The effect of macrophyte removal and nutrient addition on zooplankton abundance in a prairie wetland

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Introduction

In shallow aquatic systems there are generally thought to be two stable states assumed by the system, the clear water state and the turbid water state (Scheffer *et al.* 1993). The clear water state is characterized by transparent water and abundant submerged macrophytes. The turbid state is characterized by turbid water and few macrophytes. Macrophytes contribute to the clear water state by decreasing both wave action and re-suspension of sediments, and by increasing both competition with algae for nutrients and habitat complexity, providing refugia for filter-feeding zooplankton (Scheffer *et al*. 1993). Filter-feeding zooplankton are important grazers which stabilize the clear water state, thus the abundance of zooplankton affects the stability of the clear water state. The clear water state is a more desirable state as it is more attractive to waterfowl. This has been documented in Lake Krankesjon where the lake shifted from the turbid state to the clear water state which supported more waterfowl (Hargeby *et al.* 1994).

An increase in nutrients should decrease the stability of the clear water state (Scheffer *et al.* 1993) making a shift to the turbid state more likely. If nutrients are added to the clear water state there will be more nutrients available for phytoplankton and the system may shift to the turbid water state if the level of nutrients exceeds a critical point. Anthropogenic loading of nutrients (sewage effluent and agricultural run-off) has been shown to cause the loss of submerged macrophytes leading to this transition of states (Balls *et al.* 1989).

Nutrient addition alone may not be enough to cause a shift to the turbid state. The system has a number of features (outlined in Irvine *et al.* 1989) which make it resistant to transition. One of these features is the grazing pressure from filter-feeding zooplankton which can increase in abundance when nutrients are added, consuming the extra phytoplankton, resisting an increase in phytoplankton and turbidity (Van Donk *et al.* 1995). The combined effect of nutrient addition and removal of macrophytes should push the system to the turbid water state. It has also been suggested that increases in nutrient loading, up to a point, are actually favourable to waterfowl by increasing invertebrate production (Murkin *et al.* 1994). Cladoceran abundance should also change with the presence or absence of macrophytes. The total cladoceran population is made up of two components: true zooplankters, which filter feed in the water column, and phytophilous grazers, which feed from epiphyton on the submerged macrophytes. Examination of the ecosystem in both stable states will lead to a better understanding of the role of macrophytes in the marsh and the effect of anthropogenic nutrient loading. Quantification of the effects of nutrient addition alone will provide information on how resistant the marsh is to a shift to the turbid state. This could eventually contribute to management decisions and methods to increase waterfowl use in prairie wetlands.

Methods

Experimental enclosures (5 m by 5 m) were located in the Blind Channel (water depth about 1 m) of Delta Marsh, on the south shore of Lake Manitoba. The enclosures were constructed using impermeable polyethylene curtains, suspended from floating platforms that extended from above the water surface into the sediments, anchored with rebar. Fish were removed from all enclosures (including controls) with the use of minnow traps which were set and emptied daily.

The experimental variables considered were macrophyte removal and inorganic nutrient (nitrogen and phosphorus) addition. The treatments, assigned randomly to two replicate enclosures each, were as follows: (1) macrophyte removal with nutrient addition, (2) macrophyte removal with no nutrients added, and (3) control (with macrophytes and no nutrients added). The experiment included a pre-treatment sampling period from 5 June (week 1) to 26 June (week 3), and a treatment sampling period from 26 June (week 4) to 30 August (week 13). Macrophytes were removed weekly by clipping with long handled shears after the treatment period began. Nutrients (N and P) were added in a "press" design in which liquid aliquots were sprinkled into the enclosures three times per week throughout the treatment period. The nutrients were added in a 10N:1P

molar ratio in the form of $NaH_2PO_4 \cdot 2H_2O$ and $NaNO_3$. Standard water chemistry protocols (APHA 1985; Stainton *et al.* 1977) were used regularly to monitor nutrient concentrations, pH, and alkalinity.

Zooplankton was sampled quantitatively with a water column sampler. Three water column samples (4 L) were collected every week from each enclosure (details in Hann 1995). Each water column sample was concentrated by pouring through a 53 µm mesh net. Formalin was then added to each vial for preservation and the final volume was standardized to 20 mL (Hann 1995). A subsample of this 20 mL was counted and the abundance was calculated for the original water column volume. Zooplankton associated with the artificial substrata (acrylic rods) was also sampled weekly, 3 samples per enclosure, using a modified water column sampler (Hann 1995) and processed in the same way as the water column samples.

