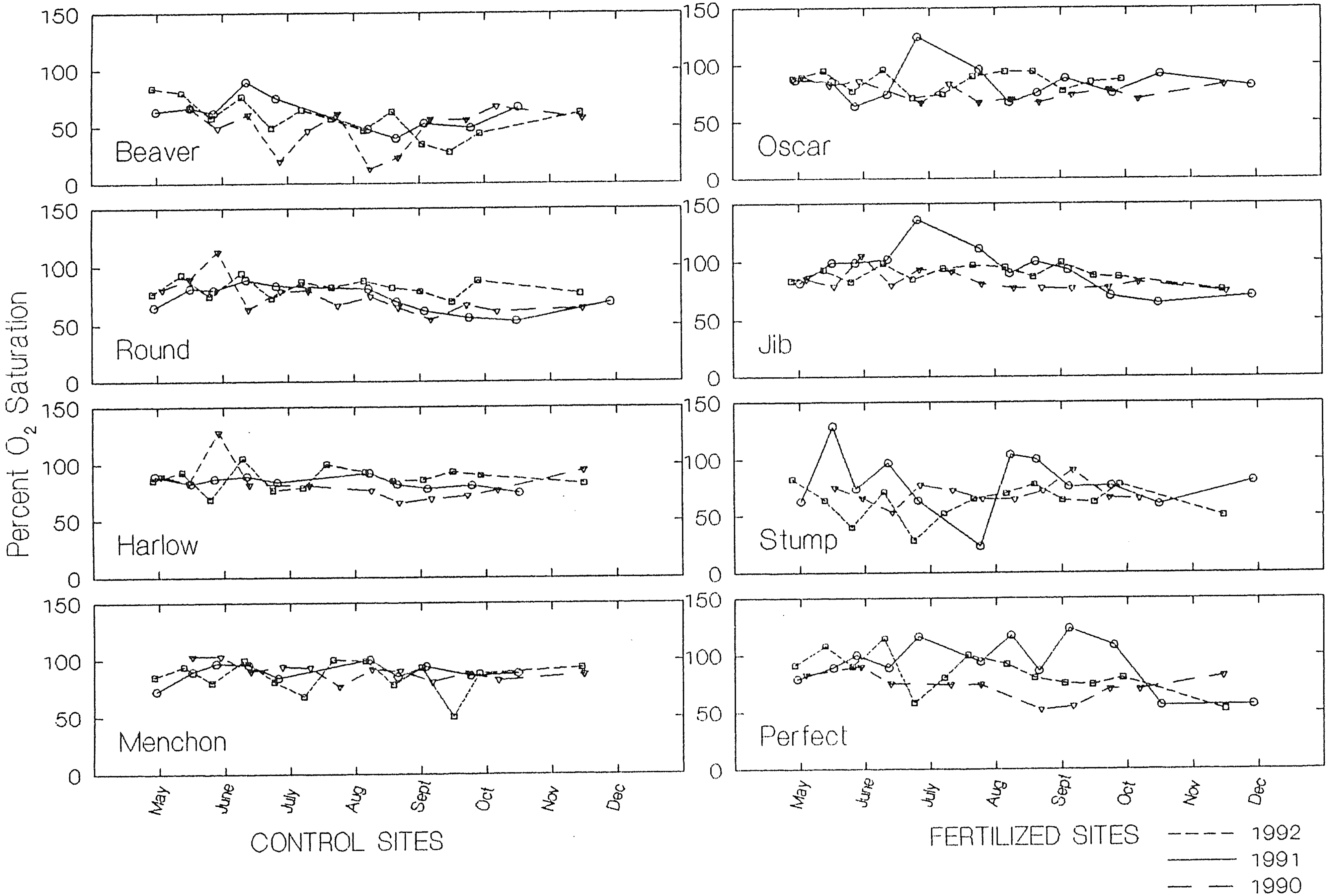
Stump - 1992
Stump - 1991
Stump - 1990
Oscar - 1992
Oscar - 1991
Oscar - 1990
meq/l
0.5
0.4
0.3
0.2
0.1
0.0
May
June
July
Aug
Sept
Oct
Nov
Dec
CA
MG
NA
K

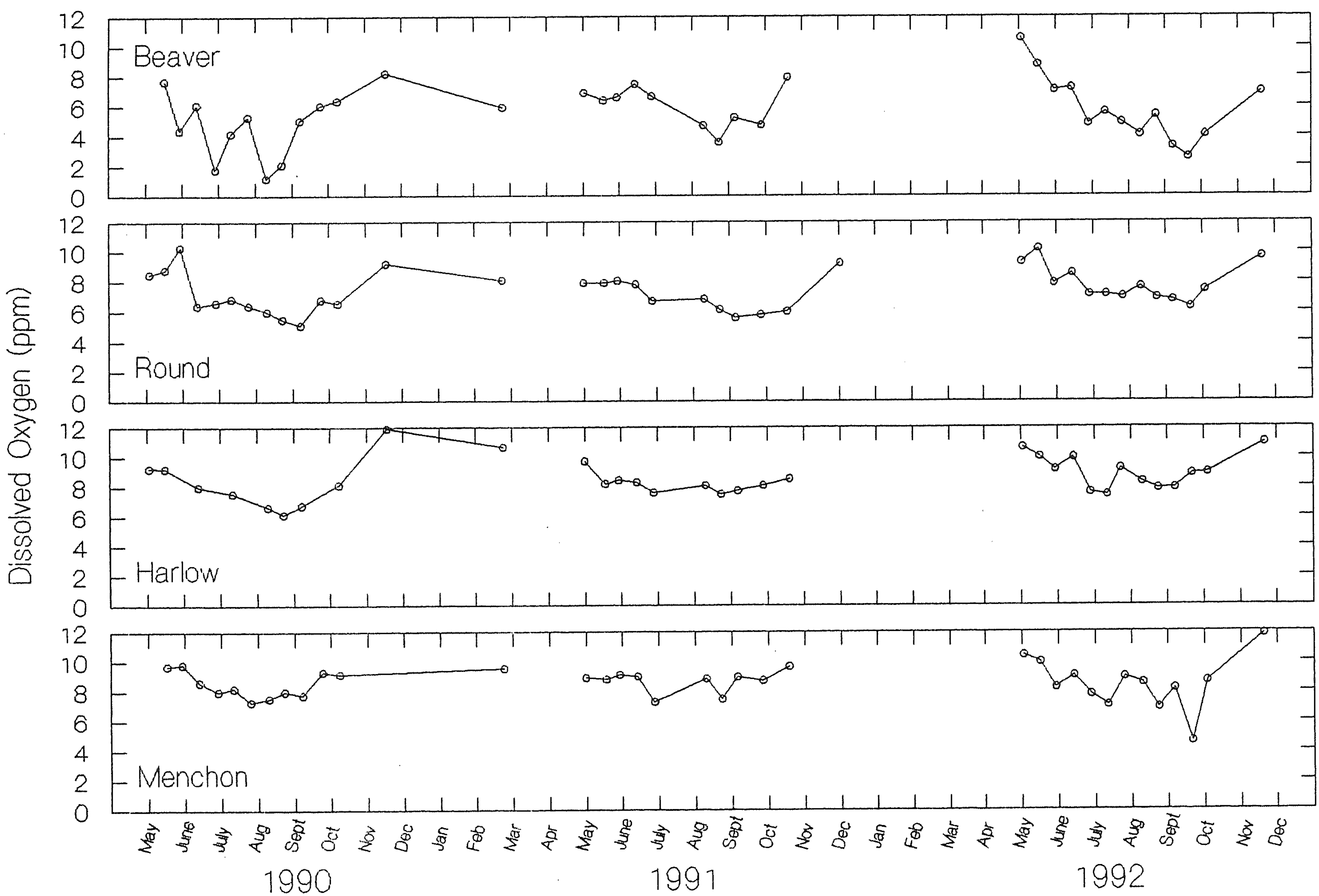


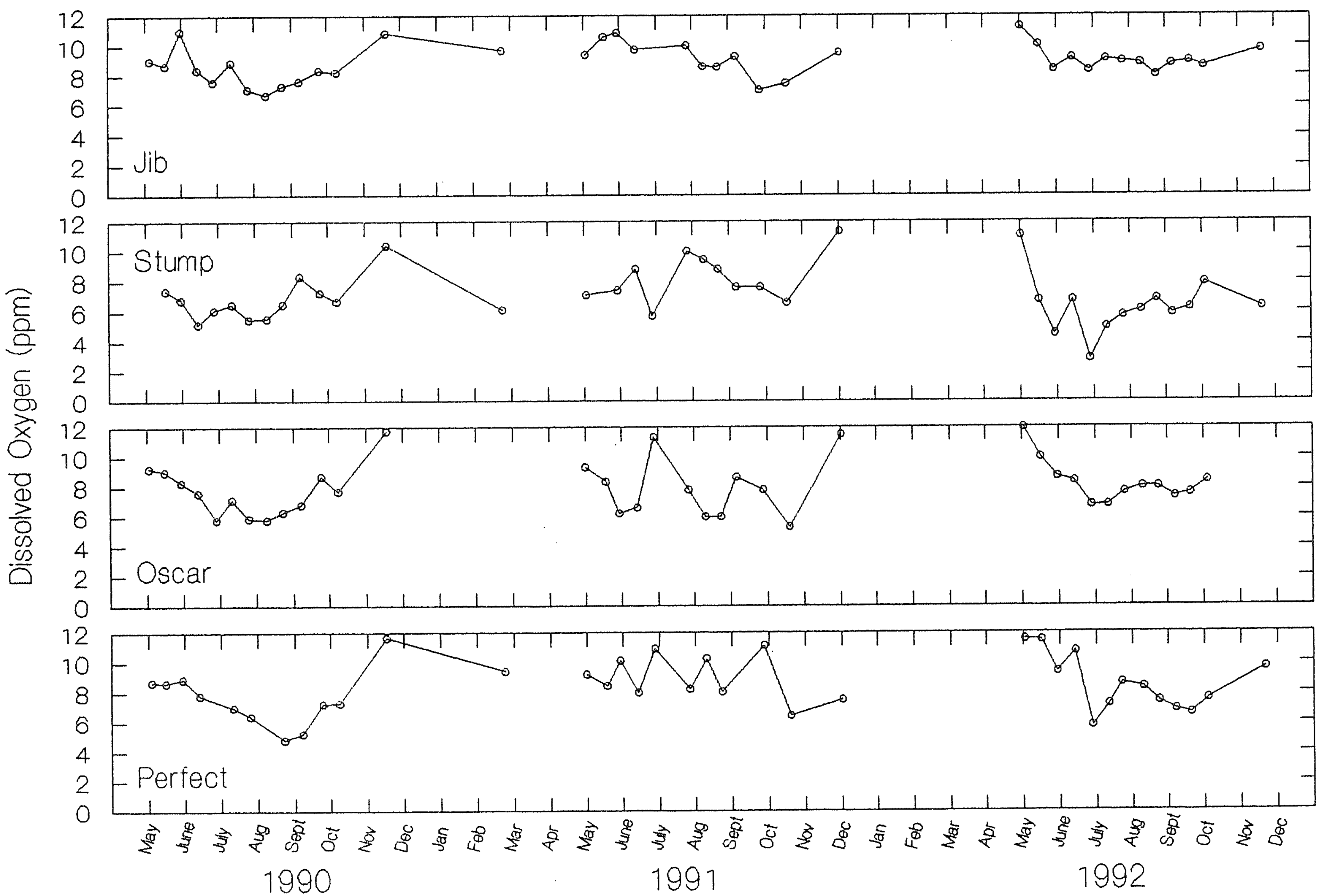
Alk. (mg/l)
15.0
10.0
5.0
0.0
-5.0
Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992


Dissolved Organic Carbon (mg/l)
Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
0
10
20
30
40
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992

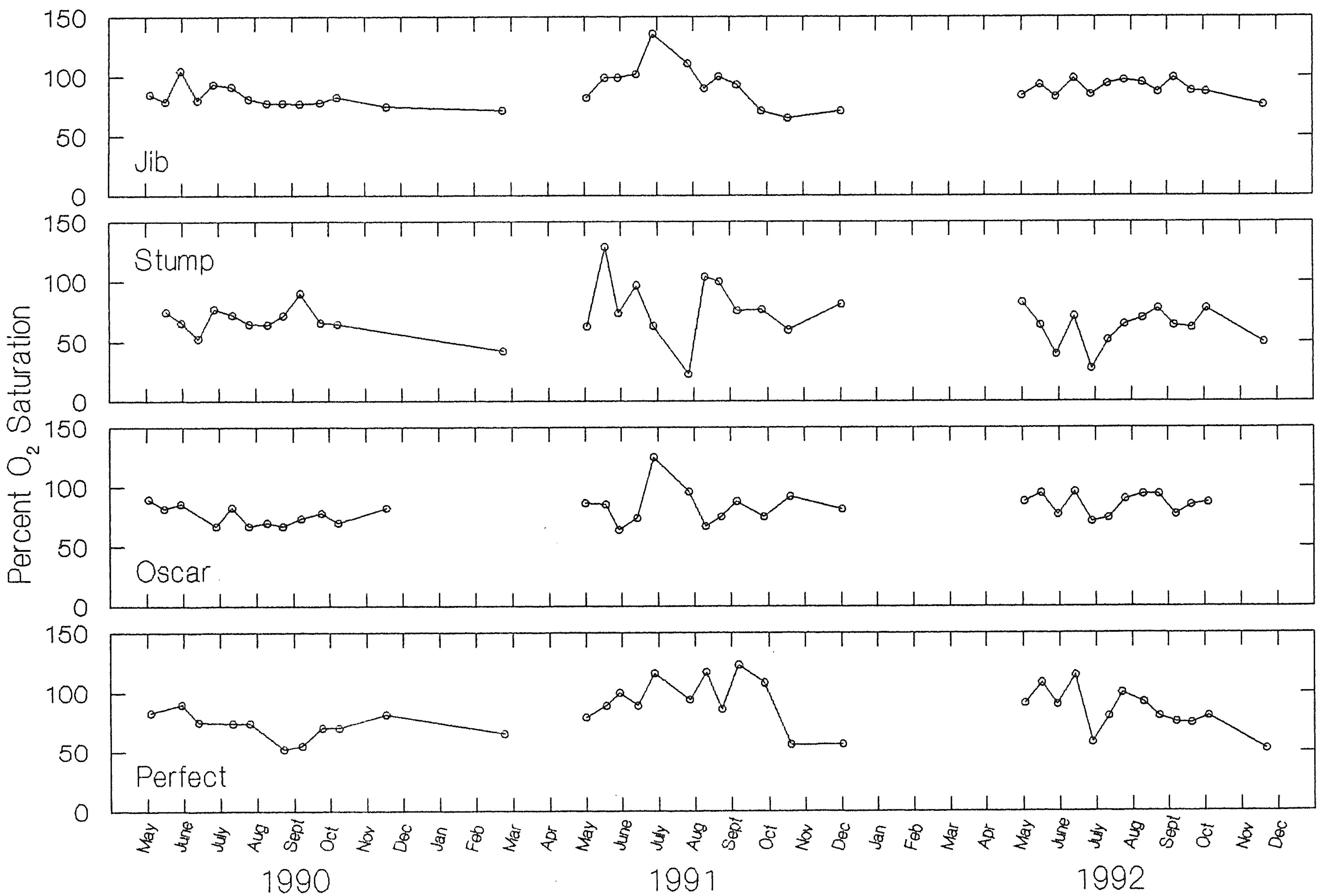

Dissolved Oxygen (ppm)
Beaver
Round
Harlow
Menchon
Oscar
Jib
Stump
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990


