

Effectiveness of a Plastic Mesh Substrate Cover for Reducing the Effects of Common Carp on Aquatic Ecosystems

JOSEPH J. PARKOS III*

Max McGraw Wildlife Foundation, Post Office Box 9, Dundee, Illinois 60118, USA;
and Department of Animal Biology, University of Illinois at Urbana–Champaign,
515 Morrill Hall, 505 South Goodwin, Urbana, Illinois 61820, USA

VICTOR J. SANTUCCI JR.

Illinois Department of Natural Resources, 8916 Wilmot Road, Spring Grove, Illinois 60081, USA

DAVID H. WAHL

Department of Animal Biology, University of Illinois at Urbana–Champaign, 515 Morrill Hall, 505 South Goodwin, Urbana, Illinois 61820, USA; and Kaskaskia Biological Station, Center for Aquatic Ecology and Conservation, Illinois Natural History Survey, Rural Route 1, Box 157, Sullivan, Illinois, USA

Abstract.—A great deal of effort has been directed at eliminating or controlling common carp *Cyprinus carpio* populations, but these efforts have had limited success. We assessed the effectiveness of an alternative approach, using plastic-mesh substrate covers, to reduce environmental effects of common carp. Multiple trophic levels were monitored in 0.06-ha enclosures in experimental ponds that contained either common carp with mesh covers, common carp with no mesh covers, no common carp with mesh covers, or neither fish nor mesh covers. Macroinvertebrates and macrophytes were also sampled over a 1-year period in six field sites with paired mesh cover and control plots. Common carp significantly increased turbidity (NTU) and total phosphorus ($\mu\text{g/L}$), decreased macrophyte cover (%), altered the relative abundance of zooplankton taxa (N/L), and suppressed macroinvertebrate abundance (N/m^2) in ponds. In contrast, carp did not significantly affect either total nitrogen ($\mu\text{g/L}$) or phytoplankton ($\mu\text{g/L}$) concentrations. Mesh substrate covers did not significantly reduce any effects of common carp in the pond enclosures. Abundances of macroinvertebrates and macrophytes also did not differ between field plots with and without mesh covers. The lack of effective reduction of common carp-induced effects limits the usefulness of mesh substrate covers as a tool for habitat restoration.

Common carp *Cyprinus carpio* are considered a nuisance in North America primarily because of their ability to achieve dense populations and their effects on habitat quality (Parkos et al. 2003). Common carp are similar to “ecosystem engineers” that can modify environments to a high enough degree that the entire system changes in important ways (Jones et al. 1994). Where common carp have been introduced

outside of their native range, their effects on shallow aquatic systems are stronger than the influence of native benthic fishes (Parkos et al. 2003). A wide variety of control techniques have been used in an attempt to manage common carp populations, with eradication being the most commonly pursued general strategy (McCrimmon 1968; Panek 1987; Marking 1992). One difficulty with relying on eradication is that carp can quickly recolonize, and the increased availability of resources for the survivors can lead to higher fecundity and increased subsequent recruitment (Thresher 1997). Nontarget species also tend to be vulnerable to removal techniques (Panek 1987; Marking 1992). If removal or control of common carp populations is not a viable option, a more practical alternative could be to reduce environmental effects of common carp. Reducing the effects of common carp on aquatic vegetation may be especially important because macrophytes compete with algae, stabilize sediments, and provide habitat for herbivorous zooplankton (Meijer et al. 1990; Hanson and Butler 1994).

One proposed technique for reducing the effects of common carp is to use a mesh substrate covering to protect aquatic macrophytes (Anderson 1996). The objective of this study was to evaluate the potential of a mesh substrate cover as a method for reducing the effects of common carp on shallow aquatic systems. Pond experiments were used to compare the effects of common carp on multiple trophic levels in mesocosms with and without a mesh substrate cover. In addition, we compared benthic invertebrate and aquatic macrophyte abundances between mesh-covered and control plots in the field to evaluate if the pond results were transferable to more natural systems.

