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Evaluation of Environmental Factors Responsible for High Waterfowl Production at the Allain's Creek Ducks Unlimited Impoundment

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SUMMARY

A study of the Allain's Creek Ducks Unlimited impoundment, a coastal salt marsh impoundment located near the town of Annapolis Royal, Nova Scotia, was carried out during 1993. The primary objective of the study was to determine the basis for the high waterfowl productivity of the impoundment through a comprehensive analysis of the physical, chemical and biological nature of the system over the course of one growing season. Phytoplankton primary production within the impoundment is very high and indicative of a hypereutrophic system. Levels of both phosphorous and nitrogen were very high and seldom appeared to be limiting. There was little evidence that these nutrients originate from outside of the impoundment and it is suggested that the productivity of the system is driven mainly by high phosphorous concentrations stored within sediment that accumulated prior to impoundment of the salt marsh. Nitrogen inputs appear to be largely allochotonous originating from nitrogen fixing cyanobacteria which were observed to produce extensive phytoplankton blooms. Periphyton growth rates and submersed macrophyte biomass are also high and probably play an important role in supporting secondary producers. Secondary producers were found to be present in high numbers, were characterized by low species diversity as a result of the brackish nature of the impoundment, and were composed mainly of organisms considered to be important food sources of waterfowl brood.

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1. BACKGROUND

In 1982 Ducks Unlimited Canada (DUC) constructed a 14.2 ha impoundment on the northern shore of Allain's Creek, a tidal river that discharges into the Annapolis Basin just south of Annapolis Royal, Nova Scotia. The area flooded by the impoundment consists of previously dyked salt marsh and since impoundment has exhibited exceptionally high biological productivity. Immediately after flooding strong algal blooms developed and there have been anecdotal reports of extremely high densities of emerging aquatic insects. The extent of these latter events have been so severe at times as to have caused a nuisance in nearby urban areas.

Waterfowl production, as defined by brood use on the impoundment, is also exceptionally high. Although the impoundment is used by a variety of waterfowl species, black ducks are by far the numerically dominant species, accounting for more than 70 percent of broods observed. Surveys conducted on behalf of the Canadian Wildlife Service during 1991 and 1992 have indicated an average of 23 waterfowl indicated breeding pairs (IBP) and 36 waterfowl broods (2.54 broods per wetland ha) per year on the impoundment (Power 1992). These data are in sharp contrast with information collected on a much larger adjoining intensive waterfowl survey plot which yielded observed densities averaging 117 IBP and 82 broods (0.04 broods per wetland ha) during the same time period (Power 1992; J.B. Pollard, IWWR/DUC, pers. comm.). Brood densities on the Allain's Creek impoundment are among the highest reported for wetlands in Atlantic Canada.

Prior to this study the reasons for this high productivity were not immediately apparent, largely because little information existed on the biological, physical or chemical characteristics of the impoundment. It had been suggested that the high productivity of the impoundment is related to periodic inputs of seawater overtoping the dykes during spring tides. Salinity readings taken on an opportunistic basis in 1988, 1990 and 1992 had values of <1, 2, and 6 ‰ respectively, suggesting that the impoundment periodically receives salt water inputs. Other impounded coastal wetlands in the Atlantic region that are subject to occasional brackish or salt water inputs (e.g., Baie Verte and Wallace Bay in New Brunswick) are also characterized by very high waterfowl use.

Ducks Unlimited Canada presently manages over 50 coastal impoundments distributed throughout Atlantic Canada. Most of these sites are located in tidal bays and are typically associated with existing tidal fresh, brackish and salt marsh habitats. The total managed wetland area of these impoundments is in excess of 1000 ha. If the factors responsible for the high waterfowl production of the Allain's Creek impoundment could be clearly defined, this information could prove extremely useful in the effective management of existing impoundments for black ducks specifically, and for regional waterfowl production in general. The primary objective of this study was to determine the basis for the high waterfowl productivity of the impoundment through a comprehensive analysis of the physical, chemical and biological nature of the system over the course of one growing season. The specific objectives were to:

1. determine the biological nature of the impoundment in terms of the species composition and biomass of pelagic and benthic organisms and how these vary seasonally;

2. make seasonal measurements of phytoplankton primary production, submersed macrophyte production, and periphyton growth;

3. monitor seasonal changes in physical factors that relate to the availability of solar energy and nutrients;

4. monitor seasonal changes in chemical factors, especially those nutrients commonly found to be limiting in aquatic systems;

5. determine the nature and magnitude of potential nutrient inputs from seawater entering from Allain's River and freshwater entering from the drainage basin; and

6. interpret this information with respect to determining the factors responsible for the high waterfowl production of the impoundment.

2. STUDY SITE

The Allain's Creek impoundment is located along the northern shore of Allain's Creek, a tidal river that discharges into the upper reaches of the Annapolis Basin (Figure 1). The impoundment was constructed in 1982 and flooded about 14.2 acres of existing salt marsh. Salt marshes in the area are typical of northern cordgrass marshes and consist of low marsh, composed primarily of *Spartina alterniflora,* and high marsh, dominated by *S. patens*. A control structure, designed to maintain water levels at *ca.* 1 m depth, is located on the south side of the impoundment. During the winter of 1985 the impoundment was drawn down to reduce salinity in the bottom sediments in order to encourage development of emergent macrophytes for nesting and loafing areas. During this drawdown two loafing bars were constructed, one in each of the main basins.

The length of the shoreline is 2.10 km. The northern and eastern shorelines contain a narrow band of dense stands of cattails (*Typha angustifolia*) and the bottom of the impoundment is covered with a dense stand of sago pondweed (*Potamogeton pectinatus*), a submersed macrophyte common in brackish water systems. The impoundment is well exposed to the prevailing northwesterly winds.

The drainage basin of the impoundment is small, about 18 ha, and confined mainly to the northern and eastern sides of the impoundment. The geological substrate is mainly sandstone, siltstone and

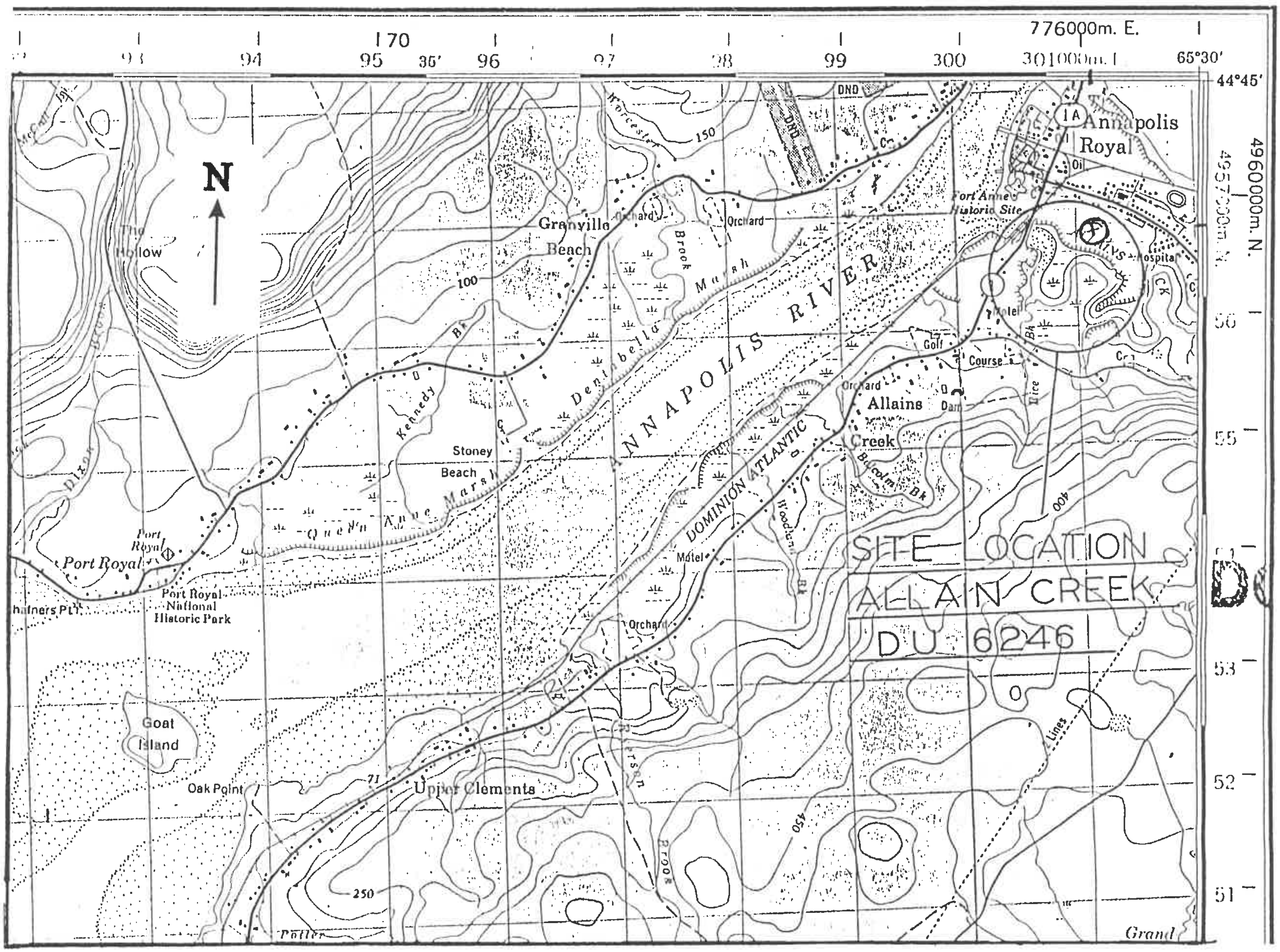

Figure 1. Location of the Allain's Creek impoundment.

shales of the Blomidon and Wolfville formations. It contains *ca.* 15 small residential dwellings, all of which are serviced by town sewer lines. Approximately one-third of the surface area consists of lawns and the remainder is mainly forested with a mixture of conifers and hardwoods. A portion of the Historic Gardens, a public botanical garden, is located in the northern portion of the drainage basin. The only obvious freshwater inflows into the impoundment are a storm sewer originating at the lower end of Babineau Heights, a residential street northwest of the impoundment, that discharges into the east corner of the impoundment, and a small stream that emanates from a fountain within the Historic Gardens. The source of water for the fountain is the town water supply, First Pond, a small lake located about 6 km west of Annapolis Royal.