Microinvertebrates (cladocerans, copepods and rotifers) were counted and identified using Pennak (1978) and Edmondson (1959). Cladocerans were counted according to species, copepods were grouped into nauplii, cyclopoid copepodites, cyclopoid adults, calanoid copepodites, and calanoid adults, and only the predatory rotifer *Asplanchna* was counted. For this preliminary report, only single samples of water column zooplankton and of zooplankton associated with artificial substrate (acrylic rods) were counted for alternate weeks of the study.

Results

Zooplankton abundance in the water column

Cladoceran abundance showed a rapid increase between week 1 and week 3 (Fig. 1), during the pre-treatment period in all 3 treatments (control, macrophyte removal with no N and P addition, and macrophyte removal with N and P addition). The abundance rapidly declined by week 5 in all enclosures. Cladoceran abundance increased between week 9 and 11 in all enclosures from which macrophytes had been removed.

Copepod abundance in the water column was initially high in all 3 treatments, declined until week 5, and remained at low abundance for the rest of the study, except for the control which increased slightly in week 11 (Fig. 2).

Zooplankton associated with artificial substrata

The cladocerans exhibited increased abundance in enclosures with macrophytes removed and no nutrients added as well as in the control enclosures during the pre-treatment period (Fig. 3). However, in the enclosures

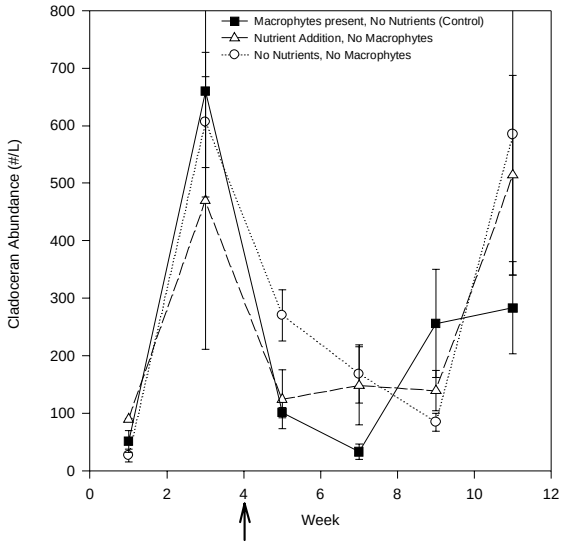

Figure 1. Water column cladoceran abundance.

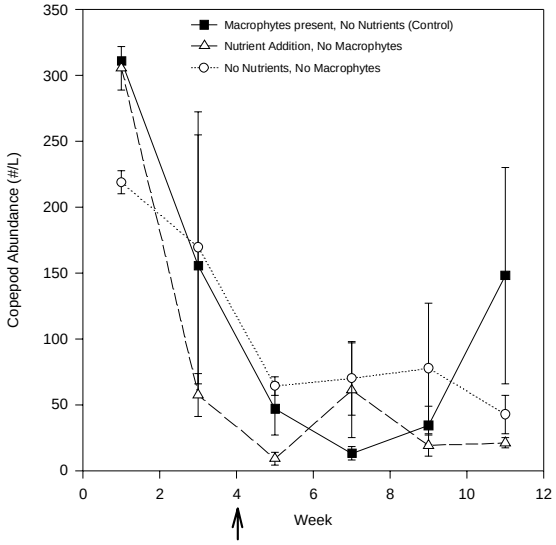

Figure 2. Water column copepod abundance.

with macrophytes removed and nutrients added, cladocerans did not show the same marked increase in abundance in week 3. All cladoceran abundances were low during weeks 5 to 7. The cladocerans did increase in abundance in the control enclosures (week 7 to 11) and enclosures with macrophytes removed and nutrients added (week 9 to 11). However, in the enclosures to which no nutrients had been added and macrophytes removed, cladoceran abundances remained low throughout the treatment period (weeks 4 to 13).