* Corresponding author: parkos@uiuc.edu

Received January 23, 2006; accepted March 27, 2006
Published online November 9, 2006

Methods

Four 0.06-ha enclosures were placed in each of four 0.4-ha clay-bottom ponds ($N = 16$ enclosures) located at the Max McGraw Wildlife Foundation in Dundee, Illinois (42°05'N, 88°16'W). The walls of the enclosures were constructed of 18-mil polyethylene liner to prevent the exchange of water across the different treatments. Each pond contained four treatments in enclosures: (1) common carp and mesh (CM), (2) common carp and no mesh (CN), (3) no carp with mesh (NM), and (4) no fish and no mesh (NN). Treatments CM and CN contained eight adult fish (430–693 mm) per enclosure for a total biomass of 18 kg, or 300 kg/ha. This biomass was chosen based on previously documented effects on vegetation (Robel 1961) and was within the range reported for field densities of common carp in North America (113–476 kg/ha; Panek 1987).

Treatments CM and NM consisted of enclosures with the entire bottom substrate covered with 2×1.5 -cm mesh plastic netting. The mesh is biodegradable and has an expected life of 5 years under typical field conditions (Santucci et al. 1996). Choice of mesh size was based on results from a preliminary study of plots with 2.5-cm, 5-cm, and 7.5-cm mesh covers in a 260-m reach of the Des Plaines River, Illinois, where densities of benthos and fish were highest in plots with the smallest mesh size (Anderson 1996). Mesh was anchored to each pond bottom with landscaping pins before the ponds were filled with water. The experiment ran from July to October 1997, after which the fish were removed and the ponds drained.

Every 2 weeks, from July through September, water samples were collected to analyze for total phosphorus, total nitrogen, chlorophyll-*a* concentration, turbidity, and zooplankton density and biomass. Vertically integrated water samples were collected with a clear acrylic tube sampler having a 7.3-cm interior diameter (DeVries and Stein 1991). Within each enclosure, five samples were collected and combined (range 7.6–12.5 L, 9.75 L mean combined volume) for chlorophyll *a*, nutrients, and turbidity analysis. Five additional samples were collected and combined for an integrated zooplankton sample. Chlorophyll-*a* concentrations were determined fluorometrically, using a nonacidification procedure (Welschmeyer and Naughton 1994). Turbidity was measured in nephelometric turbidity units (NTU) with a turbidimeter. Total phosphorus was measured after oxidation with persulfate, and total nitrogen was determined with a phenol-hypochlorite method (USEPA 1994). Zooplankton samples were filtered through a 55- μ m mesh plankton net and preserved in Lugol's solution (USEPA 1994). All

zooplankton samples were adjusted to a 100-mL volume and subsampled in 1-mL aliquots. Each taxa was identified to sub-order or family, enumerated to at least 200 individuals, and 25 random individuals from each category were measured with a digitizing pad and SIGMASCAN software (Welker et al. 1994). Zooplankton biomass was estimated with length-weight regression equations developed by Dumont et al. (1975) and Culver et al. (1985).

Every 4 weeks, from August through October, a 20-cm-diameter stovepipe sampler (McPeck 1990) was used to collect five samples of macrophytes and aquatic macroinvertebrates from each enclosure. In enclosures with the mesh cover, the mesh underneath the stovepipe was cut away to facilitate the collection of bottom samples. Stovepipe samples were always collected the day after water sampling. Benthic invertebrates were washed from sediment and vegetation into a 500- μ m mesh benthos bucket and preserved in 5% buffered formalin solution. Individuals were identified to family, measured for length, and weights calculated from length-weight regressions (Smock 1980; G. Mittlebach, University of Michigan, unpublished data). Due to the difficulty in measuring oligochaete lengths, weights were determined by drying samples to a constant weight at 80°C for 24 h and then weighing on a microbalance (USEPA 1994). Macrophytes were also dried to a constant weight at 80°C to determine total dry weight of submerged vegetation.

In addition to measuring vegetation abundance as macrophyte biomass, we estimated percent coverage of macrophytes on the bottom of each enclosure. From the shore, ropes were stretched across the area of each enclosure to form five equally spaced transects. Presence or absence of vegetation at 0.5-m intervals along each transect was recorded to determine percent vegetation coverage for each transect. Percent coverage for an entire enclosure was estimated as the average of the five transects.

