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ZOOPLANKTON DYNAMICS AND WALLEYE (*Stizostedion vitreum*) PRODUCTION IN CULTURE PONDS AT METHLEY BEACH (DAUPHIN LAKE), MANITOBA: 1985 - 1989

by

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PREFACE

Some of the research outlined in this report was conducted as part of the PhD degree of the senior author at the Department of Zoology, University of Manitoba.

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ABSTRACT

Johnston, T.A., M.K. Friesen, J.A. Mathias, and K.D. Rowes. 1992. Zooplankton dynamics and walleye (*Stizostedion vitreum*) production in culture ponds at Methley Beach (Dauphin Lake), Manitoba: 1985 - 1989. Can. Tech. Rep. Fish. Aquat. Sci. 1841: vi + 34 p.

Young-of-the-year walleye (*Stizostedion vitreum*) were cultured in four 1 ha earthen ponds at Methley Beach (Dauphin Lake), Manitoba during the spring and summer of 1985, 1987, 1988 and 1989. Ponds were fertilized with alfalfa meal (range 0-1500 $kg \cdot ha^{-1}$) and stocked with prolarval walleye at densities of 40 000 to 88 $000 \cdot ha^{-1}$. Physical and chemical data indicated that primary productivity was generally low and declined during the culture period as well as over the years. In 1985, zooplankton community structure resembled that of Dauphin Lake but shifted to larger-bodied plankters in subsequent years following successful colonization by *Daphnia pulex*. Edible zooplankton densities were well above $100 \cdot L^{-1}$ during the walleye postlarval period in 1985 but declined over the years and only reached the $100 \cdot L^{-1}$ level once in 1989. Both mean edible zooplankton density and biomass over the postlarval period were positively correlated with total P inputs. Walleye growth rate during the postlarval period increased asymptotically with zooplankton abundance and total P inputs and was maximized at zooplankton densities at or above approximately $100 \cdot L^{-1}$. Walleye survival to late summer (range 85-107 days) ranged from 0.48 to 34.49%. Survival was lowest in 1989 when ponds were unfertilized and was most variable in 1987 when forage fish were present for the entire culture period. Survival was not significantly correlated to any measures of zooplankton abundance during the postlarval period. Mean length at harvest ranged from 41 to 130 mm and showed no relationship with either postlarval growth rate or total P inputs. Total yield ranged from 0.7 to 48.3 $kg \cdot ha^{-1}$ but was not significantly correlated with total P inputs. Walleye survival, size at harvest and yield did not appear to be determined by conditions during the postlarval period.

Key words: extensive culture; growth; survival; larvae; juveniles; fertilization

RÉSUMÉ

Johnston, T.A., M.K. Friesen, J.A. Mathias, and K.D. Rowes. 1992. Zooplankton dynamics and walleye (*Stizostedion vitreum*) production in culture ponds at Methley Beach (Dauphin Lake), Manitoba: 1985 - 1989. Can. Tech. Rep. Fish. Aquat. Sci. 1841: vi + 34 p.

De jeunes dorés de l'année (*Stizostedion vitreum*) ont été élevés dans quatre étangs de 1 ha creusés à même la terre à Methley Beach (lac Dauphin), Manitoba, au cours du printemps et de l'été en 1985, 1987, 1988 et 1989. Les étangs ont été fertilisés avec de la farine de luzerne (étendue: 0-1 500 $kg \cdot ha^{-1}$) et ensemencés avec des dorés au stade prolarvaire à des densités de 40 000 to 88 $000 \cdot ha^{-1}$. Les données physiques et chimiques ont indiqué que la productivité primaire a été généralement faible et qu'elle a diminué durant la période d'élevage de même qu'au fil des ans. En 1985, la structure de la communauté zooplanctonique ressemblait à celle du lac Dauphin, mais il y a eu déplacement vers les organismes planctonique de taille plus grande au cours des années suivantes après colonisation par *Daphnia pulex*. La densité du zooplancton commestible se situait bien au-delà de $100 \cdot L^{-1}$ au cours de la période d'élevage des dorés postlarvaires en 1985, mais a diminué au cours des ans et n'a atteint qu'une seule fois le niveau de $100 \cdot L^{-1}$ en 1989. La densité et la biomasse moyennes de zooplancton commestible au cours de la période postlarvaire ont toutes les deux présenté une corrélation positive avec l'apport en P total. Le taux de croissance des dorés a augmenté de manière asymptotique en fonction de l'abondance du zooplancton et de l'apport en P total et a été maximal lorsque la densité du zooplancton se situait aux environs de $100 \cdot L^{-1}$ ou plus. Le taux de survie du doré à la fin de l'été (étendue: 85-107 jours) a varié de 0,48 à 34,49 p. 100. Le taux de survie a été le plus faible en 1989, année où les étangs n'ont pas été fertilisés, et a été très variable en 1987, année au cours de laquelle des poissons fourrage ont été présents pendant toute la période d'élevage. La survie n'a pas été corrélée de manière statistiquement significative avec les diverses mesures de l'abondance du zooplancton durant la période postlarvaire. La longueur moyenne au moment de la récolte a été de 41 à 130 mm et ne présentait aucune relation avec le taux de croissance postlarvaire ni avec l'apport en P total. Le rendement total a varié de 0,7 à 48,3 $kg \cdot ha^{-1}$, mais on n'a pas observé de corrélation statistiquement significative avec l'apport en P total. La survie, la taille à la récolte et le rendement des dorés n'ont pas semblé être déterminés par les conditions qui régnaient au cours de la période postlarvaire.

Mots-clés: culture extensive; croissance; survie; larves; juvéniles; fertilisation

INTRODUCTION

A cooperative fisheries rehabilitation research program was initiated in 1982 by the Canada Department of Fisheries and Oceans and the Manitoba Department of Natural Resources with the goal of developing methods for the enhancement and rehabilitation of freshwater fisheries. One objective of this program was to examine the impacts of prolarval (fry) and juvenile (fingerling) walleye (*Stizostedion vitreum*) introductions on the walleye population of Dauphin Lake (51°17'N, 99°48'W), Manitoba. Consequently, a large scale spawn-taking and incubation program was undertaken to produce prolarvae, and an extensive culture program was initiated to produce juvenile walleye.

Stocking prolarval and juvenile walleyes as a means of enhancing native populations has become widespread in North America (Laarman 1978). Juveniles are commonly produced by introducing newly hatched prolarvae into culture ponds and allowing them to grow for one to several months (e.g. Smith and Moyle 1943; Miller 1952; Dobie 1956). However, walleye survival and production from culture ponds has often been quite variable (Li and Ayles 1981). Starvation mortality resulting from inadequate zooplankton densities during the early stages of exogenous feeding (postlarval period) has been hypothesized as a major source of this variability (Li and Mathias 1982).

To enhance walleye survival and growth, culture ponds are often fertilized to increase secondary production, particularly zooplankton (Buttner 1989). High densities of zooplankton are essential to ensure a high feeding rate (Mathias and Li 1982) and high survival of postlarval walleye (Li and Mathias 1982). Abundant zooplankton may also reduce the incidence of cannibalism among postlarvae (Loadman et al. 1986) and juveniles (McIntyre et al. 1987).

Our main objective for this study was to examine how conditions during the early stages of walleye feeding influence juvenile production. Specifically, we wished to investigate the relationships between the numbers, size and biomass of juveniles harvested and the zooplankton abundance and walleye growth during the postlarval period. In addition, we wanted to assess the effects of fertilization on the pond environment and the zooplankton communities, particularly during the postlarval period.

MATERIALS AND METHODS

STUDY SITE

Research was conducted at the Dauphin Lake Walleye Rehabilitation and Research Station at Methley Beach on the south-east shore of Dauphin Lake, Manitoba. The facility had four 1 ha rectangular earthen ponds for walleye culture. Each pond had a maximum capacity of 15 000 m^3 and ranged in depth from 1 m at the shallow end to 2 m at the deep end. The ponds were filled with water pumped from Dauphin Lake and were drained by gravity through an underground pipe system which connected the deep end of each pond with Dauphin Lake. Water pumped into the ponds was filtered through 500 μm Nitex® mesh to prevent unwanted fish introductions. The ponds were drained during the late summers of 1985, 1987, 1988 and 1989 to harvest the fish and were refilled during the following autumn or winter of each year. Valves at the outlet of each pond allowed them to be drained separately. The underground pipe system fed into an open concrete catch kettle situated between the ponds and the lake. By screening off the kettle outflow, walleye accumulated in the kettle during draining. This allowed the fish to be sampled and enumerated prior to transport and stocking.

POND TREATMENTS

The ponds were used for walleye culture during the spring and summer of 1985, 1987, 1988 and 1989. Following ice-off in late April the ponds were fertilized by towing dehydrated alfalfa meal in a mesh bag behind an outboard motor boat. By weight, the alfalfa meal had a C:N:K:P ratio of 403.2:12.5:10.4:1. The amounts of alfalfa added and the rate of addition differed among the four years (Table 1). Equal amounts were added to each pond in 1985 and 1987. In 1988, the fertilization rate was varied in an attempt to introduce a gradient of productivity among the four ponds and in 1989 the ponds were not fertilized. Alfalfa was added in a single treatment after ice-off in 1987 but in four equal doses at one week intervals following ice-off in 1985 and 1988. In addition, 46.0 kg of ammonium chloride (12.0 kg N) and 3.7 kg of phosphoric acid (1.0 kg P) were added to each of ponds 1 and 3 on 13 May 1987.

Zooplankton from Dauphin Lake were introduced incidentally to the ponds in all years at the time of refilling. The zooplankton of Dauphin Lake consisted primarily of small-bodied plankters with low numbers of Cladocera relative to Copepoda (Friesen and Mathias 1990). *Daphnia pulex* and some other zooplankton species were collected from local farm dugouts and introduced to pond 1 on 15 May 1985 and pond 4 on 17 May 1985 to increase the abundance of large-bodied plankters in the pond communities.

Walleye were stocked within 1 to 3 days of hatching. The number of fish introduced was estimated volumetrically. Stocking densities differed among years (Table 2) but were always less than 10 larvae·m^{-3}. In addition to walleye, an assortment of other species including fathead minnow (*Pimephales promelas*), brook stickleback (*Culaea inconstans*), Iowa darter (*Etheostoma exile*), and emerald shiner (*Notropis atherinoides*) were added to the ponds as juvenile walleye forage in July, 1985. Incomplete drainage of the ponds in 1985 allowed forage fish to survive until refilling and many were still present in the ponds at the beginning of the 1987 field season. Large numbers of them were removed by trap-netting but they were not completely eliminated. Some juvenile walleye from 1985 also survived until 1987 in pond 1 (4 fish) and pond 2 (30 fish) and were present throughout the culture period. Thus the pond fish assemblages were quite diverse in 1987. Walleye was the only fish species in the ponds during the postlarval period (May-June) for 1985, 1988, and 1989.

POND SAMPLING AND MONITORING

Though the culture ponds were sampled most intensively for zooplankton and fish, physical and chemical conditions were also monitored. Pond temperature was recorded at a depth of 75 cm throughout the culture period, except during the summer of 1989, using a 7-day continuous-recording Weksler® temperature recorder (Model #06MNL). Secchi depth readings were taken at the deep end of each pond at weekly intervals in 1985, 1987 and 1988. Water samples were collected for analyses of conductivity, alkalinity, chlorophyll, particulate solids (TSS), particulate phosphorous (Susp P), particulate nitrogen (Susp N), particulate carbon (Susp C), ammonia (NH_4-N), total dissolved phosphorous (TDP), total dissolved nitrogen (TDN), dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC) on two occasions in 1985, four occasions in 1987 and on seven occasions in 1988. Chemical analyses were performed at the Analytical Laboratory of the Freshwater Institute in Winnipeg following the methodologies of Stainton et al. (1977).

Zooplankton were sampled at approximately weekly intervals throughout the walleye postlarval period in all years. Additional samples were collected before and after the postlarval period in 1985 and 1987. All collected organisms were preserved in 3-5% formalin buffered with 2% saturated sodium borate solution by volume. The sampling procedures changed over the study period.

In 1985 an integrated tube sampler was used. Collections were made by vertically lowering a clear acrylic tube (internal diameter 76 mm) to the pond bottom, capping the top end, raising the bottom end close to the water surface and capping the bottom end. The zooplankton were concentrated by pouring the tube of water through a 73 μm mesh net. Two samples, each consisting of four tubes, were taken for each pond on each sample date. Samples were taken at the deep end of the ponds early in the season and at mid-pond during the remainder of the year.

In an attempt to increase the zooplankton sample sizes from those collected in 1985, horizontal tows were conducted in 1987. Each tow consisted of hauling a 25 cm diameter, 73 μm mesh net horizontally from the deep end to the shallow end of the pond. To integrate the sample over depth the net was hauled for 22.5 m at each of the following depths; 0.00, 0.25, 0.50, 0.75, 1.00, and 1.25 m. By late spring it was suspected that increasing amounts of filamentous algae were clogging the nets and reducing filtering efficiency. For all subsequent tows a flowmeter was mounted inside the mouth of the net to estimate volume filtered. In later calculations it was assumed that filtering efficiency was 100% for the first two sampling dates (23 April and 13-14 May) when filamentous algae was sparse. The efficiency for other tows taken prior to the use of the flowmeter were corrected by using flow readings from the next nearest sampling dates. Two replicate tows were taken for each sample date by pond combination.