At the beginning of the study a breach in the dyke along the west side of the impoundment allowed large quantities of water from Allain's River to enter the impoundment at high tide. Because this area of the dyke appeared to be undergoing considerable erosion it was repaired during mid-May. It is not clear how long the breach allowed water to enter the impoundment prior to the beginning of this study, but conversations with local residents suggest that the breach was present during the previous year and that it was becoming increasingly larger until the time of its repair.

3. METHODOLOGY

3.1. Sampling Regime

Three main sampling stations were established within the impoundment (Figure 2). Two (the East and West stations) were located in the centre of each of the two basins that make up the impoundment. The third station (the Centre station) was located close to where the two basins meet. Sampling for water chemistry was also carried out at two other locations; Allain's River water samples were collected near the control structure on the seaward side of the impoundment, usually at high tide, and a number of water samples were collected from the small stream emanating from the water fountain located within the Historic Gardens. The storm sewer originating at the lower end of Babineau Heights was never observed to carry water during the study period and was therefore never sampled. Sampling was carried out at biweekly intervals between 20 May and 2 September.

3.2. Physical Parameters

Water temperature depth profiles were determined by measuring water temperature at 0.25 m depth intervals using a Yellow Springs Instrument Temperature-Conductivity-Salinity meter.

Light availability was measured using a 20 cm diameter Secchi disk. The Secchi disk was lowered into the water from the shaded side of the boat and the depths at which is disappeared as it was lowered, and then reappeared as it was raised, were recorded. Secchi disk depth was determined as the mean of the two measurements.

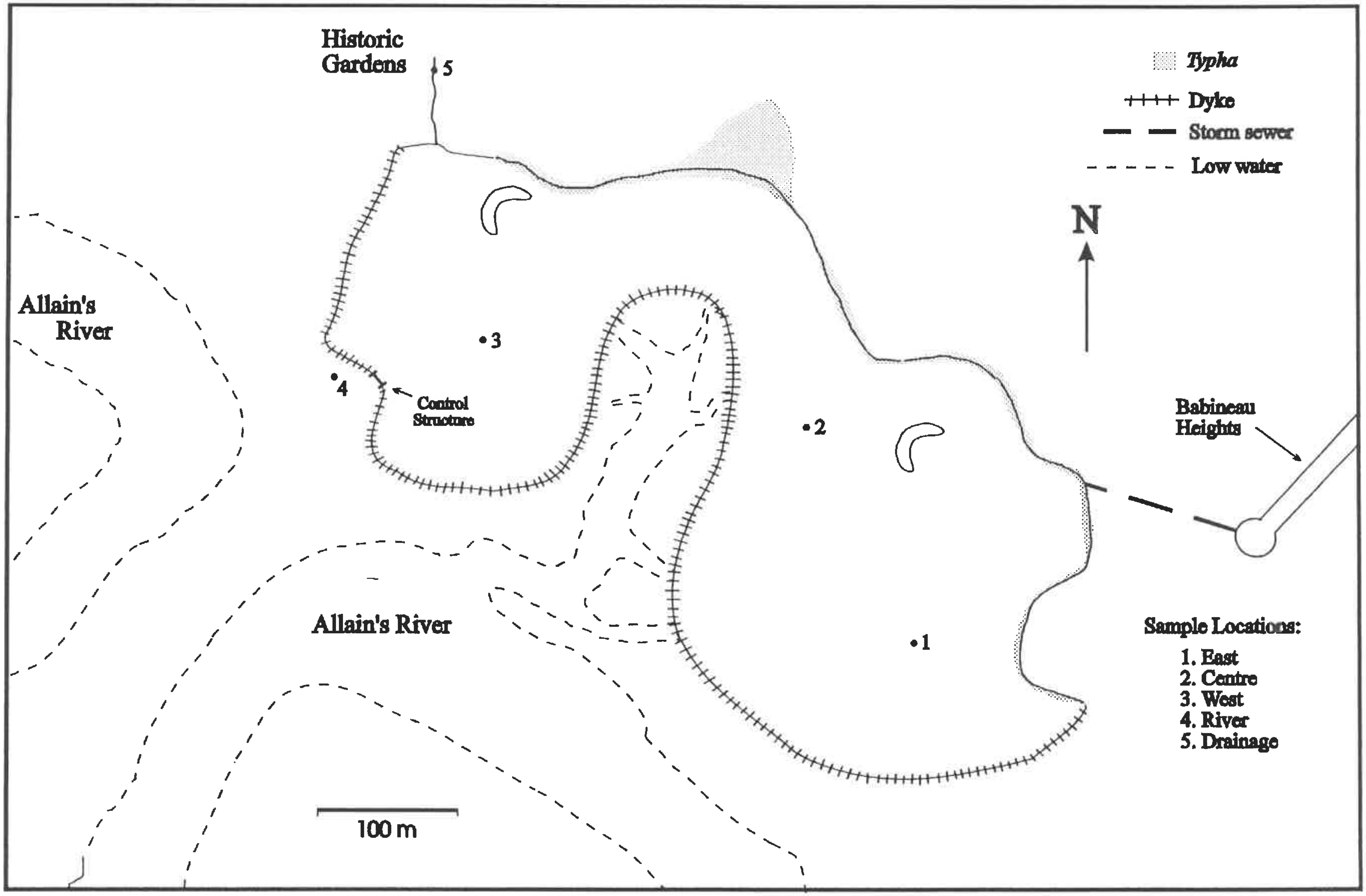

Figure 2. Location of sampling sites within the Allain's Creek impoundment.

One litre water samples for determination of suspended particulate matter (SPM) were collected from the surface at each station within the impoundment. Three measurements of SPM were made: total particulate matter (TPM), particulate inorganic matter (PIM) and particulate organic matter (POM). TPM was determined by filtering 1 litre of water onto previously combusted and tarred Whatman GF/C filters, drying the filters to a constant dry weight in a vacuum oven set at 60-70 °C, and then reweighing the filters. For determination of PIM, the dried filters were combusted for 24 hr in a muffel furnace set at 450 °C, and then reweighed. POM was calculated as the difference between TPM and PIM.

3.3. Chemical Parameters

Salinity depth profiles were determined by measuring salinity at 0.25 m depth intervals using a Yellow Springs Instrument Temperature-Conductivity-Salinity meter. Water samples for chemical analyses were collected in 1 litre acid washed polyethylene bottles and stored refrigerated until analysis. Analyses of chemical properties were carried out by the Inland Waters Resources Directorate of Environment Canada laboratory at Moncton, N.B. using procedures described in Anon (1979).

Sediment samples for determination of sediment organic matter were collected using a 5 cm diameter coring device. Only the top 5 cm was used for analysis of sediment organic content. Sediments were dried to a constant dry weight in a vacuum oven set at 60-70 °C, subsampled and the weight of the subsample determined. The subsamples were combusted for 24 hr in a muffle furnace set at 450 °C and reweighed to determine the loss of organic matter.

3.4. Biological Parameters

Samples for phytoplankton chlorophyll *a* measurements were collected in triplicate at each of the main sampling stations. One litre water samples were collected from the surface and stored refrigerated until analysis (usually within 24 hr of collection). Water samples were filtered through Whatman GF/C filters under gentle vacuum (<20 mm Hg) and chlorophyll extracted from the filters by adding 15 ml of 90 percent methanol and storing the sample refrigerated in the dark for 24 hr. After extraction the samples were centrifuged at 2500 rpm for 5 min, decanted into either 1 cm or 5 cm pathlength cuvettes depending on the concentration of chlorophyll, and absorption measured spectrophotometrically at 665 and 750 µm before and after acidification with 0.1 ml of 10 percent HCl. Chlorophyll *a* concentration was calculated according to the equations presented by Lorenzen (1967).

Water samples for determination of phytoplankton species composition were collected in 20 cm plastic scintillation vials from the surface water at each sampling station and preserved immediately with several drops of Lugol's iodine solution. Examination of these samples was carried out under an inverted microscope after placing the samples in 20 ml settling chambers for 24 hrs.

Periphyton growth was measured at each of the main stations by determining the accumulation of chlorophyll *a* on glass microscope slides incubated for a two week period. The glass slides were contained in plastic trays equipped with floats to suspend the trays *ca.* 10 cm below the water surface. Each tray contained 5-6 glass slides. After incubation the slides were collected and stored in the dark in a desiccator until analysis. Chlorophyll *a* concentration was determined by scraping the slides clean into a glass centrifuge tube, adding 15 of methanol and then extracting the chlorophyll in the dark under refrigeration for 24 hr. Chlorophyll *a* concentration was determined spectrophotometrically using the same procedure described for phytoplankton.

The above ground biomass of submersed macrophytes was determined on one occasion during early September. Seven 0.09 m^2 quadrate samples, located at random locations within the impoundment, were collected and analyzed for dry weight. Since these samples were collected at the end of the growing season just prior to the annual die off, their biomass is considered to represent a crude estimate of net annual above ground submersed macrophyte production.

Phytoplankton gross production and net pelagic community production were measured using the oxygen light-dark bottle technique. Incubations were carried out in 300 ml BOD bottles suspended within the water column at 0.25 m depth intervals. Dark bottles were made by covering the bottles with a double layer of black electrical tape. Initially, incubations were carried out for 4-5 hour periods centered around solar noon. However, during early June primary production levels were so high that water within the impoundment became supersaturated with oxygen very early in the day making it difficult to fill the BOD bottles without loosing variable amounts of dissolved oxygen. The high initial oxygen concentrations also made it difficult to accurately measure the increase in oxygen concentration resulting from photosynthesis. As a result, incubations carried out after 17 June were started at dawn and were limited to 2-3 hrs duration. Total water column productivity, expressed on a m^2 basis, was calculated by integrating the area under the depth profile obtained for each set of incubations. Total daily phytoplankton production was calculated by assuming production to be proportional to solar radiation and scaling the production determined for the incubation period by a factor proportional to the ratio of solar energy during the incubation period and for the entire day (Wetzel and Likens 1991).

Zooplankton samples were collected by filtering 100 litres of surface water through a 200 µm mesh plankton net. Samples were immediately preserved in 10 percent formalin. Zooplankton numbers were enumerated by direct counting under a stereo microscope. In some instances zooplankton densities were very high and numbers were determined on 2 or 10 ml subsamples drawn with a Hansen-Stemple volumetric pipette.