Percent O$_2$ Saturation
150
100
50
0
Beaver
Round
Harlow
Menchon
Oscar
Jib
Stump
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990

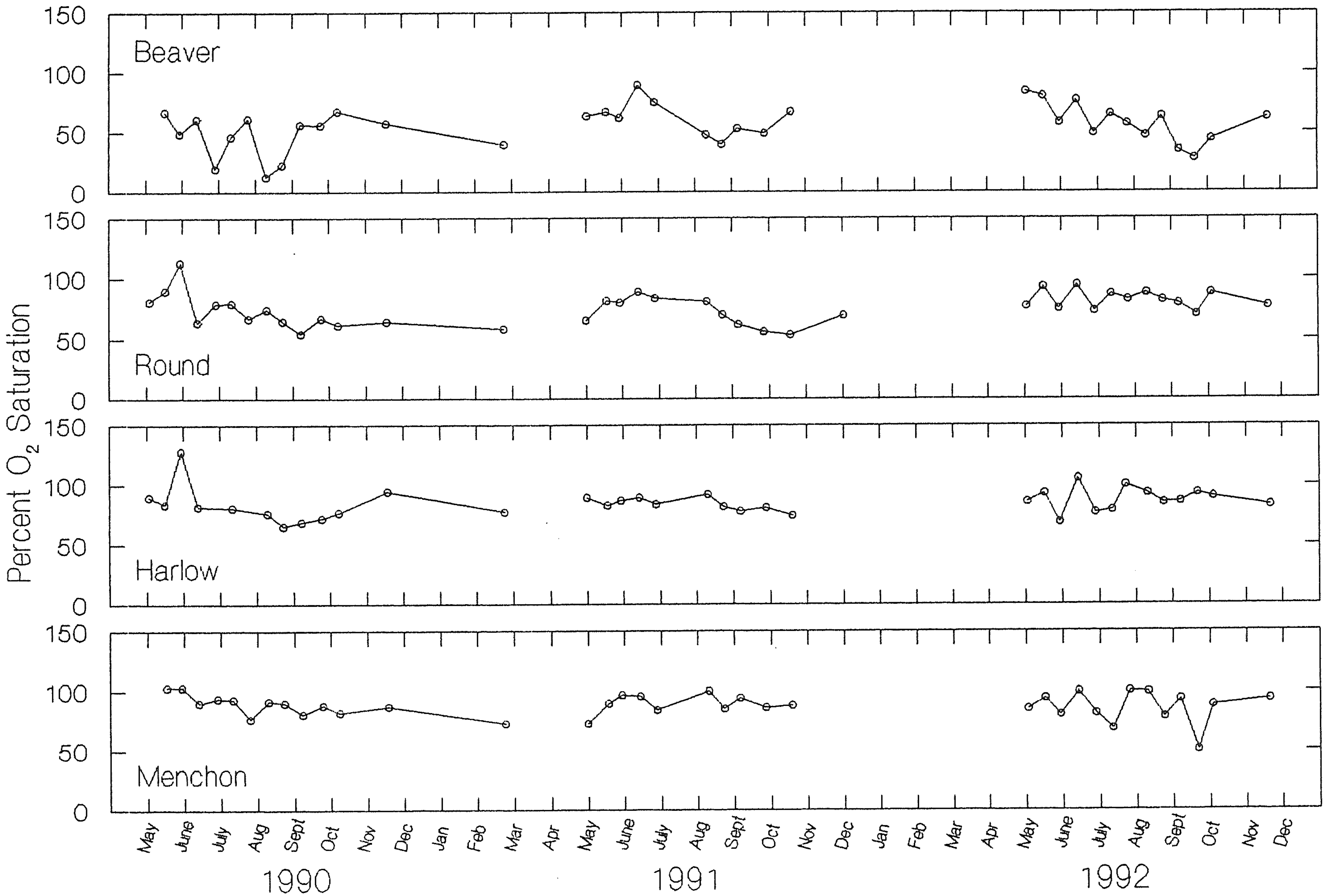

Dissolved Oxygen (ppm)
Beaver
Round
Harlow
Menchon
0 2 4 6 8 10 12
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
1990
1991
1992

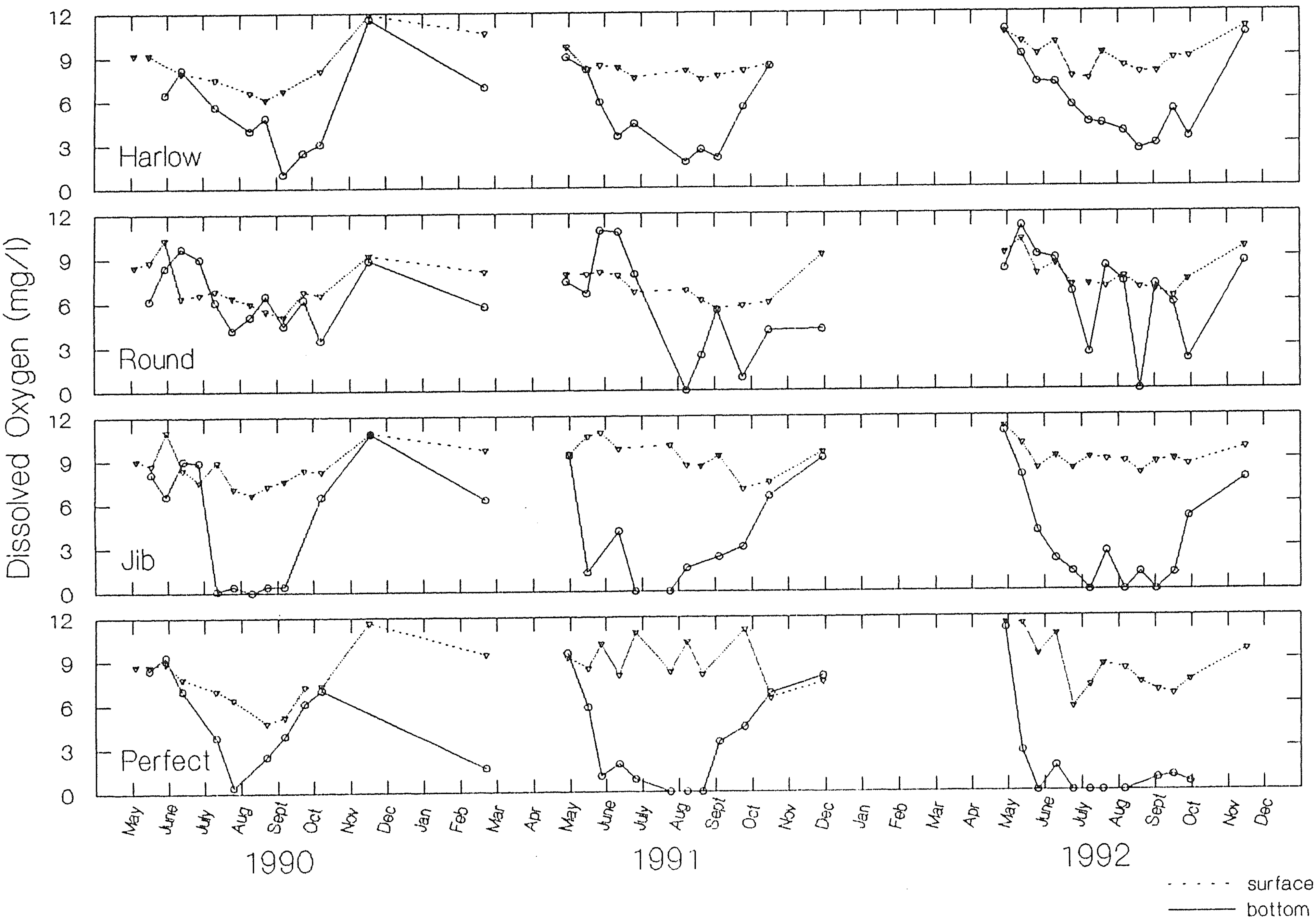


Dissolved Oxygen (ppm)
Jib
Stump
Oscar
Perfect
0
2
4
6
8
10
12
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992

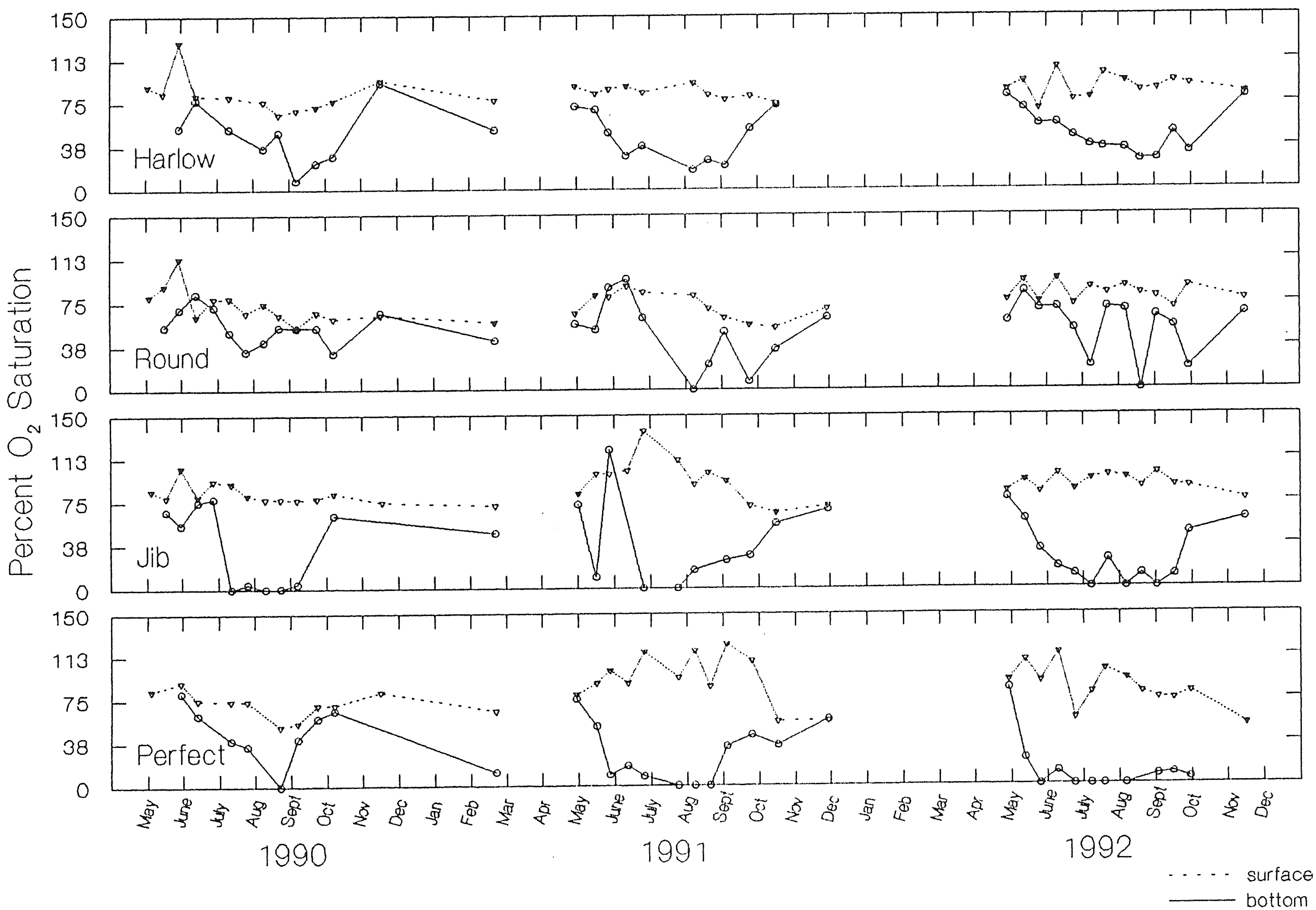


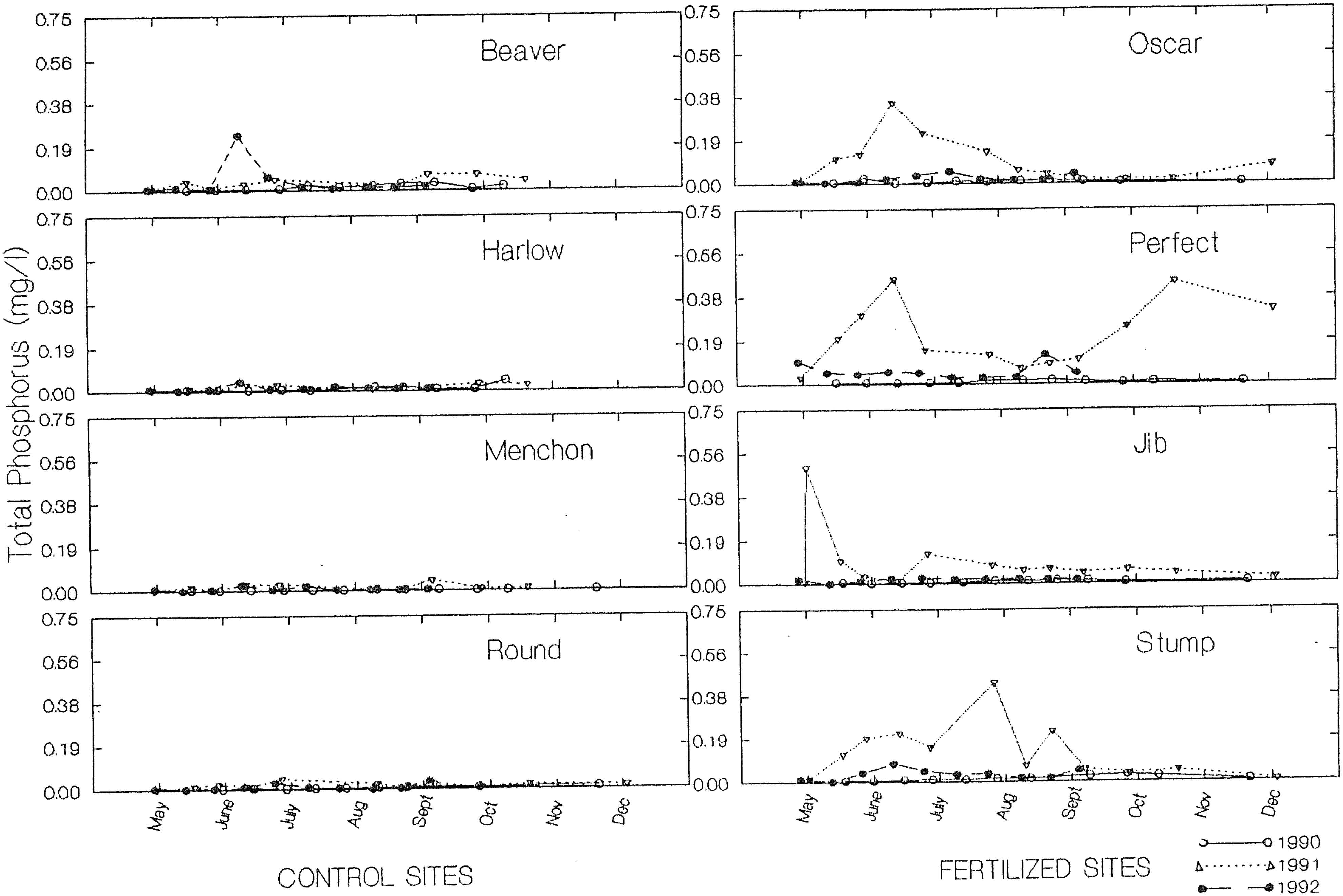
Percent O_2 Saturation
150
100
50
0
Jib
Stump
Oscar
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992