The sampling procedure used in 1988 and 1989 was chosen as a compromise between techniques used in 1985 and 1987. Vertical hauls were taken with paired Wisconsin nets (25 cm diameter; 73 μm mesh). Each sample consisted of three hauls taken at three equally-spaced points along a transect parallel to the longitudinal axis of the ponds. Three samples corresponding to three transects were taken at each sample date by pond combination. Evans and Sell (1985) found that the filtering efficiency of a 73 μm-mesh net increased with decreasing haul depth and that efficiency was near 80% for a 6 m deep haul. Because of the shallow haul depth in this study (1-2 m), it was assumed that net clogging was negligible and that filtering efficiency was 100%. In addition to these quantitative samples, several qualitative samples of zooplankton were collected in 1988 and 1989 and frozen for dry weight determinations.

Walleye were sampled primarily during the postlarval period and occasionally during the later juvenile period. In this study we defined the postlarval period as the life stage where zooplankton was the primary food source. This corresponded approximately to walleye in the 8-25 mm size range. Fish which had not begun exogenous feeding were classified as prolarvae and fish larger than 25 mm were classified as juveniles. The first sample date in each year was set to roughly coincide with the onset of first feeding and subsequent samples were taken at 4 to 10 day intervals in correspondence with the zooplankton sampling schedule. Postlarval fish were collected by trawling peired bongo samplers mounted on the front of an outboard motor boat. The bongo samplers were 315 μm mesh conical nets attached to aluminum mouth-reducing cones and were modified from the river drift samplers of Burton and Flannagan (1976). Late postlarval and juvenile fish were collected from shore using a 10 mm square mesh beach seine. All sampling was conducted between 0900 and 2000 h. Captured fish were killed in a solution of MS-222 (ethyl *m*-aminobenzoate methanesulfonate) and preserved in 3-5% buffered formalin. The fish sampling program removed only 2-3% of the number stocked in any one year and was therefore not considered to be a significant source of mortality.

Harvest dates were set for late August or early September of each year because we suspected that harvesting during the warmer part of the summer could cause significant stress and mortality in the fish. All fish were counted at harvest and subsamples were killed and preserved as described above.

ANALYSES

Preserved zooplankton samples were dyed with Rose Bengal prior to examination. Analyses were carried out on whole samples from 1985, 1988 and 1989 and on subsamples, representing 2.25% of the original sample, from the 1987 horizontal tows. In 1985 and 1987 the samples were sorted by sieving through Nitex® sieves. The procedure involved passing the zooplankton through progressively smaller mesh sizes and yielded five size fractions hereafter referred to as XL (extra large, >1050 μm), L (large, 505-1050 μm), M (medium, 315-505 μm), S (small, 202-315 μm) and XS (extra small, 73-202 μm). XL, L, M and S fractions were counted under a dissecting microscope at 10x power whereas the XS fraction was counted under a compound microscope at 40-100x power. When numbers in a given fraction were high the plankters were diluted in 40 mL of water and two 1 mL subsamples were removed, with replacement, for counting. In 1988 and 1989 entire unfractionated samples were each diluted in 2500 mL of water and ten 5.35 mL subsamples were taken, with replacement, using a glass tube. Taxonomic identifications were made using Pennak (1978) and Edmondson (1959). Copepod nauplii and rotifers were enumerated, except in 1989, but not identified beyond this taxonomic level.

Using an ocular micrometer and a dissecting microscope at 40x power, length and width measurements were taken on a subsample of 200 plankters, excluding copepod nauplii and rotifers, for each pond and sample date in all years except 1985. The number of organisms measured for each taxon was determined by its relative abundance in the sample. Lengths were measured following the criteria of Lawrence et al. (1987) whereas widths were always taken as the second longest dimension of a plankter. Thus our definition of width corresponded to width in Copepoda and depth in Cladocera as defined by Lawrence et al. (1987). We assumed that walleye feeding was more limited by zooplankton width than length and thus estimated plankton size distributions based on width. Length-width relationships were determined to estimate width for all plankters on which it was not measured. The edible portion of the zooplankton community was defined differently in 1985 than in subsequent years. For 1985, the edible portion was defined as the sum of S, M and L fractions. In all other years the edible portion was defined as all particles, except copepod nauplii and rotifers, with widths less than or equal to the maximum edible particle width (MAX) as estimated from mean walleye fork length (FL) using the empirical formula

$$MAX = -1.570 + 0.239 \cdot FL.$$

This relationship was developed from a combination of laboratory and field data relating the maximum width of ingested prey to walleye length (T.A. Johnston, unpubl. data). If mean FL was > 12 mm, all plankters, except nauplii and rotifers, were considered edible. Copepod nauplii and rotifers were considered as inedible for all sizes of walleye as they were rarely utilized as food in this study or in previous studies (Mathias and Li 1982).

Frozen zooplankton samples from late May of 1988 and 1989 were used to build length-dry weight relationships for the various crustacean taxa. $\log_e$ mean dry weight was regressed against $\log_e$ mean length for the most common genera of plankters following the guidelines of McCauley (1984). For each taxon, individuals were sorted into 0.1 or 0.2 mm length categories. For each category, groups of 10-30 individuals were placed on pre-weighed aluminum foil trays, oven-dried for 8 hr at 60°C, moved to a desiccator for 15-30 minutes and then weighed on a Cahn Electrobalance®. When estimating the dry weight of plankters from these regressions we used the correction factor of Bird and Prairie (1985) to correct for bias due to transformation. For the less common plankton taxa, dry weight was estimated using the formula of the taxon which most closely resembled its body shape. All formulae are summarized in Appendix 1.

Preserved postlarval walleye were measured using an ocular micrometer and a dissecting microscope at 8x power. Larger fish were measured using a standard ruler. Lengths were recorded as fork length (FL). Correction factors from previous work (T.A. Johnston, unpubl. data) were used to convert preserved FL to fresh FL. All subsequent analyses used fresh FL.

In order to correct for temperature differences among the four years we examined growth as a function of cumulative degree days above 10°C (CDD) rather than as a function of time. CDD was initialized to 0 at the day of hatching and was calculated from the temperature records at increments of 0.25 days thereafter. Walleye growth was analyzed only during the postlarval period. We used growth data up to and including 200 CDD which roughly corresponded to a mean FL of 25 mm. Walleye growth data are summarized in Appendix 2.

Relationships between variables were examined using linear correlation and regression analysis (Steel and Torrie 1980). All statistical analyses were performed using SAS statistical packages (SAS Institute Inc. 1985). Total P added was chosen as the variable to represent fertilizer inputs.

RESULTS

WATER QUALITY AND PRIMARY PRODUCTION

Tha physical conditions of the ponds changed considerably over the study period. Water temperatures during the spring were generally much higher in 1987 and 1988 than in 1985 and 1989 (Fig. 1a). Summer temperatures showed more uniformity among years with temperatures between 20 and 25°C for most of July (Fig. 1b). Secchi depth tended to increase, peak and then decline slightly over the spring and early summer (Fig. 2). The increase phase of this trend was much more gradual in 1985 than in 1987 and 1988. Readings for ponds 3 and 4 were generally shallower than those for the other two ponds in all years. During May 1988, Secchi depth was consistently shallower in the heavily fertilized pond, pond 4 (Fig. 2). However, by early June pond 4 Secchi depths were similar to those of the other ponds.

Results of pond water chemical analyses from 1985 and 1987 are summarized in Appendix 3. Too few samples were taken in either of these years to make generalizations about trends. However, some definite trends were evident in the 1988 data. Conductivity increased over the spring and summer probably as a result of water evaporation (Fig. 3 a). Alkalinity remained fairly stable until late June but then declined over the rest of the summer (Fig. 3 b). Chlorophyll concentrations were high in early May (12-26 $\mu g \cdot L^{-1}$) but declined by early June and stabilized at fairly low levels (0-6 $\mu g \cdot L^{-1}$) for the remainder of the summer (Fig. 3 c). Data for the three dates on which both chlorophyll and Secchi depth were measured indicated a significant negative correlation between these two variables ($r = -0.87$, $n = 12$, $P < 0.001$). Susp P, Susp N, and Susp C followed time trends similar to chlorophyll (Fig. 3

d-f). Ammonia concentrations remained below 100 $\mu g \cdot L^{-1}$ for most of the season but rose as high as 800 $\mu g \cdot L^{-1}$ by late June in pond 1 (Fig. 3 g). Similar levels of ammonia were present in ponds 1 and 3 in 1987 following inorganic nutrient addition (Appendix 3) but we have no explanation for the unusually high concentrations in 1988. DOC and TDP showed early season increases followed by stabilization whereas DIC declined until early July but then increased again towards the end of the month (Fig. 3 h-j). The water chemistry in 1988 appears to have been affected by the amount of alfalfa added. Conductivity, alkalinity, DOC, DIC, and TDP were consistently lower in pond 2, the unfertilized pond, than in the other ponds. Susp C, Susp N, and Susp P were consistently lower in pond 2 and higher in pond 4, the most heavily fertilized pond, during May but this pattern faded by early June.

Filamentous algae became very abundant in all ponds in 1987 forming extensive mats over the sediments. Only small clumps of filamentous algae were seen in other years. Submergent macrophyte growth was sparse in both 1985 and 1987, but well established in the deeper ends of all ponds in 1988 and 1989.

ZOOPLANKTON DYNAMICS

A total of five species of Copepoda and eleven species of Cladocera were identified from the zooplankton communities of the culture ponds (Table 3). Seven of these species were not found in Dauphin Lake (Friesen and Mathias 1990) and were established either by our zooplankton introductions or by natural dispersion. The dominant crustaceans in order of decreasing abundance were *Cyclops bicuspidatus*, *Daphnia pulex* and *Bosmina longirostris*. Some other species were abundant in certain ponds at certain times. Among the copepods, *C. bicuspidatus* was the only abundant cyclopoid. The only calanoid, *D. siciloides*, rarely exceeded densities of $15 \cdot L^{-1}$ and was always at densities below $3 \cdot L^{-1}$ in 1988 and 1989 (Table 4). Following the introduction of *D. pulex* in 1985, the cladoceran communities changed greatly. Initially, the Cladocera were dominated by small-bodied species, particularly *B. longirostris*, and the only common large-bodied species was *Daphnia retrocurva* (M.K. Friesen, pers. obs.). This was similar to the Dauphin Lake cladoceran community (Friesen and Mathias 1990). One month later, large Cladocera, predominantly *D. pulex* , outnumbered small Cladocera in pond 1 but small Cladocera continued to dominate in the other ponds (Table 4). *D. pulex* gradually increased in abundance over 1985 and became the dominant large cladoceran in ponds 1, 2 and 4 by 1987 and in pond 3 by 1988. *D. retrocurva* was rarely captured after 1985. With the exception of pond 3 in 1987, *B. longirostris* was generally a minor component of the zooplankton communities after 1985. *Chydorus sphaericus* was also of minor importance after 1985. *Simocephalus vetulus* was not captured in 1985 but was abundant in pond 3 in 1987 forming up to 27% of the adult crustacean community. *S. vetulus* declined thereafter as *D. pulex* increased in abundance. *Leptodora kindtii* was captured only occasionally in fish sampling gear. Another large plankter, *Chaoborus sp.* (Diptera), was rare in the ponds during 1985 and 1987 but became fairly common in the latter two years of this study.

There was a general trend of declining crustacean abundances from 1985 to 1989 (Table 4). Copepod densities, excluding nauplii, were highest in 1985 reaching peaks above $200 \cdot L^{-1}$ in all ponds (Table 4). Similar densities were seen in ponds 1 and 3 in 1987 but not in ponds 2 and 4, and not in any ponds in subsequent years. This may be partly due to the narrower range of sample dates in later years. However, sample dates in 1988 and 1989 corresponded to the dates of peak abundance in 1985. The highest densities of Cladocera were also seen in 1985 reaching over $400 \cdot L^{-1}$ in pond 3 and over $1000 \cdot L^{-1}$ in pond 4 (Table 4). Cladoceran densities exceeded $50 \cdot L^{-1}$ on only one occasion after 1987. Peak densities of Cladocera generally occurred later in the year than the peak densities of Copepoda.

Compared to the method used to estimate edible densities from 1987 to 1989, we believe that our 1985 method may have given us slightly conservative estimates of edible density. Despite this, estimates from 1985 were generally much higher than those for subsequent years. The edible density available at first feeding in 1985 was at or above $100 \cdot L^{-1}$ (Fig. 4). In subsequent years the first feeding edible densities were below the $100 \cdot L^{-1}$ level with the exception of pond 3 in 1987 and pond 4 (high alfalfa treatment) in 1988. In general, edible density declined over the postlarval period in all years except 1985. The most severe depletion of zooplankton occurred in pond 2 in 1987 when edible density declined to near $0 \cdot L^{-1}$ by mid-June. This was most likely the result of feeding by large numbers of brook stickleback and Iowa darter larvae. The mean edible density, calculated over the first four sample dates of the postlarval period, was correlated with the total P input ($r=0.56$, $n=16$, $P=0.024$).

