A Decade of Common Carp Research and **Management in Minnesota**

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Insights for managers

The common carp

Common carp is a large (~ typically 600-800 mm; 2 – 3 ft.) fish that was introduced to North America in late 1890s in response to requests from European settlers. Quickly after the introduction, it became clear that common carp (or "carp") can have devastating effects on lakes. Carp root in the bottom while looking for food and in the process, it stirs up the sediments, uproots aquatic plants, and releases sediment-bound nutrients into the water (Vilizzi et al. 2015) (Figure 1, 2). In place of rooted plants that disappear, microscopic algae and cyanobacteria take over making the water look like "pea soup." Some cyanobacteria are harmful to humans and pets because they produce toxins. The use of such lakes for recreation is therefore limited. Lakes invaded by carp are also often impaired for water quality due to excessive nutrient concentrations.

Although it has been known for decades that carp can have negative impacts on lakes in North America, efforts to successfully control them have been relatively rare, other than through whole-lake poisoning or de-watering. For example, a handful of lakes are drawned-down in Minnesota each year to affect winter freeze-out and eradicate carp. Also, the life history of carp has been relatively poorly documented. For example, prior to 2010, there was not a single publication on processes that regulate dietary preferences of larval carp or their survival in North American lakes. The research conducted in Minnesota over the last decade contributed several important pieces of information about the life history of carp and management strategies for this species. I will summarize these findings

Figure 1. Commercial fishermen catching carp in seine nets in Midwestern North America. Photo: Gary Sullivan, The Wetlands Initiative.

Figure 2. Aquatic macrophytes uprooted by common carp in Hennepin Hopper Lakes, Illinois, USA. Photo: Gary Sullivan, The Wetlands Initiative.

here to make them easily accessible to lake managers. These findings resulted from the work of many people, who are included on the referenced publications, thus I will refer to them as "our findings." Our findings are restricted largely to the lakes of central Minnesota (Temperate Forest Ecoregion; TFE), and to some extent also lakes of southern Minnesota (Great Plains Ecoregion; GPE). Most of the systems we studied were within urban or agricultural watersheds. Our work complements other recent research on common carp in the Midwest, especially in South Dakota and Iowa (many of those papers are reviewed in Vilizzi et al. 2015).

How abundant are the carp in Minnesota and why?

Carp populations show strong gradient of abundance across Minnesota. Lakes of NE Minnesota (Northern Forest Ecoregion) are generally not inhabited by this species. However, carp are nearly ubiquitous in central and southern Minnesota, with many lakes being inhabited by very abundant carp populations (biomass > 200 kg/ha; see below). Approximately ~ 23 percent of lakes in the Temperate Forest ecoregion have abundant carp populations, and 70 percent in lakes of the Great Plains (Figure 3) (Bajer et al. 2016).

Whether carp can become invasive is primarily regulated by its ability to have offspring in different habitat types. Carp's reproductive success, or survival of their young, appears to be regulated by a hierarchy of ecological filters, as indicated by an analysis of carp recruitment across 100s of lakes in Minnesota (Bajer et al. 2016). First, for reasons that are not clear, carp appear to be unable to recruit in lakes of northeastern Minnesota. This may be due to very low primary productivity of those systems and low abundance of food for larval carp (Figure 4). Over 20 years of fish surveys by the DNR, no small carp were ever caught in those lakes, and the abundance of adults is also very low or none.

Carp do not appear to be facing such recruitment bottlenecks in lakes of ETF or GP ecoregions, most of which are eutrophic or hypereutrophic. In these regions, carp's reproductive success appears to be driven primarily by the abundance of small predatory fishes that forage on carp eggs, larvae, and fry, such as the bluegill sunfish (*Lepomis macrochirus*) (Figure 5). In lakes with healthy bluegill populations, carp recruitment is usually nil. In lakes with low densities of bluegills, such as winterkill-prone marshes, abundance of YOY (young of year) carp is often extremely high. Carp have evolved