Beaver
Round
Harlow
Menchon
Percent O2 Saturation
150
100
50
0
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992

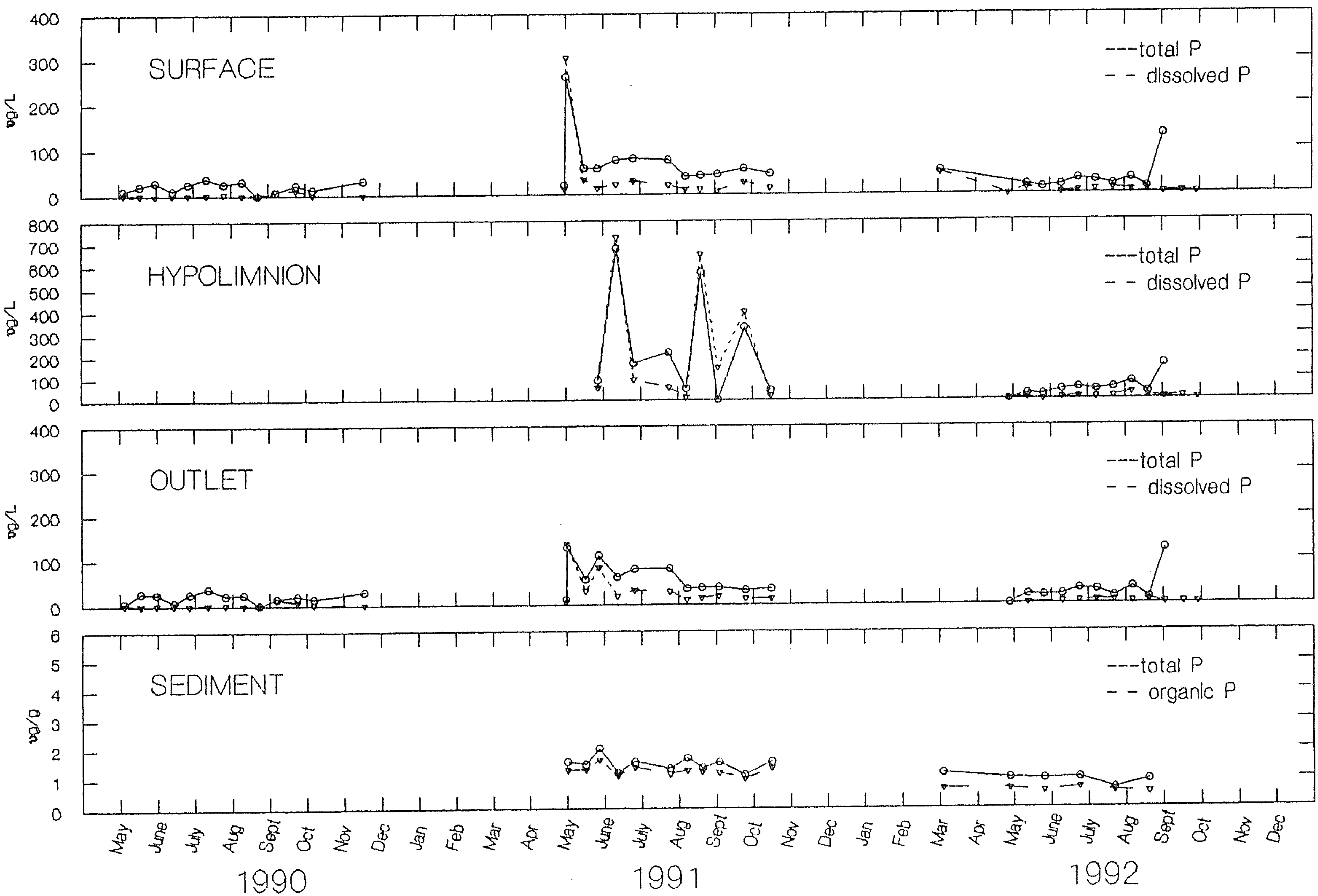


Dissolved Oxygen (mg/l)
Harlow
Round
Jib
Perfect
12
9
6
3
0
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
1990
1991
1992
surface
bottom

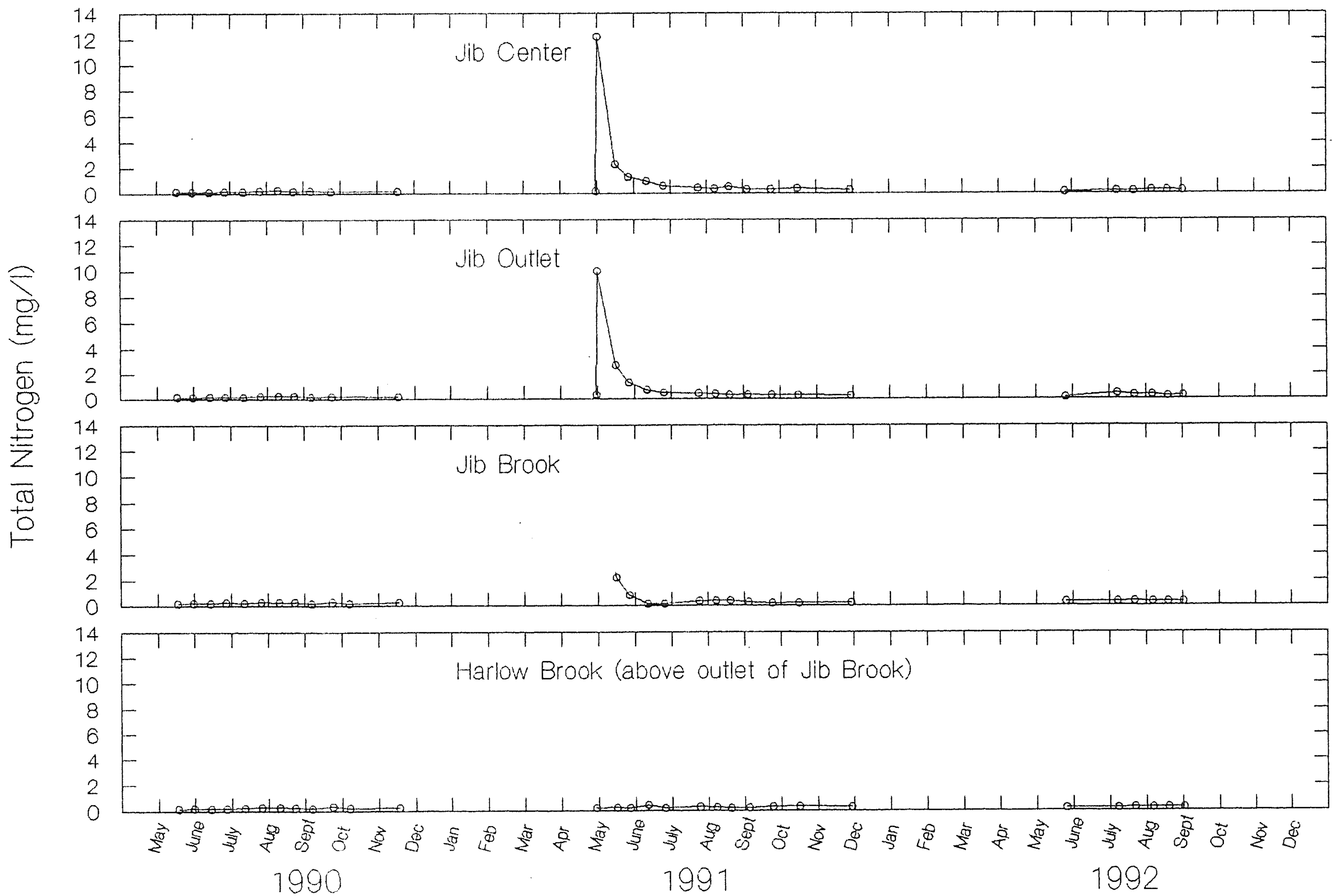

Percent O_2 Saturation
150
113
75
38
0
Harlow
Round
Jib
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992
surface
bottom


Total Phosphorus (mg/l)
0.75
0.56
0.38
0.19
0.00
Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992

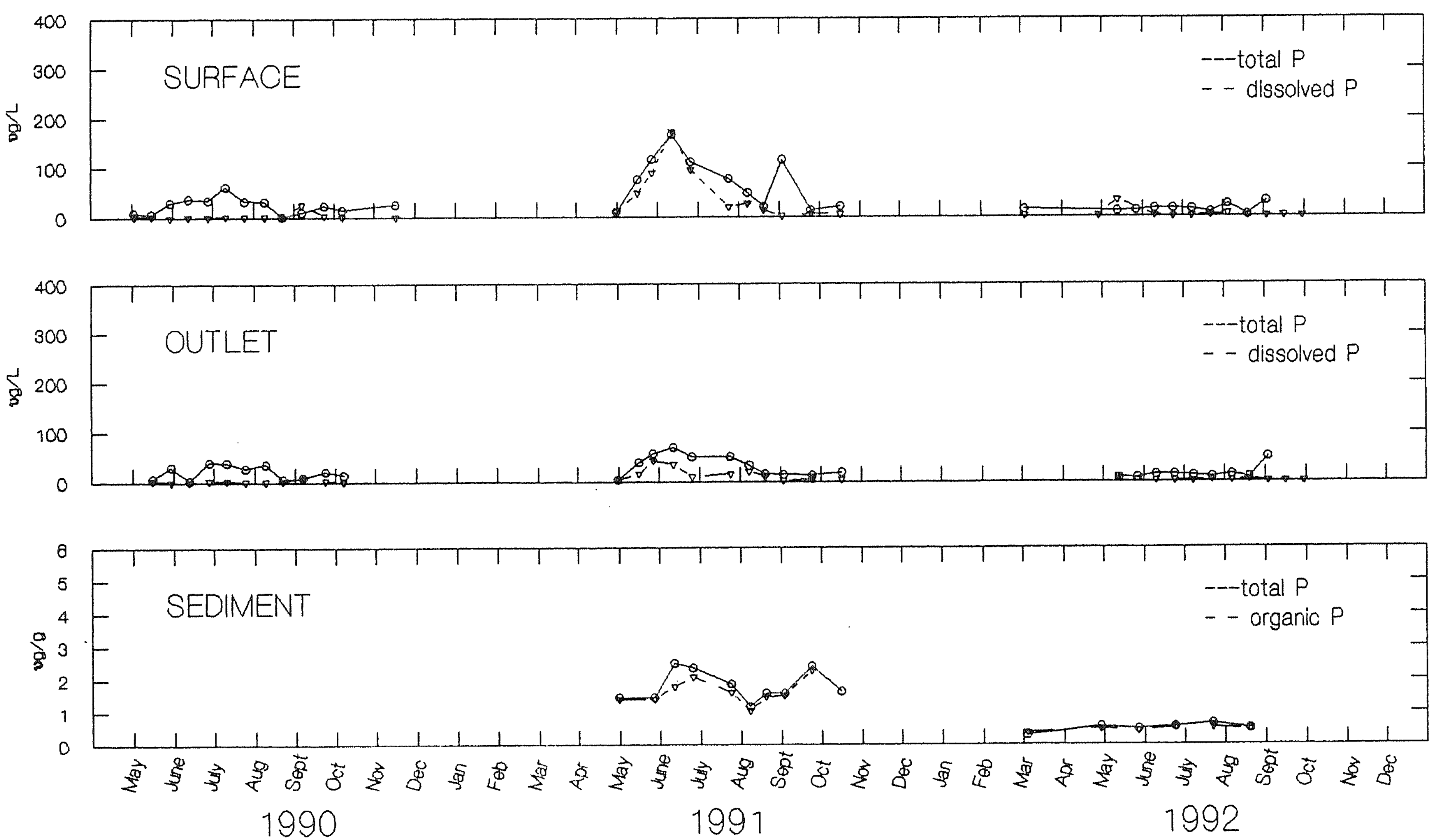
Jib



SURFACE
---total P
- - dissolved P
HYPOLIMNION
---total P
- - dissolved P
OUTLET
---total P
- - dissolved P
SEDIMENT
---total P
- - organic P
ug/L
ug/g
400
300
200
100
0
800
700
600
500
400
300
200
100
0
6
5
4
3
2
1
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
1990
1991
1992