Sampling for benthic invertebrate enumeration was originally carried out using a 5 cm diameter coring device. These samples, however, contained very low numbers of invertebrates and after 3 June samples were collected with a 350 µm D-type sweep net. Sampling was carried out at each of the three main sampling stations. The net was slowly drawn repeatedly along the bottom until enough debris was collected to fill a 500 ml sample container. The samples were stored frozen until analyses which was carried out by sorting in flat white pans in the laboratory, identifying to Order and preservation in 70 percent alcohol.

One emergent insect trap was set at each of the main sampling stations. The traps were constructed of fiberglass door screening and were conical shaped with a 50 cm diameter bottom opening and a 6 cm diameter top opening. The opening at the top was fitted with an open ended plastic bottle having a rubber stopper at the top and an inverted plastic funnel at the bottom. The bottle was filled with 10 ml of conc. formalin to kill and preserve the insects.

Minnow trap collections were also made at each of the three main sampling stations. The organisms collected were identified and enumerated in the field.

3.5. Waterfowl Survey

Systematic bi-weekly waterfowl surveys specifically for indicated breeding pairs (IBP) were carried out at the Allain's Creek impoundment between 20 April and 31 May. These dates encompass the peak of nest initiation for species documented as, or potentially, breeding at the site. Breeding pair observations were conducted using quiet observation from a series of vantage points around the wetland. Sex, species composition and behavioral observations were documented for all waterfowl observed. Optimal IBP dates were selected based on peak nest initiation estimates from brood back-dating. IBP were calculated according to a modification of the methods described by Dzubin (1969) and Erskine et al. (1990) indicated as follows:

American Black Duck IBP	= lone birds + 2 bird groups
Other Dabbling Duck IBP	= pairs + lone females + females in groups <5
Diving Duck IBP	= pairs + lone females

Brood observations were conducted using quiet observation from several vantage points from the date the first brood was observed (24 May) until 11 August. Brood records were tallied by species and number of ducklings. A conservative estimate of brood use of the wetland was estimated by crossing-off repeated observations of broods based on brood species, size and age (Gollop and Marshall 1954).

4. RESULTS

4.1. Physical Characteristics

Water level within the impoundment decreased gradually from about 100 to 50 cm between June and mid-August (Figure 3a) and then increased slightly until the end of the study. The decrease in level was probably a result of low water inputs as a result of the generally dry summer (total precipitation during the study period (Figure 4c) amounted to only 232.7 mm), and leakage of water from the impoundment. Evaporation probably also played a role, but was probably not as important as leakage since salinity values increased < 50 percent (see Section 4.2.1) despite a decrease of nearly 100 percent in the volume of the impoundment.

Water temperature within the impoundment (Figure 3b) varied between 13.2 and 26.6 °C over the study period. Although the top few cm of surface water often exhibited higher temperatures than the underlying water, particularly when measured after mid-day, there was no evidence of

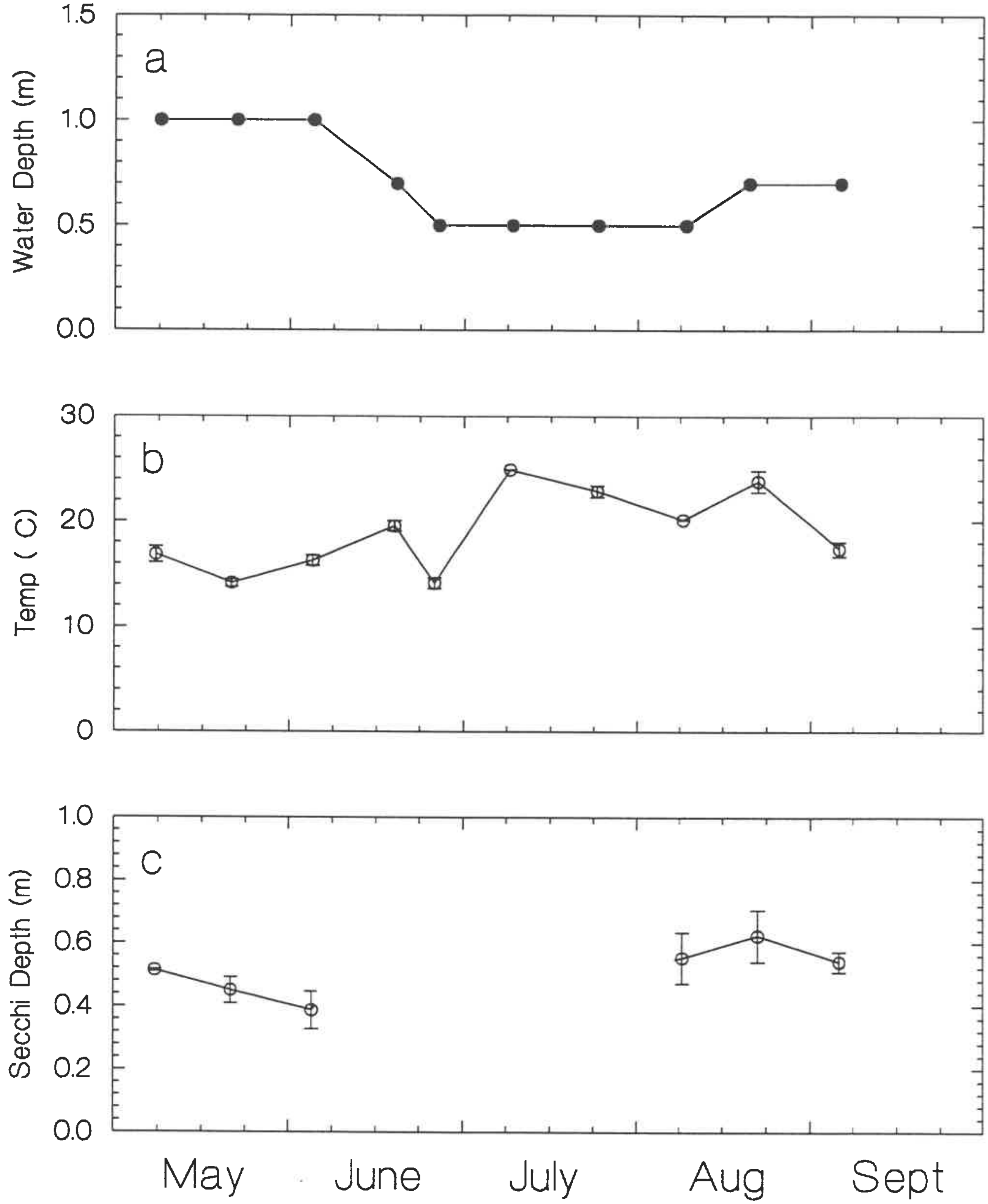

Figure 3. Seasonal variation in (a) water depth, (b) water temperature and (c) Secchi disk depth within the impoundment (error bars are one standard error of the mean).

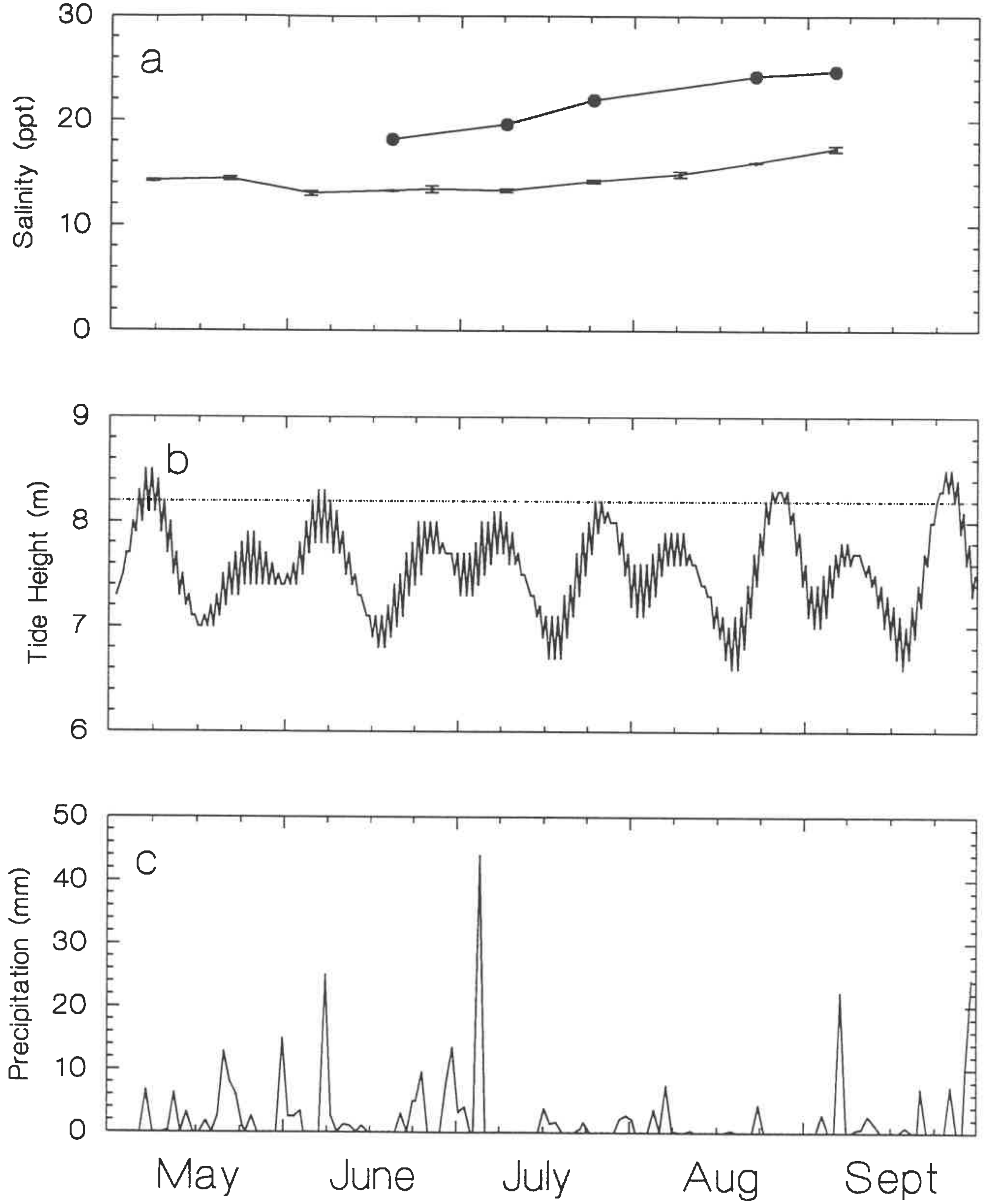

Figure 4. Seasonal variation in (a) salinity within the impoundment (·) and the River (•), (b) height of high tide in Allain's River and (c) precipitation at Annapolis Royal (error bars are one standard error of the mean).

persistent thermal stratification of the water column. Except for a period of low temperatures during late June, there was a general increase in temperature from May to mid-July followed by a gradual decline. There is no obvious explanation to account for the low temperatures observed in late June.