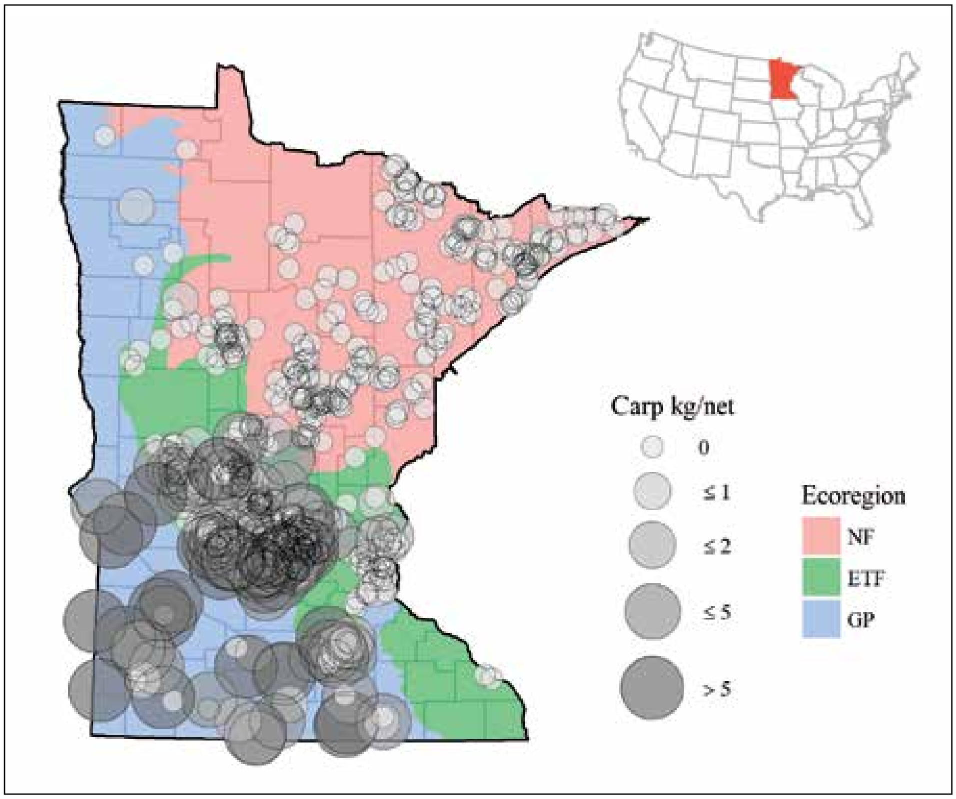

Figure 3. Abundance (catch, kilograms per gillnet) of common carp in lakes of three ecoregions in Minnesota. NF = Northern Forests, ETF = Eastern Temperate Forests, GP = Great Plains. Also shown is the species richness of aquatic macrophytes, which is used to assess impact of carp. Modified after Bajer et al. 2016.

Figure 4. Common carp larvae after feeding for 20 days with water and zooplankton collected from an oligotrophic (top) mesotrophic (middle) or eutrophic (bottom) lake in Minnesota. From Lechelt and Bajer (2016).

Figure 5. Top: Winter fish kills (winterkills) cause massive mortality of native fish (along with carp that overwinter there) in shallow marshes and lakes in Minnesota. These events create "predator-free" patches of habitat within systems of interconnected lakes and marshes. Adult carp migrate to such system from deeper lakes in the spring to spawn. This photograph was taken shortly after ice-out (photo: P. Bajer). *Bottom: bluegill sunfish is an important predator on carp eggs and larvae in Minnesota. Flushing the stomach content of this individual revealed hundreds of carp eggs (*photo: Chris Chizinski).

strategies to exploit bluegill-free habitats as nurseries for their young by employing spring spawning migrations from lakes into marshes. After spawning, most adults return to the lakes, while the young disperse into lakes. Dispersal of young is poorly documented, but it appears that relatively few young disperse in the first and second year of life, but then dispersal increases in year three (Lechelt et al. 2017). Many young carp perish in the marshes before they disperse, especially during severe winters. For this reason, carp populations do particularly well if marshes winterkill every three to five years, giving the young plenty of time to disperse before a next winterkill occurs (Figure 5). This explains why carp populations in metro lakes are dominated by strong year classes that coincide with winterkill events in adjacent marshes (Lechelt and Bajer 2016).

Carp populations appear to be driven by slightly different dynamics in shallow lakes in southern and western Minnesota (GP ecoregion); although carp populations have not been studied in detail in those types of systems. Those systems often do not support abundant bluegill populations due to shallow depth and periodic occurrence of summer and winter hypoxia. Consequently, carp are able to produce young more consistently within the lakes and fewer of them might migrate into adjacent marshes. Recruitment in such systems is thought to be density dependent: few young carp are found in lakes with very high abundance of adults or older siblings, but production of young might increase in response to adult removal.

