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North American Journal of Fisheries Management

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ujfm20

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Published online: 01 Aug 2012.

To cite this article: Przemyslaw G. Bajer & Peter W. Sorensen (2012) Using Boat Electrofishing to Estimate the Abundance of Invasive Common Carp in Small Midwestern Lakes, North American Journal of Fisheries Management, 32:5, 817-822, DOI: 10.1080/02755947.2012.690822

To link to this article: http://dx.doi.org/10.1080/02755947.2012.690822

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North American Journal of Fisheries Management 32:817–822, 2012
© American Fisheries Society 2012
ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2012.690822

MANAGEMENT BRIEF

Using Boat Electrofishing to Estimate the Abundance of Invasive Common Carp in Small Midwestern Lakes

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Abstract

The common carp *Cyprinus carpio* is among the most invasive fish worldwide, but practical methods for estimating its abundance have not yet been developed. Particularly needed are methods that can accurately assess low densities of common carp to enact proactive management strategies before populations reach damaging levels. In this study we tested whether the density of adult common carp in small Minnesota lakes could be accurately predicted from their catch rates using boat electrofishing. We used mark and recapture to estimate the abundance of common carp in eight Midwestern lakes with a wide range of common carp densities (13–400 carp/ha), while also surveying each lake using boat electrofishing. In addition, we reduced common carp abundance by up to 90% in two lakes to test whether this was accompanied by a similar drop in electrofishing catch rates. A regression analysis showed that electrofishing catch rates increased linearly with increasing densities of common carp. A cross-validation procedure showed that boat electrofishing can accurately estimate common carp densities; however, we observed a tendency to overestimate low densities and underestimate high densities. Our results suggest that electrofishing surveys can be routinely employed to estimate common carp densities in small lakes.

Common carp *Cyprinus carpio* is among the most widespread and damaging invasive fish worldwide (Weber and Brown 2009), but practical methods for assessing its abundance have not been developed. Native to the Ponto-Caspian region, the carp is particularly damaging in temperate regions of North America and Australia (Lougheed et al. 1998; Parkos III et al. 2003; Koehn 2004; Lougheed et al. 2004; Schrage and Downing 2004; Bajer et al. 2009). Because introductions of carp have been associated with dramatic declines in vegetation, water quality, and native fauna (Haas et al. 2007; Kloskowski 2011), this species has been aggressively managed using toxins, barriers, and mechanical removal (Marking 1992; Schrage and Downing 2004; Bajer et al. 2009). However, carp management has largely been reactive, usually being conducted only after ecological damage has already been done. A proactive management approach in which the biomass of carp is suppressed before it reaches an ecologically damaging threshold would be useful. Such an approach may be practical in some regions because thresholds for damage have recently been developed (Bajer et al. 2009) and selective means to remove adult biomass also now exist (Bajer et al. 2010, 2011). However, for this combination of strategies to be practical, methods to accurately assess carp abundance are needed. Having the ability to accurately and rapidly estimate carp abundance would also aid studies of the invasiveness of carp and its ecological impacts (Kulhanek et al. 2011).

Although the densities of common carp can be estimated using mark-and-recapture approaches (Bajer and Sorensen 2010; Bajer et al. 2011), these methods require substantial effort and cannot be easily employed in large numbers of lakes. Alternatively, carp densities could also be estimated using catch-per-unit-effort (CPUE) data collected from common survey techniques such as trap nets, gill nets, and boat electrofishing. However, while age-0 carp appear to be captured relatively easily using these techniques (Barko et al. 2006; Phelps et al. 2008; Bajer et al., in press), older carp appear to be more "gear-shy" to passive capture techniques, especially trap nets (Clark et al. 1991). A study of common carp catchability by a boat electrofisher in enclosures and ponds showed that although catch rates were influenced by fish size and habitat characteristics, carp are relatively vulnerable to electrofishing (Bayley and Austen 2002), suggesting that this technique might also be effective in natural systems.