Secchi disk depth (Figure 3c) and water colour exhibited considerable seasonal variation. During early May to mid-June Secchi disk depths varied between 40-50 cm and the water appeared light green, typical of the colour characteristic of dense algal blooms. This was followed by a period of clear water and shallow water depths when the bottom of the impoundment was always visible. During early August water clarity again decreased and Secchi disk depths averaged 50-60 cm, but in this instance the water colour was reddish-brown, typical of the colour imparted by 'red tide' type of organisms. Microscopic examination of water samples revealed that these water colours were due to blooms of cyanobacteria in the first instance, and cyanobacteria and dinoflagellates in the second instance (see Section 4.3.1).

TPM values were relatively high, ranging between 9.8 and 57.2 mg l^{-1}, and showed a strong seasonal variation (Figure 5). Most of the variation was in POM, as opposed to PIM, and closely followed the seasonal variation in phytoplankton chlorophyll *a* (see Section 4.3.1) suggesting that most of the TPM is derived from biological activity as opposed to resuspension of sediments or allochotonous inputs entering the impoundment from the drainage basin.

4.2. Chemical Characteristics

4.2.1. Salinity

Salinity within the impoundment ranged between 12.6 and 17.9 ‰. There was generally little spatial variation in salinity within the impoundment, either between sampling stations, or with depth within the water column and, other than a slight increase with time, there was also surprisingly little seasonal variation in salinity (Figure 4a). On one occasion, in an attempt to locate possible groundwater inputs entering the impoundment from below the shoreline, an extensive series of transects were carried out over the entire impoundment while measuring salinity just above the bottom. On that particular day (12 August) the range in salinity over most of the impoundment was only 17.5 to 17.9 ‰. The only area detected to have a significantly different salinity was a small area near the northern shore where freshwater enters the impoundment from the stream emanating from the fountain at Historic Gardens. The lowest salinity observed in this area was 16.5 ‰. Salinity within Allain's River, based on samples collected from the River side of the control structure at high tide, was always higher than within the impoundment and ranged between 18.2 and 24.7 ‰ (Figure 4a).

On a number of occasions water was observed entering the impoundment through the control structure. In an attempt to determine how often this occurred during the study period, a number of measurements were made to determine the height differential between the top of the control structure and the surface of the River at high tide. Based on these measurements it was determined that tide heights greater than 8.2 m could result in water entering the impoundment. Figure 4b presents a time series of tide heights, based on tide table predictions for the Annapolis

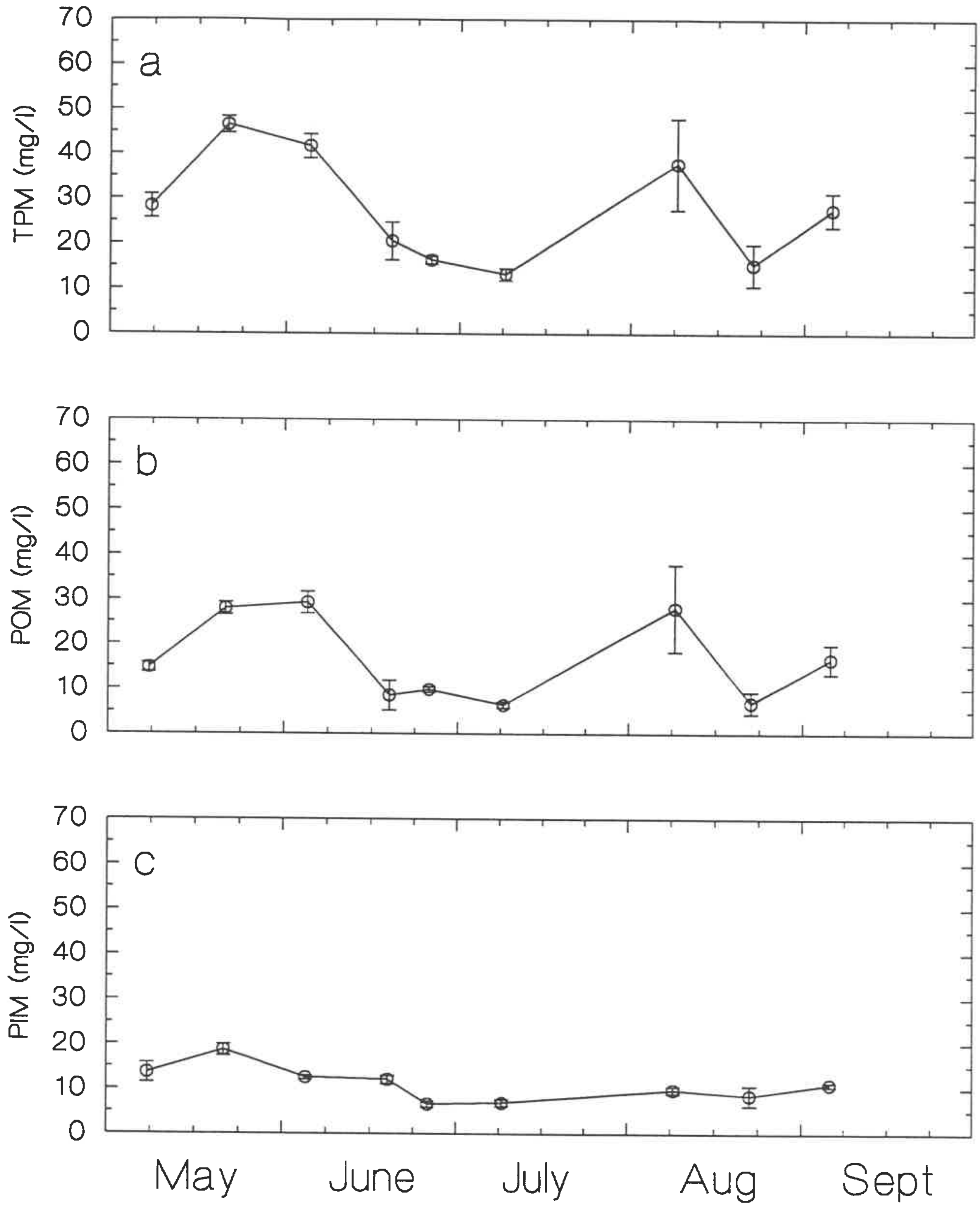

Figure 5. Seasonal variation in (a) total particulate organic matter, (b) particulate organic matter and (c) particulate inorganic matter within the impoundment (error bars are one standard error of the mean).

Basin, and indicates that this would have occurred three to four times during the study period. It is difficult to predict how much water would have entered during these periods because this depends largely on how well the flap-gate of the control structure seals. For example, on one occasion it was noted that a large piece of wooden debris had been trapped in the lower part of the gate. If this occurred during a period of spring tides it is likely that considerable River water would enter the impoundment. The fact that there was no obvious relationship between salinity at the East station, which is located closest to the control structure, and the time of the greatest tide heights suggests that significant volumes of water did not enter the impoundment from the River during the study period. The relatively high salinity of the impoundment could very likely be a result of River water entering the impoundment prior to repair of the breach. If this is the case, it is likely that salinity within the impoundment will show a decrease in the spring of 1994 due to freshwater inputs resulting from snowmelt.

4.2.2. Nutrients

Phosphorous and nitrogen, the major nutrients required by aquatic primary producers, were present in high concentrations within the impoundment (Figure 6). Both showed similar seasonal variations (Figure 7) with peaks in late May and early August, and lower values during mid-June to mid-July. On no occasion, however, were either of these nutrients found to be present in quantities that would be considered limiting. Total phosphorous concentrations ranged between 0.053 and 0.440 mg l^{-1} with a mean value of 0.175 mg^{-1}. These values are high and characteristic of hypereutropic conditions (Vollenweider and Kerekes 1982). Total nitrogen levels ranged between 0.030 and 4.10 mg l^{-1} with a mean of 1.03 mg l^{-1}. N:P ratios ranged between 0.2 and 17.6 with a mean of 6.2. These ratios are relatively low and indicate that, despite the high phosphorous concentrations, nitrogen was probably seldom limiting.

In contrast to phosphorous and nitrogen, silicate concentrations were relatively low ranging between 0.026 and 2.60 mg $^{-1}$ with a mean of 0.667 $^{-1}$. Although these values are mostly above those considered to be limiting, they may explain the general lack of diatoms observed in phytoplankton samples (see Section 4.3.1).

In an effort to determine the major nutrient sources to the impoundment, water samples were collected from the River and areas where water was observed to drain into the impoundment. The concentrations of total phosphorous and total nitrogen in the River varied little seasonally and, although relatively high, were always less than those within the impoundment. Mean values of total phosphorous and total nitrogen were 0.066 and 0.23 mg l^{-1} respectively, almost an order of magnitude lower than that of the impoundment. Silicate concentrations, however, were greater in the River than in the impoundment. The only obvious input of water entering the impoundment from the drainage basin was the small stream originating at the fountain in the Historic Gardens. On two occasions water samples were collected from the stream at a point where it just entered the impoundment. In both cases, phosphorous and nitrogen contents were always much lower (<0.012 and 0.21 mg l^{-1} respectively) than levels observed within the impoundment. Drainage of water into the impoundment from other areas of the drainage basin, including the storm sewer originating at Babineau Heights, was never observed during the study period.

