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Research note

The effects of carp (*Cyprinus carpio* L.) on sediment export from a small urban impoundment

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Abstract

Significantly higher concentrations of suspended inorganic matter were observed in the outflows than the inflows of three impoundments along an urban stream in southern Ontario during baseflow conditions. This pattern was observed during two summers at two of the reservoirs. After carp (*Cyprinus carpio* L.) were eliminated (490 kg ha^{-1}) from the third reservoir, significantly less suspended sediment was found in the outflow. Burrowing benthic invertebrates (*Chironomus* sp. and Tubificidae) which dominated the benthic fauna were replaced by less tolerant, more lithophilic taxa after carp removal. Tubifids dominated the fauna again after carp recolonized the impoundment. These data suggest that carp removal can have a significant positive effect on water quality.

Introduction

Relative to their inflowing streams, impoundments typically export water with higher concentrations of suspended organic matter (in the form of plankton) but very little inorganic sediment (Ward & Stanford, 1987). A common biological consequence is high densities of filter-feeding insects downstream, so it was surprising that deposit-feeders dominated the benthos below two of three small reservoirs on Laurel Creek, a small stream flowing through the city of Waterloo in southern Ontario (Winter & Duthie, 1998; Barton, 2000). Poor water quality below these reservoirs was also manifest in high BOD and concentrations of total phosphorus and suspended solids (Winter & Duthie, 1998).

Biological turbidity in lentic habitats may be caused by phytoplankton, especially if there are external loadings of nutrient from sources such as agricultural runoff or large concentrations of waterfowl (Manny et al., 1994). Inorganic turbidity may be the result of sediment resuspension by wave action (Bengtsson & Hellstrom, 1992) or bioturbation by fish such as carp (*Cyrinus carpio*) (e.g. Cahn, 1929; Meijer et al., 1990; Breukelaar et al., 1994; Roberts et al., 1995; Drenner et al., 1997; King et al., 1997).

Of these potential causes of increased suspended sediment in reservoirs, carp density is the most readily manipulated. The composition of the benthic communities in Laurel Creek led us to hypothesize the inorganic sediment was being exported by the reservoirs, so removal of carp should be an effective remedial action. We monitored the quantities and composition of the suspended material being exported from three reservoirs in the summer of 1998, then removed carp from one reservoir during the following spring and again monitored the suspended load. Our results confirm that carp removal can have a beneficial effect on water quality.

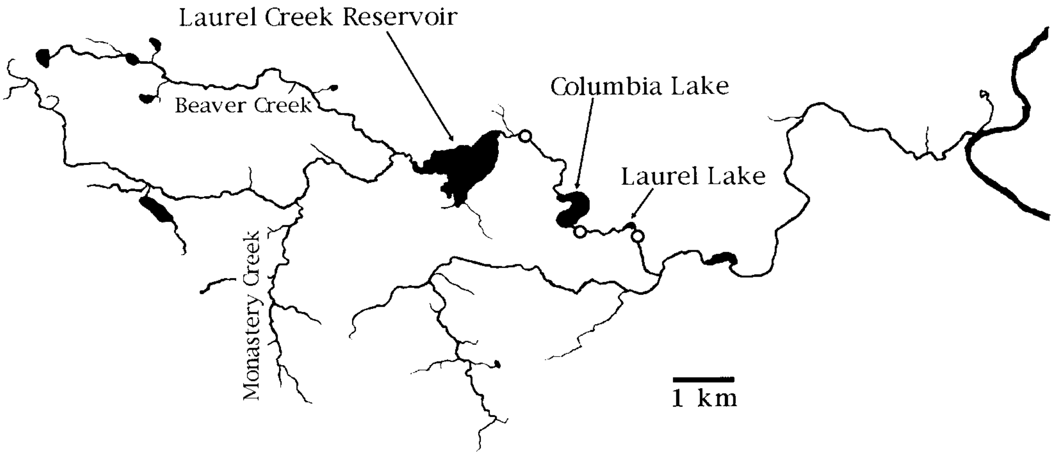

Figure 1. Laurel Creek and its major tributaries showing the locations of the reservoirs sampled for suspended inorganic material in 1998 and 1999. Circles indicate sites where benthic invertebrates were collected in May 1998–2000.