The field experiment consisted of plots of mesh substrate cover (2×1.5 -cm mesh) in six sites located in the Des Plaines River and Fox River drainages in northeastern Illinois. Half of the sites were backwaters (Lyons Marsh, Fox River, Des Plaines) and the others were impoundments (Lasalle, UC Pond, Waterford Lake), and each site contained a large common carp population (J. Parkos, personal observation). Each plot was 24 m long and 8 m wide. Mesh was pinned with rebar stakes to the substrate near a shoreline. Every 4 weeks, five stovepipe samples were collected from the mesh plots and five samples from an adjacent untreated area at each site. Stovepipe samples for benthic invertebrates and aquatic macrophytes were processed

in the same manner as described for the experimental ponds. Field sites were monitored for 1 year, beginning in September 1997.

Two-way repeated-measures analysis of variance (ANOVA) was used to correct for the correlation of data taken from the same experimental units on different dates (von Ende 1993). Ponds were treated as blocks and each enclosure in a pond as a replicate. Tests were between-subjects effects of carp, mesh, and carp-mesh interactions, and within-subjects effects of time and its interactions with carp and mesh. The univariate test was used, unless the variance-covariance matrix of the data failed a test for sphericity, making the multivariate test more appropriate (Potvin et al. 1990; von Ende 1993). All results of repeated-measures MANOVA were based on Pillai's Trace statistics, which are considered to be the most conservative (Scheiner 1993). For the field experiment, paired *t*-tests were used to compare aquatic macrophyte and benthos abundance between control and mesh plots within each site. Significance was determined at an alpha level of 0.05, and PROC GLM was used for repeated measures ANOVAs and PROC MEANS for *t*-tests in SAS version 8.1 (SAS 1999).

Results

Common carp increased both nutrient levels and turbidity, and a mesh covering did not significantly alter these effects. Both total phosphorus (TP) and total nitrogen (TN) concentrations changed significantly during the experiment (within-subjects effect; $P < 0.001$), but common carp only influenced TP (carp effect: $P = 0.01$). Throughout the entire experiment, TP was higher with common carp present ($527.3 \pm 23.1 \mu\text{g/L}$) than without ($430.6 \pm 32.9 \mu\text{g/L}$). Turbidity levels were more consistent over the course of the experiment and were significantly higher in treatments with common carp (49.6 ± 4.3 NTU) than in treatments without (6.08 ± 1.1 NTU; carp effect: $P = 0.02$). A portion of this higher turbidity may have been due to phytoplankton. However, despite generally higher chlorophyll-*a* concentrations ($\mu\text{g/L}$) in the presence of common carp, the fish did not significantly affect chlorophyll-*a* concentrations (carp effect: $P = 0.33$). Overall, chlorophyll-*a* levels were not influenced by any of the treatments ($P \geq 0.33$) and did not change over the time of the experiment ($P = 0.13$).

Total zooplankton density, but not biomass, was higher in the presence of common carp (carp effect-density: $P = 0.03$; carp effect-biomass: $P = 0.21$; Figure 1). The mesh covering did not significantly influence this effect (carp \times mesh: $P = 0.21$; Figure 1). Dominant taxa were small cladocerans (primarily *Ceriodaphnia*, Chydoridae, *Diaphanosoma*, and *Bosmina*), rotifers

(*Branchionus*, *Kellicottia*, *Keratella*, and *Lecane*), and calanoid and cyclopoid copepods (adult and nauplii). Common carp did not significantly increase total biomass because the only zooplankton taxa that changed in abundance, copepod nauplii and ceriodaphnia (carp effect: $P \leq 0.01$), were small in size. Total zooplankton biomass and density were variable over time (within subjects: $P < 0.05$), and in general, zooplankton abundance declined over the duration of the experiment. In treatments with mesh covering, cladoceran biomass declined more slowly, resulting in a significant mesh \times time interaction in total zooplankton biomass ($P = 0.02$).