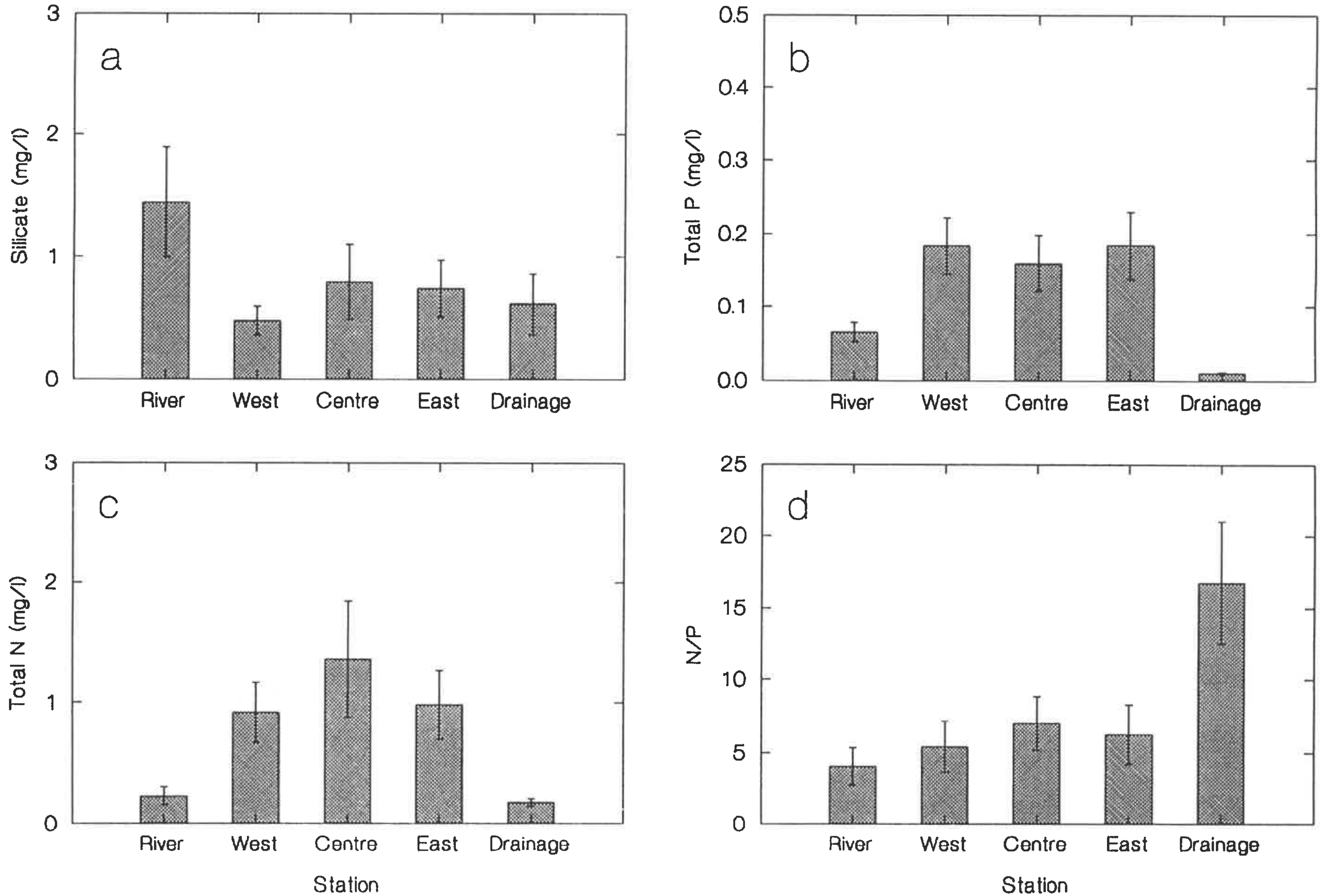

Figure 6. Comparison of mean nutrient concentrations at each sampling station (error bars are one standard error of the mean).

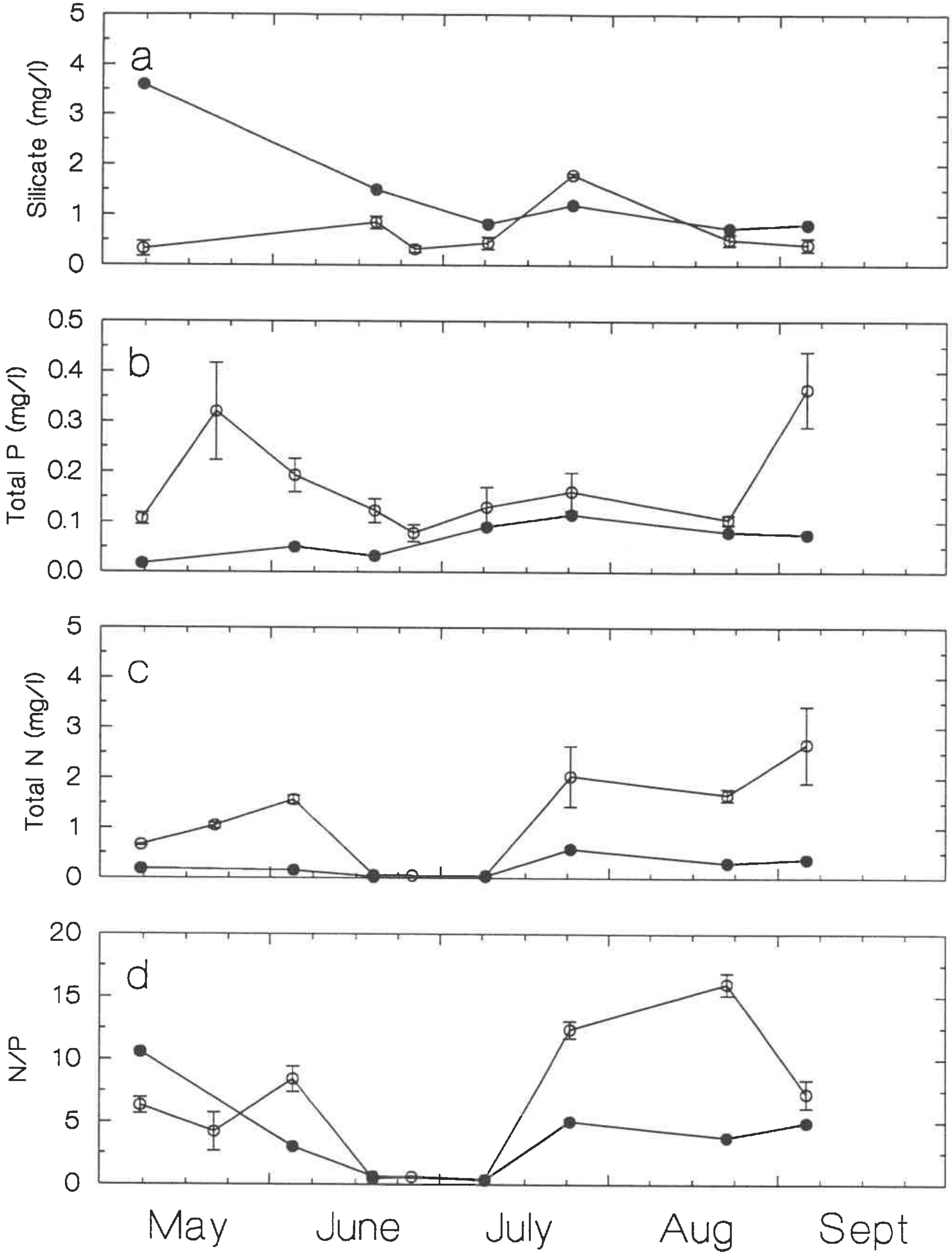

Figure 7. Seasonal variation in nutrient concentrations within the impoundment (○) and the River (•) (error bars are one standard error of the mean).

4.2.3. Sediment Organic Content

The organic content of sediments within the impoundment was high ranging between about 5 and 16 percent. The high organic content of the sediments is probably a result of accumulation of plant material in the past, when the impoundment was a salt marsh, as well as of the present dense growth of pondweed. The high organic contents suggests that nutrient contents within the sediments are also high.

4.3. Biological Characteristics

4.3.1. Phytoplankton Chlorophyll *a*

Phytoplankton chlorophyll *a* concentrations were highly variable over the study period and followed the same seasonal trend as phosphorous and nitrogen concentrations. There were two distinct periods of high chlorophyll *a* concentration (Figure 8a). The first occurred from mid-May to mid-June when chlorophyll *a* reached levels >25 $\mu g\ l^{-1}$. This was followed by a period of relatively low chlorophyll *a* levels that lasted until late July when a second, more intensive, bloom developed. In this instance chlorophyll *a* concentrations were much greater reaching values in excess of 300 $\mu g\ l^{-1}$. This bloom lasted until late August. Microscopic examination of phytoplankton samples revealed the first bloom to be caused by small (<10 μm), spherical algal cells that appeared to be cyanobacteria, a non-colonial form of blue-green algae that possess the ability to fix nitrogen. This explains the high nitrogen levels observed at this time. The second bloom also consisted of small cyanobacteria, but was dominated primarily by dinoflagellates and some diatoms were also present. There was never any indication that filamentous or mat forming algae were present within the impoundment in significant amounts.

4.3.2. Phytoplankton Gross Production

Gross phytoplankton production (Figure 8b) closely followed the seasonal trends in phytoplankton chlorophyll *a* concentrations. During the first bloom gross production attained levels close to 2 gm C m^2 day^{-1}. During the second bloom, levels above 6 gm C m^2 day^{-1} were measured. These are exceptionally high values and are attainable only under the most optimum conditions. Gross phytoplankton production over the entire study period amounted to 202 gm C m^2, an average of 1.7 gm C m^2 day^{-1}.

4.3.3. Net Pelagic Community Production

Net pelagic community production values were low as a result of high respiration rates (Figures 8c and 8d). This indicates that most of the phytoplankton primary production is quickly utilized and little remains to settle and accumulate within sediments.

