12-2017

Sparta Training Area Asian Carp Removal Report

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Recommended Citation

Rude, Neil, Coulter, David, Coulter, Alison and Whitledge, Gregory. "Sparta Training Area Asian Carp Removal Report." (Dec 2017).

SPARTA TRAINING AREA ASIAN CARP REMOVAL REPORT

Report to the Sparta Training Area, Illinois Army National Guard

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EXECUTIVE SUMMARY

Aquatic invasive species have long been associated with negative ecological and socio-economic impacts on freshwater ecosystems. In order to mitigate these potential negative effects of invasive species introductions, management and control techniques must be developed. Asian carp species (Silver Carp, Bighead Carp, Grass Carp, and Common Carp) are a problematic group of invasive species that can cause negative effects on native fish species and freshwater ecosystems through a series of trophic cascades. The current focus of Asian carp management and control techniques is directed at reducing population sizes in the upper Illinois River to reduce probability of invasion further upstream at the Illinois River-Great Lakes connection. However, smaller freshwater systems and their associated lakes and impoundments are also vulnerable to invasion and may require management techniques to reduce Asian carp populations. Flooding has resulted in strip mine lakes within the Army National Guard Sparta Training Area being invaded by Asian carps. Therefore, we sought to develop a harvest protocol to remove Asian carps from three Sparta Training Area lakes (S3, S5, and S6) based on a technique developed for Illinois River floodplain lakes that combines multiple net types, electrofishing, and surface sounds and disturbances to drive fish to a pre-determined harvest location. More specifically, lakes were divided into three zones and fish were funneled and herded through strategically-placed monofilament gill nets by surface sounds and disturbances and electrofishing from one end of the lake (zone 1) to the other end of the lake (zone 3) where congregated fish could be more efficiently harvested. To determine our effectiveness of removing Asian carps from these lakes, we used hydroacoustic surveys to estimate reductions in Asian carp density and biomass pre- and post-harvest. A total of 1,232 kg (n = 469) of Asian carps were removed from the three lakes, with much of the biomass being Silver Carp from S5 (n

= 250; 720 kg) and S6 (n = 155; 272 kg); S3 contained few Asian carps and removal was minimal (97 kg). Harvest times ranged from 4.25-6.50 hours with a crew of nine people with three boats resulting in 7-14 kg of Asian carp biomass removed per person-hour of work in S5 and S6. Pre- and post-harvest Asian carp density (number of fish / 1000 m^3) and biomass (kg / 1000 m^3) were reduced by 58-75% in S5 and S6. Effectiveness of the harvest protocol was predicated on our ability to drive fish from zone 1 to zone 3 in each lake. Catch per unit effort for our capture gears was often double to one-hundred fold higher in zone 3 compared to zone 1, indicating that efforts to herd fish into zone 3 were successful. The harvest protocol was effective at removing Asian carps in a relatively short time period. Refining our techniques by adding more zones, or increasing entanglement gears or number of electrofishing boats may improve harvest rates and biomass removed from each lake. The harvest protocol used in this project would likely be applicable to other Sparta Training Area lakes infested with Asian carps that have similar lake morphologies and characteristics; it is unknown how effective this technique will be in larger lakes such as L1, L2 or S11. However, physical barriers would likely be needed at Sparta Training Area lakes to prevent future Asian carp (young-of-year or juvenile) invasions during flooding, particularly lakes in close proximity and elevation to Plum Creek. This study improved our knowledge and techniques for removing Asian carp populations from Sparta Training Area lakes and is anticipated to be applicable to similar small, recreational fishing lakes in other areas. Use of the removal technique described herein would help mitigate the negative ecological effects and nuisances of invasive Asian carps in small lakes. However, future research investigating the techniques used in this study and their effectiveness at removing invasive species should be conducted on lakes with different morphometric characteristics.