Study sites

Laurel Creek arises to the northwest of the City of Waterloo, Ontario, and flows through the centre of the city before emptying in the Grand River (Figure 1). Prior to 1998, most of the riparian portion of the mainstem west of Laurel Creek Reservoir was wooded and water quality was generally good (Barton, 2000). Both of the major tributaries drain agricultural land: on the headwaters of Monastery Creek and along most of Beaver Creek.

Laurel Lake (LL) was constructed in 1960 by the University of Waterloo for aesthetic purposes. It has a surface area of ca. 0.6 ha and a maximum depth of 1.4 m in the original stream channel just above the dam. Much of the pool is filled with accumulated sediment, so the mean depth is <0.5 m.

Laurel Creek Reservoir (LCR) and Columbia Lake (CL) were built in 1967 by the Grand River Conservation Authority for flood control and are now managed for that purpose, as well as for recreation. Both reservoirs are shallow, with extensive deposits of fine sediments, and are deepest in the original channel just above the dams (ca. 4 m in LCR, 2.5 m in CL). LCR had a surface area of 67 ha and a mean depth of 1.3 m in 1980 (Sephton et al., 1983); CL is smaller (16.8 ha) with a mean depth of ca. 1 m.

Each of the three reservoirs is drawn down in autumn and refilled in spring (usually November and April, depending on precipitation). Only a small area adjacent to the dam remains flooded throughout the winter in LCR; the winter pool covers ca. 25% of the summer area in CL, and >75% in LL. There are no submerged macrophytes in any of the reservoirs.

Methods

Triplicate water samples were collected in 1 L polyethylene bottles from 10 cm below the water surface at the inflow and outflow of each reservoir. Sampling began 19 May 1998, and was repeated at weekly intervals through 30 August 1998, except that no samples were collected within 3 days of precipitation heavy enough to cause a perceptible increase in discharge of Laurel Creek. The same methods and schedule were used beginning on 26 May 1999. Sampling stopped after 22 June when adult carp were observed to have recolonized LL.

A subsample of at least 250 mL from each sample was passed through a pre-combusted (400 °C for 2 hours), pre-weighed (±0.1 mg) borosilicate filter (Whatman GF-F, nominal pore size = 0.45 μm). Filters were then dried at 60 °C, weighed, combusted and weighed again to determine the concentration of suspended inorganic matter.

Paired t-tests (Systat, Version 5.2.1 for Macintosh) were used to evaluate the significance of differences between the mean (on each sampling visit) concentrations of suspended inorganic matter in the inflow and outflow of each reservoir. All means were log-transformed prior to analyses.

On 20 April 1999, carp were removed from LL. Fish were first concentrated in the channel immediately above the dam by removing all of the control logs