Edible biomass was much higher in 1987 than in either 1988 or 1989 (Fig. 5). Zooplankton size distributions and hence biomasses were not estimated in 1985. However, for the remaining three years, a significant correlation existed between total P input and the mean edible biomass as calculated over the first four sample dates of the postlarval period ($r=0.72$, $n=12$, $P=0.008$). In 1987, pond 3 had edible biomasses similar to those in ponds 1 and 4 (Fig. 5) even though the zooplankton composition of these ponds differed greatly (Table 4).

WALLEYE SURVIVAL, GROWTH AND YIELD

Walleye survival from the time of stocking to the time of harvest varied greatly over the four years from a low of 0.48% to a high of 34.49% (Table 5). Among the four years, 1988 showed the highest mean survival (24.13%) and 1989 showed the lowest (1.52%). The highest variation in survival occurred in 1987. The lowest survival in this year was reported from ponds 1 and 2, the only ponds which contained survivors of the 1985 walleye stocking. These larger 1985 walleye (270-300 mm FL as of 1 August 1987) may hava preyed upon the 1987 walleye. The effect of the forage fish on walleye survival in 1987 was less clear. Survival of the two stocks used in 1988 was unequal. Genetic analysis of the pond walleye in 1988 indicated that the Crean Lake fish (introduced one week after Swan Creek fish, Table 2) were reduced to negligible densities within two weeks of stocking (Brown 1990). Gut analysis of Swan Creek fish indicated that cannibalism was the likely cause. Thus the survival of Crean Lake fish in 1988 was near 0%. In further analyses, only estimates for Swan Creek larvae were used to represent 1988 survival. Survival to harvest was significantly correlated with initial stocking density ($r=-0.58$, $n=16$, $P=0.019$) but not with any measures of edible zooplankton density or biomass during the postlarval period. The relationship with stocking density should be considered with caution as all the lowest stocking densities come from a single year, 1988. Thus year to year differences may have confounded stocking density effects.

A simple linear model of mean FL versus CDD described postlarval growth well and scatter plots indicated that a more complex model was not necessary. Postlarval growth showed marked year to year differences (Table 6). The fastest growth rates (b_1 values from Table 6) in descending order were in 1985, 1988, 1987 and 1989. The most distinct difference in growth rates between years was between 1989 and the other years. The ponds received no fertilization in 1989. Similarly, the unfertilized pond in 1988, pond 2, had the lowest postlarval growth rate in that year. Plots of postlarval growth rate versus mean edible zooplankton density over the postlarval period, mean edible zooplankton biomass over the postlarval period and total P inputs all indicated curvilinear responses (Fig. 6). The data suggest that postlarval growth rate increased asymptotically with increases in these variables. Growth rate reached a maximum at approximately 100 edible zooplankters$\cdot L^{-1}$ (Fig. 6a), 250 μg edible zooplankton$\cdot L^{-1}$ (Fig. 6b), and 2 kg P$\cdot ha^{-1}\cdot yr^{-1}$ (Fig. 6c). When the independent variable of these relationships was transformed by $\log_e(x + 1)$, we found strong correlations between growth rate and mean zooplankton density ($r=0.69$, $n=16$, $P=0.0034$), and total P inputs ($r=0.77$, $n=16$, $P=0.0005$), but not mean zooplankton biomass ($r=0.42$, $n=12$, $P=0.17$).

At the time of harvest, juvenile walleye ranged from 41 mm to 130 mm FL (Table 5). As with survival, the size at harvest showed the greatest variation in 1987. The two largest as well as the two smallest mean FL values at harvest occurred in 1987 (Table 5). Brook sticklebacks and Iowa darters in ponds 1 and 2 in 1987 produced large numbers of offspring in late May and early June. This was most evident in pond 2 where seine hauls in late June indicated that walleye were outnumbered by a factor of 100-200 by young-of-the-year forage fish (T.A. Johnston, pers. obs.). Forage species in ponds 3 and 4 produced only small numbers of offspring. The forage fish populations in ponds 1 and 2 were therefore largely composed of smaller individuals (relative to the walleye) and represented food sources whereas the populations of ponds 3 and 4 were composed of larger individuals and acted only as competitors. Similarly, forage fish introduced to the ponds in July 1985 were apparently too large to be consumed and did not produce sufficient numbers of offspring to constitute a major walleye food source. With the exception of ponds 1 and 2 in 1987, the largest mean walleye lengths at the time of harvest were seen in 1988. High densities of Chironomidae seen in all ponds during 1988 may have enhanced juvenile growth. Mean length at harvest was not significantly correlated to either postlarval growth rate ($r=0.15$, $n=16$, $P=0.59$) or total P inputs ($r=0.36$, $n=16$, $P=0.18$).

The yield of walleye from the ponds ranged from 0.7 to 48.3 $kg \cdot ha^{-1}$ (wet weight) (Table 7). The three highest yields were all from 1988 and the four lowest yields were all from 1989. The yields in 1988 did not reflect the influence of different fertilization rates as expected. Pond 4 which received the highest alfalfa inputs also had the lowest yield (Table 7). Overall, yield was not significantly correlated with total P inputs ($r=0.27$, $n=16$, $P=0.31$). Because the time from stocking to harvest was roughly the same across the four years (range 85-107 days) estimates of production showed a similar pattern to estimates of yield.

DISCUSSION

The overall physical conditions of the Methley Beach culture ponds could be considered suitable for walleye culture. The late spring and early summer temperatures were close to the 22°C optimum for juvenile walleye growth as determined by Smith and Koenst (1975). However, temperatures during the postlarval period were generally below this optimum, particularly in 1985 and 1989. Temperatures never reached the upper lethal range of 27.0-31.6°C (Smith and Koenst 1975). Ammonia concentrations in some ponds rose to 800 $\mu g \cdot L^{-1}$ or more on at least two occasions. Concentrations of unionized ammonia in the range of 600 to 2000 $\mu g \cdot L^{-1}$ can be toxic to fish (Boyd 1982). However, there was no evidence of fish die-offs or low survival in the ponds as a result of high ammonia concentrations. Though dissolved oxygen was not measured, we feel that the long fetches of the ponds allowed wind action to keep oxygen at near saturation levels. Indications of potential summerkill such as high chlorophyll concentrations (>100 $\mu g \cdot L^{-1}$) and high conductivity (800-2000 $\mu S \cdot cm^{-1}$)(Barica 1975) were not recorded. The increasing abundance of macrophytes over the study period may have caused some oxygen depletion. Dense stands of submerged macrophytes can cause diel changes in oxygen concentration as great as 8 $mg \cdot L^{-1}$ (Carpenter and Lodge 1986). Future culture programs should examine methods of controlling macrophyte growth.

High Secchi depths are often indicative of low levels of particulate organic matter, particularly phytoplankton (Almazan and Boyd 1978). Our data also demonstrate a strong inverse relationship between Secchi depth and phytoplankton abundance as determined by chlorophyll concentration. Boyd (1982) suggested that a Secchi visibility of 40 to 80 cm was desirable for pond culture of warmwater species. The relatively high readings obtained in the Methley Beach ponds, particularly during 1987 and 1988, suggest that the abundance of phytoplankton and other organic particles may have been low.

Consistently lower conductivity readings and alkalinity levels in pond 2 (unfertilized) in 1988 suggest that the alfalfa increased the ionic concentration of the fertilized ponds. Pond conductivities were markedly higher than those of Dauphin Lake over the same part of the season (Babaluk and Friesen 1990). High alkalinity, as seen in the Methley Beach ponds, has been associated with high productivity in walleye culture (Moyle 1946). However, other characteristics of the Methley Beach ponds would suggest that they were relatively unproductive. With the exception of one sample date in 1987 and the first sample date in 1988, chlorophyll concentrations were lower than those recorded from Dauphin Lake (Babaluk and Friesen 1990) and only slightly higher than those recorded from Precambrian shield lakes (Schindler and Holmgren 1971). Similarly, particulate C, N and P, and TDP concentrations in early May 1988 were as high as those in Dauphin Lake but soon declined and were lower than those in Dauphin Lake over the remainder of the culture period.

Both the Secchi depth data and water chemistry data indicate a declining abundance of phytoplankton and possibly other organic particles over the season. In lakes, the biomass of zooplankton is positively related to the biomass of phytoplankton and zooplankton production is strongly related to phytoplankton production (McCauley and Kalff 1981). Thus the standing stock and production of zooplankton in the ponds may have been limited by primary production and ultimately by nutrient availability. Fertilization appears to have stimulated productivity early in the season but this effect diminished quickly.

The structure of zooplankton communities depends not only on the trophic status of the waterbody but also on the type and abundance of predators. In this study the zooplankton community was also influenced by the successful introduction of large-bodied Cladocera. In general, large Cladocera will outcompete suspension-feeding rotifers (Gilbert 1985) and small Cladocera such as *Bosmina sp.* (Lynch 1979) and will depress calanoid but not cyclopoid copepod abundances (Soto and Hurlbert 1991). The decline in abundance of small Cladocera, and to a lesser extent calanoids, was evident in the Methley ponds after *D. pulex* inoculations. Fish predation tends to drastically reduce the abundance of large Cladocera (Lynch 1979; Soto and Hurlbert 1991), but causes only moderate and negligible reductions in calanoids and cyclopoids respectively (Soto and Hurlbert 1991). Consequently, zooplankton communities are typically dominated by rotifers, cyclopoid copepods and small-bodied Cladocera in lakes with abundant vertebrate zooplanktivores such as Lake Ontario (Johannson and O'Gorman 1991) and Dauphin Lake (Friesen and Mathias 1990). Such plankton communities were seen in all the Methley ponds prior to *D. pulex* introductions in 1985, and in ponds 2 and 3 in 1987. In 1987, pond 3 had the largest forage fish population of any pond prior to fish removals, and pond 2 had the highest abundance of larval fish following the successful spawning of Iowa darters and brook sticklebecks. In these two cases, predation pressure on the zooplankton was most intense and probably caused the shift to small-bodied plankters in the communities. After 1987 however, the zooplankton communities never showed as distinct a shift towards small-bodied plankters as a result of fish predation. Walleye feeding alone was not sufficient to induce a major community shift during the postlarval periods of 1988 and 1989. However, such a change could have occurred later in the summer as walleye grew and consumed larger sizes and quantities of zooplankton.

It is unlikely that postlarval walleye feeding was ever limited by the species composition of the pond zooplankton. Numerous studies indicate that both *Cyclops sp.* and *Daphnia sp.* are readily consumed by larval walleye (e.g. Houde 1967; Spykerman 1974). However, the density of edible particles may have limited feeding, particularly during 1988 and 1989. In laboratory studies, postlarval walleye fed at maximal rates in zooplankton densities at or above $100 \cdot L^{-1}$ (Mathias and Li 1982). Mean zooplankton densities were generally below this level after 1985, but the heterogenous distribution of zooplankton would undoubtedly result in local patches of much higher density. The feeding success of walleye under conditions of low mean zooplankton density probably depended on their ability to associate with high density patches. Significant correlations between both the edible zooplankton density and biomass during the postlarval period and total P inputs in this study suggest that zooplankton abundance was enhanced by fertilization. McIntire and Bond (1962) observed higher abundances of both zooplankton and benthos in fertilized ponds. Hall et al. (1970) noted that zooplankton production in experimental ponds increased with nutrient additions but that community composition was not greatly affected.

Laboratory studies have indicated that walleye survival to the end of the larval period increases with zooplankton density (Li and Mathias 1982). No relationship between zooplankton abundance during the postlarval stage and survival to the time of harvest was evident in this study. Similarly, Fox (1989) found no significant correlation between prey density and walleye survival in culture ponds. Quantitative sampling during the postlarval period in 1987, 1988 and 1989 indicated that survival from stocking to a mean FL of 12 mm (approximately 5 days after initiation of feeding) was roughly 50% in 1987 and 90% in 1988 and 1989 (T.A. Johnston, unpubl. data). We believe that predation by the forage fish in 1987 reduced postlarval survival. However, the average survival to the time of harvest in 1987 was higher than in 1989. Mortality between the zooplanktivorous postlarval stage and the time of harvest would seem to obscure any relationship which may have existed between zooplankton abundance and postlarval survival in this study. Our data indicate that survival may be negatively correlated with initial stocking density. Fox and Flowers (1990) found no correlation between survival and stocking density in culture ponds but worked with much higher stocking densities (20-60 $fish \cdot m^{-3}$) than we did. Li and Ayles (1981) also found no relationship between walleye survival and stocking density. Food may have been less abundant during our study and this may have resulted in more pronounced density-dependent effects.

Growth during the postlarval period showed positive relationships with both zooplankton abundance and total P inputs. Postlarval growth rate was maximized at zooplankton densities of roughly $100 \cdot L^{-1}$ which corresponds to the density at which maximum feeding rate is attained according to Mathias and Li (1982). However, rapid growth during the postlarval period did not ensure a large mean size at harvest. Mean FL at harvest was not significantly correlated with either postlarval growth rate or the rate of fertilization. Our data suggest that conditions during the juvenile period were more important than those during the postlarval period in determining walleye body size at harvest.