Total aquatic macroinvertebrate (benthos) biomass was lower in the enclosures with common carp than in those without (carp effect: $P = 0.007$; Figure 1). Mesh substrate covers did not prevent decreases of benthos biomass in the presence of common carp (mesh effect: $P = 0.19$). In treatments without common carp, benthos biomass increased over the course of the experiment (carp \times time: $P = 0.06$). Annelids (hirudinea and oligochaeta), chironomids, and odonates (anisoptera and zygoptera) were the most common macroinvertebrates in all of the experimental ponds.

All treatments with common carp had the lowest aquatic macrophyte biomass and cover (carp effect: $P < 0.05$; Figure 1). Macrophytes in the ponds included *Chara*, pondweed (*Stuckenia* and *Potamogeton*), and naiad (*Najas*) species. During the experiment, macrophyte abundance declined, though only the common carp treatments exhibited consistent declines in macrophyte cover (carp \times time: $P = 0.01$; Figure 1). Overall, macrophyte cover in the CM treatment was intermediate between CN and the enclosures without common carp (CM: $74\% \pm 3$; CN: $56\% \pm 4$; NM: $97\% \pm 1$; NN: $94\% \pm 2$). This influence of the mesh cover on reduction in aquatic macrophyte abundance was not significant (carp \times mesh: $P > 0.05$; Figure 1).

In the field experiment, no differences were found between plots with and without mesh covers in aquatic macrophyte abundance (Table 1). Aquatic macrophytes did not grow in either plot at two of the field sites (Des Plaines and Fox River). Macrophyte biomass was highly variable among the remaining sites, ranging from 0.18 to 6.01 g/m^2 . Aquatic macrophyte percent cover was only marginally greater in plots with a mesh cover ($49 \pm 10\%$) compared with nonmesh plots ($40 \pm 5\%$), and this difference was not significant (Table 1).

Total macroinvertebrate biomass also did not significantly differ between mesh and control plots (Table 1). At two field sites, Fox and Lyons, benthos biomass was generally higher in the plots with mesh covering versus control plots, but these differences