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INTRODUCTION

Aquatic invasive species have long been associated with negative ecological and socio-economic impacts on freshwater ecosystems where they have been introduced (Lodge et al. 2006; Vitule et al. 2009). Given these threats, management and eradication techniques have been developed to reduce, control, and manage invasive species populations to limit their spread and associated negative effects (Lodge et al. 2006; Keller et al. 2007). For example, chemical compounds have been developed to control invasive Zebra Mussel (*Dreissena polymorpha*) populations to potentially reduce their effects on aquatic ecosystems (Whitledge et al. 2014). Similarly, an intensive commercial netting harvest program was developed to capture Silver Carp (*Hypophthalmichthys molitrix*) and Bighead Carp (*H. nobilis*) in the upper Illinois River to curtail population sizes to reduce probability of their invasion into the great lakes (Tsehaye et al. 2013; MacNamara et al. 2016).

Asian carp species (Silver Carp, Bighead Carp, and Grass Carp *Ctenopharyngodon idella*), along with the Common Carp (*Cyprinus carpio*) have been introduced across North America through intentional stocking (Common Carp) or unintentional escapees (Silver, Bighead and Grass Carp; Guillory and Gasaway 1978; Freeze and Henderson 1982). Invasion by these species, particularly Silver Carp and Bighead Carp, could cause negative ecological effects on freshwater ecosystems through a series of trophic cascades (Cooke 2016; Solomon et al. 2016; Zhao et al. 2016). Silver Carp and Bighead Carp can potentially outcompete native fish and mussels for plankton (Laird and Page 1996; Sampson et al. 2009), resulting in declines in native fish biomass (Irons et al. 2007) and reduced plankton densities (Radke and Kahl 2002). The aforementioned commercial harvest programs in the Illinois River were developed to mitigate these potential ecological effects and reduce the likelihood of range expansion.

Continued improvement of techniques and methods to capture Asian carps is needed to effectively capture Asian carps and to reduce their populations and impacts (Garvey 2012). Removal can be difficult because Asian carps exhibit avoidance of traditional sampling, including gill nets (Williamson and Garvey 2005; Irons et al. 2007) and electrofishing tactics (Bouska et al. 2017). To combat this gear avoidance and improve harvest efficiency, a new approach was developed that focuses on slowly driving fish to a pre-determined harvest location using a combination of nets, electrofishing and sound disturbances (Irons 2016). This technique was used by the Illinois Department of Natural Resources to remove Asian carps from an Illinois River floodplain lake and was successful at removing a large proportion of fish biomass from the lake (50-80% reductions in biomass; Irons 2016). Although much of the Asian carp management and harvest techniques used so far have been developed for and focused on the Illinois River-Great Lakes connection, other, much smaller freshwater systems are vulnerable to invasion and may require management techniques to reduce invasive fish populations.

Small watersheds that occur within larger drainage basins invaded by Asian carps (e.g., Kaskaskia River, IL watershed within the Mississippi River drainage) are prone to invasion of Asian carps through fish movement (Deters et al. 2013; Hayer et al. 2014), especially during flooding. Lakes and impoundments linked to small streams are also subject to invasion if flooding elevation is great enough to overtop impoundments or provide sufficient flow in natural or artificial waterways that connect streams and lakes. Asian carps pose similar ecological issues in lakes as they do in rivers (Irons et al. 2007). For example, Silver Carp and Bighead Carp can indirectly affect sportfish populations (e.g., Largemouth Bass *Micropterus salmoides*) by reducing Gizzard Shad (*Dorosoma cepedianum*) abundance (Irons et al. 2007), which are an important prey fish in lakes (Storck 1986). Additionally, these species can redirect pelagic energy in the water column to the benthic habitats which can alter food webs (Collins and Wahl 2017), and possibly affect fish community structures. In addition to the negative ecological effects in lakes, Silver Carp also are a nuisance for recreational users, boaters, and anglers because of their jumping ability (Vetter et al. 2017). Despite the potential problems Asian carps pose to these lake ecosystems, limited techniques exist to manage these populations. Therefore, new techniques or improvements to existing methods are needed to aid control of Asian carps in lakes.