In this study we tested whether densities of adult common carp in small lakes can be accurately predicted from boat electrofishing catch rates. This was accomplished by estimating the abundance of carp using mark-and-recapture techniques in eight lakes having a wide range of carp densities, while sampling each lake on several occasions with a boat electrofisher to estimate

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Received December 13, 2011; accepted April 26, 2012

TABLE 1. Sampling protocols and common carp population estimates in study lakes; lake size and maximum depth, mark-and-recapture type (simple, S; multiple, MT), sampling used to conduct mark and recapture (SS, summer seining; WS, winter seining; EF, electrofishing; BT, baited trap; numbers indicate how many samples were collected), numbers of marked (M) and recaptured (R) carp, carp population estimate (*N*); carp length, density, and biomass; and electrofishing CPUE (carp/h). Carp abundances in Lake Susan in 2009 and Lake Riley in 2010 were reduced (see Methods for details).

	Lake characteristics			Mark-and-recapture techniques				Estimated carp population and characteristics				
Name	Year sampled	Size (ha)	Depth (m)	Type	Sampling	M	R	*N*, mean (95% CI)	Length, mean (SD) (mm)	Density mean (carp/ha)	Biomass mean (kg/ha)	CPUE, mean (SE)
Echo	2006	33.2	3.0	MT	2SS, 4EF	726	37	6,213 (4,891–8,516)	521 (76)	187.1	326.8	32 (28.90)
Dutch	2006	64.4	6.3	MT	3SS, 4EF	1,444	66	15,550 (12,528–20,495)	524 (83)	241.5	494.81	64.4 (38.61)
Dog	2007	38.4	7.5	MT	4EF, 1SS	59	3	514 (263–1,022)	699 (51)	13.4	69.6	2.98 (4.30)
Susan	2008	35.1	5.1	S	1SS, 1WS	101	79	4,181 (3,292–5,069)	598 (67)	119.1	307.1	17.26 (9.28)
	2009	35.1	5.1	S	Reduced			756	609 (139)	21.5	64.5	8.52 (0.52)
Riley	2009	118.8	14.7	S	1WS, 1WS	600	462	6,419 (6,132–6,706)	585 (74)	54.0	176.1	12.16 (9.55)
	2010	118.8	14.7	S	Reduced			3,025	612 (84)	25.6	90.0	4.66 (2.82)
Lucy	2010	34.6	6.0	S	1WS, 1WS	642	282	808 (768–851)	670 (116)	23.3	69.8	8.15 (5.22)
Gervais	2010	152.0	5.8	S	1WS, 1WS	1,035	200	9,864 (8,538–11,144)	622 (52)	64.9	145.9	11.03 (6.85)
Staring	2011	65.7	4.8	S	1BT, 1WS	331	71	26,228 (20,938–31,472)	444 (69)	399.3	489.3	58.54 (11.85)

CPUEs. In addition, carp densities in two lakes were experimentally manipulated to test whether CPUEs would decline in a predictable manner. Our results have implications for basic and applied studies of carp in lake ecosystems.

STUDY LAKES

We conducted this study in eight lakes in the upper Mississippi River basin (south-central Minnesota) in which common carp populations have been studied over the past several years (Bajer and Sorensen 2010; Bajer et al. 2010, 2011; Table 1). These systems, which range in size from 33 to 152 ha, have maximum depths of 3–15 m and water conductivities between 300 and 600 µS/cm (Table 1), typical of small lakes in this region (Downing et al. 2006). The bottom substrate in these lakes varies from sandy to soft, and vegetative coverage and water clarity vary from relatively high in lakes with carp density below 100 kg/ha to extremely low in lakes with higher biomasses of carp (P. G. Bajer, unpublished data).