4.3.4. Periphyton Growth Rates

Periphyton growth rates ranged between 12 and 420 μg chlorophyll *a* $slide^{-1}$ and exhibited spatial and seasonal trends very similar to phytoplankton chlorophyll *a* concentrations. These values are

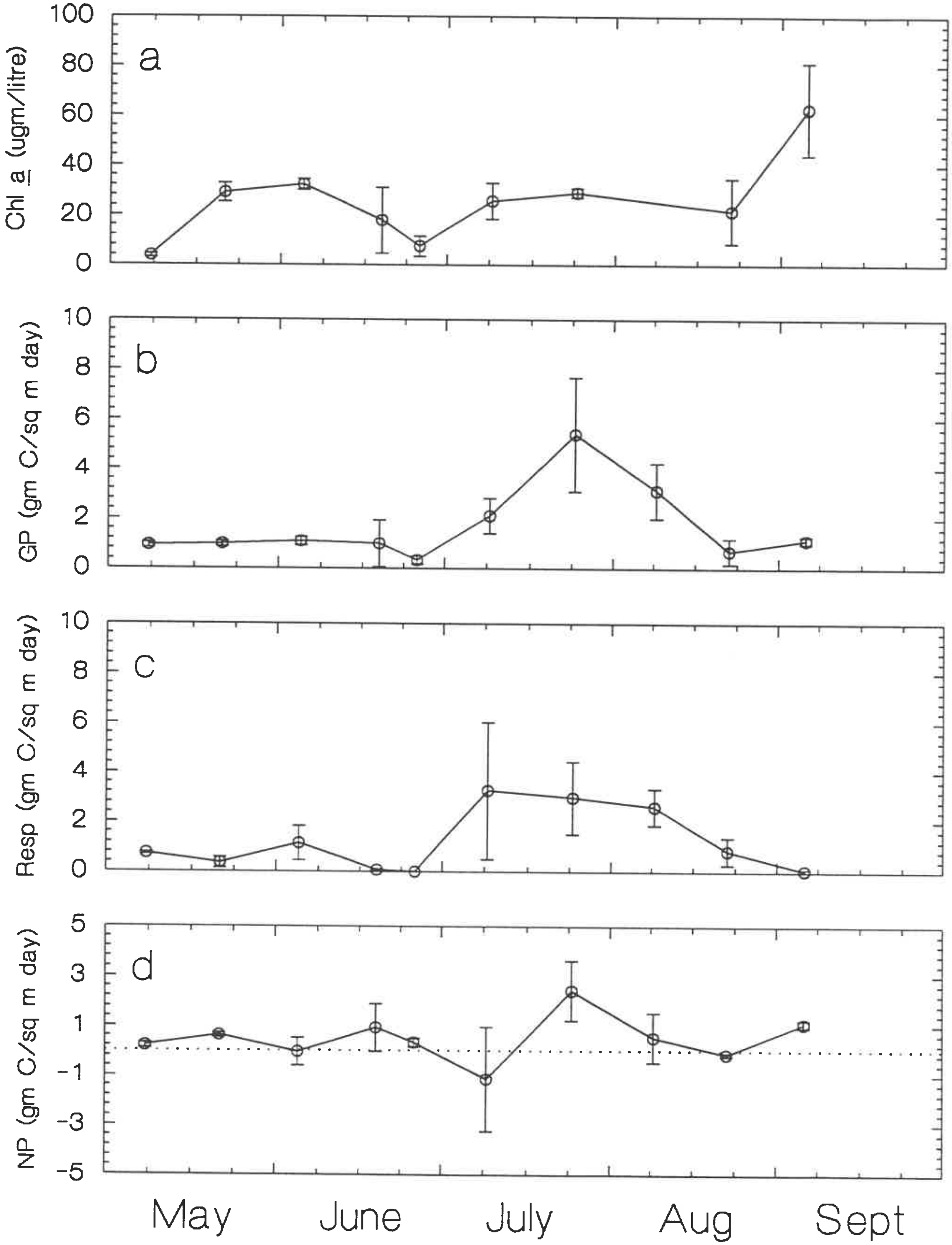

Figure 8. Seasonal variation in (a) phytoplankton chlorophyll a concentration (b) phytoplankton gross production (c) pelagic community respiration and (d) pelagic community net production (error bars are one standard error of the mean).

high and indicate that periphyton are probably an important source of organic production in the system, especially since the high biomass of submersed macrophytes provides a readily available substrate for their growth.

4.3.5. Submersed Macrophyte Biomass and Net Production

The mean biomass of submersed macrophytes, which consisted almost exclusively of sago pondweed (*Potamogeton pectinatus*), was 10.43 (SD ± 8.85) gm dry weight m^2. There was considerable spatial variation in biomass over the impoundment, the higher biomass occurring at the shallower depths. It is probable that this is a result of light limitation at deeper water depths resulting from turbidity caused by phytoplankton blooms.

4.3.6. Zooplankton

Zooplankton numbers within the impoundment varied greatly and exhibited a seasonal variation closely following that of phytoplankton (Figure 9). The highest zooplankton numbers (>2000 l^{-1}) occurred at about the same time as the first phytoplankton bloom and consisted largely of nauplii (immature copepods). Adult copepods were also relatively abundant during this period. During the latter part of the study, zooplankton composition changed markedly and was dominated by rotifers, although low numbers of ostracods were also present. The disappearance of nauplii and the lack of adult copepods after early June suggests that predation pressure is high on this group. The high numbers of fish (see Section 4.3.9), many of which are major zooplankton predators, supports this idea.

The species composition of zooplankton was very limited and almost monospecific. The most common copepod was *Eurytemora hirundoides*, a calanoid typical of estuarine systems. The rotifer population consisted primarily of *Brachionus plicatus*.

4.3.7. Benthic Invertebrates

Benthic invertebrate numbers averaged about 200 per sample (Figure 10b). Chironomids dominated the benthic invertebrate samples but some gammarids and corixids were also present.

4.3.8. Emergent Insects

Although emergent insects were collected in all traps over the entire course of the study, there was substantial variation among stations in the numbers collected at any one time. There were three distinct periods of insect emergence (Figure 9d). The first occurred during mid-June and was observed mainly at the East station. The second occurred during late June and was observed at all three stations. The third emergence period occurred during mid-July and was observed mainly at the West station. Numbers during these periods ranged between *ca.* 50-500 individuals per trap.

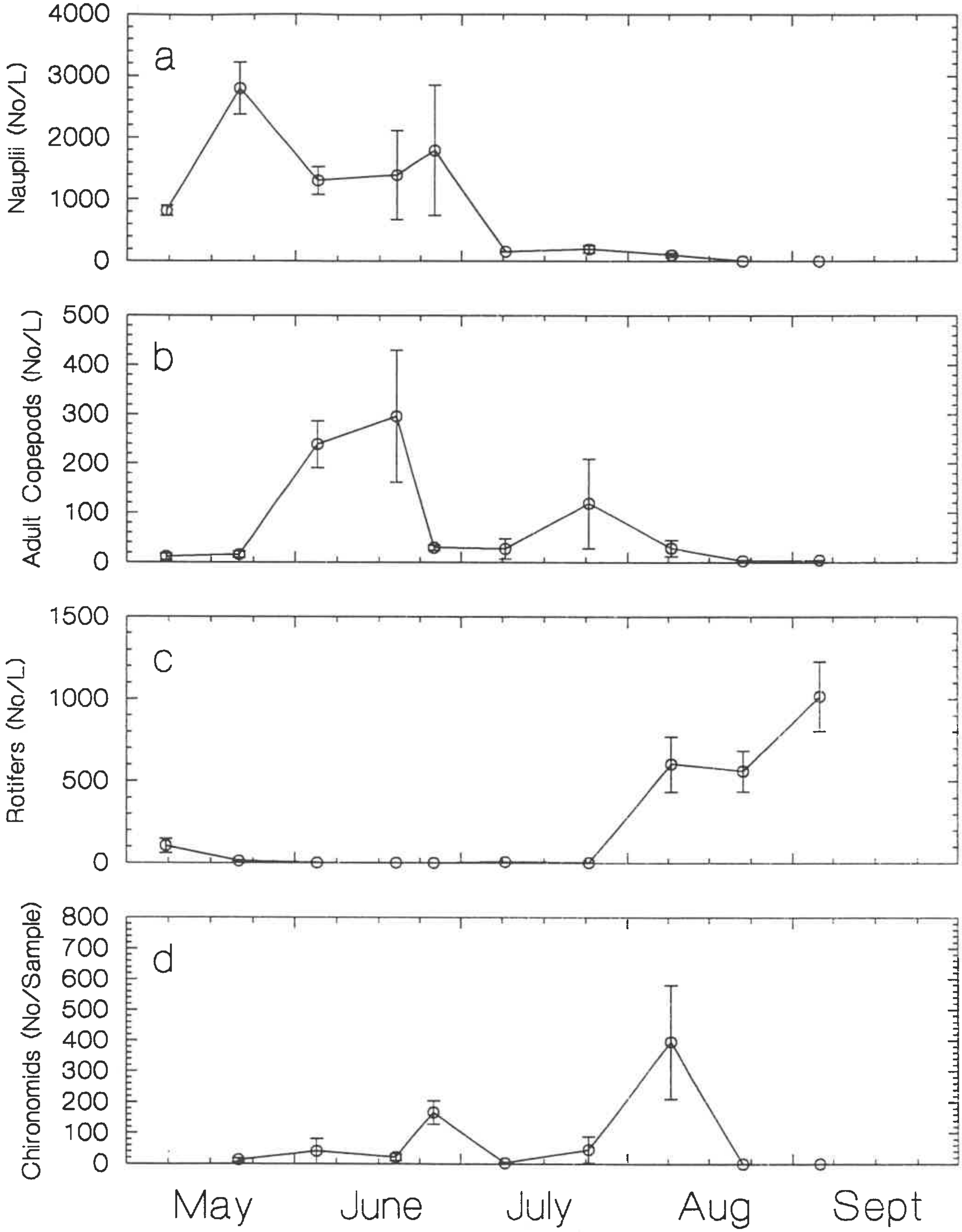

Figure 9. Seasonal variation in (a) copepod nauplii, (b) adult copepods, (c) rotifers and (d) chironomids collected in emergence traps (error bars are one standard error of the mean).