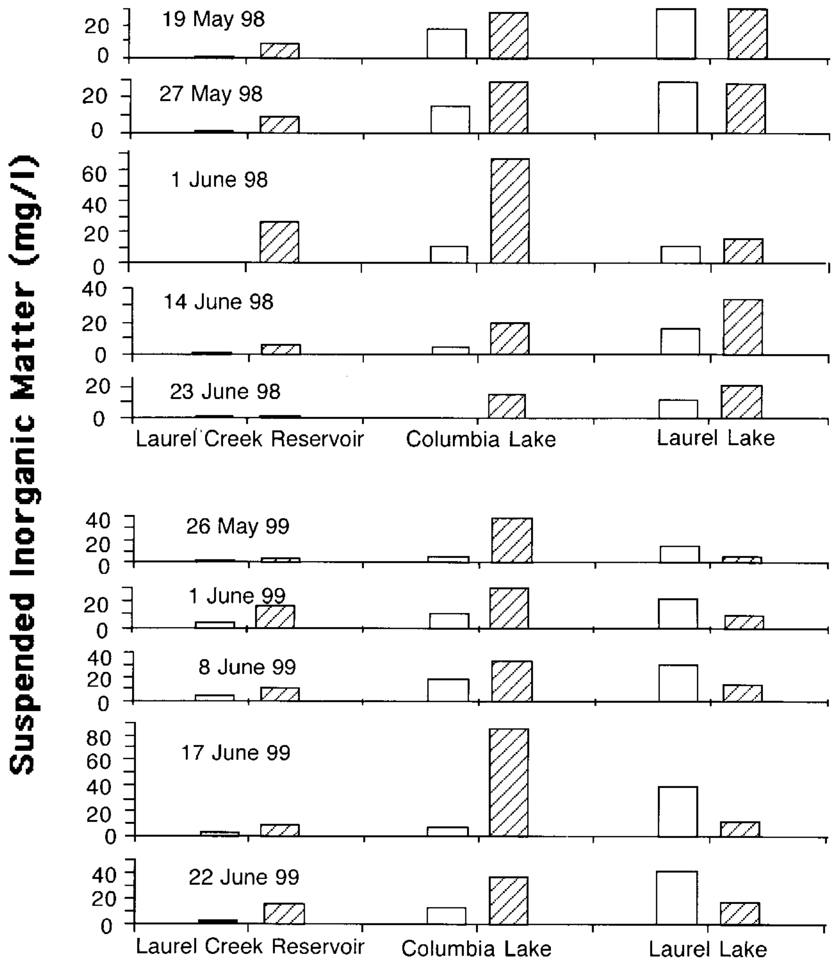

Figure 2. Concentrations of suspended inorganic matter (mg l^{-1}) at the inflow (open bars) and outflow (hatched bars) of three reservoirs on Laurel Creek in 1998 and 1999.

from the spillway, and then collected using seine nets (6 mm square mesh) and a backpack electofishing unit. Carp were weighed and removed from the study area; all other fish were released at the point of capture. The control logs were replaced, and LL was filled during the next week.

As part of a more extensive monitoring program (Barton, 2000), qualitative kick samples of benthic macroinvertebrates were collected at a site downstream of each of the reservoirs (Figure 1) in mid-May of 1998, 1999 and 2000. At least 250 animals were identified from each sample and used to calculate a Biotic Index (Hilsenhoff, 1987), the values of which decrease with improving water quality. While this Biotic Index was developed specifically to reflect organic pollution (Hilsenhoff, 1987), similar indices have also been shown to be responsive to a variety of stressors (e.g. Wallace et al., 1996).

Results

Concentrations of suspended sediment tended to increase downstream in Laurel Creek. On most sampling dates in 1998, there was an abrupt increase in suspended load at the outflow of each reservoir followed by some decrease at the inflow of the next reservoir downstream (Figure 2). Inorganic material accounted for about 30% of total suspended solids entering LCR, 63% entering CL and 70% entering LL. Just over 70% of the total suspended solids in the outflow of each reservoir was inorganic.

Over the entire study period (May through August) in 1998, suspended inorganic sediment concentrations were significantly greater in the outflow than the inflow of LCR ($t = -3.993$, $p < 0.001$), CL ($t = -5.970$, $p < 0.003$) and LL ($t = -4.81$, $p < 0.001$). Concentrations were higher in the outflow than the inflow of LL during May through June (Figure 2), but not significantly so ($t = -2.066$, $p = 0.108$) because of large concentrations in the inflow on the first two sampling visits. Suspended inorganic sediment concentrations were significantly higher in the outlets of both LCR ($t = -4.755$, $p = 0.009$) and CL ($t = -3.477$, $p = 0.025$) during the same period.

Approximately 200 carp, with an aggregate weight of 290 kg, were removed from LL in April 1999. The smallest fish were about 15 cm in length, the largest individuals weighed >4.5 kg; no age 0+ carp were captured. A small number of other fish were caught and released, including white sucker (*Catastomus commersoni*), pumpkinseed (*Lepomis gibbosus*), rockbass (*Ambloplites rupestris*) and brown bullhead (*Ameiurus nebulosus*).