The objectives of this study were to 1) develop a harvest protocol based on Illinois River floodplain lake harvest techniques (Irons 2016), 2) remove Asian carps from small lakes at the Sparta Training Area, and 3) determine the effectiveness of removal techniques using hydroacoustic assessments of fish density pre- and post-harvest. Adapting new harvest techniques for removal of Asian carps in small lakes at Sparta Training Area is expected to improve knowledge and techniques for managing the ecological and nuisance impacts on lake ecosystems and their recreational users.

METHODS

Study Area

The Sparta Training Area (STA) is a 1133-ha property located near Sparta, Illinois (38°09′24″N, 89°43′43″W; Figure 1). The STA property is a reclaimed coal mine excavation area that is managed by the Illinois Army National Guard. The STA contains numerous coal mine excavation lakes that filled with groundwater seepage, but are connected to the Plum Creek drainage (within the Kaskaskia River watershed) during flooding (Heatherly et al. 2005). The STA coal mine lakes contain a diverse fish community dominated by sportfishes which were introduced through stocking (Heatherly et al. 2005; Phelps and Garvey 2009), but recent flooding has enabled colonization of some lakes by riverine fishes, including invasive Asian carps, and Common Carp. Although many STA coal mine lakes now contain invasive species due to flooding (A. Janas, personal communication), three lakes (S3, S5, and S6; Figure 1) were selected for this study as they are similar in size (2.5-3.6 ha) but have different depth profiles and were accessible by boat (Table 1).

Fish Harvest Protocol

Targeted harvest of invasive fishes from STA coal mine lakes was based on a Chinese fishing method ("Unified Fishing Method") for large, shallow water bodies in China (Irons 2016). This technique combines multiple gear types with lake morphology and depth and commercial fishing techniques in attempt to drive fish to a pre-determined collection location to then remove a large proportion of fish biomass from a water body. We used this approach to develop lake-specific methods for the targeted harvest of invasive species from each study lake.

Each study lake was divided into three zones prior to harvest with zone 1 as the end of the lake where herding began and zone 3 as the harvest end of the lake (Figures 2 - 4). In zone 1, a combination of 50 mm, 75 mm, and 100 mm mesh monofilament gill nets (46 m panel length, 3 m panel depth) along with 61 m experimental gill nets (15.2 m panels of 12, 25, 50, and 75 mm mesh) were deployed from shore at approximately 45° angles towards the intersection of zone 2 (Figure 2 - 4; Table 2). After nets were set in zone 1, two net boats started at the beginning of zone 1 and moved slowly towards zone 2 while making sounds (banging on boat with metal, and revving raised motors to produce propeller spray) in an attempt to drive fish into the next zone for approximately 30 - 45 minutes. A pulsed-direct current electrofishing boat (60 hertz standardized to a 3000 watt power goal; Burkhardt and Gutreuter 1995) also operated in close synchrony with net boats to drive fish in a similar fashion for 20 - 25 min of pedal time (Table 2); both invasive and native fish species were collected during this period (see fish sampling below). When net boats reached zone 2, a large multifilament block net (25 mm mesh, 10 m panel depth, 152 m panel length) was deployed across the lake at the beginning of zone 2 to prevent fish movement back into zone 1 (Figures 2 - 4). After deployment of block nets, a 100 mm mesh monofilament gill net was set directly behind (in zone 1) the block net in a 'C' shape, and a 50 mm monofilament gill net was set in front of the block net (parallel to block net in zone 2; Figures 2 - 4). These nets were placed to capture fish that attempted to jump over the block net between zones. After zone 1 activities were finished, all boats moved to zone 2, deployed nets, and drove fish with the same techniques described in zone 1 (Figures 2 - 4; Table 2). After a second block net and associated monofilament gill nets were deployed at the end of zone 2, all boats moved into zone 3. Throughout zone 3, the principal area where fish were harvested, monofilament gill nets were deployed in C and S shapes (Figures 2 - 4; Table 2) in an attempt to improve entanglement of invasive species. Net boats used sound to drive fish into nets for approximately one hour; an electrofishing boat drove fish into nets while collecting fish at locations away from nets (e.g., near shore and in shoreline snags and vegetation).