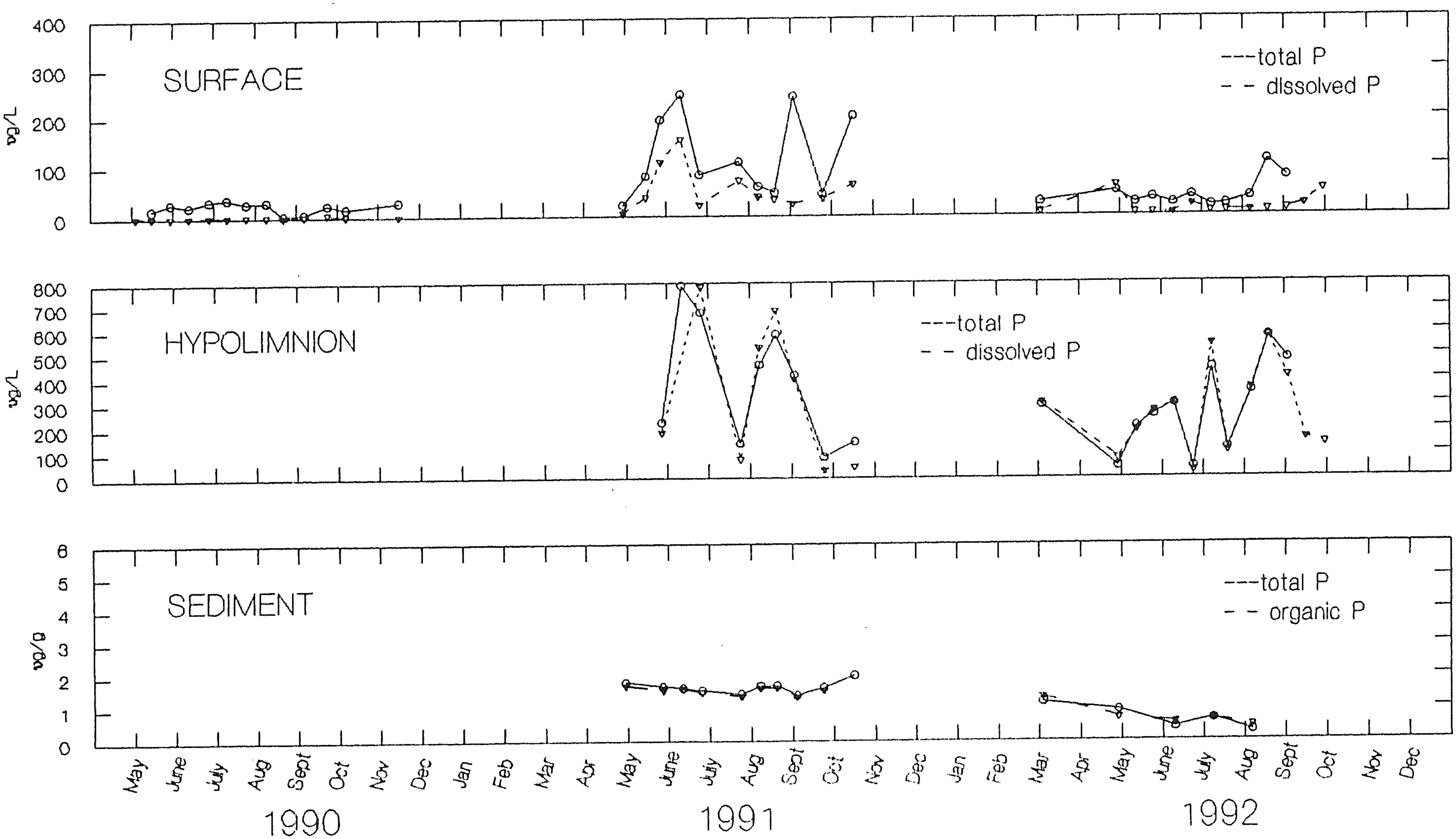

Total Nitrogen (mg/l)
Jib Center
Jib Outlet
Jib Brook
Harlow Brook (above outlet of Jib Brook)
0 2 4 6 8 10 12 14
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
1990
1991
1992

OSCAR



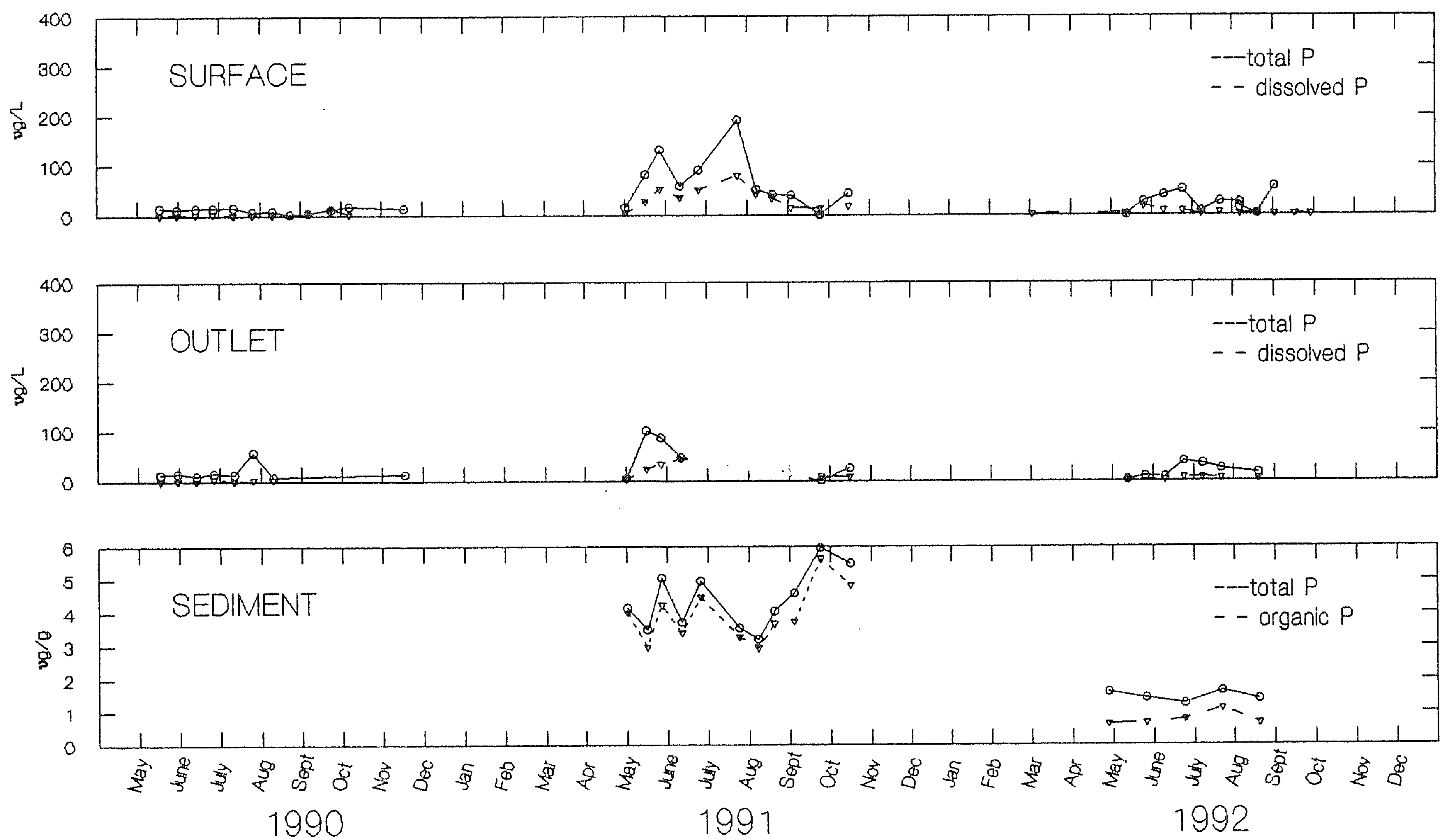
SURFACE
---total P
- - dissolved P
ug/L
400
300
200
100
0
OUTLET
---total P
- - dissolved P
ug/L
400
300
200
100
0
SEDIMENT
---total P
- - organic P
ug/g
6
5
4
3
2
1
0
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
1990
1991
1992

PERFECT

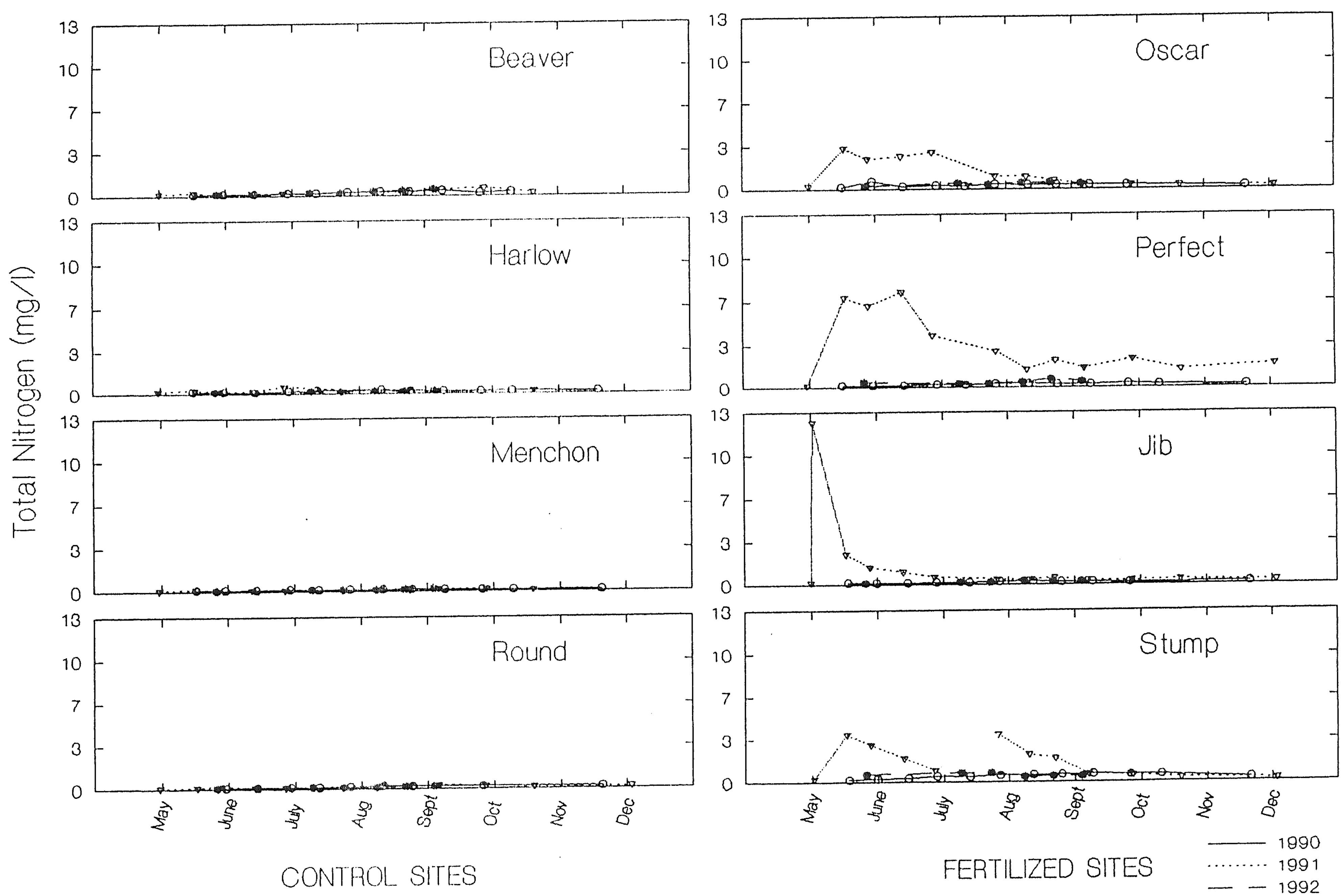


SURFACE
ug/L
400
300
200
100
0
---total P
- - dissolved P
HYPOLIMNION
ug/L
800
700
600
500
400
300
200
100
0
---total P
- - dissolved P
SEDIMENT
ug/g
6
5
4
3
2
1
0
---total P
- - organic P
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
1990
1991
1992