The same pattern of increasing suspended inorganic sediment with distance downstream as far as the inflow of LL was observed in 1999 (Figure 2). Significantly higher concentrations of suspended inorganic material in outflow samples were observed for LCR ($t = -4.644$, $p = 0.010$) and CL ($t = -4.125$, $p = 0.015$) in 1999 (Figure 2). In contrast, suspended inorganic sediment concentrations at the outflow of LL were significantly lower ($t = 10.910$, $p < 0.001$) than at the inflow. The ratios of inorganic to total suspended solids were similar to those measured in 1998, except that the inorganic fraction was lower (ca. 45%) in the outflow of LL in 1999.

Biotic Index scores differed little in 1998, 1999 and 2000, at the sites below LCR (6.4, 6.6 and 6.2, respectively) and CL (8.4, 8.2 and 7.8). The slight improvement indicated by the lower scores in May 2000 reflects much heavier precipitation than in previous years. In contrast, samples from below LL had lower Biotic Index scores in 1999 (7.8) than in 1998 (9.1) or 2000 (8.2). These scores reflected changes in the most abundant organisms from *Chironomus* and Tubificidae in 1998, to Orthocladiinae and *Nais* spp. in 1999. Tubificidae and Isopoda were the dominant animals in May 2000 when carp had recolonized LL.

Discussion

Most sediment is transported along Laurel Creek during storm events (Stone, 2000), at least some of which settles in the reservoirs. During low flow more suspended sediment exits than enters the impoundments. Winter and Duthie (1998) speculated that the increased sediment output from the reservoirs on Laurel Creek might be due to turbidity currents generated by the lake inflow washing out sediments accumulated from upstream. Our observations suggest that sediment resuspension by carp was responsible for most of the sediment exported, at least from LL. We suspect this applies to CL and LCR as well, but it is also possible that wind-generated waves may also lead to resuspension in these larger reservoirs (Lougheed et al., 1998; Chow-Fraser, 1999).

Experimental studies have shown that turbidity tends to increase with carp biomass (e.g. King et al., 1997), although the relationship may not be linear (Zambrano & Hinojosa, 1999). Removal of about 480 kg ha^{-1} from LL in spring 1999, resulted in a significant reduction in concentrations of suspended sediment at the outflow. This yield of carp is similar to the densities reported in a number of lakes and ponds (Breukelaar et al., 1994; Roberts et al., 1995; Denner et al., 1997) and represented nearly the entire population: we were able to catch virtually every fish while LL was drawn down to the level of the original channel. If the density of carp in 1998 was the same as that removed from LL in April 1999, the mean concentration of suspended inorganic material exiting LL in 1998 was very similar to that predicted from the carp biomass: suspended solids relationship in Breukelaar et al. (1994).

This suggests that bioturbation by carp was the primary cause of elevated sediment export from LL, and probably the other impoundments on Laurel Creek. Use of LL by waterfowl was not noticeably different in 1999, suggesting that while ducks and geese may add substantial amounts of nutrients (Manny et al., 1994), they probably do not resuspend much inorganic sediment. The role of wind-generated resuspension in the other reservoirs remains unclear because LL has a relatively small surface area and is largely sheltered from wind by the surrounding terrain and vegetation. If turbidity currents were important, we would have expected some relationship between suspended sediment concentrations in the inflows and outflows of the reservoirs. No such relationship was evident in our data.

Monitoring of invertebrate communities on Laurel Creek indicated that water quality improved after carp were removed from LL, then deteriorated again after the impoundment was recolonized. The differences between the sites below LCR and CL are consistent with apparent differences in the densities of carp in the reservoirs, and those densities appear to reflect the relative size of the pool left during winter drawdown. Reducing the size of the overwinter pool, however, cannot be recommended as a strategy for improving water quality: freezing of exposed sediments during winter reduces the growth of submerged macrophytes during the following summer, which promotes increased turbidity (e.g. Blindow et al., 2000).