Effect of carp biomass on ecosystems: shallow vs deep lakes

Effects of carp on ecosystems can be quite complex, and vary among lakes and lake-types. To facilitate a synthesis of observed trends, it is useful (although simplistic) to split lakes into two distinct categories, with the understanding that many lakes fall in-between these conditions: (1) shallow lakes (usually < 3 m max depth), well mixed year-round and whose entire bottoms can be colonized by macrophytes and (2) deep lakes where thermal stratification sets up in early summer and persists through fall (although periodical mixing can occur) and where macrophytes can only occur in the littoral, because other parts of the lake are too deep for the plants to grow (light penetration). While carp have been shown to impact various characteristics of water quality (clarity, turbidity, chlorophyll-*a*, suspended solids, nutrient concentrations), and biota (macrophytes, plankton, invertebrates, fish, waterfowl), we will focus on macrophytes, water clarity, and total phosphorus (TP), because these are best documented and of main interest.

Impacts of carp appear to be more severe and multifaceted in shallow lakes. This is illustrated by a carp eradication experiment in Lake Casey in St. Paul (area 5 ha, max depth 1 m). Initially, this small lake was inhabited by ~ 6,000 carp (biomass 500 kg/ha), it had virtually no macrophytes, very turbid water, and high TP (Bartodziej et al. 2017). After removal, macrophytes blanketed the entire lake, water clarity increased, and TP declined by 48 percent (Bartodziej et al. 2017). Similar responses were reported from other shallow lakes in the region. This suggests that in shallow lakes, carp has strong effect on macrophytes, water clarity, and TP (Ginger et al. 2017). The experiment in Lake Casey also illustrated that management of carp, which allowed for the recovery of macrophytes that were then harvested from the lake, was a cost-effective P removal strategy ($670 per 1 kilogram of P removed [Bartodziej et al. 2017]).

Effects of carp on deep lakes appear to be subtler and are much less documented than in shallow lakes. This is exemplified in a carp removal in Lake Susan (Bajer and Sorensen 2015). Lake Susan (35 ha; 5 m max depth) is thermally stratified during July-October, but it briefly de-stratifies in the summer during windy days. This system was inhabited by approximately 4,000 carp (biomass 307 kg/ha), which were then reduced to 40 kg/ha using selective removal (winter seining). Before removal (2008), the lake had relatively turbid water year-round (Secchi depth < 2 m), and only sparse littoral (< 2 m depth) vegetation (cover < 10 percent). Removal of carp was associated with an increase in littoral macrophytes (>50 percent cover by 2010), a significant increase in water clarity in May and June (Secchi ~5 m). However, removal of carp had no appreciable effect on TP concentrations. Analyses of thermal profiles showed that TP was driven by abiotic internal loading: TP accumulated in hypoxic hypolimnion during calm summer periods and was brought to the surface during windy days, causing rapid increase in epilimnetic TP in mid-summer. This process was independent of carp abundance. This experiment suggested that in deep lakes, carp impact primarily the ecology of shallow, well-mixed areas, but have little effect on offshore and deep (below thermocline) areas. Shallow areas represent biodiversity hotspots in deep lakes.

Is there a threshold in carp biomass that managers should aim for?

Carp are almost impossible to eradicate. Thus, it is more practical to determine a threshold in their abundance that is not associated with ecological damage, and manage populations accordingly. While defining such a threshold, we chose the decline in aquatic macrophytes (density and diversity) as an index of carp's impact because this impact is very clear, direct, and consistent across shallow and deep lakes (see above). It is useful to focus on macrophytes in shallow areas (< 2 m), to avoid confounding effects of water clarity (i.e.. in shallow areas, macrophytes are rarely limited by light, so carp is the main driver, but in deep areas macrophytes can be limited by clarity regardless of carp abundance). We conducted several whole-lake manipulations to determine the relationship between carp biomass and macrophytes (Figure 6). These experiments showed that at 50 kg/ha, effects of carp on macrophytes were minor, at 100 kg/ha ~50 percent declines in macrophyte cover occurred, and at 200 kg/ha almost no rooted vegetation remained in lakes (Figure 6). For practical purposes, 100 kg/ha is often used as a management threshold for carp populations because reducing carp to that biomass level is more affordable than say to 50 kg/ha, and such a level in carp biomass allows for relatively healthy macrophyte community to develop. However, if possible, biomass should be reduced to ~ 50 kg/ha to allow for full recovery of macrophytes.