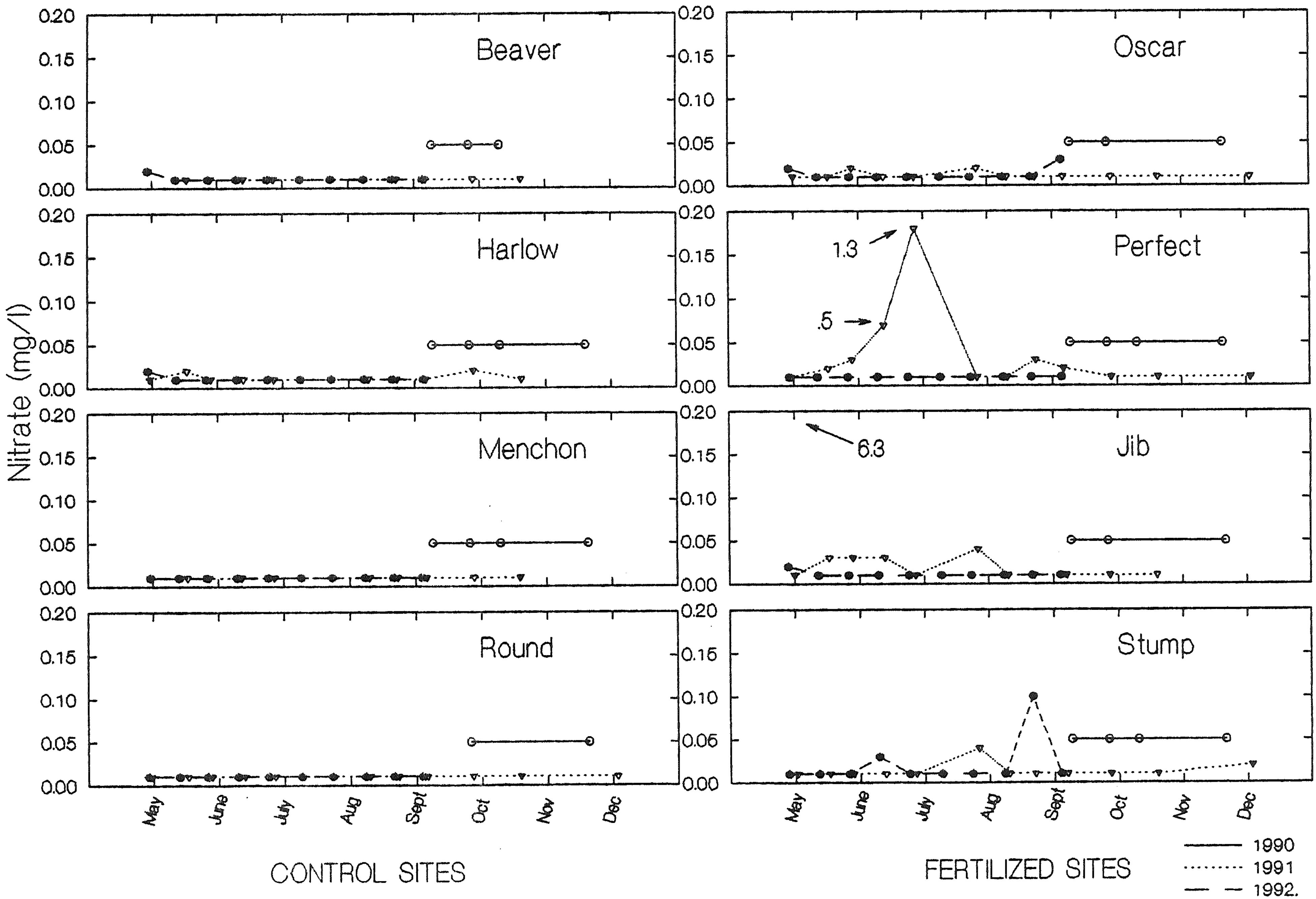
STUMP

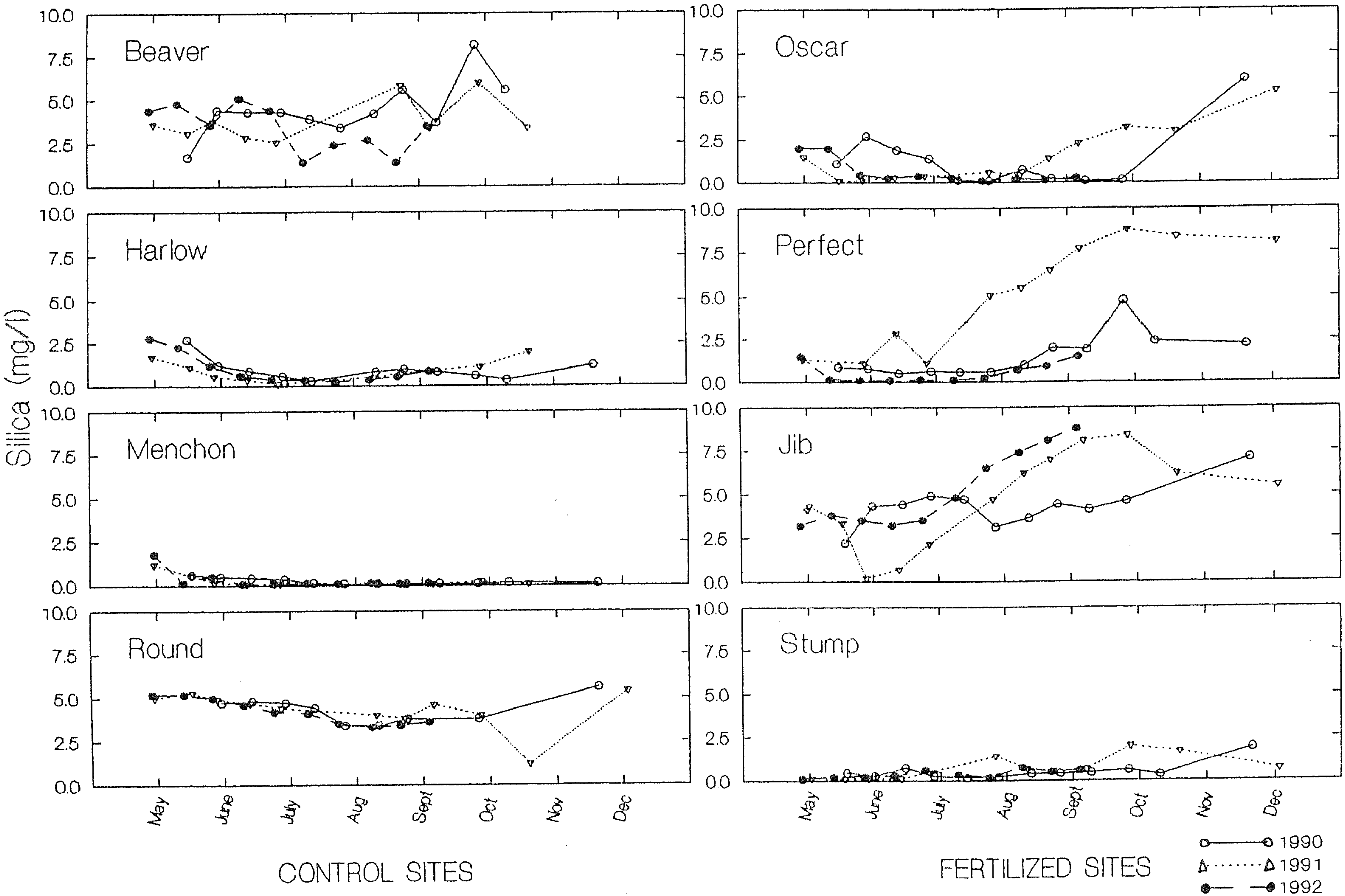


SURFACE
---total P
- - dissolved P
OUTLET
---total P
- - dissolved P
SEDIMENT
---total P
- - organic P
ug/L
ug/g
400
300
200
100
0
6
5
4
3
2
1
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr
1990
1991
1992



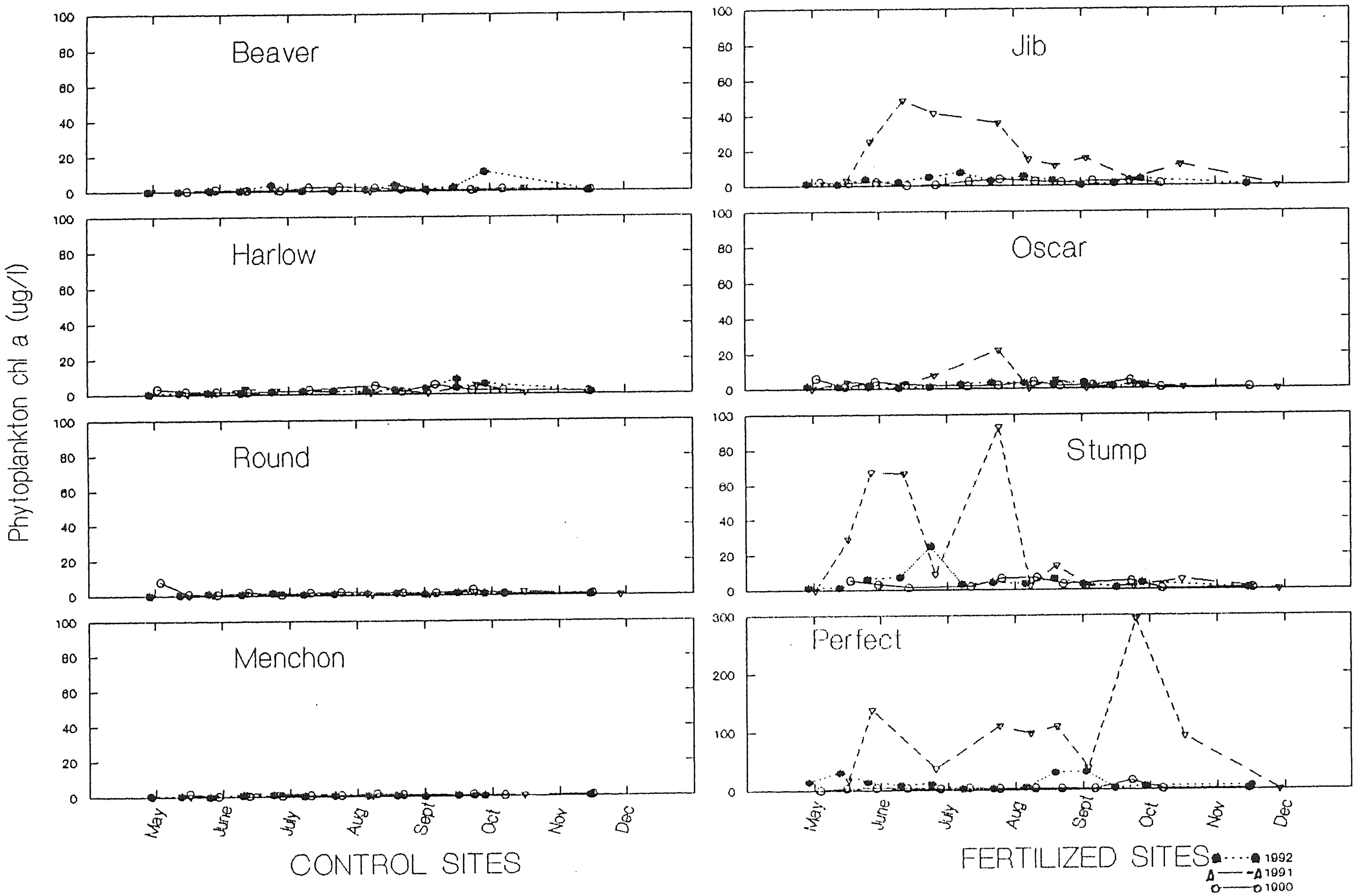
Total Nitrogen (mg/l)
Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
13
10
7
3
0
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992


Nitrate (mg/l)
Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
1.3
.5
6.3
0.20
0.15
0.10
0.05
0.00
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992.

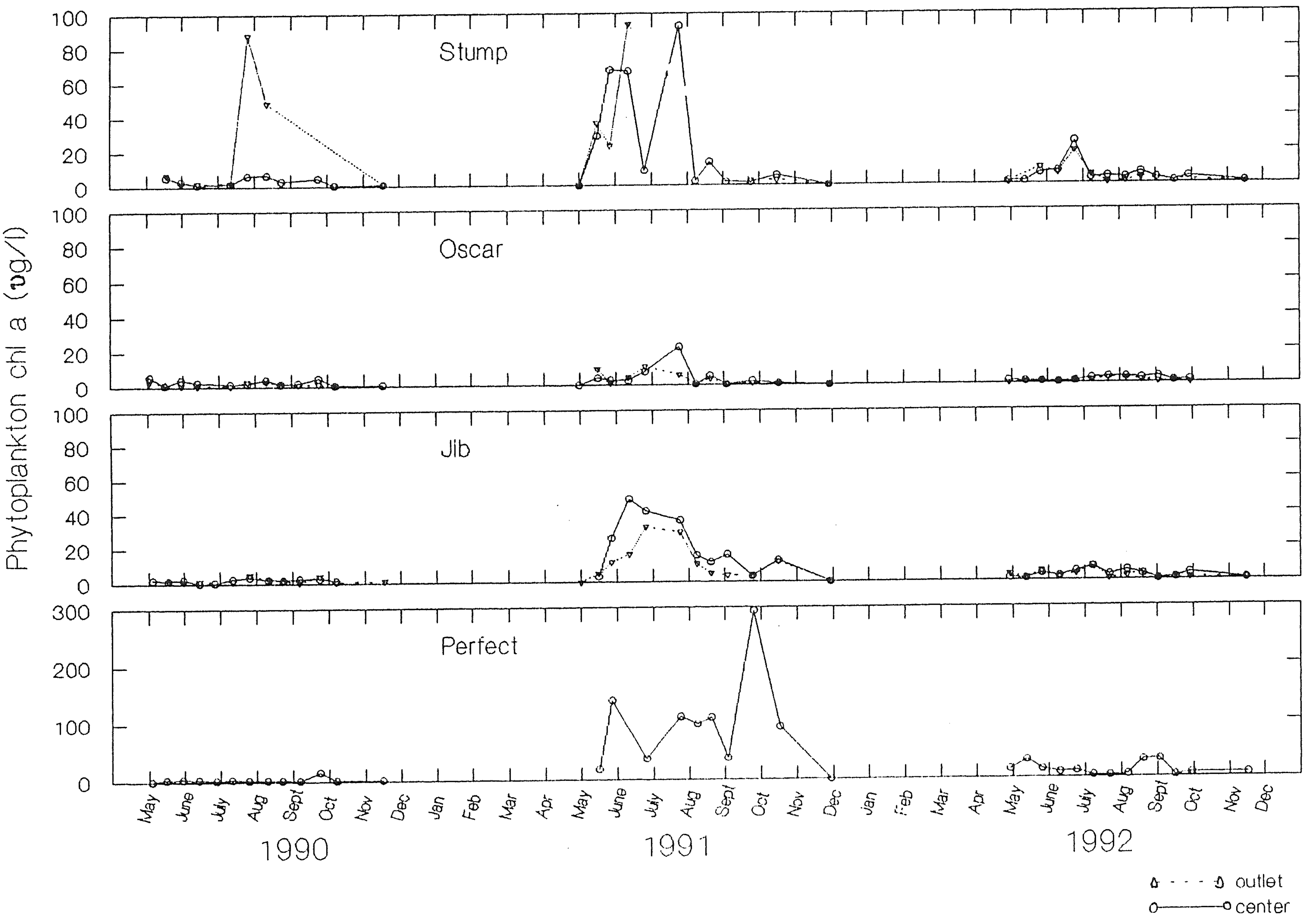


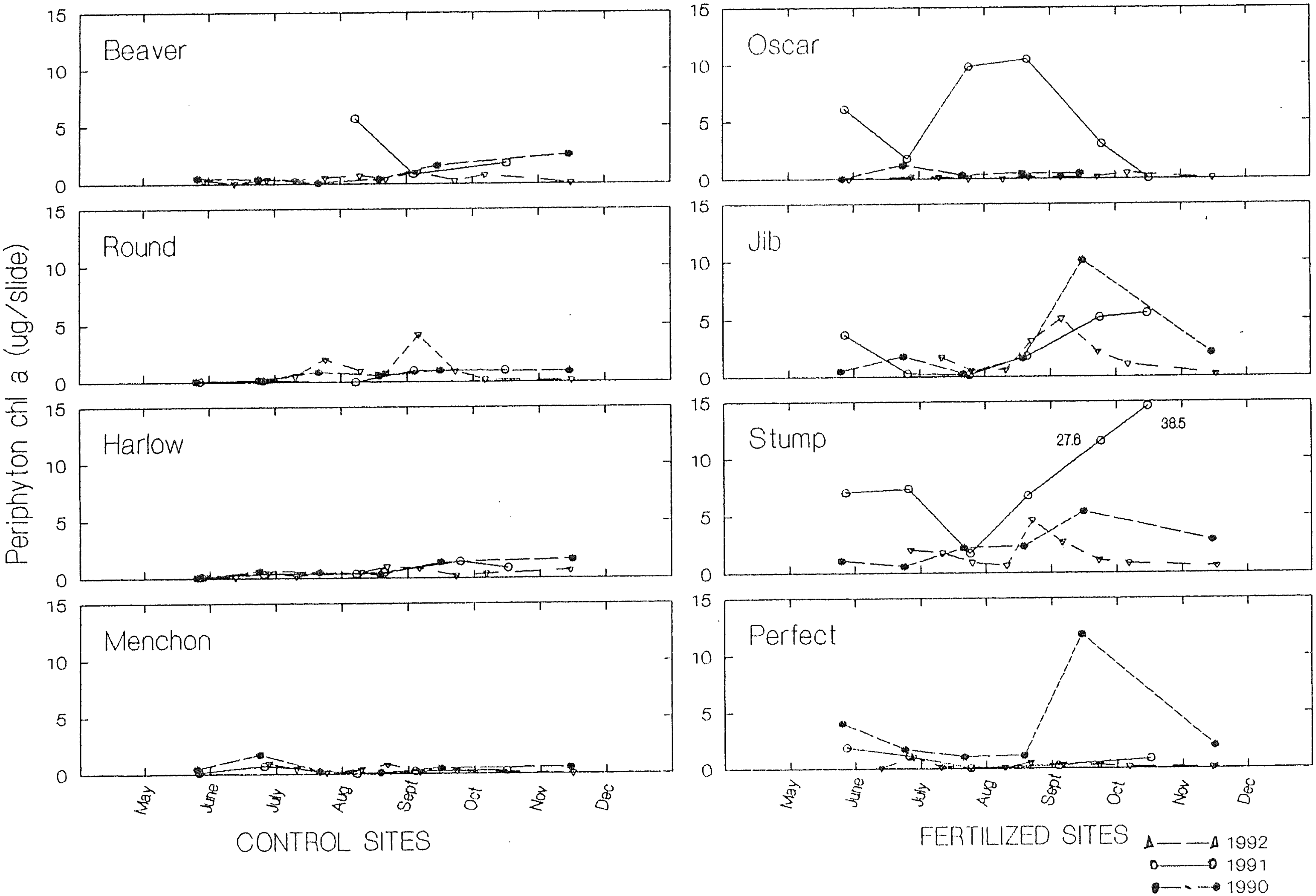
Silica (mg/l)
Beaver
Harlow
Menchon
Round
Oscar
Perfect
Jib
Stump
10.0
7.5
5.0
2.5
0.0
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1990
1991
1992