After electrofishing was completed in zone 3, monofilament gill nets were retrieved and data were collected from all fish (see fish sampling below). After all zone 3 nets were removed, all boats moved to zone 2 and monofilament gill nets in zone 2 were retrieved. Additional electrofishing (20 min) was conducted in zone 2 to attempt to collect fish that may have been missed by netting (Table 2). When zone 2 was complete, all boats moved to zone 1 and retrieved nets and additional electrofishing (20 minutes) was conducted to collected fish not entangled in nets. After all zones were cleared of nets, both multifilament block nets were removed.

Fish Sampling

Invasive species harvest at STA was conducted on 24-26 of April 2017 at lakes S3, S5, and S6. All fish species collected during harvest procedures (netting and electrofishing) from each lake within each zone were identified, measured (total length; mm), and weighed (g). Native fish community data were collected to interpret hydroacoustic data (see hydroacoustic section below). Both gear types were used to collect native fish to provide a representative sample of the fish community within each lake. Invasive fish species biomass (kg) removed from each lake was calculated, and all invasive fish were disposed of on STA property. Catch per unit effort (CPUE) for each gill net type and electrofishing was calculated for each lake by zone. Total time spent sampling each lake was documented to calculate biomass removed per person-hour of work.

Pre- and Post-Harvest Hydroacoustic Surveys

Mobile hydroacoustic surveys were used to assess effectiveness of harvest by comparing fish densities and spatial distributions before (4 April 2017) and after (10 May 2017) harvest. Due to the shallow water depth in all lakes, hydroacoustic sampling consisted of a 200-kHz split-beam BioSonics DT-X transducer (BioSonics Inc., Seattle WA, USA) oriented horizontally (-3.3°) to maximize the volume of water sampled. The transducer was set to sample a maximum distance of 50 m away from the vessel and a ping rate of 5 pings/s and 0.4 ms pulse duration (see (MacNamara et al. 2016) for a complete description of data collection settings, equipment setup, and sampling design). Surveys were conducted in each lake by travelling < 7.25 kph along a transect path parallel to shore approximately following the 1.0 m depth contour.

Hydroacoustic data were post-processed using Echoview 5.4 software (Echoview Software Pty Ltd, Hobart, Tasmania, Australia). A nearfield exclusion line was set at 1.0 m away from the transducer and the bottom exclusion line where the acoustic beam intersected the lake bottom was manually drawn. Fish targets and water volume sampled were then determined in between these nearfield and bottom exclusion lines. When analyzing data, a -60 dB threshold was first set to filter out background noise and Echoview's 'fish track detection' algorithm was used to identify fish targets that were then manually inspected. Fish length was estimated from each fish's mean dB value using the side aspect equation from Love (1971). Surveys were divided into 185 m replicate intervals for data analysis. See MacNamara et al. (2016) for detailed descriptions of all post-processing procedures that were followed.

Species-specific densities were estimated using electrofishing and netting data from each lake (see fish sampling). Catch data from both gears were pooled within a lake to minimize gear-specific bias. Relative abundance was then calculated for each species within every 2 cm length bin which was then estimated for every 1.0 mm length bin using linearly interpolation. The number of fish targets from hydroacoustic surveys were then calculated for the same 1.0 mm length bins. Within each replicate interval, the number of hydroacoustic fish targets in each 1.0 mm bin were then multiplied by the relative abundance of each species to provide the number of individuals in a length bin by species. Species-specific biomass in each length bin was then estimated by multiplying the number of individuals of each species by species-specific length-weight relationships determined from the catch data. This provided an estimate of species-specific length distributions, numerical densities (number of fish summed across length bins / water volume sampled), and biomass density (kg summed across length bins / water volume sampled) within each lake before and after harvest. These are the same procedures for estimating size distributions and densities from mobile hydroacoustic surveys as outlined in MacNamara et al. (2016).