Steps involved in developing successful carp management

Developing a strategy to control common carp populations is not necessarily straightforward given the relatively complex life history of this species. For example, in chains of

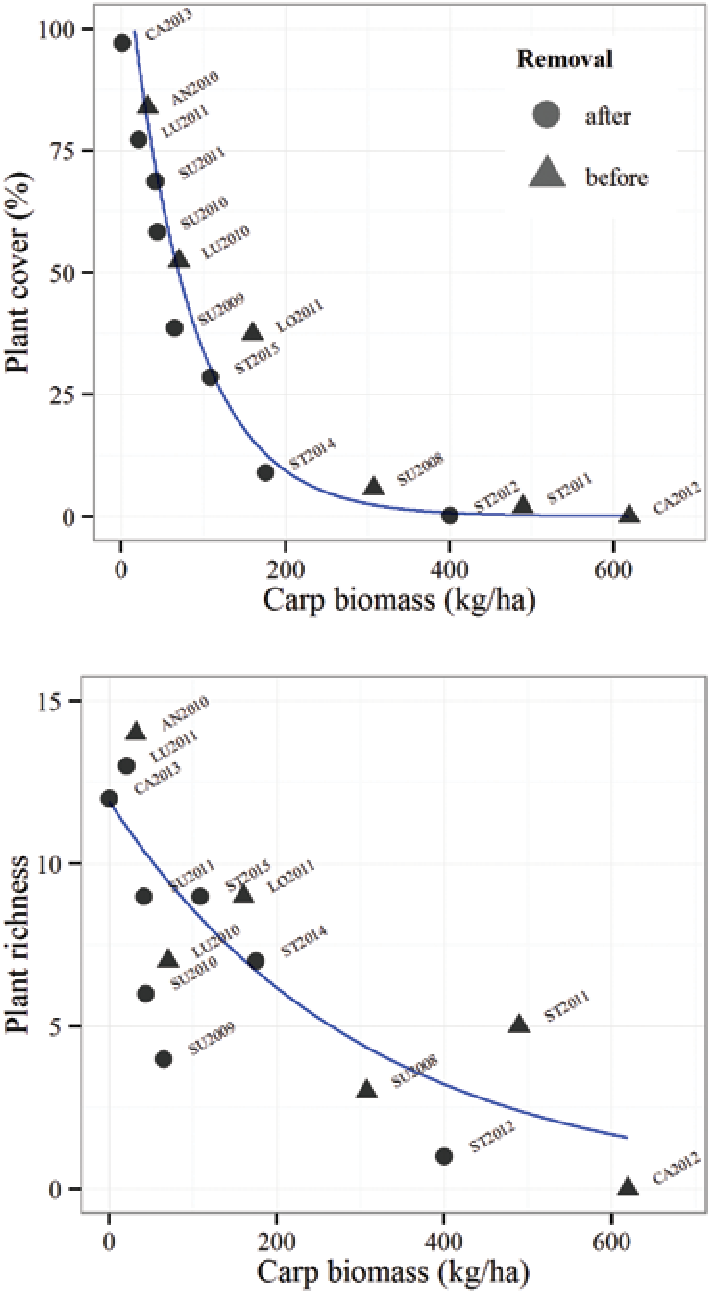

Figure 6. Macrophyte cover (top) and species richness (bottom) is shallow areas (< 2 m depth) of lakes with different carp biomass. From Bajer et al. 2016.

interconnected lakes, a single winterkill-prone marsh or stormwater pond might constitute key carp nursery that needs to be identified before management commences, in which case barriers to adult movement or juvenile dispersal might be needed. Locating carp nurseries within the landscape and determining migration routes for adults and juveniles is very important. It is a good idea to first collect key data on carp abundance and processes that drive it within a particular lake or chain of lakes over one or two seasons, before management occurs, to avoid costly management mistakes.

As a first step, carp abundance should be estimated in all bodies of water within a management unit, to determine if it exceeds the management threshold, and by how much. Among commonly applied sampling techniques, boat electrofishing surveys appear to be most reliable in quantifying carp abundance and biomass. The number of carp caught per hour is used to estimate the density and biomass of carp per hectare using published equations (Bajer and Sorensen 2012). It is recommended that these initial estimates are verified using mark-recapture analyses, especially when removal methods are tested (see below).