The copepods showed basically the same pattern of low abundance in association with the rods as they did in the water column. A deviation from this pattern occurred in week 7 in the enclosures to which no

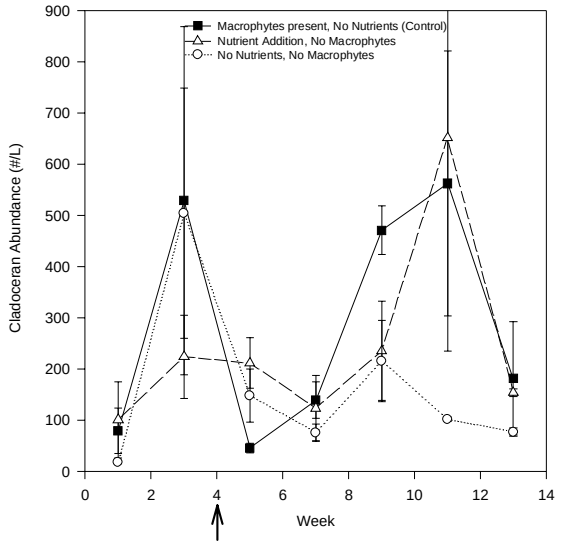

Figure 3. Cladoceran abundance on artificial substrata.

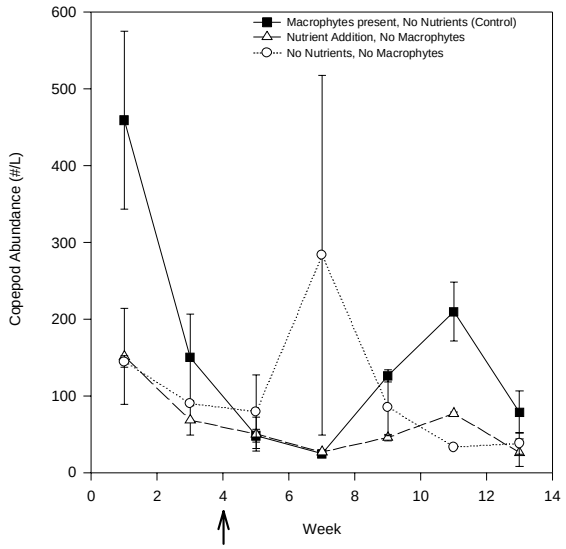

Figure 4. Copepod abundance on artificial substrata.

nutrients had been added (Fig. 4) where a markedly elevated abundance was noted.

Discussion

The first experimental effect observed in all enclosures was an enclosure effect where cladoceran abundance increased markedly in 2 to 3 weeks immediately following installation of the enclosures in the Blind Channel. This is likely a consequence of a rapid increase of parthenogenetically reproducing cladoceran females in response to the sudden absence of predation from fish after the enclosures were installed. The large numbers of cladocerans cannot apparently be sustained for long as their abundance declined again within 1 to 2 weeks. This pattern in the abundance of Cladocera has been well documented as an enclosure effect (Hann 1995, Pettigrew and Hann 1996).

The rapid increase in abundance of cladocerans just after installation of the enclosures can also be attributed to the high biomass of phytoplankton present at that time (McDougal and Goldsborough 1996, Fig.1). It is expected that when there are many cladocerans, there is high grazing pressure and therefore low phytoplankton biomass, and conversely, when grazing pressure is low, there could be a high biomass of phytoplankton. Phytoplankton biomass (chlorophyll *a*) was high at the beginning of the study and decreased rapidly at the same time the cladocerans were increasing in abundance.

Zooplankton in the water column

The cladoceran abundance was higher in the treatments without macrophytes than in the control in week 7 and 11 (Fig. 1). This suggests that this increased cladoceran abundance may be a response to macrophyte removal, although it cannot be determined if the response is to nutrient addition or macrophyte removal as the error bars are large in week 11. The absence of the fourth treatment combination (nutrient addition with macrophytes present) makes it impossible to separate the effects of macrophyte removal and nutrient addition. In the Norfolk Broadlands, zooplankton communities did not increase in numbers when phosphorus was loaded to experimental ponds (Irvine *et al.* 1989). The higher cladoceran abundance in the enclosures with macrophytes removed than in the control enclosures in week 11 may be a response to an increase in phytoplankton. Increased phytoplankton biomass may not be measured, however, because it was effectively grazed (McDougal and Goldsborough 1996). Where there was a low abundance of grazers in the control, the phytoplankton biomass was greater, as would be expected.