METHODS

Estimating common carp abundance.—We estimated the population abundance of common carp in all study lakes using either multiple or simple mark-and-recapture analyses in which we employed summer seining (400-m-long net with 35-mm-bar mesh-size pulled across obstacle-free areas; Bajer and Sorensen 2010), telemetry-guided winter seining (400-m-long net with 35-mm-bar mesh-size that targeted under-ice carp aggregations; Bajer et al. 2011), baited traps (20 m × 20 m box trap baited with corn), and boat electrofishing (described in detail below; Table 1). Estimates for five of our study lakes (Lakes Echo, Susan, Riley, Lucy, and Gervais) were recently published (Bajer and Sorensen 2010; Bajer et al. 2011), but were revised for the purpose of this analysis to achieve statistical independence between population estimates and CPUE estimates. Specifically, in Lake Echo, in which the population had previously been estimated using both summer seining and boat electrofishing (Bajer and Sorensen 2010), four electrofishing surveys were randomly excluded and used exclusively to calculate CPUEs in this study. In Lakes Susan, Riley, Lucy, and Gervais, in which carp populations had previously been estimated using a combination of winter seining and boat electrofishing, population estimates are now revised by excluding all summertime electrofishing surveys (now used to calculate CPUEs) and incorporating new winter seining data. Estimates for Lakes Dog, Dutch, and Staring have not been previously reported. Sampling methodologies employed in each lake are presented in Table 1 and described in detail in the following paragraphs.

In Lakes Echo, Dutch, and Dog, we estimated common carp populations using a multiple mark-and-recapture approach that involved repeated summer seinings and boat electrofishing surveys (Table 1). All carp captured on each sampling occasion were counted, measured, tagged with an individually numbered plastic tag (model TBA-1; Hallprint, Australia), fin clipped to take into account possible tag loss, and released. All carp were also examined for marks from previous surveys. These data were then used to calculate the mean and 95% confidence interval (CI; 1.96 · SE) of carp population in each lake using Schnabel's equations (Ricker 1975). We sought to randomize spatial distribution of marked individuals by seining in two different areas of each lake and electrofishing along at least 50% of the shoreline. All sampling was conducted during a relatively narrow time window (3 months) to minimize the effects of mortality rates on population estimates. In cases where the lakes were connected with other water bodies (Lake Echo), these connections were blocked with a metal grate to prevent immigration and emigration (Bajer and Sorensen 2010).

Common carp populations in Lakes Susan, Riley, Lucy, Staring, and Gervais were estimated using simple mark-and-recapture approaches (Table 1). We accomplished this in Lakes Susan and Staring by employing open-water seining or baited traps, respectively, to mark and release carp, and conducted winter seining approximately 3 months later to estimate recapture rates. In Lakes Riley, Lucy, and Gervais, we employed two winter seinings: carp caught in the first seining were marked and released, and recapture rates were determined a year later when the second seining was conducted. The adjusted Petersen's formula was used to calculate mean population estimates and 95% CIs (Ricker 1975). To randomize distribution of marked individuals within the population, we seined when carp from different areas aggregated in common locations (Bajer et al. 2011). We blocked the inlets and/or outlets of Lakes Susan, Riley, Lucy, and Gervais with horizontal PVC pipes spaced every 20 mm (Lake Staring had a natural barrier at the outflow) to minimize carp immigration and emigration; to verify that no recruitment occurred throughout the study, we surveyed each lake for age-0 carp using small-mesh trap nets (Bajer et al., in press). In addition to calculating initial population estimates, we reduced populations in Lakes Susan and Riley by removing carp caught in the second winter seining (Table 1). We included these data in this analysis because we were particularly interested in whether electrofishing could predict low carp densities in lakes and because we wanted to verify, to some extent, that our population estimates were unbiased; i.e., unexpectedly low postremoval electrofishing CPUEs would indicate that marked carp avoided second capture and that our initial population estimates were inflated (Beukema and de Vos 1974). The postremoval estimates were adjusted for mortality rates estimated from the survival of radiotagged carp by using Mayfield's equation (Winterstein et al. 2001); of 25 and 15 radiotagged carp present in Lakes Susan and Riley, respectively, 3 in each lake perished during the study, which suggested finite annual mortality rates of 14% and 17%, respectively.