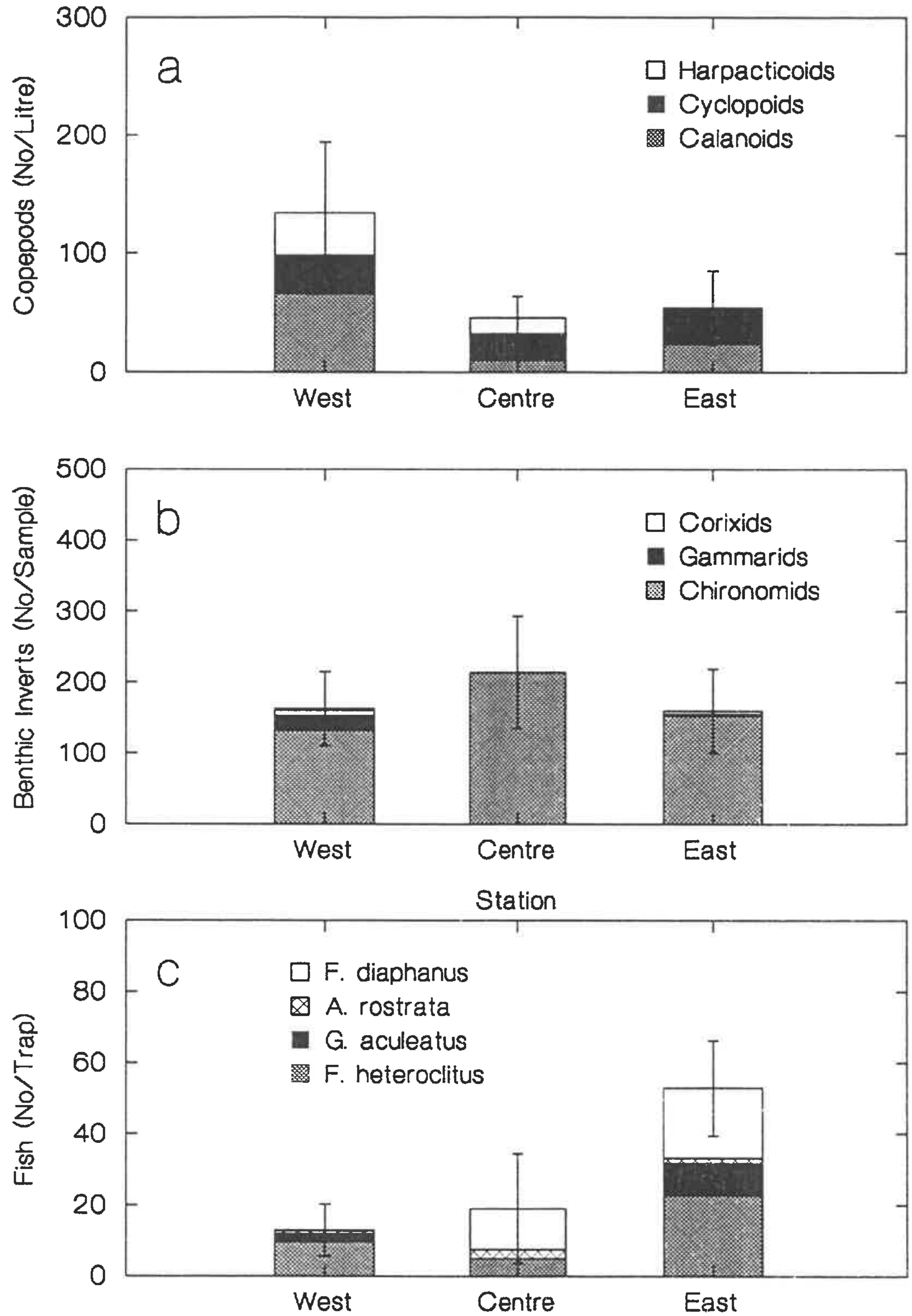

Figure 10. Composition of (a) adult copepods, (b) benthic invertebrates and (c) fish collected in minnow traps.

Most emergents were chironomids and all appeared to be of only two or three species. Attempts to identify these organisms to the species level were unsuccessful and specimens have been sent to appropriate experts in Ottawa and Winnipeg for identification.

4.3.9. Minnow Trap Collections

Minnow trap collections revealed the presence of large numbers of small fish (Figure 10c), most of which were banded killifish (*Fundulus diaphanus*) and mummichogs (*F. heteroclitus*). Eels (*Anguilla rostrata*), threespine stickleback (*Gasterosteus aculeatus*) and fourspine stickleback (*Apeltes quadracus*) were also collected, but never in large numbers. There appeared to be some seasonality in the presence of the two species of *Fundulus*, with *F. heteroclitus* being dominant during the early part of the study and *F. diaphanus* during the latter part. It is not clear how this could occur, however, since there was little evidence that significant quantities of water either entered or left the impoundment during the study period.

4.3.10. Waterfowl

In 1993, IBP were recorded for five species of ducks, consisting of American Black Duck, American Green-winged Teal, Hooded Merganser, Blue-winged Teal and Ring-necked Duck in order of calculated IBP abundance (Table 1).

Table 1. Indicated breeding pairs and broods, Allain's Creek Impoundment, 1991-1993.

Species[1]	1991		1992		1993	
	IBP	BROODS	IBP	BROODS	IBP	BROODS
ABDU	7.0	28	6.5	25	3.5	31
MALL	1.0	1	1.5	0	0.0	0
MBDH	0.0	2	1.0	0	0.0	0
AGWT	2.0	3	5.0	7	3.0	9
BWTE	3.0	3	1.0	3	0.5	4
COME	1.0	0	0.0	0	0.0	0
HOME	0.0	0	0.0	0	2.0	0
RNDU	2.0	0	1.0	0	0.5	0
TOTAL	16.0	37	16.0	35	9.5	44

[1]Species abbreviations according to A.O.U. protocol

Although there is some degree of variation in observed IBP between years, Black Ducks are consistently the most common IBP recorded. Data on IBP from 1991 and 1992 are included in Table 1 for comparative purposes. Over the course of the three year observation period, several other species were documented at the site, however these were not noted as breeding in the area, or were found at a time inconsistent with breeding chronology for the species and thus not included as IBP (Wood Duck, American Wigeon, Bufflehead, Red-breasted Merganser and Garganey).

In 1993, a total of 132 broods were observed on 21 dates. Observations were generally conducted at three to four day intervals, with the interval between site visits never exceeding 10 days. After crossing-off of repeated observations, it is estimated that 44 separate broods of three species used the wetland: 31 Black Duck, 9 Green-winged Teal, and 4 Blue-winged Teal broods. Over the course of the three year period for which there are data, these three species are consistently the most abundant found on the wetland (Table 1). A summary of brood observations by year, for the period 1991 through 1993, is provided in Table 1.

5. DISCUSSION

The Allain's Creek impoundment is a very productive system with respect to both primary and secondary production. Rates of daily gross phytoplankton production were often greater than 2 mg C m^2 $day^{-1}$and averaged >1.5 mg C m^2 day^{-1} over the course of study. These rates are among the highest reported for aquatic systems in the Atlantic Maritimes. Periphyton growth rates and net production of submersed macrophytes is also high. Although secondary production was not measured directly, the numbers of zooplankton, emergent insects and fish in the impoundment suggest that this is also very high. These observations indicate that the impoundment has characteristics that result not only in high levels of primary production, but also in the efficient transfer of this production to secondary producers. In addition, most of the secondary producers present are of the type thought to be major food sources of waterfowl brood.

Understanding the reasons for this high productivity requires consideration of the general factors that drive the productivity of aquatic systems. The two most basic factors required to create and maintain high levels of productivity are high nutrient availability, resulting from either continuous nutrient inputs or efficient nutrient recycling, and high availability of solar energy. In freshwater systems, the nutrient most often considered to be limiting is phosphorous. In estuaries, nitrogen is usually considered to be the critical limiting nutrient, but some recent studies have suggested that phosphorous may also be important under certain conditions (D'Elia et al. 1986). Although silicate is also often considered to be a major limiting nutrient in freshwater and marine systems, it is required mainly for the skeletal structure of diatoms, and its absence usually influences species composition rather than productivity. In situations where nutrient levels are high, the ultimate limiting factor becomes the availability of solar energy. In turbid systems, penetration of light into the water column is attenuated rapidly and the system becomes light limited at very shallow depths. In less turbid systems, light becomes limiting through self-shading as a result of the high concentrations of phytoplankton.

Despite the shallowness of the impoundment, it is likely that light availability at times seriously limits phytoplankton primary production. Phytoplankton chlorophyll *a* concentrations recorded during the second phytoplankton bloom observed were as high as 300 μg^{-1}. This is above the theoretical maximum concentration that can exist in an aquatic system (Wetzel 1983) unless the water column is extremely well mixed, and it is likely that the termination of this bloom was caused by a reduction in light availability resulting from the high chlorophyll *a* concentrations. However, the single factor that is probably most important in driving the productivity of the Allain's Creek impoundment is the high level of phosphorous in the water column. The levels measured were typical of those found in hypereutrophic systems. Since there were no obvious sources of phosphorous entering the impoundment from either the drainage basin or the River, the source of this phosphorous is most probably sediments that had accumulated phosphorous prior to impoundment. Salt marshes are depositional environments and tend to accumulate sediments carried to the intertidal suspended within the water column of the estuary. Suspended sediments in estuaries typically contain high levels of phosphorous as a result of physico-chemical interactions between phosphorous and clay particles (Stumm and Leckie 1971). The Allain's River contains unusually high levels of phosphorous and it is likely that, prior to impoundment of the salt marsh, considerable amounts of phosphorous accumulated within the sediments of the salt marsh, and that this now serves as the major store of phosphorous within the impoundment. Although this store is within the sediments, the shallow nature of the impoundment and its exposure to wind allows it to be easily resuspended into the water column making it available to primary producers.

In freshwater systems enriched with phosphorus, nitrogen usually becomes the major limiting nutrient and this often leads to the development of dense blooms of nitrogen fixing forms of algae, particularly filamentous and mat-forming bluegreens. Marine systems enriched with phosphorous, however, seldom develop colonial forms of blue green alga and, in general, nitrogen fixing alga are much rarer. The reason for this is not entirely clear, but it has been suggested that the ability to synthesize nitrogen reductase, the enzyme required for nitrogen fixation, is inhibited by the presence of high levels of sulfate (Cole et al. 1986). Sulfate is a major component of the salinity of seawater and it is thought to decrease the bioavailabilty of molybdenum, a necessary cofactor of nitrogen reductase. The nitrogen fixing algae that do occur in marine systems are mainly the small non-colonial types of cyanobacteria. The major source of nitrogen in the impoundment is most likely fixation by these small forms of cyanobacteria. There was little evidence that filamentous blue green alga are abundant within the impoundment and the seasonal variation in total nitrogen concentration closely followed that of the small cyanobacterial forms observed in the phytoplankton samples. Exactly why these forms, as opposed to filamentous blue greens, predominated is unclear, but could be related to the same factors that limit filamentous forms in marine systems. The presence of the smaller cyanobacteria forms in the impoundment at concentrations much higher than usually occur in marine systems may be a result of the reduced salinity of the impoundment, which would reduce the inhibitory effects of sulfate, and the shallow nature of the impoundment which could increase the availability of cofactors by resuspension from the sediments.

In addition to the high levels of nitrogen and phosphorous available to support primary production, it is likely that the availability of nutrients within the impoundment is also enhanced by the secondary producers present. Both zooplankton and small fish were exceptionally abundant within the impoundment. There currently exists considerable evidence indicating that the rate at which nutrients are recycled within the water column is just as, and in some cases more, important in sustaining phytoplankton production as is the absolute concentration of nutrients, and that zooplankton and small fish play a primarily role in recycling nutrients (Kitchell et al. 1975; Lehman 1980; Brabrand et al. 1990; Carpenter et al. 1992).