The goal in most fish culture programs is to maximize survival and growth. To do so requires knowledge of the trophic interactions within the system and how to best manipulate them. In the extensive culture of walleye, ponds are fertilized to stimulate the production of phytoplankton, protozoa and bacteria which serve as food for zooplankton and benthos which in turn are consumed by walleye. As the walleye grow, their diet progresses from small zooplankton to larger zooplankton to benthos. In some cases an additional trophic level is added to the system by introducing forage fish. Pond management tries to divert energy and nutrients into walleye biomass and away from dead ends such as macrophytes, and forage fish and invertebrates which are too large to be consumed.

Our management approach with the Methley Beach walleye culture ponds was to fertilize early and harvest late. Fertilization was concentrated during the early part of the season to stimulate zooplankton production over the postlarval period. Though primary and secondary production were initially stimulated, the effect diminished over time. Many extensive culture programs continue fertilization at regular intervals throughout the culture period to maintain zooplankton abundance (Cheshire and Steele 1972; Beyerle 1979; Geiger 1983; Buttner 1989). Regular fertilization may also greatly enhance the biomass of benthos (Fox et al. 1989). Our approach of harvesting in late summer, well after the zooplankton decline, may have compounded the problem by allowing cannibalism to occur. To prevent cannibalism, walleye are often harvested at a mean FL of 50 mm or less, or whenever a zooplankton crash occurs (Beyerle 1979; Buttner 1989). Alternatively, juvenile food sources could be enhanced. Using forage fish as a juvenile food base showed some potential in this study and has been recommended in the past (Smith and Moyle 1943). As a group, ponds which contained forage fish in this study had the most variable size at harvest. Li and Ayles (1981) noted a similar pattern in their work. The major problem appears to be providing the proper size of forage at the proper time. The timing and success of forage fish reproduction seems to be quite variable.

CONCLUSIONS

The physical and chemical conditions of the Methley Beach culture ponds were suitable for walleye culture. Zooplankton in the ponds were qualitatively adequate as walleye food but generally at suboptimal densities. Walleye growth during the postlarval period was maximized at mean zooplankton densities above $100 \cdot L^{-1}$. Low zooplankton abundance was likely the direct result of insufficient fertilization. Walleye survival to harvest and size at harvest did not appear to depend on conditions during the postlarval period. It is likely that trophic and intraspecific interactions during the juvenile stage exerted a stronger influence. Future extensive culture programs should consider more intensive and/or prolonged fertilization, enhancement of juvenile food sources such as benthos or forage fish, and possibly earlier harvest dates.

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Table 1. Alfalfa meal additions and total nutrient additions for each of the Methley Beach walleye culture ponds in 1985, 1987, 1988 and 1989. All added nutrients came from the alfalfa meal except in 1987 when inorganic fertilizer was also applied to ponds 1 and 3 (see text).

Year	Pond(s)	Alfalfa additions ($kg \cdot ha^{-1}$)	Total nutrient additions ($kg \cdot ha^{-1}$) N	P
1985	All	750	22.5	1.8
1987	1,3	750	34.5	2.8
	2,4	750	22.5	1.8
1988	1,3	750	22.5	1.8
	2	0	0.0	0.0
	4	1500	45.0	3.6
1989	All	0	0.0	0.0

Table 2. Origin of stock, stocking density and stocking date for prolarval walleye introduced into the Methley Beach walleye culture ponds in 1985, 1987, 1988 and 1989.

Year	Pond(s)	Stock	Stocking Density ($fish \cdot ha^{-1}$)	Stocking Date
1985	All	Crean Lake, Saskatchewan	74 000	22 May
1987	All	Crean Lake, Saskatchewan	84 000	25 May
1988	All	Lake Manitoba (Swan Creek)	40 000	13 May
		Crean Lake, Saskatchewan	40 000	20 May
1989	1	Lake Manitoba (Swan Creek)	60 000[1]	23 May
	2,4	Lake Winnipegosis (Duck Bay)	70 000	17 May
	3	Falcon Lake, Manitoba	88 000	1 June

[1] probably an overestimate; some larvae lost during stocking

Table 3. Crustacean zooplankton species identified from the Methley Beach walleye culture ponds. Species not found in the Dauphin Lake crustacean community are indicated by ** (modified from Friesen and Mathias 1990).

COPEPODA	
	Cyclops bicuspidatus Claus 1857
	Cyclops vernalis Fischer 1853
	Cyclops navus Herrick 1882 **
	Diaptomus siciloides Lilljeborg 1889
	Eucyclops agilis (Koch) 1838
CLADOCERA	
	Alona quadrangularis (O.F. Müller) 1785 **
	Bosmina longirostris (O.F. Müller) 1785
	Ceriodaphnia quadrangula (O.F. Müller) 1785
	Chydorus sphaericus (O.F. Müller 1785) **
	Daphnia pulex Leydig 1860 emend. Richard 1896 **
	Daphnia retrocurva Forbes 1882
	Diaphanosoma leuchtenbergianum Fischer 1850
	Leptodora kindtii (Focke) 1844
	Macrothrix rosea (Jurine 1820) **
	Pleuroxus denticulatus Birge 1878 **
	Simocephalus vetulus Schødler 1858 **

Table 4. Mean densities (particles·L^{-1}) of major zooplankton taxa in the Methley Beach walleye culture ponds during 1985, 1987, 1988 and 1989. *Daphnia sp.*, *Simocephalus sp.*, *Ceriodaphnia sp.* and *Leptodora sp.* were categorized as large Cladocera whereas all other Cladocera listed in Table 3 were categorized as small. Note that in 1985 Cladocera were separated into large and small size categories for only two sample dates. Dates of walleye first feeding in 1985 and 1987 were 25 May and 29 May respectively. First feeding corresponded with the first zooplankton sample date for each pond in 1988 and 1989.

Year	Pond	Date	Large Cladocera	Small Cladocera	Cyclopoid copepods[1]	Calanoid copepods[1]	Nauplii	Rotifers	Total Crustacea[1]
1985	1	1 May	0.08		111.89	7.01	169.05	123.62	118.97
		8 May	0.07		22.78	1.43	184.50	69.77	24.27
		15 May	0.18	0.09	140.54	2.37	162.02	9.80	143.20
		22 May	0.78		152.72	2.06	59.33	0.78	155.56
		29 May	6.48		192.04	4.43	13.30	2.42	202.96
		5 June	44.23		359.67	25.53	3.98	0.92	429.43
		13 June	84.87	52.02	165.83	16.36	11.76	2.61	319.09
		27 June	44.22		32.60	11.97	6.53	0.65	88.79
		4 July	22.42		90.65	9.85	15.93	3.37	122.92
1985	2	2 May	0.49		174.61	9.34	151.52	24.68	184.44
		8 May	0.20		99.13	5.45	198.34	55.35	104.77
		15 May	0.15	0.08	48.75	1.23	125.12	35.75	50.21
		22 May	2.74		284.28	3.61	47.33	3.92	290.63
		29 May	26.97		231.08	11.17	25.99	0.44	269.22
		5 June	92.84		215.34	11.02	6.80	9.05	319.20
		13 June	13.63	137.80	28.73	11.18	42.15	3.59	191.33
		26 June	196.34		60.34	10.68	29.73	3.92	267.36
		4 July	108.51		73.41	5.96	21.56	10.46	187.89
1985	3	27 April	0.12		1.68	0.19	0.46	0.00	1.98
		3 May	0.35		83.66	1.89	144.69	143.71	85.90
		8 May	0.07		71.92	3.73	134.29	54.75	75.72
		15 May	0.02	0.01	54.53	1.17	137.75	10.95	55.73
		22 May	1.62		176.91	3.81	65.58	2.88	182.33
		29 May	2.66		232.17	7.07	34.46	0.88	241.89
		5 June	24.43		172.34	10.83	58.79	1.35	208.59

Table 4. Continued

<table>
<tr><th>Year</th><th>Pond</th><th>Date</th><th>Large Cladocera</th><th>Small Cladocera</th><th>Cyclopoid copepods[1]</th><th>Calanoid copepods[1]</th><th>Nauplii</th><th>Rotifers</th><th>Total Crustacea[1]</th></tr>
<tr><td>1985</td><td>3</td><td>13 June</td><td>4.84</td><td>156.44</td><td>178.35</td><td>10.25</td><td>21.49</td><td>0.63</td><td>349.88</td></tr>
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<tr><td></td><td></td><td>22 May</td><td colspan="2">0.07</td><td>257.41</td><td>3.03</td><td>93.84</td><td>2.35</td><td>260.51</td></tr>
<tr><td></td><td></td><td>29 May</td><td colspan="2">0.61</td><td>66.19</td><td>2.66</td><td>200.11</td><td>0.68</td><td>69.46</td></tr>
<tr><td></td><td></td><td>5 June</td><td colspan="2">9.04</td><td>203.74</td><td>5.19</td><td>24.03</td><td>0.32</td><td>217.98</td></tr>
<tr><td></td><td></td><td>13 June</td><td>0.46</td><td>45.88</td><td>152.54</td><td>6.21</td><td>24.86</td><td>1.40</td><td>205.10</td></tr>
<tr><td></td><td></td><td>26 June</td><td colspan="2">733.19</td><td>93.63</td><td>7.93</td><td>51.04</td><td>1.69</td><td>834.75</td></tr>
<tr><td></td><td></td><td>3 July</td><td colspan="2">1087.65</td><td>77.68</td><td>6.86</td><td>65.35</td><td>6.86</td><td>1172.18</td></tr>
<tr><td>1987</td><td>1</td><td>23 April</td><td>1.09</td><td>0.00</td><td>4.38</td><td>0.04</td><td>2.90</td><td>0.90</td><td>5.50</td></tr>
<tr><td></td><td></td><td>14 May</td><td>16.16</td><td>0.06</td><td>5.11</td><td>0.07</td><td>25.00</td><td>1.10</td><td>21.40</td></tr>
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<tr><td>1987</td><td>2</td><td>23 April</td><td>5.30</td><td>0.00</td><td>5.62</td><td>0.18</td><td>5.20</td><td>8.00</td><td>11.10</td></tr>
<tr><td></td><td></td><td>14 May</td><td>7.19</td><td>0.02</td><td>7.38</td><td>0.01</td><td>35.90</td><td>1.70</td><td>14.60</td></tr>
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<tr><td>1987</td><td>3</td><td>23 April</td><td>0.05</td><td>0.01</td><td>5.50</td><td>0.04</td><td>6.80</td><td>13.40</td><td>5.60</td></tr>
<tr><td></td><td></td><td>13 May</td><td>0.03</td><td>2.75</td><td>23.04</td><td>0.78</td><td>81.00</td><td>5.70</td><td>26.60</td></tr>
</table>

Table 4. Continued

Year	Pond	Date	Large Cladocera	Small Cladocera	Cyclopoid copepods[1]	Calanoid copepods[1]	Nauplii	Rotifers	Total Crustacea[1]
1987	3	29 May	11.30	77.50	295.50	3.90	811.90	205.20	388.20
		4 June	31.89	100.07	179.64	4.70	868.30	94.10	316.30
		8 June	28.99	64.77	122.44	3.80	180.70	42.70	220.00
		14 June	56.80	82.60	61.80	3.20	212.90	45.70	204.40
		23 June	1.60	138.60	28.50	18.70	331.80	32.50	187.40
1987	4	23 April	1.84	0.47	4.04	1.15	2.90	13.30	7.50
		14 May	3.77	0.00	13.48	0.74	103.00	1.10	18.00
		29 May	22.09	0.41	43.88	0.62	146.30	2.90	67.00
		4 June	12.49	0.22	31.55	1.44	94.20	3.10	45.70
		8 June	64.44	0.49	18.52	1.65	84.50	3.60	85.10
		14 June	34.55	1.00	9.25	1.90	68.10	0.30	46.70
		23 June	0.00	10.68	25.60	1.62	85.00	12.40	37.90
1988	1	21 May	9.90	0.00	65.79	0.28	74.10	13.40	75.97
		26 May	24.85	0.14	24.42	0.28	28.40	9.60	49.70
		6 June	17.22	0.67	18.08	0.56	228.00	1.80	36.53
		21 June	20.96	1.75	30.87	2.72	27.20	86.70	56.30
1988	2	21 May	8.52	0.95	69.63	0.36	63.20	2.90	79.47
		26 May	14.58	3.23	44.97	0.25	30.70	0.60	63.03
		5 June	11.60	1.91	9.62	0.22	40.20	1.70	23.35
		21 June	0.86	10.90	14.60	1.34	74.10	19.60	27.70
1988	3	21 May	0.32	0.11	85.73	0.11	75.60	16.60	86.27
		26 May	0.51	0.62	66.51	0.18	48.90	3.40	67.83
		4 June	64.25	2.37	74.07	0.36	61.90	1.30	141.05
		21 June	17.64	1.38	18.30	1.68	60.50	0.70	39.00
1988	4	22 May	5.19	1.39	152.44	0.07	76.40	20.20	159.10
		26 May	10.67	3.62	135.07	0.21	25.20	2.00	149.57
		5 June	28.04	2.67	26.25	0.33	49.90	0.30	57.28