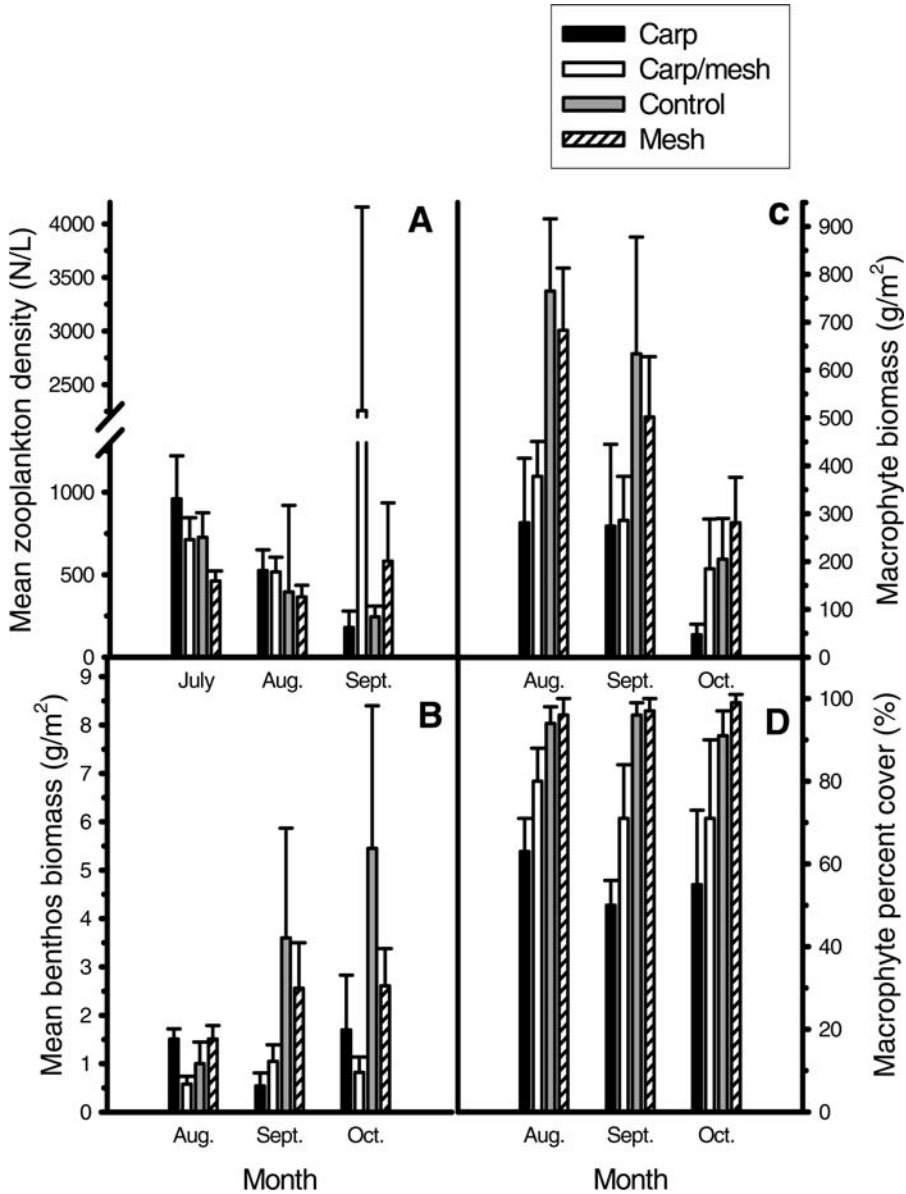


FIGURE 1.—Monthly averages of (A) zooplankton density (N/L \pm SE), (B) benthos biomass (g/m² \pm SE), (C) aquatic macrophyte biomass (g/m² \pm SE), and (D) percent cover of bottom (% cover \pm 1 SE) in 0.06-ha enclosures with common carp and no mesh (solid bars), common carp and mesh (open bars), no fish and no mesh (shaded bars), and mesh and no fish (hatched bars).

were not significant (Fox: $P = 0.07$; Lyons: $P = 0.10$; Table 1). Across all field sites, annelids (Oligochaeta and Hirudinea), chironomid larvae, and odonate nymphs tended to be more abundant in plots with mesh covering (annelids = 2.24 ± 0.57 g/m², chironomids = 14.9 ± 4.86 g/m², and odonates = $1,161 \pm 1,148$ g/m²) than in those without covering (annelids = 1.35 ± 0.32 g/m², chironomids = $6.79 \pm$

2.05 g/m², and odonates = 14.7 ± 7.11 g/m²); however, these differences also were not significant (annelids: $P = 0.06$; chironomids: $P = 0.08$; and odonates: $P = 0.39$).

Discussion

We found that common carp altered zooplankton composition, increased turbidity and total phosphorus

TABLE 1.—Means (\pm SE) and *P*-values from paired *t*-tests of differences in benthos biomass, aquatic macrophyte biomass, and aquatic macrophyte percent cover between plots with and without mesh substrate covering at six field sites. Mean biomass of aquatic macrophytes and benthos was measured in September 1997, May–July 1998, and September 1998. Aquatic macrophyte percent cover was measured June, July, and September 1998.

Site	Benthos (g/m ²)			Macrophyte					
	Control	Mesh	<i>P</i> -value	Biomass (g/m ²)			Cover (%)		
				Control	Mesh	<i>P</i> -value	Control	Mesh	<i>P</i> -value
Des Plaines	719 (719)	2.87 (1.83)	0.39	0	0	n/a	0	0	n/a
Fox River	38.5 (28)	62.7 (28.9)	0.07	0	0	n/a	0	0	n/a
LaSalle	9.25 (3.07)	4.43 (0.85)	0.13	0.005 (0.004)	0.065 (0.04)	0.22	3 (1)	8 (5)	0.35
Lyons marsh	50.6 (10.4)	103 (28.1)	0.1	0.92 (0.23)	1.49 (0.27)	0.18	82 (7)	86 (2)	0.46
UC Pond	36 (20.7)	1410 (1399)	0.39	1.16 (0.65)	0.66 (0.36)	0.21	52 (22)	10 (2)	0.37
Waterford Lake	2.68 (0.57)	7.15 (2.55)	0.25	0.46 (0.37)	0.30 (0.04)	0.66	24 (6)	53 (16)	0.17

concentrations, and reduced benthos abundance and macrophytes. Because of these effects, common carp may be an important obstacle to aquatic habitat management. Systems with high nutrient inputs and turbidity can be very difficult to change to a clear-water, macrophyte-dominated condition (Scheffer et al. 1993). Aquatic macrophytes in particular are very important to the long-term success of restoration efforts (Barthelmes 1988; McQueen 1990; Hanson and Butler 1994). The environmental effects of common carp (e.g., high turbidity and macrophyte reduction) persisted in our treatments with mesh substrate covers. Therefore, common carp influenced ecosystem structure and function in a manner too strong for this substrate modification to be effective as a tool for habitat restoration.