Our observations demonstrate that carp removal can effectively improve water quality below a degraded impoundment on an urban watercourse. Benefits are manifest downstream in the form of clearer water and "healthier" benthic communities. The effects of bioturbation are greatest in shallow reservoirs, but these also offer better opportunities for efficient removal operations if water levels can be reduced sufficiently.

References

Barton, D.R., 2000. Laurel Creek Watershed Monitoring Program, 1999: Aquatic habitat – benthic macroinvertebrate monitoring. Report to City of Waterloo, Ontario: 14 pp.

Blindow, I., A. Hargeby, B.M.A. Wagner & G. Andersson, 2000. How important is the crustacean plankton for the maintenance of water clarity in shallow lakes with abundant vegetation? Freshw. Biol. 44: 185–197.

Breukelaar, A.W., E.H.R.R. Lammens, J.G.P. Klein Breteler & I. Tátrai, 1994. Effects of benthivorous bream (*Abramis brama*) and carp (*Cyprinus carpio*) on sediment resuspension and concentratioons of nutrients and chlorophyll *a*. Freshw. Biol. 32: 113–121.

Cahn, A.R., 1929. The effect of carp on a small lake: the carp as a dominant. Ecology 10: 271–274.

Chow-Fraser, P., 1999. Seasonal, interannual, and spatial variability in the concentrations of total suspended solids in a degraded coastal wetland of Lake Ontario. J. Great Lakes Res. 25: 799–813.

Drenner, R.W., K.L. Gallo, C.M. Edwards, K.E. Rieger & E.C. Dribble, 1997. Common carp affect turbidity and angler catch rates of largemouth bass in ponds. N. Am. J. Fish. Manag. 12: 1010–1013.

Hilsenhoff, W.L., 1987. An improved biotic index of organic stream polution. Great Lakes Entomol. 20: 31–39.

King, A.J., A.I. Robertson & M.R. Healey, 1997. Experimental manipulations of the biomass of introduced carp (*Cyprinus carpio*) in billabongs. I. Impacts on water-column properties. Mar. Freshw. Res. 48: 435–443.

Lougheed, V.L., B. Crosbie & P. Chow-Fraser, 1998. Predictions on the effect of common carp (*Cyprinus carpio*) exclusion on water quality, zooplankton, and submergent macrophytes in a Great Lakes wetland. Can. J. Fish. Aquat. Sci. 55: 1189–1197.

Manny, B.A., W.C. Johnson & R.G. Wetzel, 1994. Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality. Hydrobiologia 279/280: 121–132.

Meijer, M-L., E.H.R.R. Lammens, A.J.P. Raat, M.P. Grimm & S.H. Hosper, 1990. Impact of cyprinids on zooplankton and algae in ten drainable ponds. Hydrobiologia 191: 275–284.

Roberts, J., A. Chick, L. Oswald & P. Thompson, 1995. Effect of carp, *Cyprinus carpio* L., and exotic benthivorous fish, on aquatic plants and water quality in experimental ponds. Mar. Freshw. Res. 46: 1171–1180.

Sibbing, F.A., J.W.M. Osse & A. Térlouw, 1986. Food handling in the carp (*Cyprinus carpio*): its movement patterns, mechanisms and limitations. J. Zool. Lond. (A) 210: 161–203.

Stone, M. 2000. Laurel Creek Water Quality Monitoring Program – 1999 Report. Report to City of Waterloo, Ontario: 24 pp.

Wallace, J.B., J.W. Grumbaugh & M.R. Whiles, 1996. Biotic indices and stream ecosystem processes: results from an experimental study. Ecol. Appl. 6: 140–151.

Winter, J.G. & H.C. Duthie, 1998. Effects of urbanization on water quality, periphyton and invertebrate communities in a southern Ontario stream. Can. Wat. Resources J. 23: 245–257.

Zambrano, L. & D. Hinojosa, 1999. Direct and indirect effects of carp (*Cyprinus carpio* L.) on macrophyte and benthic communities in experimental shallow ponds in central Mexico. Hydrobiologia 409: 131–138.