And how much sampled

Table 4. Continued

Year	Pond	Date	Large Cladocera	Small Cladocera	Cyclopoid copepods[1]	Calanoid copepods[1]	Nauplii	Rotifers	Total Crustacea[1]
1988	4	22 June	9.72	0.17	15.76	0.45	74.90	0.90	26.10
1989	1	31 May	21.62	0.04	40.77	0.07	-	-	62.50
		7 June	23.69	0.04	32.12	0.08	-	-	55.93
		10 June	13.60	0.12	15.74	0.04	-	-	29.50
		15 June	7.69	0.08	20.35	0.16	-	-	28.28
1989	2	22 May	12.66	0.96	52.91	0.17	-	-	66.69
		26 May	23.21	1.42	77.60	0.00	-	-	102.22
		3 June	10.33	2.02	31.86	0.13	-	-	44.34
		7 June	11.34	1.82	20.47	0.04	-	-	33.67
1989	3	4 June	23.41	0.04	38.43	0.09	-	-	61.98
		8 June	15.07	0.05	20.72	0.09	-	-	35.93
		13 June	7.64	0.05	7.64	0.23	-	-	15.55
		19 June	0.96	0.05	21.36	0.62	-	-	22.99
1989	4	21 May	21.22	0.11	62.86	0.23	-	-	84.42
		26 May	22.11	0.15	35.81	0.19	-	-	58.27
		2 June	11.38	0.12	39.14	0.04	-	-	50.67
		7 June	3.88	0.20	20.87	0.00	-	-	24.95

[1] excluding nauplii

Table 5. Harvest dates, numbers of juveniles harvested, percent survival and length and wet weight measurements at the time of harvest for walleye from the Methley Beach walleye culture ponds in 1985, 1987, 1988 and 1989. Harvest figures for 1989 were obtained from Manitoba Department of Natural Resources, Fisheries Branch, Brandon, Manitoba (W.N. Howard, pers. comm.).

Year	Pond	Date	Number harvested	Survival (%)	Fork length (mm) n	Fork length (mm) x	Fork length (mm) sd	Wet weight (g) n	Wet weight (g) x	Wet weight (g) sd
1985	1	28 Aug	10 187	13.77	27	51.7	5.87	27	1.32	0.49
	2	4 Sept	8 548	11.55	15	58.0	2.79	15	1.59	0.32
	3	5 Sept	5 429	7.34	17	51.9	4.17	17	1.24	0.32
	4	6 Sept	7 825	10.57	13	55.0	2.65	13	1.46	0.25
1987	1	19 Aug	400	0.48	80	130.0	17.12	80	24.52	-
	2	21 Aug	1 469	1.80	60	125.3	1.27	60	18.50	5.53
	3	22 Aug	21 531	25.79	16	49.2	2.20	16	0.97	0.16
	4	22 Aug	8 230	9.86	16	41.0	2.87	16	0.56	0.94
1988	1	15 Aug	13 795	34.49[1]	200	77.8	8.05	200	3.54	1.04
	2	16 Aug	12 156	30.39[1]	200	68.1	4.11	200	2.54	0.49
	3	17 Aug	9 050	22.63[1]	200	73.0	5.32	200	3.05	0.69
	4	18 Aug	3 595	8.99[1]	200	79.7	7.51	200	4.20	1.30
1989	1	25 Aug	450	0.75	-	50.0	-	100	1.60	-
	2	22 Aug	2 033	2.90	-	56.0	-	100	2.00	-
	3	24 Aug	1 425	1.62	-	56.0	-	100	1.75	-
	4	23 Aug	560	0.80	-	56.0	-	100	3.25	-

[1] Values are for Swan Creek stock only; Crean Lake stock survival was 0% (see text)

Table 6. Fitted parameters and statistics resulting from the regression of mean walleye fork length (FL) against cumulative degree days > 10°C (CDD) for postlarval walleye sampled from the Methley Beach walleye culture ponds in 1985, 1987, 1988 and 1989. b_0 and b_1 represent the intercept and slope of the regression respectively. Only samples collected within the first 200 CDD were used in this analysis.

Year	Pond	b_0	b_1	F	(df_{error})	P>F	R^2
1985	1	6.70	0.108	54.4	(2)	0.0179	0.965
	2	6.89	0.098	51.5	(2)	0.0189	0.963
	3	7.33	0.097	459.8	(2)	0.0022	0.996
	4	7.25	0.093	260.2	(2)	0.0038	0.992
1987	1	8.08	0.093	251.1	(3)	0.0005	0.998
	2	8.31	0.083	58.5	(3)	0.0046	0.951
	3	7.71	0.085	3269.4	(3)	<0.0001	0.999
	4	7.60	0.082	1732.3	(3)	<0.0001	0.998
1988[1]	1	8.46	0.091	575.9	(2)	0.0017	0.997
	2	8.67	0.079	1861.0	(2)	0.0005	0.999
	3	8.46	0.104	827.4	(3)	<0.0001	0.996
	4	8.52	0.093	1075.3	(2)	0.0009	0.998
1989	1	8.19	0.071	84.5	(3)	0.0027	0.966
	2	8.41	0.068	542.3	(3)	0.0002	0.995
	3	8.23	0.071	101.7	(3)	0.0021	0.971
	4	8.01	0.072	195.5	(4)	0.0002	0.980

[1] Results are for Swan Creek stock only

Table 7. Estimated fish yield and production (wet weight) from the Methley Beach walleye culture ponds at time of harvest in 1985, 1987, 1988 and 1989. All harvested fish were young-of-the-year (YOY) walleye except in 1985 and 1987. Forage fish yield was not calculated in 1985. 1985 year class walleye captured in 1987 are not included in these figures. Data for 1989 were obtained from Manitoba Department of Natural Resources, Fisheries Branch, Brandon, Manitoba (W.N. Howard, pers. comm.).

		Pond Yield ($kg \cdot ha^{-1}$)				Pond Production ($kg \cdot ha^{-1} \cdot day^{-1}$)			
Year		1	2	3	4	1	2	3	4
1985	YOY Walleye	13.4	13.6	6.7	11.4	0.14	0.13	0.06	0.11
	Forage fish[1]	-	-	-	-	-	-	-	-
1987	YOY Walleye	9.8	27.2	20.9	4.6	0.11	0.31	0.24	0.05
	Forage fish[1]	14.3	1.8	14.1	-	-	-	-	-
1988	YOY Walleye	48.3	32.4	27.6	15.1	0.51	0.34	0.29	0.16
1989	YOY Walleye	0.7	4.1	2.5	1.8	0.01	0.04	0.03	0.02

[1] forage species harvested included brook stickleback, fathead minnow, Iowa darter, emerald shiner, spottail shiner (*Notropis hudsonius*), yellow perch (*Perca flavescens*), log perch (*Percina caprodes*), short head redhorse (*Moxostoma macrolepidotum*) and white sucker (*Catostomus commersoni*)

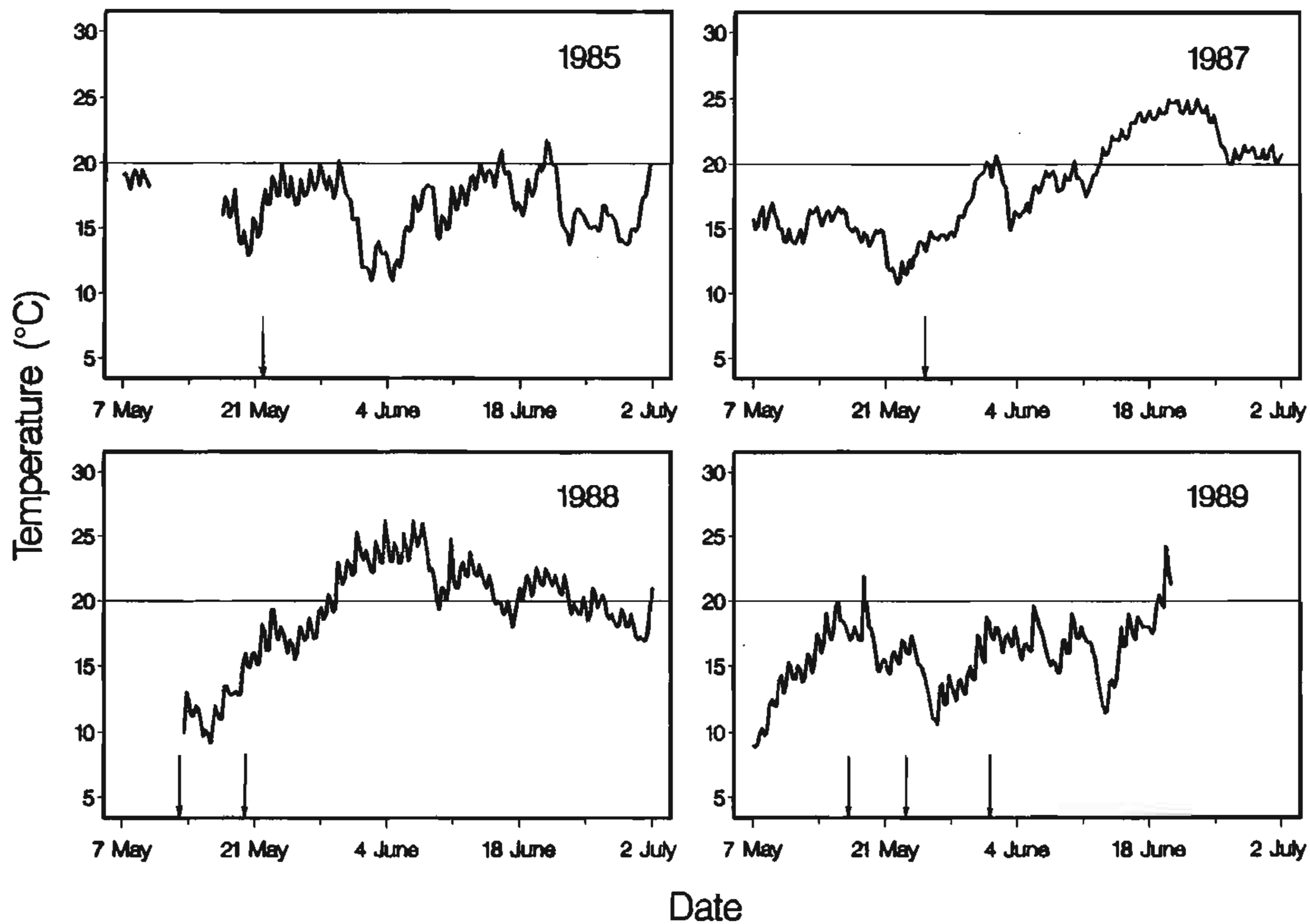

Fig. 1 a). Water temperature of the Methley Beach walleye culture ponds during spring (May-June) of 1985, 1987, 1988 and 1989. Reference line indicates 20°C. Arrows indicate walleye stocking dates as listed in Table 2.

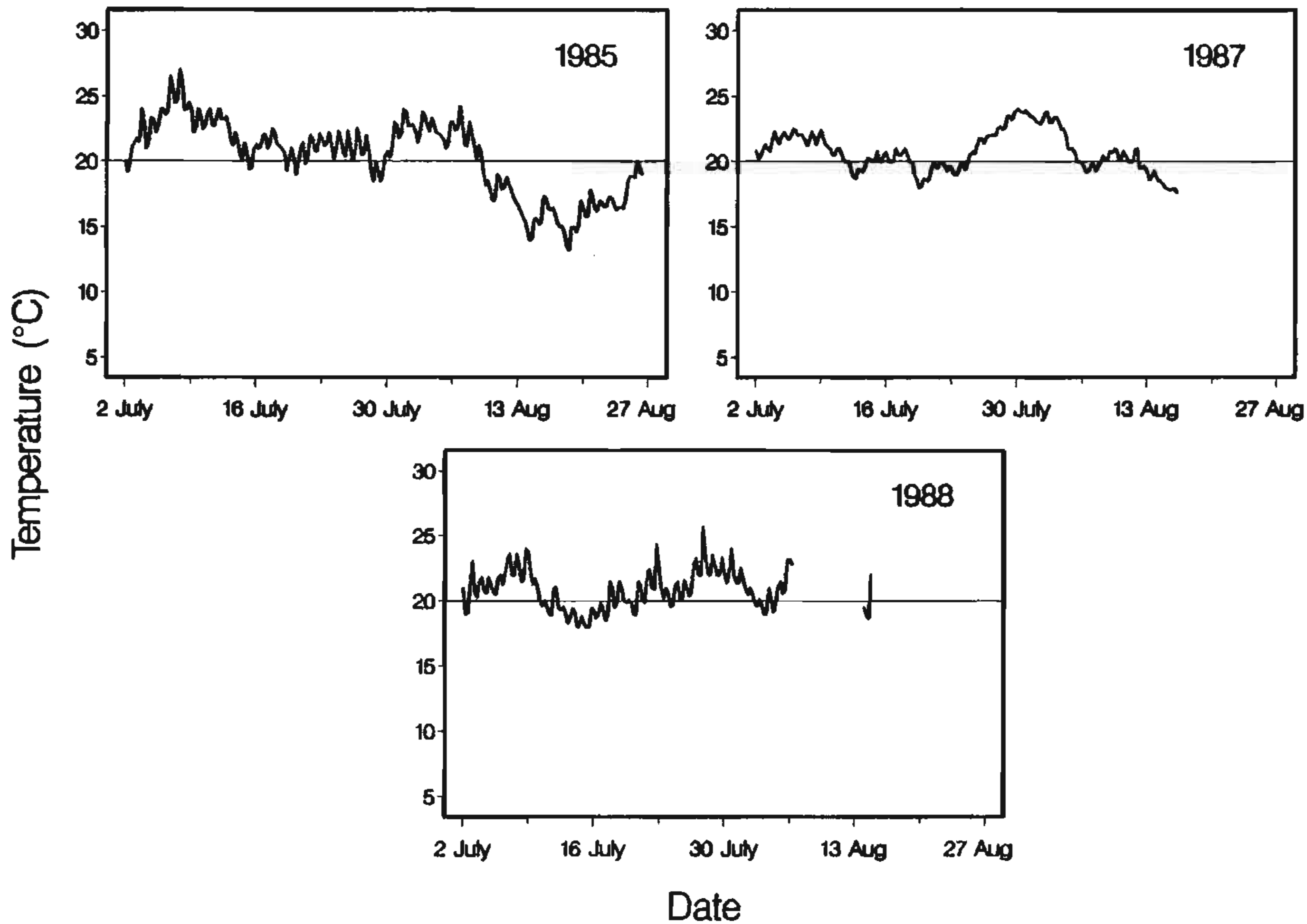

Fig. 1 b). Water temperature of the Methley Beach walleye culture ponds during summer (July-August) of 1985, 1987 and 1988. Reference line indicates 20°C.