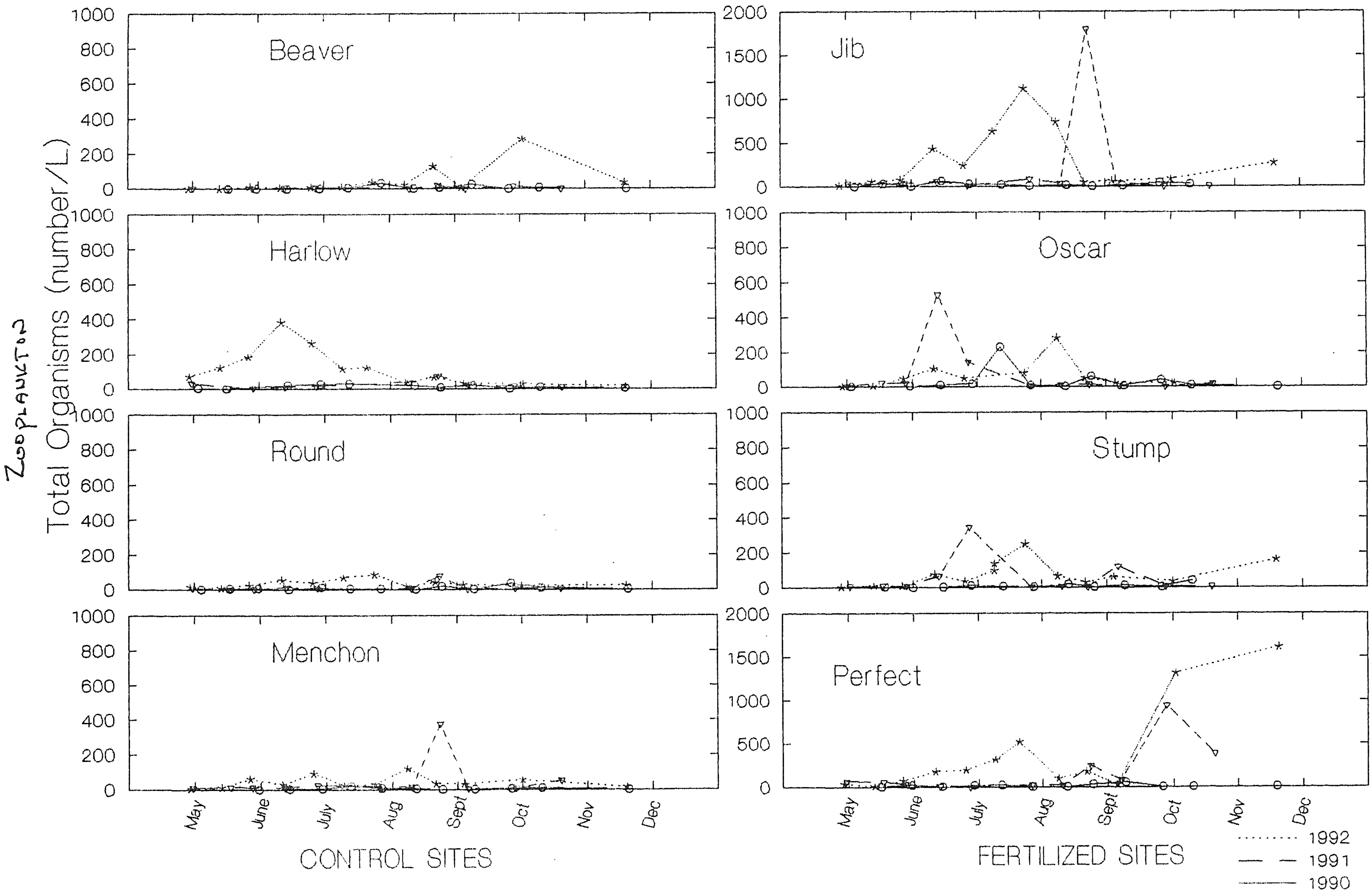
Appendix F. Graphical summaries of biological data

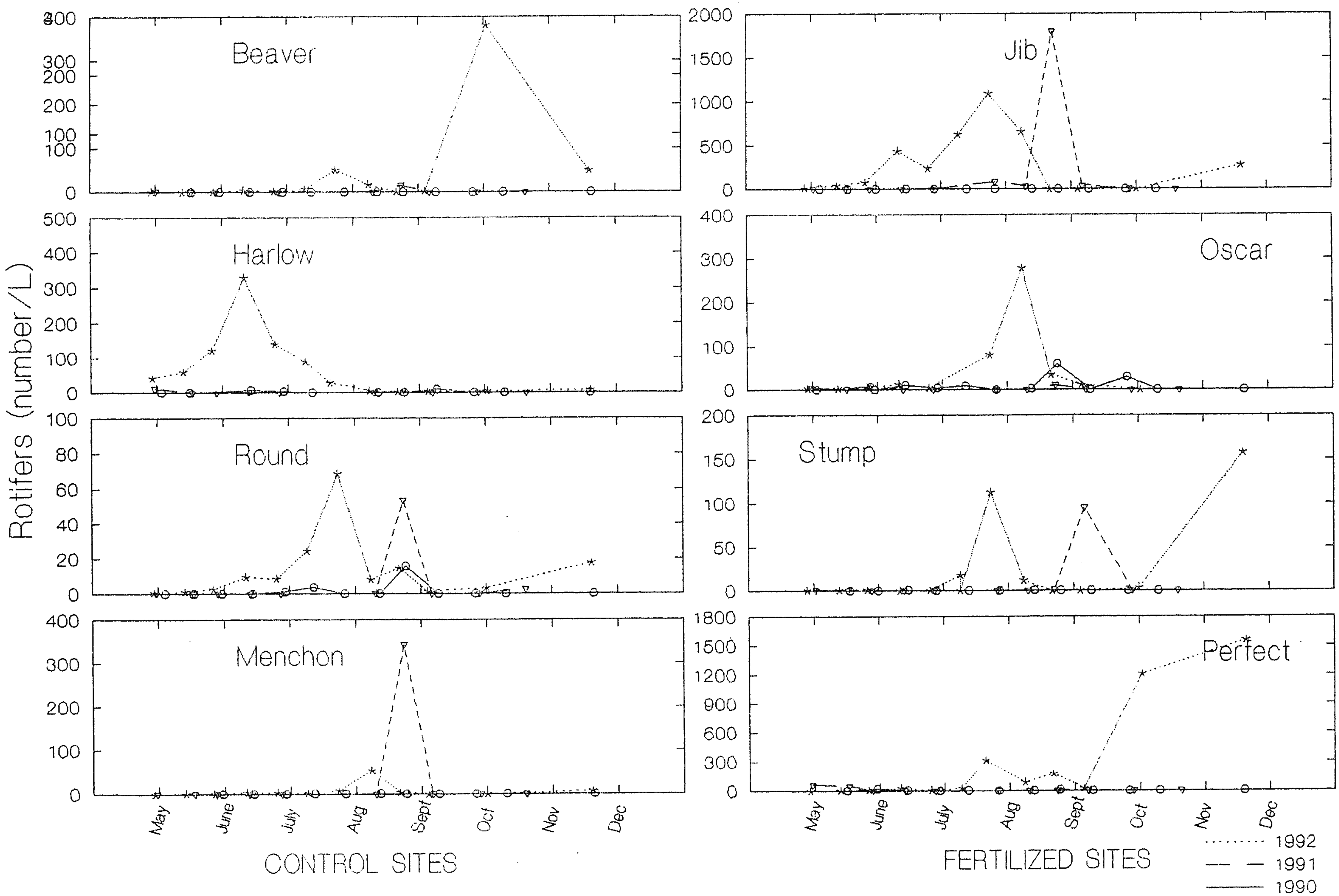


Phytoplankton chl a (ug/l)
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990

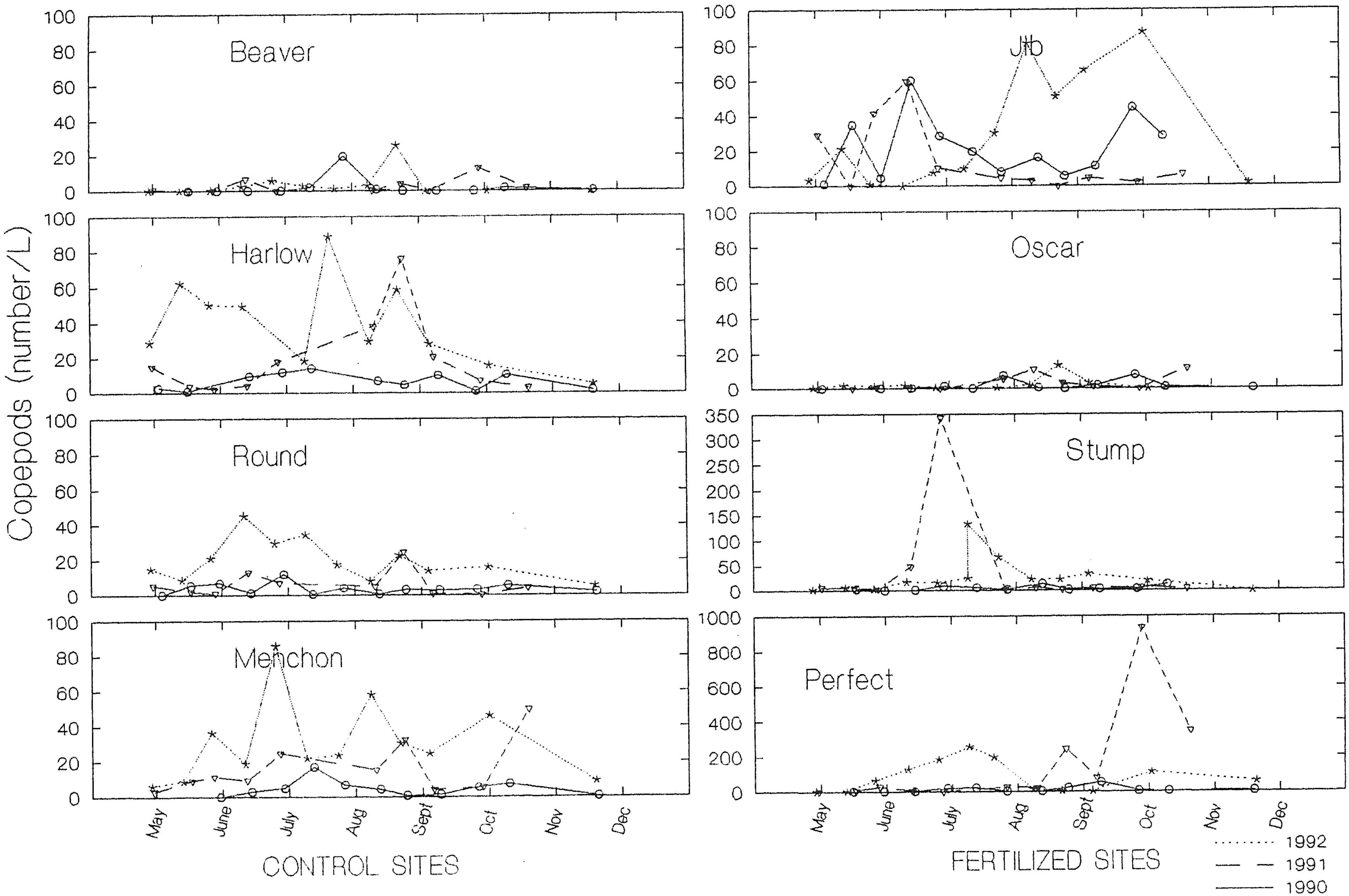

Stump
Oscar
Jib
Perfect
Phytoplankton chl a (ug/l)
0
20
40
60
80
100
200
300
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1990
1991
1992
outlet
center

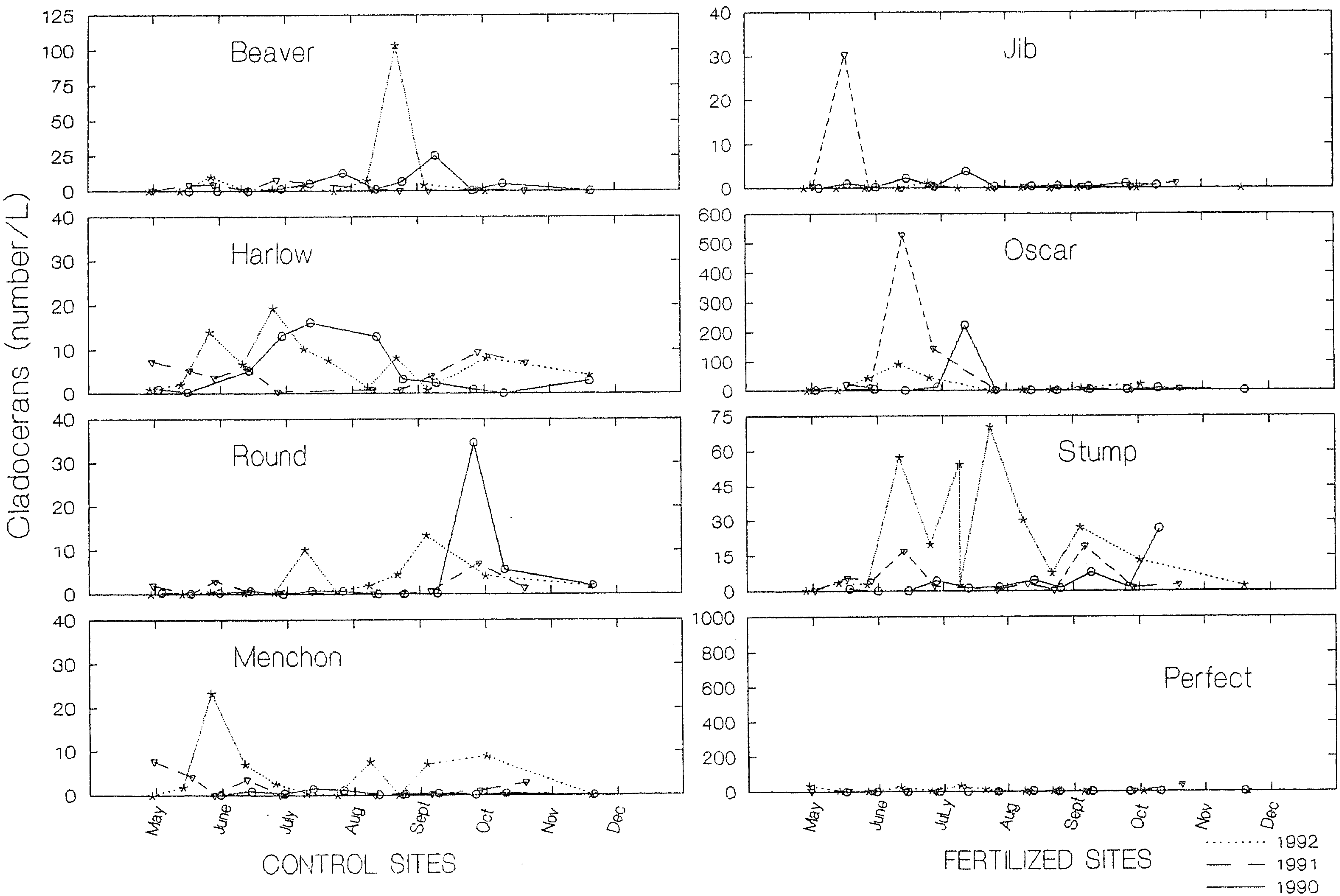

Periphyton chl a (ug/slide)
Beaver
Round
Harlow
Menchon
Oscar
Jib
Stump
Perfect
27.6
38.5
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990