Estimating electrofishing CPUEs.—In each study lake, three to four electrofishing surveys (each on separate dates) were conducted to calculate mean CPUE values. All surveys were conducted between August and October when water temperature ranged between approximately 25°C and 15°C, respectively, and common carp were relatively evenly dispersed throughout the lakes (Bajer et al. 2010, 2011). In Lakes Echo, Dutch, and Dog, electrofishing surveys were conducted concurrently with mark–recapture sampling. In Lakes Susan, Riley, Gervais, Lucy, and Staring, electrofishing surveys were conducted during the summer/fall between the winter seinings and additionally after the second seining in Lakes Susan and Riley to calculate the postremoval estimates. The same protocols were followed in each lake. Each electrofishing survey consisted of three transects lasting approximately 20 min each. These transects were conducted in three different areas of each lake and collectively covered 50% to 100% of the shoreline. Surveys were confined to the littoral zone because carp could not be effectively captured in waters deeper than approximately 1.5 m. We used a 5.4-m-long flat-bottom aluminum boat (Midwest Lake Management, Missouri) that generated a pulsed DC electric field (5–12 A, 80–150 V, 20% duty cycle, 120-pulse frequency). The boat was equipped with two anodes, each consisting of five stainless steel pipes 25 mm in diameter and 260 mm long. The anodes were located approximately 3 m in front of the boat and spaced 1.5 m apart. Only 10–20 cm of the electrodes was submersed in the water during electrofishing. The boat was maneuvered at a slow speed (~0.5 to 1 m/s) in a zigzagging fashion along the shore while two netters collected stunned carp and placed them in a live well. Although habitat characteristics differed among study lakes, we aimed at standardizing our surveys by maximizing carp catch rates within each transect. To do this, we briefly increased boat speed to capture carp that were observed escaping in front of the boat, electrofished around downed trees that carp were using for shelter, and made an additional pass through vegetation patches if we observed signs of carp (movement of vegetation) after the first pass. For each transect, electrofishing time was recorded and CPUE (carp/ha) calculated. Catch-per-unit-effort values were then averaged among transects and among sampling dates in each lake.

Statistical analyses.—To analyze the data, we calculated common carp density in each lake by dividing the population estimate by the lake area and developed a linear regression between carp density and mean electrofishing CPUE in each lake. To cross-validate this relationship, we used the "leave-one-out" approach. A single data point (lake) was removed from the data set and the regression was re-fitted and used to predict the density of carp in that lake by using the CPUE value. This was repeated for all study lakes and resulted in two sets of carp densities: those predicted with the regression analysis and those estimated with mark and recapture for each study lake. The predicted densities were regressed against those estimated by mark and recapture, and the 95% CIs for the intercept and slope estimates were calculated to determining whether they overlapped with zero and one, respectively. All analytical procedures were conducted in SAS 9.2 (SAS Institute, Cary, North Carolina).

RESULTS

Common carp populations in the study lakes ranged from approximately 500 to 26,000 individuals, or 13 to 400 carp/ha, and were mainly comprised of individuals that were 400 to 700 mm in length (Table 1; Figure 1A). Electrofishing CPUEs increased linearly with increasing carp densities ($r^2 = 0.83$; $P < 0.001$) and a particularly good fit occurred at densities below 200 carp/ha (Figure 1A). Postremoval CPUEs for Lakes Susan and Riley clustered tightly with the other data, suggesting that our population estimates were unbiased (Figure 1A). Cross validation demonstrated that carp densities in lakes can be reasonably accurately predicted from electrofishing CPUEs (Figure 1B) as