Zooplankton associated with artificial substrata (acrylic rods)

The Cladocera increased in abundance in the control and the nutrient addition treatments in week 11. The number of Cladocera in the treatment with just macrophyte removal and no nutrient addition remained low at this time. This suggests that macrophyte removal may result in a decrease in phytophilous cladocerans associated with the rod late in the season, and nutrient addition an increase in Cladocera. The cladocerans sampled by this method could also be mostly filter feeders in the water column. It might be expected that

there would be fewer phytophilous Cladocera where macrophytes are removed because of loss of habitat. This habitat may not be simulated by rods, as they lack complexity. It would also be expected that there may be more phytophilous grazers when N and P are added. The increase in N and P could result in more periphyton growth and more food for cladocerans.

It would be expected that phytophilous grazers would not show the enclosure effect when the habitat is complex because the predation pressure has not been released when fish are excluded. Habitat complexity from the macrophytes offers a refuge against fish predation (Diehl 1992), but probably not a refuge from predation from macroinvertebrates that also live in the macrophytes. If habitat complexity is low, fish predation could be higher and show the enclosure effect. Habitat complexity is low around the rods, and so it is not surprising that the enclosure effect is seen.

It might be expected that the Cladocera associated with the rods would not show an enclosure effect because phytophilous grazers would not be able to take advantage of the high phytoplankton biomass and would actually be feeding from periphyton on the rods. The periphyton biomass on the rods is low in the first two weeks (McDougal and Goldsborough 1996). This could be because there had not yet been sufficient colonization of the rods by periphyton, or that any algae which had colonized the rods was quickly eaten. It is impossible to tell which is the case without experimentally removing the grazers and measuring biomass of periphyton.

The cladocerans were present in high numbers near the end of the treatment period in the control and macrophyte removal with nutrient addition treatment. At this time periphyton biomass was relatively low in these enclosures (McDougal and Goldsborough 1996, Fig. 1) and macrophytes were removed, so there was little algal biomass available for grazing by cladocerans. The periphyton biomass was greatest where macrophytes were removed and no nutrients were added (McDougal and Goldsborough 1996). Assuming bottom up control, there should be an increase in biomass when N and P are added. The macrophyte removal, N and P addition treatment showed the lowest abundance of Cladocera throughout the study and should therefore have the lowest grazing rate, allowing the periphyton biomass to be elevated. This reinforces the pattern observed previously for zooplankton grazing on phytoplankton in the water column, i.e. a negative correlation between zooplankton grazer abundance and phytoplankton biomass (Hann 1991, 1995; Pettigrew and Hann 1996). In this study, in the enclosures where the periphyton biomass was high (macrophytes removed, no nutrients added), the cladoceran grazers were in low abundance; where periphyton biomass was low (macrophytes removed, nutrients added), grazer abundance was high. Therefore, the top-down control by grazers is emphasized, especially in light of the counter-intuitive observation that periphyton biomass was actually higher in the enclosures to which no nutrients had been added.

The dominant Cladocera (*Ceriodaphnia dubia*, *Bosmina longirostris*) were similar in the water column and associated with acrylic rods, although the rod samples have a slightly higher number of species present. This also supports the idea that this later method is sampling mostly water column Cladocera and that rods are not providing an adequate habitat for phytophilous grazers.

The copepods did not show a clear response to experimental treatments in either the water column or in association with the artificial substrata. Copepods have not responded strongly to other treatments (Hann 1995; Pettigrew and Hann 1996). Copepods are less able to respond quickly because of their sexual mode of reproduction and extended life cycle which can last up to a year.

Conclusion

These preliminary results indicate that zooplankton abundance in the water column increased in the macrophyte removal treatments, but because the experiment was not of complete design, this increase in abundance cannot be attributed as a response to either macrophyte removal or nutrient addition. The fourth treatment (nutrient addition with macrophytes present) must be examined concurrently with the others to determine the likely cause of the response. Invertebrate predation was not investigated in this study and could play an important role in the control of abundance of zooplankters. A future experiment will examine top-down control on zooplankton by invertebrate predators.

Sampling of phytophilous cladocerans by sampling around artificial substrata (e.g. acrylic rods) is probably not very useful, as these results suggest that most of these samples showed the same pattern of abundance and species composition as the water column samples. Hence, for phytophilous cladocerans, acrylic rods do not appear to adequately mimic submersed macrophytes, except as a substratum for epiphytic algal colonization. Other aspects of the macrophytes themselves (e.g., complexity, and suitability as refugia) also strongly influence the abundance and community composition of phytophilous Cladocera.

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