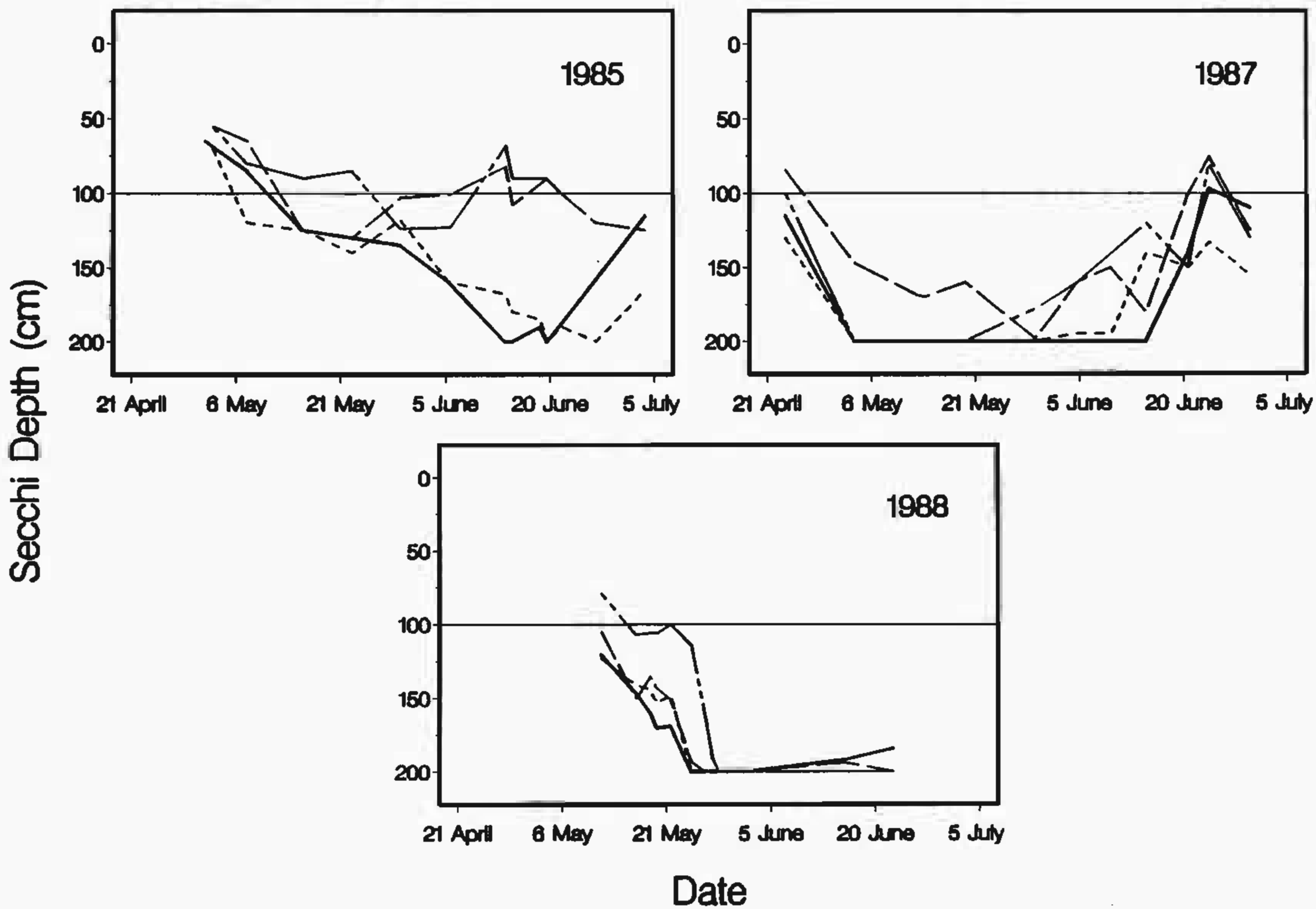

Fig. 2. Secchi depth readings of the Methley Beach walleye culture ponds (———— = pond 1, - - - - - - - = pond 2, — — — = pond 3, ——-·-—— = pond 4) during 1985, 1987 and 1988. Readings of 200 cm indicate that the disc was seen resting on bottom and that the true reading was actually greater.

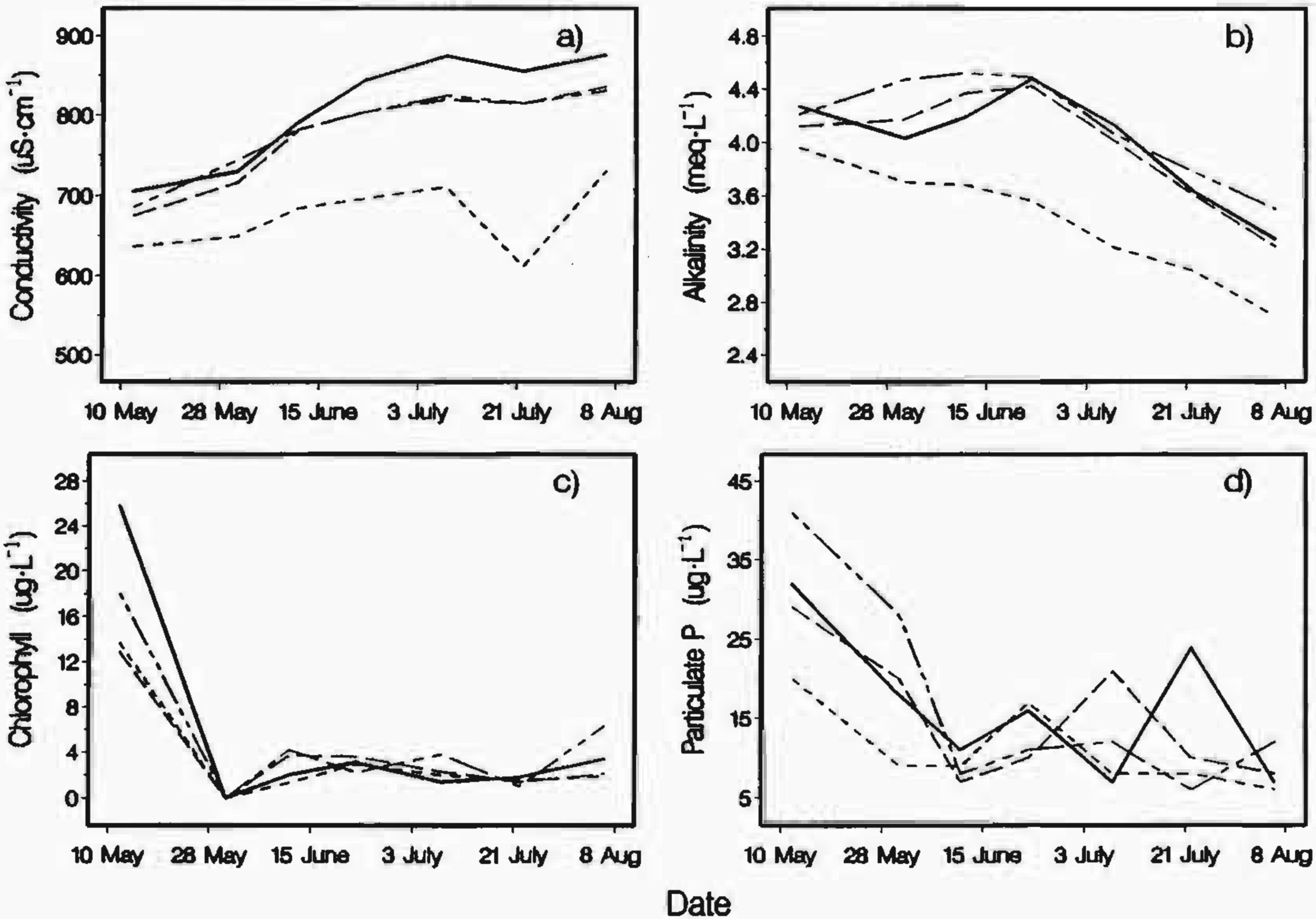

Fig. 3. Water chemistry characteristics of the Methley Beach walleye culture ponds during May, June and July of 1988 (———— = pond 1, - - - - - - - = pond 2, — — — — = pond 3, ——·-—— = pond 4); a) conductivity, b) alkalinity, c) chlorophyll and d) particulate phosphorous.

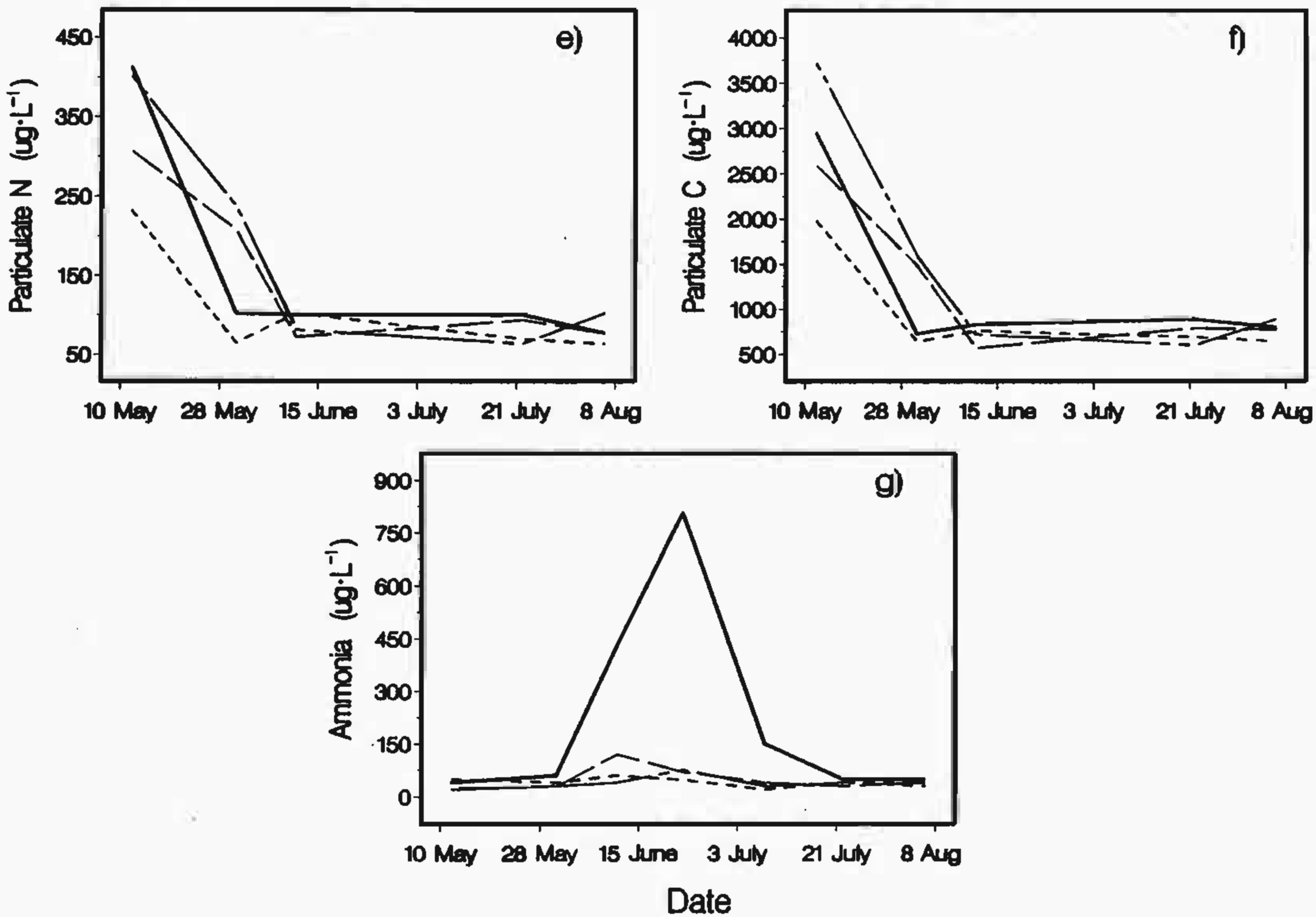

Fig. 3. Water chemistry characteristics of the Methley Beach walleye culture ponds during May, June and July of 1988 (———— = pond 1, - - - - - - - = pond 2, — — — = pond 3, ——-—-— = pond 4); e) particulate nitrogen, f) particulate carbon and g) ammonia.