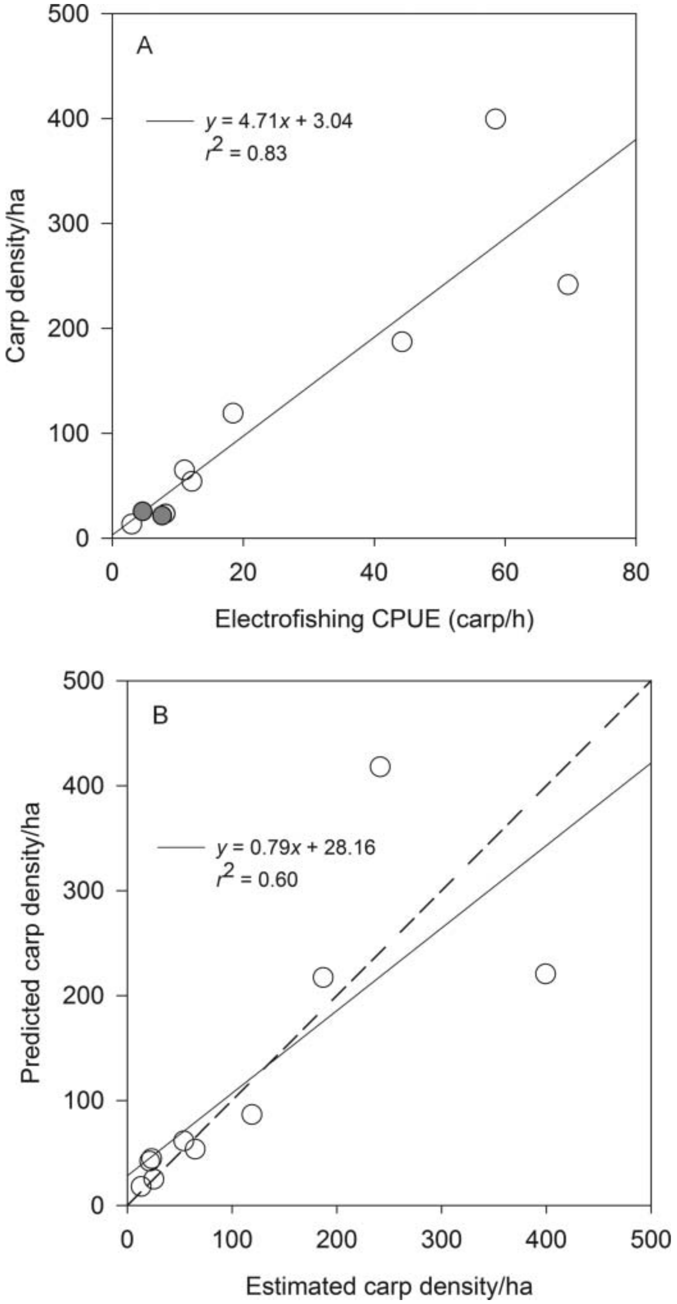

FIGURE 1. **(A)** Linear regression between common carp densities estimated using mark-and-recapture approaches and electrofishing CPUE values in study lakes. The regression line was fitted to all data; shaded circles indicate postremoval estimates in Lakes Susan and Riley. **(B)** Relationship between common carp densities predicted using electrofishing CPUE values and those estimated using mark-and-recapture approaches in study lakes. Predicted densities were calculated using model cross-validation approach. The dashed line is a 1:1 reference line and the solid line is a regression line fitted to the data.

the slope (0.73 ± 0.43 [mean ± SE]) and intercept (22 ± 73.3) of the regression between carp densities predicted from CPUEs and those estimated by using mark and recapture were not significantly different from one and zero ($P > 0.05$), respectively (Figure 1B). However, a slight bias toward overestimating low carp densities and underestimating high densities was observed (Figure 1B).

DISCUSSION

This study demonstrates that densities of adult common carp in small Midwestern lakes can be predicted from boat electrofishing catch rates. This technique appears to be especially accurate at low and moderate densities, which is particularly desirable when developing proactive management schemes. The relationship between electrofishing CPUE and carp density we present should aid lake managers in assessing carp abundance and determining if and how many carp need to be removed from ecosystems to prevent excessive biomass build-up and ecological damage (Bajer et al. 2009). This management tool may be particularly effective in conjunction with targeting winter aggregations of carp by using the “Judas” technique (Johnsen and Hasler 1977; Penne and Pierce 2008), which employs radiotelemetry to locate carp aggregations and which can be highly selective and efficient (Bajer et al. 2011). Ecological studies of carp abundance, distribution, niche requirements, invasiveness, and ecological damage also require practical and accurate tools for assessing their abundance (Egertson and Downing 2004; Barko et al. 2006; Zambrano et al. 2006; Jackson et al. 2010; Weber et al. 2010; Kulhanek et al. 2011) and may benefit from incorporating electrofishing surveys as standard survey methods.