The hypothesized benefits of the mesh substrate covering were to prevent the uprooting of aquatic vegetation, protect benthic macroinvertebrates, and stabilize sediments in the presence of common carp. Unfortunately, the mesh covering did little to alter the impacts of common carp. Treatments with common carp and mesh together were just as turbid as those with common carp and no mesh, with about the same amount of water column nutrients (total phosphorus and total nitrogen), chlorophyll *a*, and macroinvertebrates. The only positive effect of the mesh covering was to allow for the establishment of more aquatic macrophytes. However, macrophyte biomass and percent cover in the common carp plus mesh treatment was intermediate between those measured in the no mesh treatments with and without common carp. A longer period of time than the duration of our experiment may be needed to see a stronger reduction in the effects of common carp on macrophyte abundance.

At six field sites over the course of 12 months, neither macrophytes nor macroinvertebrates increased

in abundance in mesh plots relative to control areas. Aquatic macrophytes only grew in four of the sites, and within these four sites there were no differences in overall macrophyte biomass and percent cover. Natural variability in aquatic macroinvertebrate abundance was stronger than any variability due to mesh covering. Common carp did not appear to avoid the mesh-covered areas, as they were observed actively feeding over these plots. To have a more positive effect on macrophyte abundance, either a larger area may need to be covered with the mesh, or it may be necessary to combine the mesh-covering treatment with plantings of aquatic vegetation and other habitat improvements.

Overall, the mesh treatment did not show great promise in reducing the effects of common carp on aquatic ecosystem structure. It is possible that a longer monitoring time or different treatments (i.e., cover larger area, combine with plantings) will be needed for the mesh cover to reduce the effects of common carp presence. However, other potential problems with the mesh cover include inhibition of mussel movement (Santucci et al. 1996), difficulty in keeping the mesh covering from sinking into soft substrates, and silt covering the mesh covers through time (J. Parkos, personal observation). Because of these issues and the ineffectiveness of the mesh cover to reduce the effects of common carp the mesh covers are not recommended for habitat restoration.

Acknowledgments

This research was funded by the Max McGraw Wildlife Foundation and the Illinois Natural History Survey. We are extremely grateful for the assistance of J. Strange, M. Chowanec, and R. Stockman in the field and laboratory. We also thank the research personnel of the Kaskaskia and Sam Parr Biological Stations for further laboratory assistance, especially E. Effert. We appreciate the cooperation of all the landowners that

allowed us to use their property for monitoring our field sites. A. Pyatt and D. Hey of Wetlands Initiative, Inc., Chicago, Illinois, provided helpful suggestions at the onset of the project and supplied the mesh substrate covering. We thank Steve Kohler and the Aquatic Ecology Discussion Group of the Kaskaskia Biological Station for their critical comments on an earlier version of this manuscript.