Following the initial assessment, a more detailed analysis of the population is conducted. This is done primarily to determine past patterns in recruitment. Recruitment history is determined by ageing a sample of the population (100-200 carp) and plotting the abundance of each age class. This shows how often "strong year classes" occur. Ageing analysis also informs about the longevity, mortality rate, and growth rate of the carp.

To determine which lakes/marshes in the watershed function as sources of recruits, all waterbodies are surveyed in late summer or fall with fine-mesh (~ 10 mm bar) trapnets to look for age-0 carp. At the same time, a sample of adult carp, ~ 10-20 per lake, is implanted with radio transmitters in all major water bodies. These fish are followed during spring to document the routes of their spawning migrations. Adult carp often home to nurseries they were born in, so a strong migration suggests a key nursery at its end.

Management of carp populations needs to include selective and effective removal methods. It is recommended that one or several of such methods are tested in the early stage of management development to assess the feasibility and efficacy of removal, which can vary considerably among lakes. In the Midwest, carp are known to form tight winter aggregations. These can be located using the radiotagged individuals, and removed using large seine nets (Figure 7). This strategy can be quite effective. For

Figure 7. Winter seining for carp in Lake Susan, Minnesota. Top left: "submarines" used to pull rope between holes; the rope is then used to pull the net under the ice. Top right: putting net into the lake. Bottom left: final stage of the seine with carp caught in the "bag" of the net. Bottom right: debris on the bottom can ruin a seine by lifting the lead line above the bottom allowing carp to escape.

example, in Lake Lucy (36 ha), 94 percent of carp (685 individuals) were removed in a single haul. In Lake Riley (120 ha), 89 percent of population (~6,900 carp) were removed in three hauls. In Lake Gervais (95 ha), 52 percent population (~3,500 carp) were removed in a single haul), but subsequent several hauls were unsuccessful. In Lake Susan (35 ha), approximately 80 percent were removed in one haul (~ 3,000 carp). However, this strategy was less effective in Long Lake (68.8 ha), where two seine hauls conducted during two consecutive winters captured <5 percent of population (300 carp). Success was also low in Lake Staring (< 10 percent population caught per seine). In each of those cases, carp aggregations could be easily located. However, the nets either snagged on debris on the bottom, or the carp escaped from the area before the net could be "landed." Also, if unsuccessfully targeted multiple times, carp can easily learn how to escape from the nets. The long-term efficacy of winter seining in the same ecosystem has not been evaluated but avoidance behaviors might pose a challenge. It is also important to realize that each seining event requires extensive preparation, repeated telemetry surveys and a crew of at least 10 people.

As an alternative to winter seining, carp can also be removed in the summer, by conditioning them to aggregate within areas baited with food attractants (Bajer et al. 2010). An experiment in Lake Susan (35 ha) showed that 70 percent of carp were attracted to the bait at night (at the same time), after only few days of baiting. This suggests that baited traps could be used to manage carp populations. However, this approach has not been aggressively pursued.

Developing a model of the population

Once abundance estimates are conducted, recruitment patterns documented (i.e., how often strong year classes occur and by how many individuals are they comprised), nurseries located, movement patterns mapped, and removal methods assessed, it is useful to construct a model of the population. This might start as a "conceptual" model that simply puts all these pieces together. However, it is even more useful to develop a numerical model that can be used to "run" different management scenarios and single out those that are most likely to be efficient, practical, and cost effective.

Final thoughts

While we advise local watershed districts and lake managers on how to manage common carp in Minnesota, several common issues occur. First, managers often tend to overlook the fact that carp are very mobile, and that lake chains rather than individual lakes need to be managed. Within chains of lakes, some systems might function as overwintering sites, while entirely different ones might function as nurseries, and carp can extensively migrate between the two. These dynamics need to be recognized and documented, for example, by using telemetry. Second, managers instinctively focus on removing the adult carp, while neglecting efforts to manage recruitment of juveniles. Third, while carp management often begins with much enthusiasm and financial support, managers often do not fully appreciate the long-term commitment and planning needed to keep carp populations at low level; the amount of "maintenance" will vary among individual lakes. Despite these limitations, evidence from our whole-lake experiments shows that carp removal usually has strong positive effects on various components of ecosystems (macrophytes, water clarity, nutrients), and that these benefits often outweigh the challenges and costs associated with carp management.

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