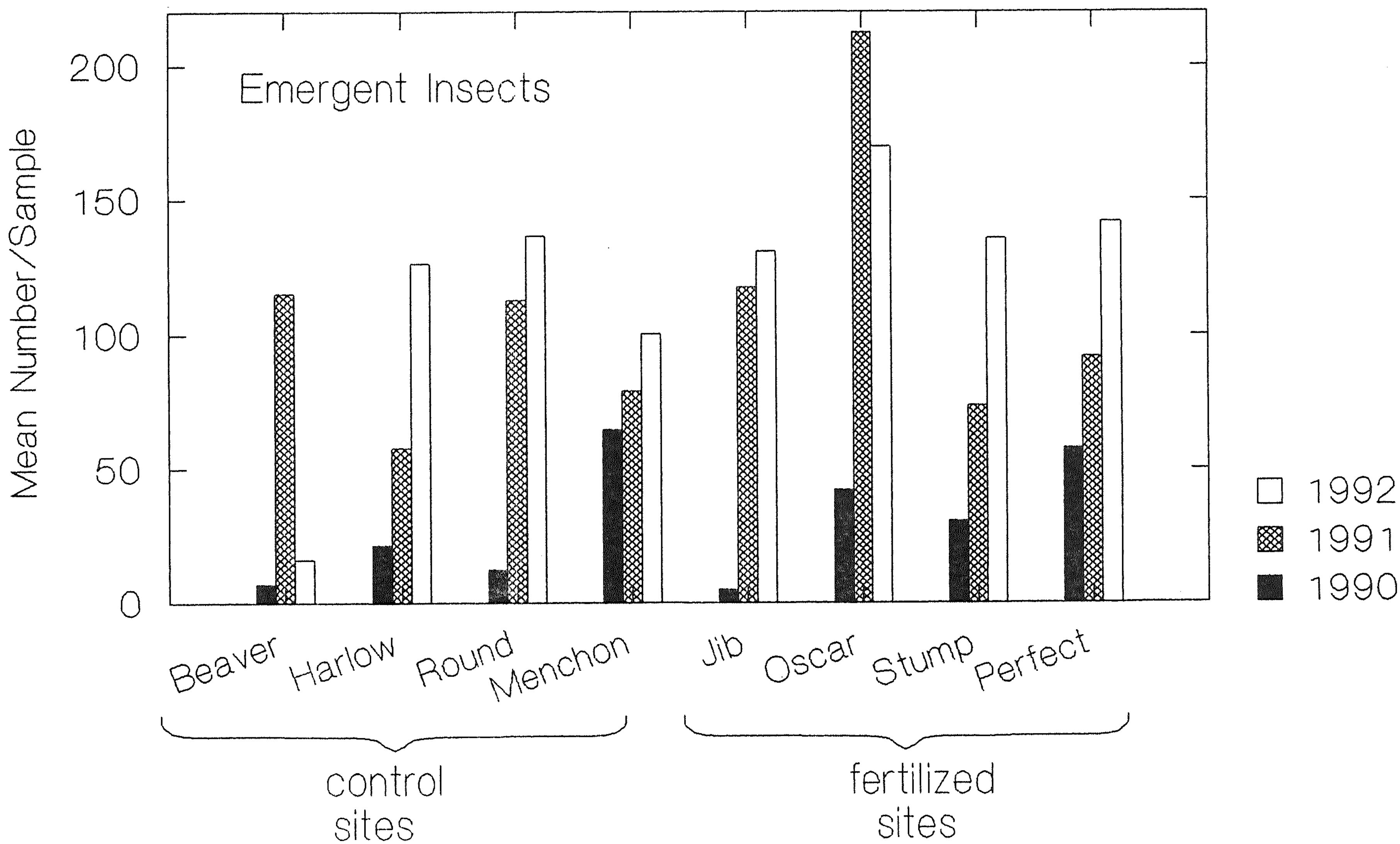

Zooplankton
Total Organisms (number/L)
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990

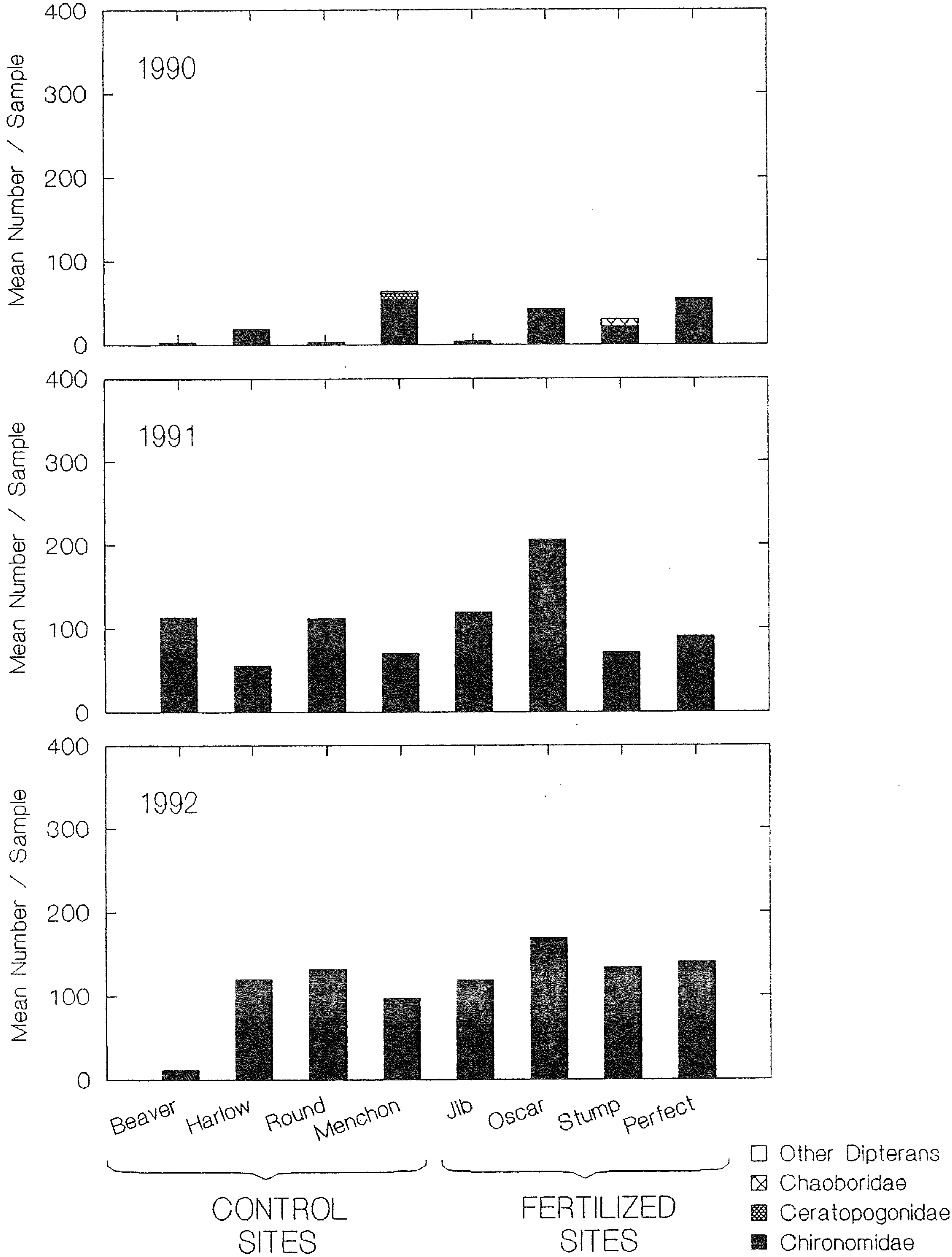


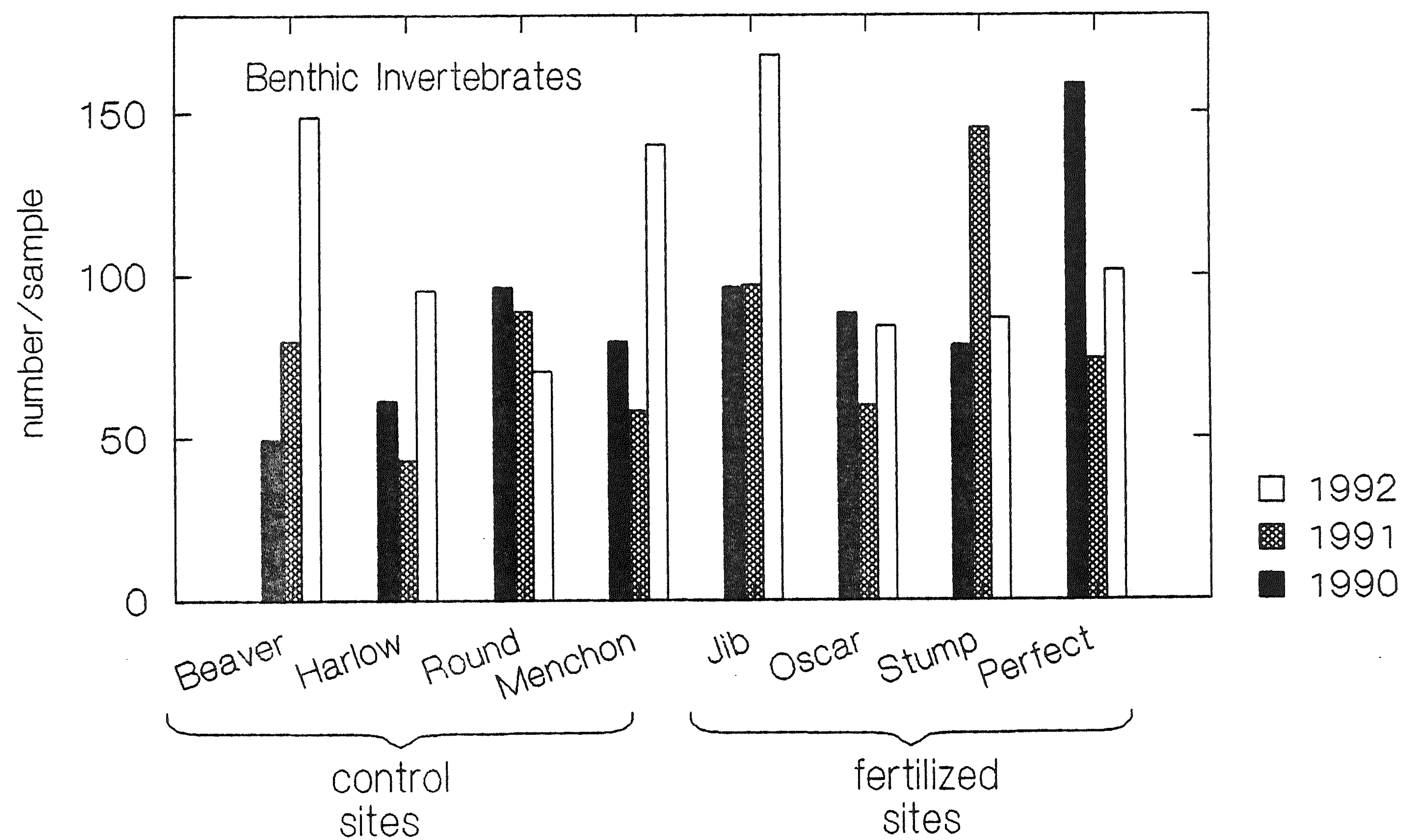
Rotifers (number/L)
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990


Copepods (number/L)
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
May June July Aug Sept Oct Nov Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990

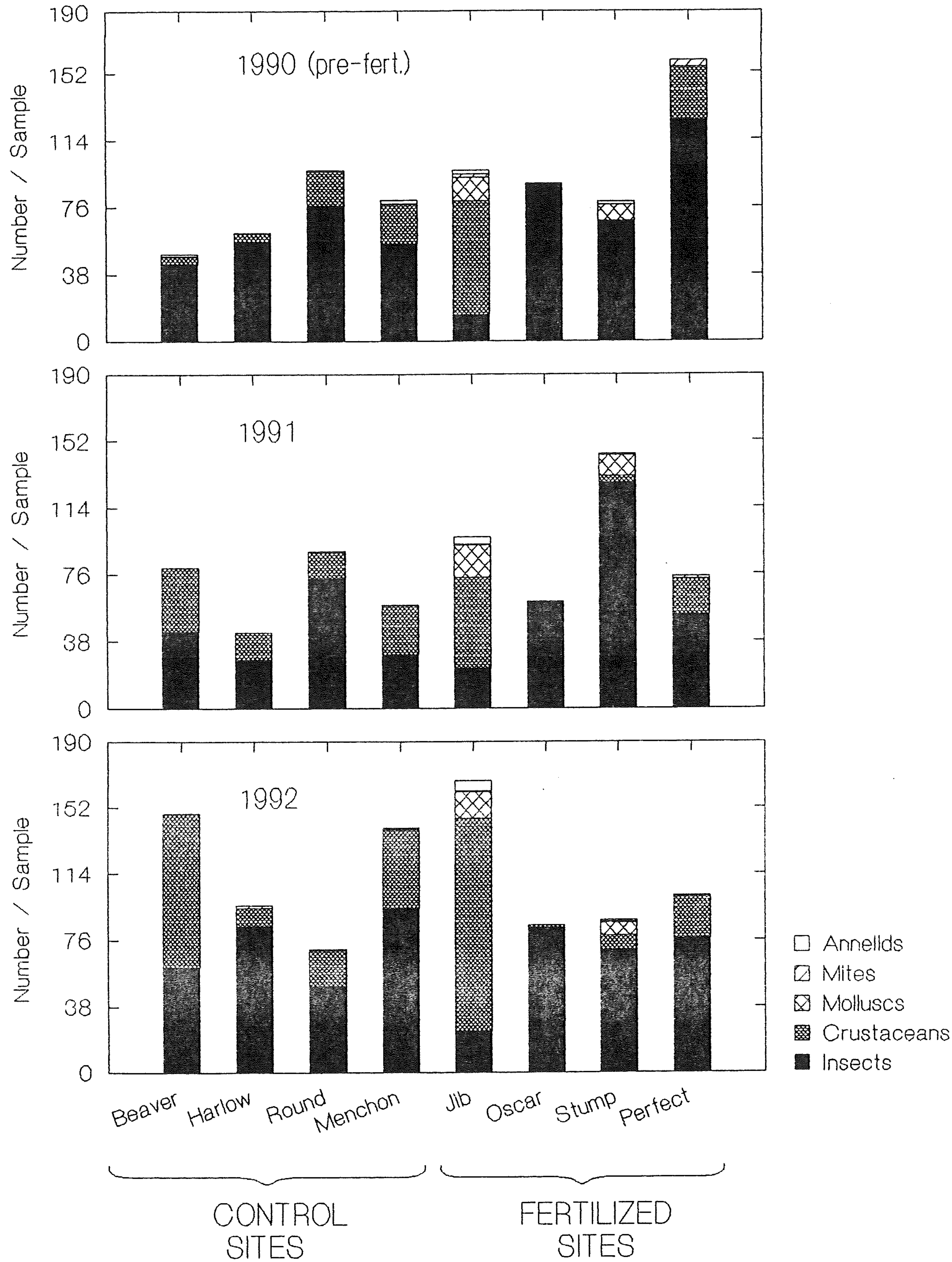

Cladocerans (number/L)
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
May
June
July
Aug
Sept
Oct
Nov
Dec
CONTROL SITES
FERTILIZED SITES
1992
1991
1990