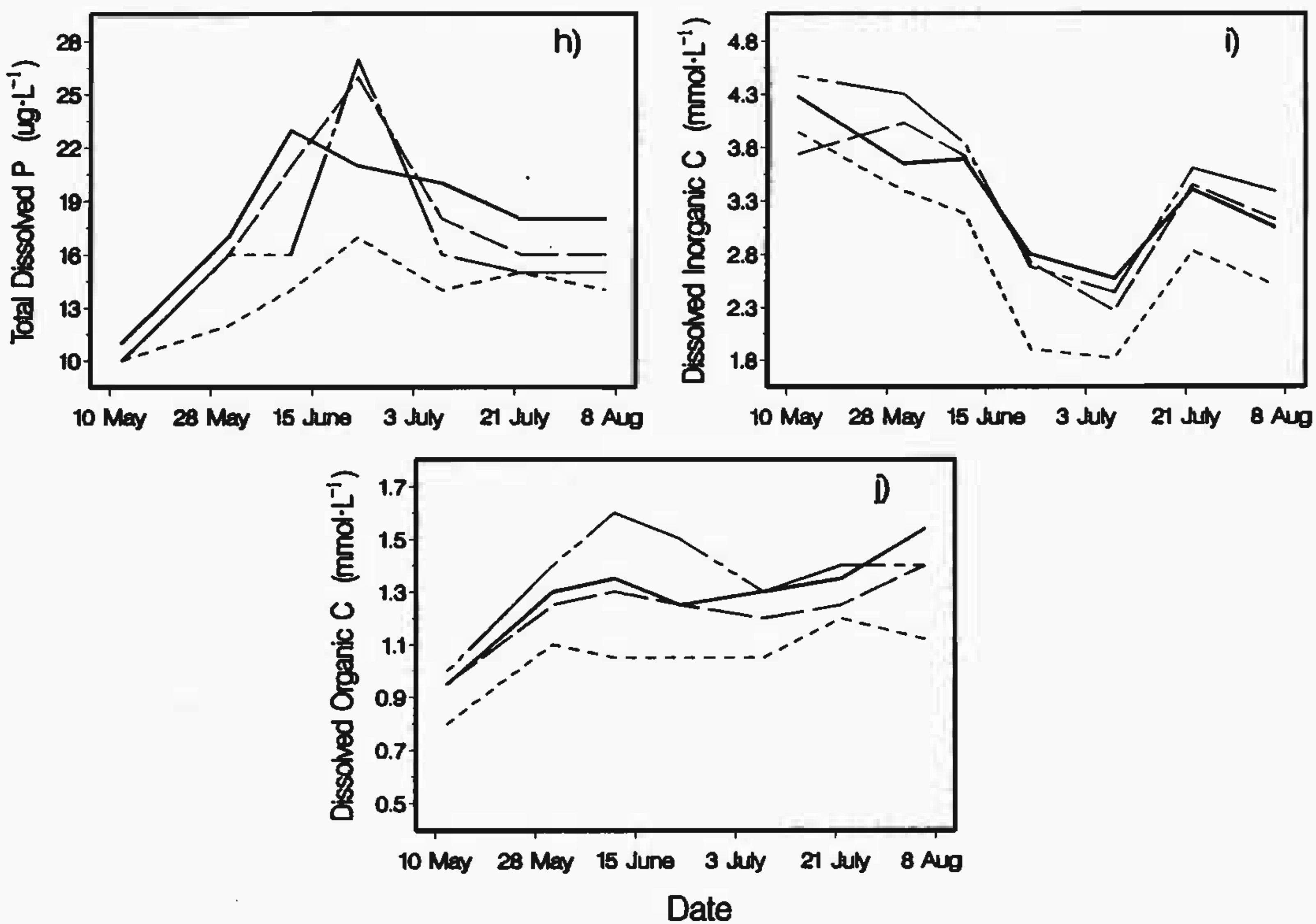

Fig. 3. Water chemistry characteristics of the Methley Beach walleye culture ponds during May, June and July of 1988 (———— = pond 1, - - - - - - - = pond 2, — — — = pond 3, —- - - — = pond 4); h) total dissolved phosphorous, i) dissolved inorganic carbon and j) dissolved organic carbon.

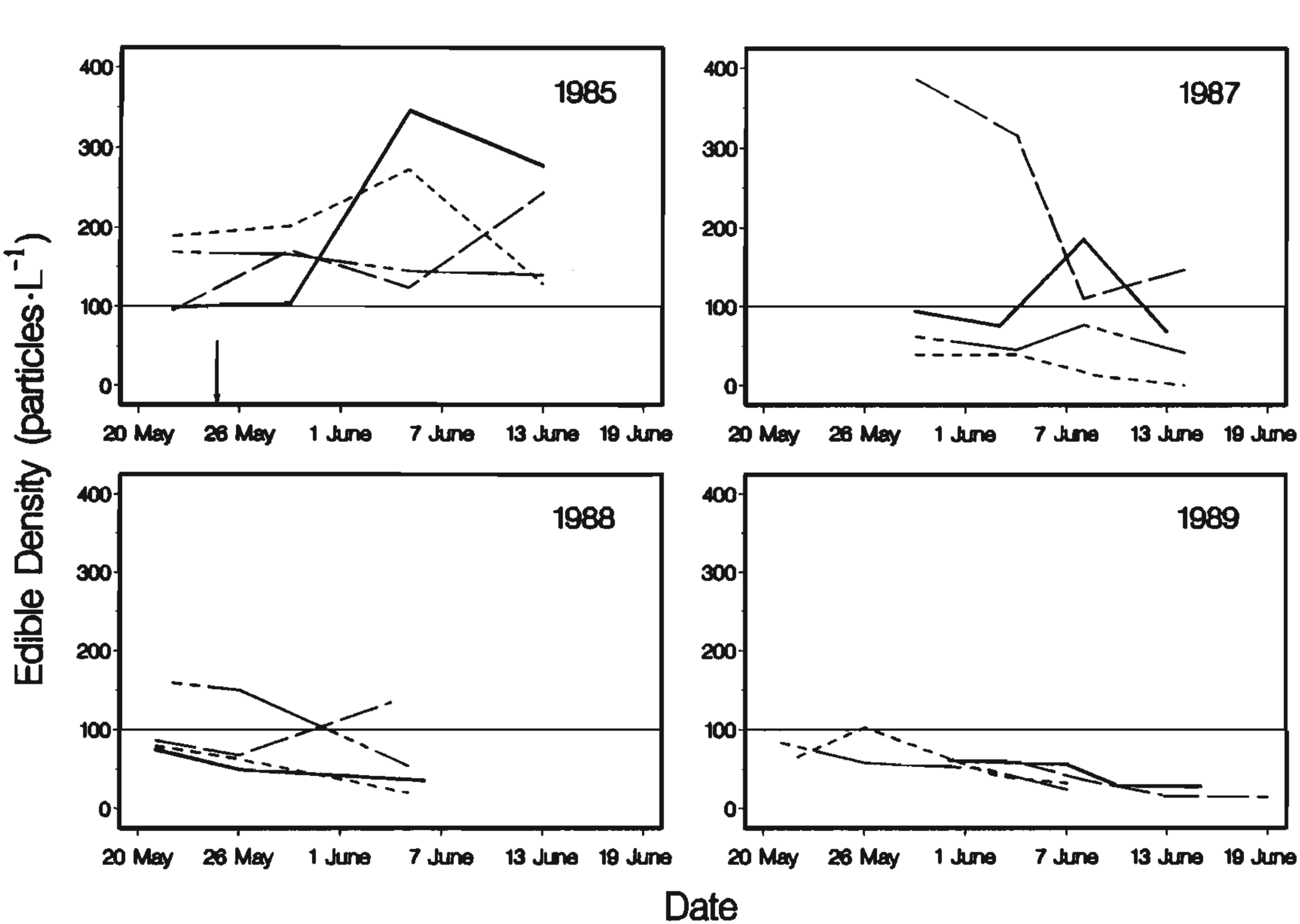

Fig. 4. Edible zooplankton densities in the Methley Beach walleye culture ponds (———— = pond 1, - - - - - - = pond 2, —— —— = pond 3, —— - - —— = pond 4) during the first month of walleye feeding in 1985, 1987, 1988 and 1989. Arrow indicates approximate date of first feeding in 1985. Date of first feeding for other years corresponds to the first sample date in each pond.

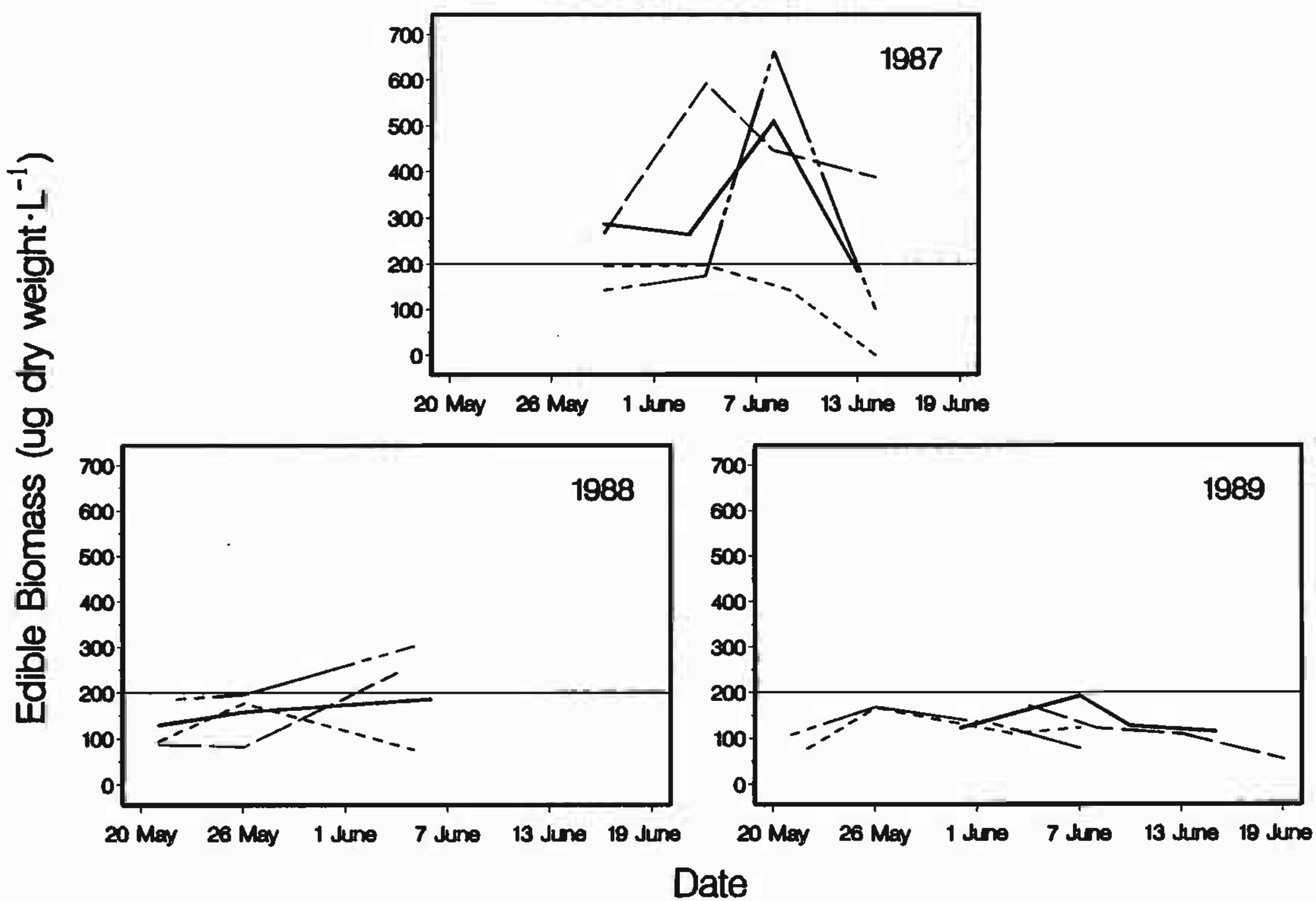

Fig. 5. Edible zooplankton biomasses in the Methley Beach walleye culture ponds (———— = pond 1, - - - - - - - = pond 2, —— —— —— = pond 3, ——- - -—— = pond 4) during the first month of feeding in 1987, 1988 and 1989. Date of first feeding corresponds to the first sample date in each pond for all years.