Electrofishing catch rates of fish have been shown to be influenced by seasonal patterns and habitat conditions (McInerny and Cross 2000; Bayley and Austen 2002). Seasonal effects were minimized in this study by sampling during late summer and fall, when common carp were not spawning and were relatively uniformly distributed in lakes (Penne and Pierce 2008; Bajer et al. 2010), but the effect of habitat was not controlled. Bayley and Austen (2002) suggested that common carp electrofishing catch rates decline with increasing lake size and increasing vegetation density. The relationship between estimated carp densities and electrofishing CPUE presented in this study was surprisingly tight despite the fact that lakes varied both in size and vegetative cover (>60% in Lakes Lucy and Dog to <10% in Lakes Susan, Echo, and Staring; P. G. Bajer, unpublished data). The fact that habitat conditions had only a relatively minor effect on capture rates in our study lakes might be attributable to our sampling approach in which we aimed at maximizing common carp catch rates within each transect by targeting visible signs of their presence. This more aggressive sampling strategy probably reduced the effect of habitat complexity on catch rates. Also, although detailed, the study of Bayley and Austen (2002) was conducted in relatively small enclosed areas (0.1 to 5 ha) and may not be directly comparable with our study.

The effects of learning and gear avoidance on common carp mark-and-recapture experiments have not been studied in detail, but a pond study in which carp were repeatedly (multiple times per day) sampled with a seine suggested that carp can learn how to avoid repeatedly used gear, thus leading to biased population estimates (Beukema and de Vos 1974). Several pieces of evidence suggest that the single-gear mark-and-recapture population estimates we conducted in some of the study lakes were accurate. First, estimates generated by using either single or multiple gears clustered together and could be equally well predicted from observed CPUEs. Second, single-gear population estimates for Lakes Riley and Lucy reported in this study differ only slightly (3–15%) from those previously published for use of multiple-gear types (Bajer and Sorensen 2010; Bajer et al. 2011). Third, postremoval CPUEs in Lakes Riley and Susan, which declined in a predictable manner, suggested that the initial population estimates in those lakes were unbiased.

While our study shows that boat electrofishing is sensitive and accurate enough to estimate even low densities of common carp in lakes, the applicability of this technique to other geographic regions and ecosystem types needs to be examined. In particular, our study systems did not include large lakes, shallow marshes, or rivers, and so our regression relationship should be applied with caution in those systems. Independent tests of our regression relationship are especially important because the small sample size precluded thorough cross-validation analyses. Our sampling protocols should also be mimicked to reduce bias. Nonetheless, given the current lack of practical tools for assessing carp densities in lakes, the relationship presented in this study should be useful in many ecosystems in which the carp are currently excessively abundant and damaging, especially when mark and recapture is not practical or feasible. The regression relationship presented in this paper would be also useful in regional studies in which it is necessary to rapidly obtain estimates of carp abundance in a large numbers of lakes (e.g., Egertson and Downing 2004; Jackson et al. 2010).

ACKNOWLEDGMENTS

This research was funded by the Riley Purgatory Bluff Creek Watershed District, the Ramsey-Washington Metro Watershed District, the Minnesota Environment and Natural Resources Trust Fund, and the Minnesota Agricultural Experiment Station. Daryl Ellison and Gerry Johnson (Minnesota Department of Natural Resources) provided technical support and fish collection permits. Brett Miller and Mary Headrick (University of Minnesota) helped with data collection. We thank Jacob Osborne and Paul Venturelli (both University of Minnesota) as well as three anonymous reviewers for providing useful comments that improved this manuscript.

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