Emergent Insects
Mean Number/Sample
200
150
100
50
0
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
control sites
fertilized sites
1992
1991
1990

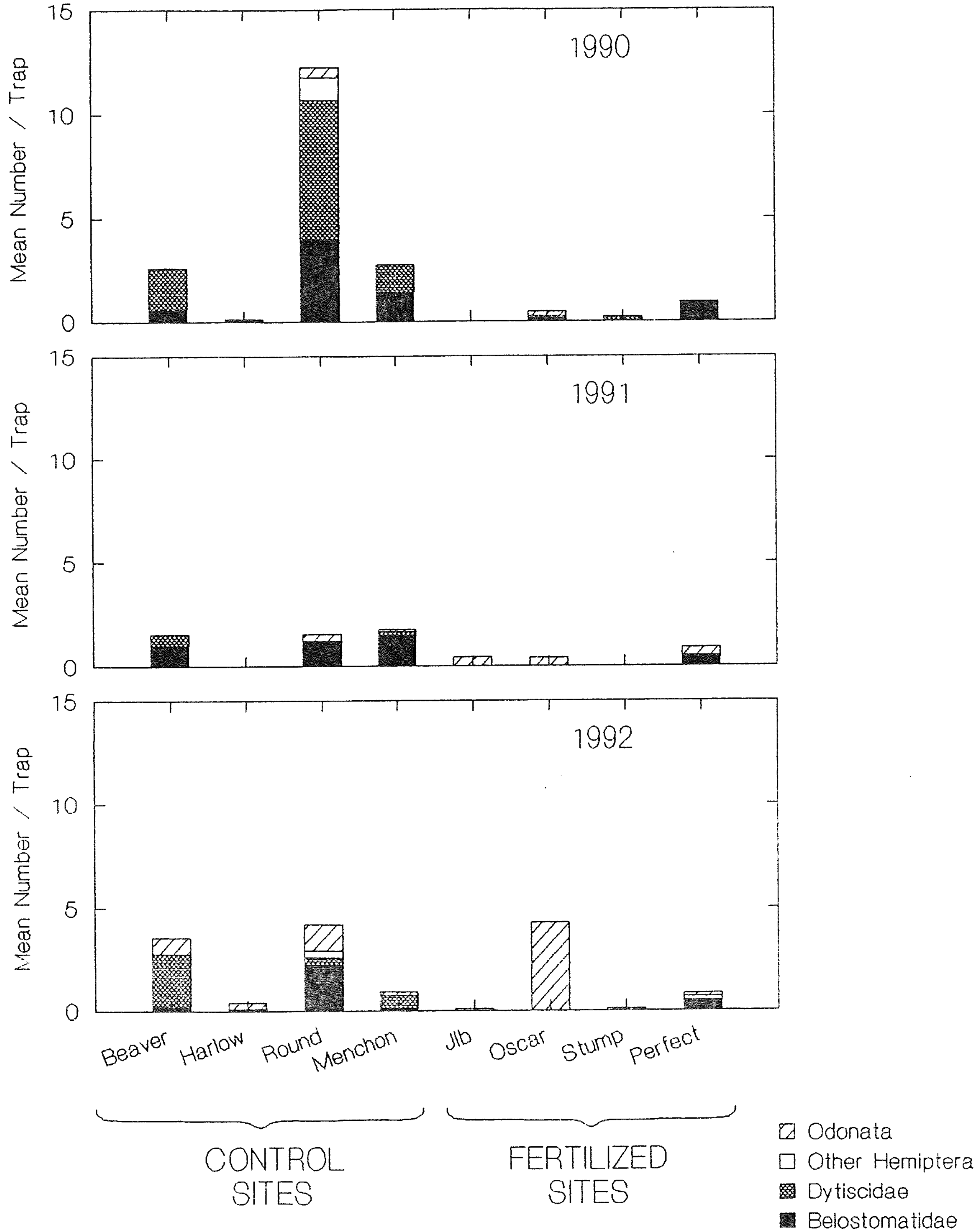

1990
1991
1992
Mean Number / Sample
0
100
200
300
400
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
CONTROL SITES
FERTILIZED SITES
Other Dipterans
Chaoboridae
Ceratopogonidae
Chironomidae

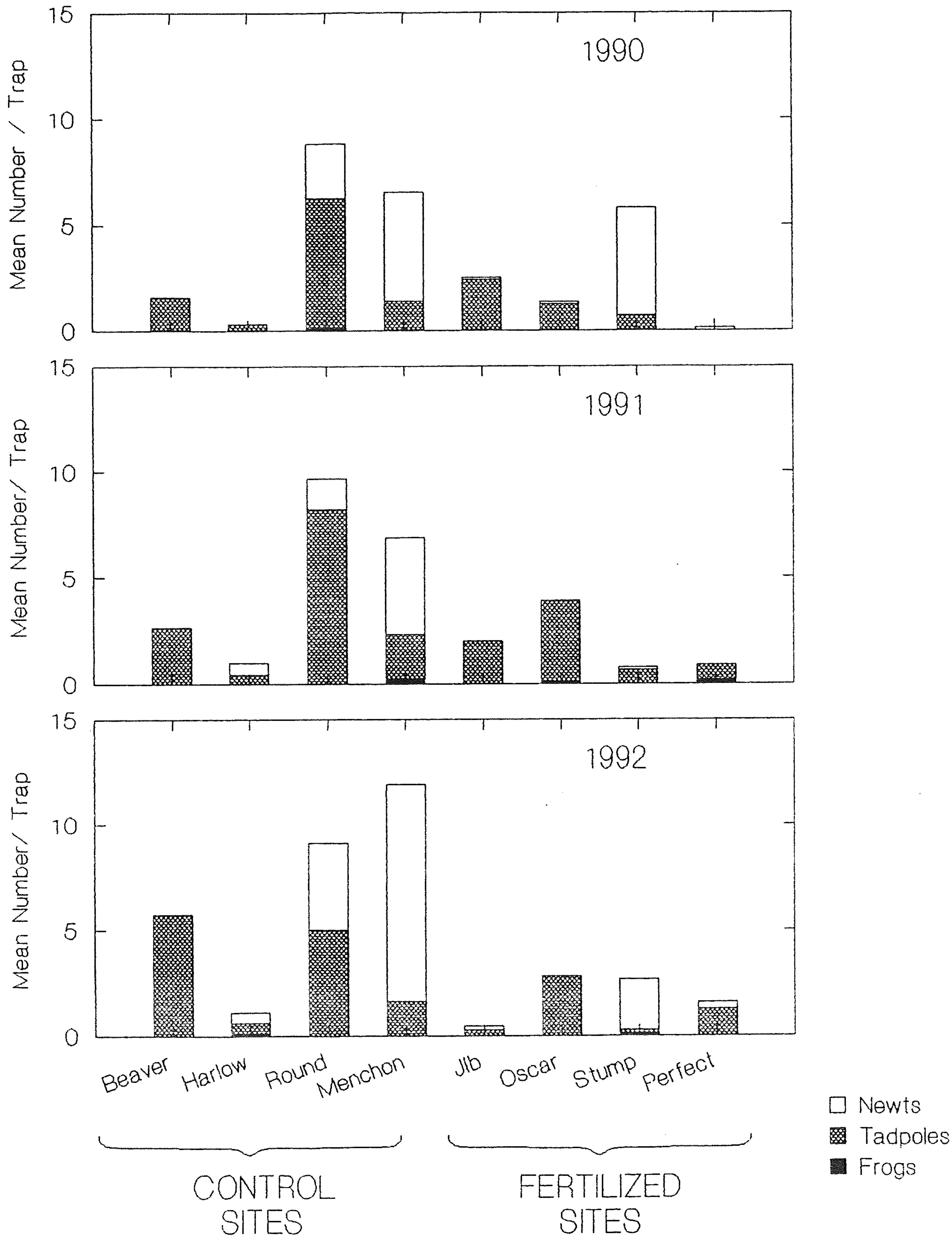


Benthic Invertebrates
number/sample
150
100
50
0
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
control sites
fertilized sites
1992
1991
1990

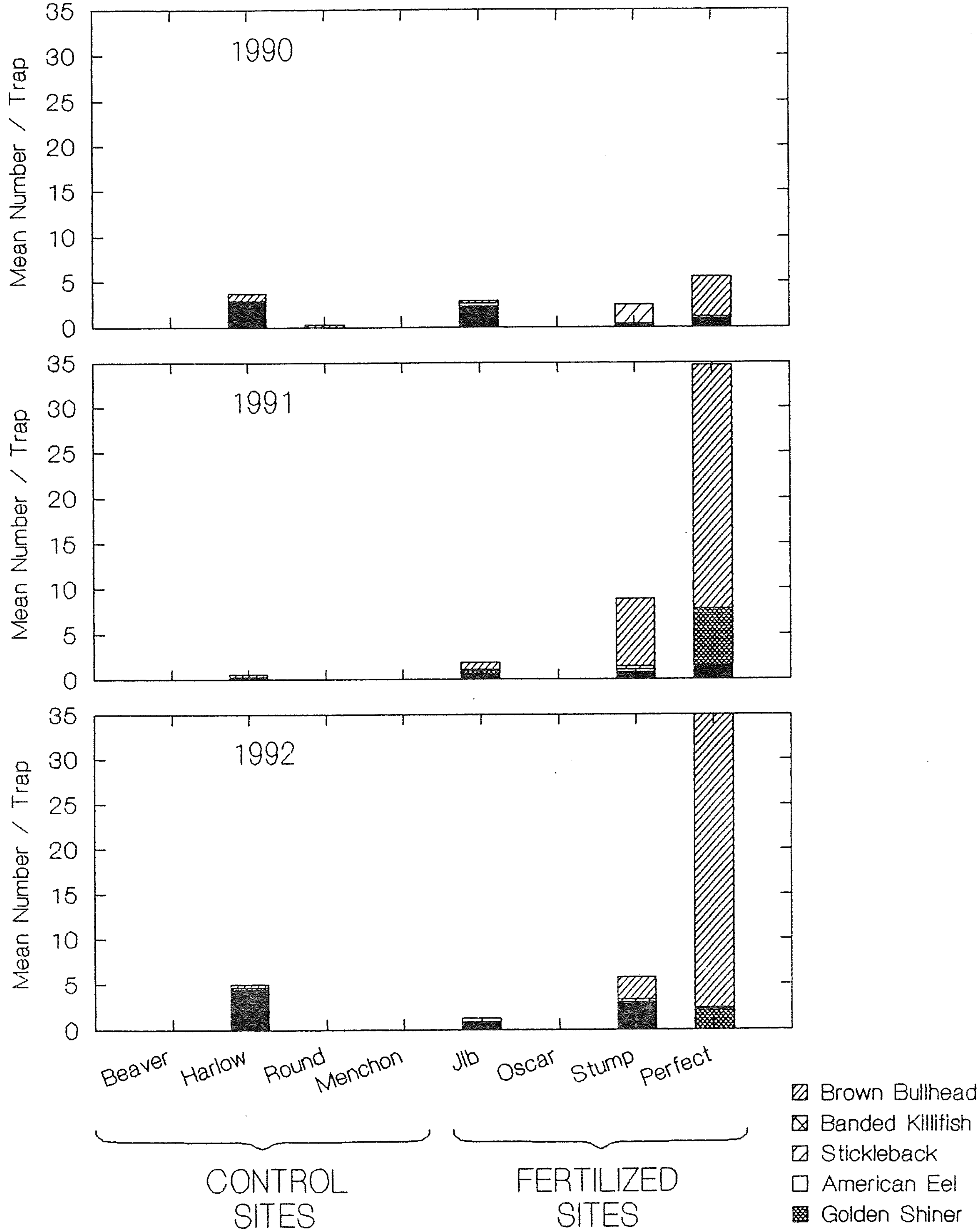


1990 (pre-fert.)
1991
1992
Number / Sample
0
38
76
114
152
190
Beaver
Harlow
Round
Menchon
Jib
Oscar
Stump
Perfect
CONTROL SITES
FERTILIZED SITES
Annelids
Mites
Molluscs
Crustaceans
Insects


15
10
5
0
Mean Number / Trap
1990
1991
1992
Beaver
Harlow
Round
Menchon
Jlb
Oscar
Stump
Perfect
CONTROL SITES
FERTILIZED SITES
Odonata
Other Hemiptera
Dytiscidae
Belostomatidae



1990
1991
1992
Mean Number / Trap
Mean Number/ Trap
Mean Number/ Trap
15
10
5
0
Beaver
Harlow
Round
Menchon
Jlb
Oscar
Stump
Perfect
CONTROL SITES
FERTILIZED SITES
Newts
Tadpoles
Frogs



1990
1991
1992
Mean Number / Trap
35
30
25
20
15
10
5
0
Beaver
Harlow
Round
Menchon
Jlb
Oscar
Stump
Perfect
CONTROL SITES
FERTILIZED SITES
Brown Bullhead
Banded Killifish
Stickleback
American Eel
Golden Shiner
Yellow Perch