If it is true that the primary productivity of the impoundment is driven primarily by sediment phosphorous that accumulated prior to construction of the impoundment, it is likely that productivity will decrease with time since some flushing of nutrients from the impoundment is inevitable. How long this will take is difficult to predict. Other studies on impounded marshes have shown decreases in nutrient and productivity levels after only a few years of impoundment (Beauchamp and Kerekes 1980). However, this depends largely on the amount of phosphorous stored within the sediments and the rate at which it is flushed from the system. If present phosphorous levels within Allain's River, which are very high, are indicative of phosphorous levels prior to impoundment, it is probable that the store of phosphorous within the sediments is very large. In addition, since the size of the drainage basin is very small relative to the surface area and volume of the impoundment, the flushing rate is probably also low. A simple calculation of the flushing rate, based on average annual precipitation for the Annapolis Royal area, the size of the drainage basin and the volume of the impoundment at maximum water level, results in a rate of 2.3 times yr^{-1}. This is a relatively low value. Furthermore, the time when most flushing occurs is probably in early spring during snowmelt. At that time most of the phosphorous may be tied up in the sediments as opposed to being suspended within the water column and, therefore, may be less susceptible to being flushed out of the impoundment, particularly if the impoundment is stratified.

With respect to secondary production, there are a number of physical and biological characteristics of the impoundment that lead to enhanced transfer of primary production products to secondary producers. Primary among these is the shallow depth and high exposure to wind which allows the water column to be easily mixed preventing the system from becoming stratified and undergoing periods of anaerobic conditions. In stratified systems the sediments tend to accumulate and store organic materials that settle out of the water column. If these sediments become anaerobic, conditions become inhospitable for most organisms and much of the organic material remains unutilized by secondary producers. Since stratification and anaerobic conditions were never observed within the water column of the impoundment, it is probable that most of the primary production is utilized by secondary producers as opposed to being stored within the sediments. A second factor leading to enhanced utilization of primary production relates to the species composition of the major phytoplankton primary producers. These were almost exclusively non-colonial forms of cyanobacteria during the early part of the study, and non-colonial cyanobacteria and dinoflagellates during the latter part of the study, both of which are readily assimilable by secondary consumers. Of particular significance is that the dominant nitrogen fixing organisms were small non-colonial cyanobacteria which, unlike filamentous forms, are easily assimilated by consumers and are a highly nutritious energy source because of their high nitrogen content. In addition, as previously noted, the types of secondary producers present are those considered to be important food sources of waterfowl brood (e.g., see Mendall 1949, McAuley 1986, Reinecke and Owen 1980) and this also partly explains the high waterfowl productivity of the impoundment.

A striking characteristic of the species composition of the various communities within the impoundment is that they were comprised of relatively few species. The phytoplankton community consisted almost exclusively of two species, the zooplankton community of one species of copepod and one species of rotifer, the benthic invertebrate community of very few species, and the emergent insect community was dominated by what appears to be two or three species of chironomids. The major reason for this low diversity is probably the salinity of the impoundment, which would classify it as a brackish water system. These are transitional systems between freshwater and oceanic environments and are generally characterized by low species diversity. Relationships developed between the number of species present and the salinity of a system (e.g., Figure 11) show a clear trend of reduced species diversity as one moves to either side of 5-6 ‰. The usual explanation for the low species diversity at these intermediate salinities is that few organisms have been able to adapt to the osmoregulatory stress imposed by these salinities. However, this relationship is based largely on organisms in estuarine environments that undergo relatively large changes in salinity over short (hours) periods of time and the stress is probably also partly due to the necessity for constant expenditure of energy for osmoregulation under the varying salinity. The Allain's Creek impoundment is somewhat different since the salinity variation over short time periods was very small and, in this respect, it is probably not as stressful an environment as is an estuarine environment. As a result, those organisms that are able to live at that salinity are probably less stressed than their estuarine counterparts, and are able to channel more of the energy they consume into growth and reproduction which may partly explain the high abundance's observed. The low diversity within the impoundment is probably also due to factors other than the intermediate salinities. At 12-17 ‰, the salinity range observed in the impoundment over the entire study period, the number of species that would be expected based on the relationship illustrated in Figure 11 would be about 20-50 percent of that found in freshwater or oceanic systems. This is a much higher percentage than what was observed.

Estimates of waterfowl brood use for the Allain's Creek impoundment of 2.6, 2.5 and 3.1 broods per hectare for 1991, 1992, and 1993 respectively, are exceptionally high in a regional context (DUC files, Amherst, N.S.). Data across the three year period for which detailed information have been collected, indicate a consistently high degree of use of this wetland. In view of the discrepancy between IBP and brood data, it is reasonable to assume that waterfowl nesting in areas relatively close to the impoundment site travel with broods to the site. High primary and secondary productivity found at this site may allow hens with broods to take advantage of enhanced foraging opportunities. Although pairing sites may be limited on the wetland itself as indicated by the relatively low IBP:Brood ratio's observed, the extensive tidal creek complex immediately adjacent to the impoundment may provide additional pairing and nesting sites for many of the waterfowl using the site as a brood rearing area.

Although this site was established more than 10 years ago (1982) a substantial influx of Mallard ducks has yet to have occurred. American Black Ducks represent the largest component of

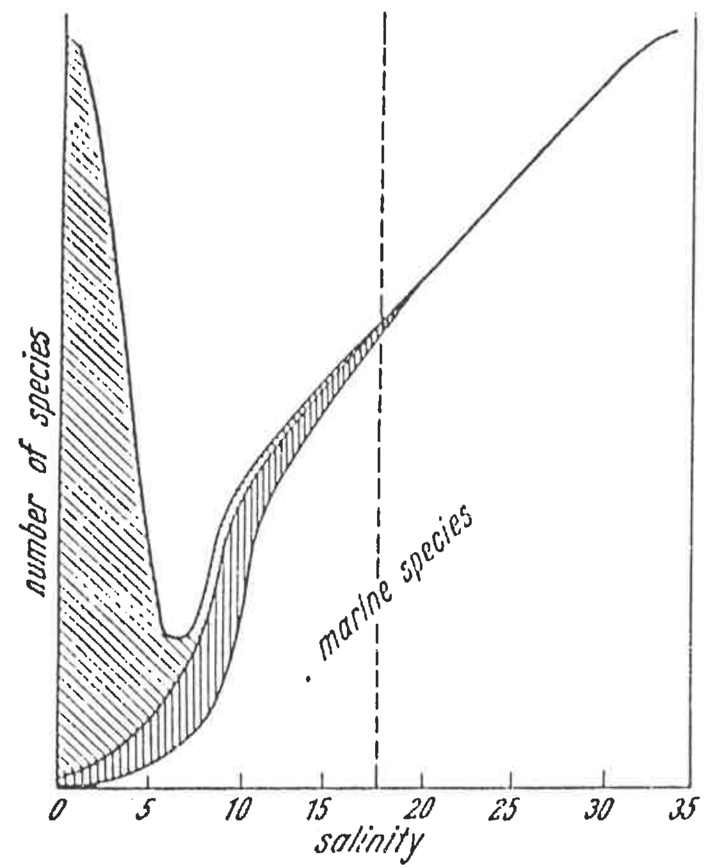

Fig. 11. Number of species in relation to salinity. The graph has been based on numerous single records. Obliquely hatched: Proportion of fresh-water species. Vertical hatching: Proportion of specific brackish-water species. Light: marine species. Black (at base): holeuryhaline species. In each case the number of species corresponds to the vertical extent of the respective area. After Remane and Schlieper (1971).

Anatidae establishing territories at the wetland (IBP) and are by far the most abundant waterfowl species to use the site for brood rearing. Based on the observations of this study, the provision of high quality habitat (i.e., impounded wetland) within the Black Duck's range does not apparently necessitate an automatic increase in mallard use of the area as current hypotheses of this nature may imply (Merendino et al. 1993).

In summary, it appears that a number of factors, physical, chemical and biological, are responsible for the high levels of production that characterizes the impoundment. Unlike most aquatic systems, the impoundment requires little input from the drainage basin to maintain its productivity. However, if it is true that the phosphorous contained within the sediments is the major store of nutrients, and that this is what ultimately drives the productivity of the system, it is probable that the productivity of the system will decrease with time since some flushing of the system is inevitable.

A potentially productive exercise would be to determine if the Allain's Creek impoundment represents a unique system or one that is typical of other coastal impoundments. Two other salt marsh impoundments, Baie Verte and Wallace Bay, both of which are located in New Brunswick, also support high numbers of waterfowl brood. Information on the biological and chemical characteristics of these impoundments is limited, but both resemble the Allain's Creek impoundment in having relatively high salinities. Information also exists on other coastal impoundments currently managed by Ducks Unlimited and it would not be difficult to assimilate this information to determine what characteristics they have in common with the Allain's Creek impoundment, and to relate this to levels of waterfowl production. Of particular importance would be to determine if there is a strong relationship between water column phosphorous levels, salinity and production of waterfowl brood.

6. CONCLUSIONS

1. The Allain's Creek impoundment exhibits high primary and secondary productivity that appears to be driven largely by phosphorous stored within the sediments and rapid recycling of phosphorous within the water column.

2. The major primary producers in the system are cyanobacteria, periphyton and submersed macrophytes, each of which plays an important role in enhancing the productivity of the impoundment and in sustaining the secondary producers potentially utilized by waterfowl brood:

    a. the cyanobacteria fix nitrogen and thereby provide an autochotonous source of this nutrient preventing it from becoming limiting when phosphorous levels are high. In addition, these organisms are an exceptionally nutritious food source for zooplankton;

b. the periphyton provide a food source for epiphytic communities which are in turn important food sources of aquatic invertebrates;

c. the submersed macrophytes provide a substrate for epiphytes and their associated communities, as well as a direct source of organic detritus that is utilized as both food and habitat by aquatic invertebrates.

3. The high levels of zooplankton and small fish present in the impoundment further enhance primary productivity by recycling nutrients rapidly during feeding activities.

4. The exposure and shallowness of the impoundment allow it to be easily mixed by wind forcing. In addition to enhancing the resuspension of nutrients from the sediments, this mixing prevents the system from becoming stratified or developing anaerobic conditions, both of which could result in reduced levels of secondary production.

5. The brackish nature of the impoundment results in biological communities, at both primary and secondary producer levels, characterized by very low species diversity. The relative constancy in the salinity of the impoundment, however, lessens the osmoregulatory stress on those species that are present and they exist at exceptionally high numbers.

6. All of these factors combine to produce a system that requires very little input from the drainage basin to maintain its productivity. However, if it is true that the phosphorous contained within the sediments is the major store of nutrients, and that this is what ultimately drives the productivity of the system, it is probable that the productivity of the system will decrease with time.

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