References

- Anderson, R. V. 1996. Effects of streambed modification on stream quality and carp in the Des Plaines River. Wetlands Research, Inc., Technical Paper 6, Chicago.
- Barthelmes, D. 1988. Fish predation and resource reaction: biomanipulation background data from fisheries research. *Limnologia* 19:51–59.
- Culver, D., M. Boucherle, D. Bean, and J. Fletcher. 1985. Biomass of freshwater crustacean zooplankton from length-weight regressions. *Canadian Journal of Fisheries and Aquatic Sciences* 42:1380–1390.
- DeVries, D. R., and R. A. Stein. 1991. Comparison of three zooplankton samplers: a taxonomic assessment. *Journal of Plankton Research* 13:53–59.
- Dumont, H. J., I. Van de Velde, and S. Dumont. 1975. The dry weight estimate of biomass in a selection of Cladocera, Copepoda, and Rotifera from plankton, periphyton, and benthos of continental waters. *Oecologia* 19:75–97.
- Hanson, M. A., and M. G. Butler. 1994. Responses of plankton, turbidity, and macrophytes to biomanipulation in a shallow prairie lake. *Canadian Journal of Fisheries and Aquatic Sciences* 51:1180–1188.
- Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos* 69:373–386.
- Marking, L. L. 1992. Evaluation of toxicants for the control of carp and other nuisance fishes. *Fisheries* 17(6):6–11.
- McCrimmon, H. R. 1968. Carp in Canada. *Bulletin of the Fisheries Research Board of Canada* 165.
- McPeck, M. A. 1990. Determination of species composition in the *Enallagma* damselfly assemblages of permanent lakes. *Ecology* 71:83–98.
- McQueen, D. J. 1990. Manipulating lake community structure: where do we go from here? *Freshwater Biology* 23:613–620.
- Meijer, M.-L., M. W. de Haan, A. W. Breukelaar, and H. Buiteveld. 1990. Is reduction of the benthivorous fish an important cause of high transparency following biomanipulation in shallow lakes? *Hydrobiologia* 200/201:303–315.
- Panek, F. M. 1987. Biology and ecology of carp. Pages 1–15 in E. L. Cooper, editor. *Carp in North America*. American Fisheries Society, Bethesda, Maryland.
- Parkos, J. J., V. J. Santucci, Jr., and D. H. Wahl. 2003. Effects of adult common carp (*Cyprinus carpio*) on multiple trophic levels in shallow mesocosms. *Canadian Journal of Fisheries and Aquatic Sciences* 60:182–192.
- Potvin, C., M. J. Lechowicz, and S. Tardif. 1990. The statistical analysis of ecophysiological response curves obtained from experiments involving repeated measures. *Ecology* 71:1389–1400.
- Robel, R. J. 1961. The effects of carp populations on the production of waterfowl food plants on a western waterfowl marsh. *Transactions of the North American Wildlife Conference* 26:147–159.
- Santucci, V. J., Jr., J. D. Thompson, and D. F. Stokes, Jr. 1996. Effects of a biodegradable mesh substrate covering on survival and movement of unionid mussels. Summary report to Max McGraw Wildlife Foundation, Dundee, Illinois.
- SAS. 1999. SAS/STAT user's guide, version 8.1. SAS Institute, Inc., Cary, North Carolina.
- Scheffer, M., S. H. Hosper, M.-L. Meijer, B. Moss, and E. Jeppesen. 1993. Alternative equilibria in shallow lakes. *TREE* 8:275–279.
- Scheiner, S. 1993. MANOVA: multiple response variables and multispecies interactions. Pages 94–112 in S. Scheiner and J. Gurevitch, editors. *Design and analysis of ecological experiments*. Chapman and Hall, New York.
- Smock, L. A. 1980. Relationships between body size and biomass of aquatic insects. *Freshwater Biology* 10:375–383.
- Thresher, R. 1997. Physical removal as an option for the control of feral carp populations. Pages 58–73 in J. Roberts and R. Tilzey, editors. *Controlling carp: exploring the options for Australia*. CSIRO Land and Water, Griffith, Australia.
- USEPA (U.S. Environmental Protection Agency). 1994. Methods for chemical analysis of water and wastes. National Environmental Research Center, EPA-600/4-79-020, Cincinnati, Ohio.
- von Ende, C. N. 1993. Repeated-measures analysis: growth and other time-dependent measures. Pages 113–137 in S. Scheiner and J. Gurevitch, editors. *Design and analysis of ecological experiments*. Chapman and Hall, New York.
- Welker, M. T., C. L. Pierce, and D. H. Wahl. 1994. Growth and survival of larval fishes: roles of competition and zooplankton abundance. *Transactions of the American Fisheries Society* 123:703–717.
- Welschmeyer, N. A., and S. L. Naughton. 1994. Improved chlorophyll *a* analysis: single fluorometric measurement with no acidification. *Lake and Reservoir Management* 9:123.