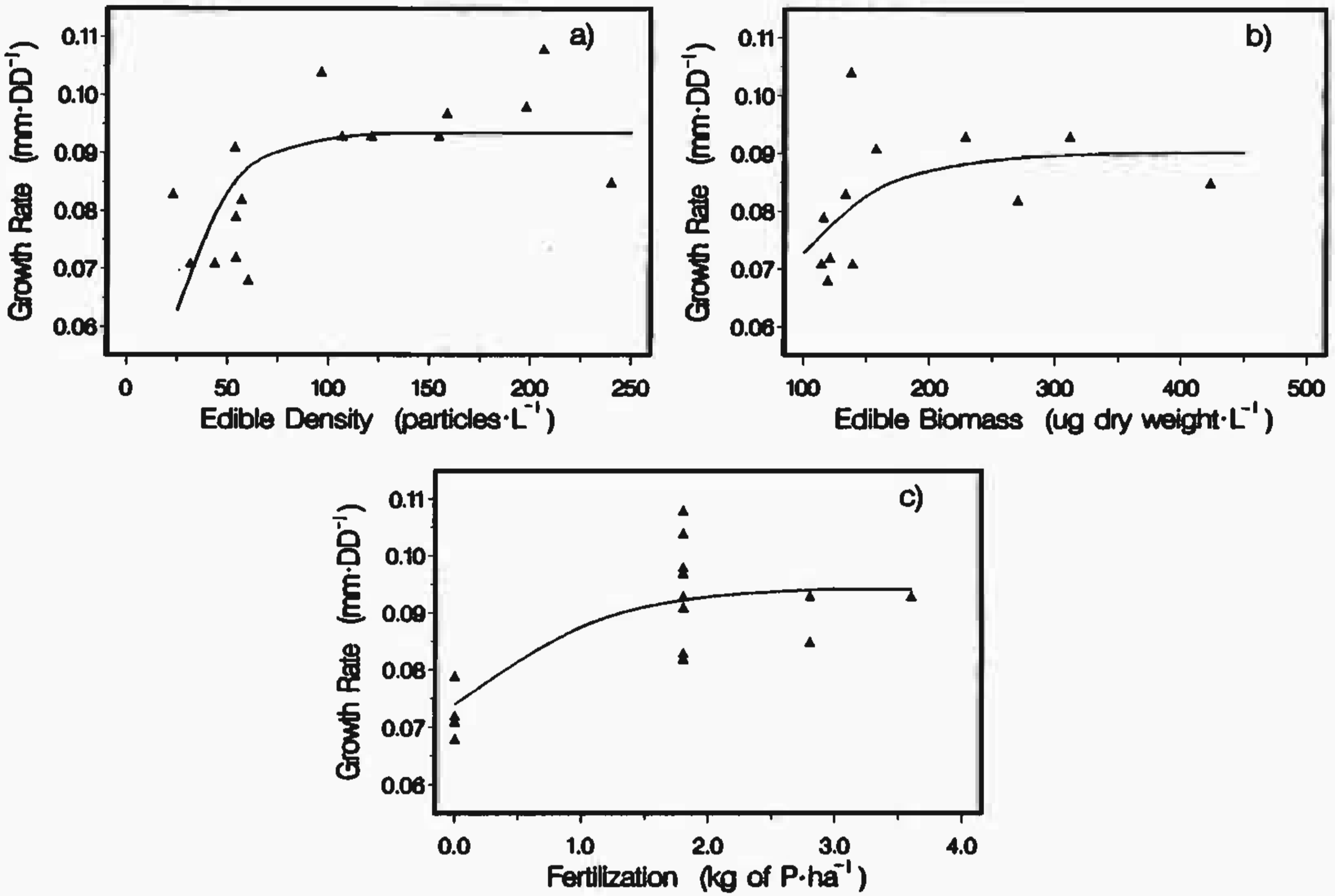

Fig. 6. Scatter plots of walleye postlarval growth rate (mm per degree day >10°C) versus a) mean edible density of zooplankton over the postlarval period, b) mean edible biomass of zooplankton over the postlarval period and c) total annual P inputs. Curves are eye-fitted interpretations of the relationship between the variables. Data are from the Methley Beach walleye culture ponds from 1985, 1987, 1988 and 1989 for plots a) and c), and from 1987, 1988 and 1989 for plot b).

Appendix 1. Fitted parameters (a,b), correction factors (CF) and regression statistics for $\log_e$length-$\log_e$dry weight relationships used to estimate biomass of various crustacean genera. Dry weight (DWT) in μg is estimated from length (L) in mm by the formula DWT = $a \cdot L^b \cdot CF$. The correction factor was estimated using the formula of Bird and Prairie (1985). Relationships were built from zooplankton sampled from the Methley Beach walleye culture ponds with the exception of *Ceriodaphnia sp.* which was collected from a pond in Winnipeg, Manitoba.

Taxon	a	b	CF	F	(df_{error})	R^2
Bosmina sp.	10.69	2.70	1.016	56.88	(6)	0.90
Ceriodaphnia sp.	9.05	2.54	1.017	84.89	(9)	0.90
Cyclops sp.	3.47	3.70	1.062	171.43	(21)	0.89
Daphnia sp.	3.70	3.41	1.013	443.01	(16)	0.97
Diaptomus sp.	2.82	3.36	1.068	78.70	(13)	0.86

Appendix 2. Sample sizes, means and standard deviations of FL (mm) for walleye sampled from the Methley Beach walleye culture ponds in 1985, 1987, 1988 and 1989. All 1988 fish were of the Swan Creek stock. Note that mean lengths for the first sample date in each year were calculated by pooling across ponds.

		Pond 1			Pond 2			Pond 3			Pond 4		
Year	Date	n	x	sd	n	x	sd	n	x	sd	n	x	sd
1985	21 May[1]	45	7.68	0.23	45	7.68	0.23	45	7.68	0.23	45	7.68	0.23
	23 May	92	8.59	0.51	50	8.76	0.37	20	8.95	0.37	30	8.79	0.49
	29 May	86	12.10	0.68	48	11.67	0.52	38	13.32	0.79	46	12.77	0.70
	12 June	31	22.92	0.91	25	21.57	0.93	35	21.42	0.83	21	20.73	0.85
	26 June	10	37.76	1.47	30	35.99	1.60	88	34.80	2.12	34	33.72	2.16
	17 July	10	50.56	4.05	10	51.07	1.33	10	46.46	2.31	10	50.97	6.15
	8 Aug	30	50.89	2.06	30	52.92	5.43	33	47.69	2.91	30	52.62	2.38
	20 Aug	21	50.96	2.16	31	55.11	4.02	30	49.11	3.39	19	53.11	4.14
	29 Aug	27	52.48	5.67	-	-	-	-	-	-	-	-	-
1987	23 May	45	7.68	0.23	45	7.68	0.23	45	7.68	0.23	45	7.68	0.23
	29 May	22	10.48	0.36	-	-	-	-	-	-	-	-	-
	30 May	-	-	-	15	10.62	0.32	20	10.37	0.33	25	10.22	0.30
	3 June	20	13.75	0.51	21	13.70	0.59	31	13.18	0.44	20	12.52	0.45
	8 June	26	18.67	0.98	23	18.61	0.81	22	16.37	0.56	-	-	-
	9 June	-	-	-	-	-	-	-	-	-	20	16.85	0.83
	13 June	32	21.53	1.34	42	19.63	1.66	20	20.73	0.90	-	-	-
	14 June	-	-	-	-	-	-	-	-	-	28	20.98	0.98
	22 June	16	30.90	1.61	20	31.47	6.82	-	-	-	-	-	-
	23 June	-	-	-	-	-	-	20	30.66	1.64	20	25.60	1.36
1988	14 May	25	9.06	0.47	25	9.06	0.47	25	9.06	0.47	25	9.06	0.47
	17 May	-	-	-	-	-	-	11	9.26	0.43	-	-	-
	21 May	20	10.26	0.45	20	10.29	0.56	20	10.24	0.40	21	10.34	0.45
	25 May	-	-	-	19	12.57	0.55	-	-	-	21	13.03	0.45
	26 May	25	13.18	0.56	-	-	-	26	14.03	0.46	-	-	-
	4 June	20	23.37	0.99	20	21.57	1.15	20	26.11	1.53	20	23.91	1.14

Appendix 2. Continued

		Pond 1			Pond 2			Pond 3			Pond 4		
Year	Date	n	x	sd	n	x	sd	n	x	sd	n	x	sd
1989	17 May	-	-	-	25	8.59	0.47	-	-	-	25	8.59	0.47
	20 May	-	-	-	-	-	-	-	-	-	43	8.88	0.37
	22 May	-	-	-	20	10.54	0.33	-	-	-	20	10.73	0.26
	23 May	25	8.59	0.47	-	-	-	-	-	-	-	-	-
	26 May	-	-	-	22	11.82	0.45	-	-	-	20	11.73	0.35
	31 May	24	10.30	0.48	-	-	-	-	-	-	-	-	-
	1 June	-	-	-	-	-	-	25	8.59	0.47	-	-	-
	2 June	-	-	-	-	-	-	-	-	-	20	14.14	0.58
	3 June	-	-	-	20	15.28	0.71	-	-	-	-	-	-
	4 June	-	-	-	-	-	-	25	10.13	0.30	-	-	-
	5 June	20	12.13	0.53	-	-	-	-	-	-	-	-	-
	7 June	-	-	-	20	16.64	1.32	-	-	-	20	17.18	1.02
	8 June	-	-	-	-	-	-	20	11.17	0.28	-	-	-
	9 June	25	14.23	1.30	-	-	-	-	-	-	-	-	-
	13 June	-	-	-	-	-	-	20	13.09	0.50	-	-	-
	16 June	25	18.43	0.97	-	-	-	-	-	-	-	-	-
	19 June	-	-	-	-	-	-	20	17.38	0.35	-	-	-

[1] Larval sizes at hatch in 1985 were estimated from 1987 data

Appendix 3. Water chemistry characteristics of the Methley Beach walleye culture ponds on several sampling dates during 1985 and 1987.

Year	Pond	Date	Cond ($\mu S \cdot cm^{-1}$)	Alkal ($meq \cdot L^{-1}$)	Chlor	TSS	Susp P	Susp N	Susp C	NH_4-N	TDN	TDP	DIC	DOC
					($\mu g \cdot L^{-1}$)								($mmol \cdot L^{-1}$)	
1985	1	1 May	1020	3.4	6.0	11	22	173	1810	50	-	15	3.3	0.51
		13 June	1250	3.7	0.3	8	16	71	830	90	-	26	3.3	0.78
	2	1 May	831	3.4	1.4	8	19	1530	1205	20	-	17	3.1	0.55
		13 June	1010	3.7	1.3	7	19	179	1240	50	-	27	3.3	0.83
	3	1 May	775	3.2	3.8	12	24	-	-	20	-	14	2.9	0.56
		13 June	965	3.7	2.5	12	32	214	1830	70	-	25	3.4	0.95
	4	1 May	861	3.4	3.1	10	21	-	-	20	-	18	3.1	0.57
		13 June	1060	3.9	4.0	39	62	455	5050	40	-	25	3.5	0.82
1987	1	19 May	-	-	-	-	6	41	450	-	700	17	-	-
		27 May	-	-	-	-	-	-	-	50	-	-	-	-
		28 May	-	-	-	-	-	-	-	930	-	123	-	-
		3 June	1070	3.6	16.3	3	16	176	1110	50	800	21	3.85	0.91
	2	19 May	-	-	-	-	10	83	740	-	650	18	-	-
		27 May	-	-	-	-	-	-	-	50	-	-	-	-
		3 June	892	3.77	3	3	8	66	620	30	760	19	4.21	1.26

Appendix 3. Continued

Year	Pond	Date	Cond ($\mu S \cdot cm^{-1}$)	Alkal ($meq \cdot L^{-1}$)	Chlor ($\mu g \cdot L^{-1}$)	TSS	Susp P	Susp N	Susp C	NH_4-N	TDN	TDP	DIC ($mmol \cdot L^{-1}$)	DOC
1987	3	19 May	-	-	-	-	13	104	820	-	640	14	-	-
		27 May	-	-	-	-	-	-	-	40	-	-	-	-
		28 May	-	-	-	-	-	-	-	670	-	127	-	-
		3 June	809	3.43	14.7	7	20	180	1570	30	760	16	3.26	1.10
	4	19 May	-	-	-	-	9	53	480	-	760	18	-	-
		27 May	-	-	-	-	-	-	-	40	-	-	-	-
		3 June	887	3.44	18.8	10	10	128	3670	30	730	15	3.71	1.17