Statistical Analyses

Differences between pre- and post-harvest invasive species density (number / 1000 m^3) and biomass (kg / 1000 m^3) estimated by hydroacoustic sampling were assessed using a one-way analysis of variance. A Kolmogorov–Smirnov test was used to determine if fish size structure estimated by hydroacoustic sampling (size-frequency distribution of all fish >300 mm total length) differed pre- and post-harvest following removal of invasive species through targeted harvest. Furthermore, harvested invasive species size structures were calculated to visually compare to pre- and post-harvest hydroacoustic size structures.

To determine whether our sampling techniques successfully drove fish into zone 3, we first calculated the percentage of all fish (>300 mm total length) occupying each zone during pre-harvest hydroacoustic surveys for each lake. Secondly, we calculated the percentage of total CPUE for all fish (>300 mm total length) from each zone for electrofishing, all gill nets combined, and 75 mm gill nets. We then compared pre-harvest percentages with CPUE percentages using chi-square tests for each lake by each gear type (all gill nets combined, 75 mm mesh, and electrofishing). Because of nine potential multiple comparisons from this test, significance values were Bonferroni corrected to $\alpha = 0.0055$. A significance level of 0.05 was used for all other statistical tests, and all statistical analyses were performed using SAS 9.3 (SAS Institute, Inc., Cary, NC).

RESULTS

Harvest

Harvest techniques captured 722 total native and invasive fish >300 mm total length from all STA study lakes (85, 377, and 260 from S3, S5, and S6, respectively). A total of 1,232 kg (n

= 469 fish) of invasive fish were removed from all STA study lakes combined. Only 94.7 kg (n = 9) of invasive species were removed from S3 (Table 3), and a large proportion of the total catch of invasive fish was removed from S5 (n = 286; 820.8 kg) and S6 (n = 174; 316.5 kg; Figure 5). Silver Carp dominated the invasive species catch and biomass from S5 (n = 250) and S6 (n = 155), but no Silver Carp were captured from S3 (Table 3). Harvested Silver Carp were larger in S5 (mean TL; 629.9) compared to S6 (mean TL; 537.8 mm; Figure 6).

Total time required to complete net deployment, fish sampling, herding, and removal of invasive individuals, and net retrieval ranged from 4.25 to 6.50 hours per lake with a crew of nine people using three boats (Table 4). Total person-hours required to complete net deployment, fish sampling, and invasive fish removal in each lake ranged from 38.25-58.50 hr. Biomass of invasive species and Silver Carp were highest in S5 at 14.03 kg and 12.31 kg removed per person-hour of work, respectively (Table 4).

Pre- and Post-Harvest Hydroacoustics

Based on hydroacoustic assessments pre- and post-harvest, invasive species density (number of fish / 1000 m^3) and fish biomass (kg / 1000 m^3) was reduced through targeted harvest in both STA study lakes (S5 and S6) that contained large populations of invasive species. Mean post-harvest Silver Carp density and biomass in S5 was reduced by 58% and was significantly lower than pre-harvest density ($F_{1,5} = 30.17$, $P = 0.0027$; $F_{1,5} = 28.77$, $P = 0.0030$; Figures 7 - 8). Similarly, S6 Silver Carp mean density and mean biomass were reduced by 75% and were significantly lower post-harvest ($F_{1,6} = 60.16$, $P = 0.0002$; $F_{1,6} = 87.92$, $P < 0.0001$; Figure 7-8). In S3, no Silver Carp or Bighead Carp were collected, therefore pre- and post-harvest differences could be not be assessed, and no significant differences were detected in Grass Carp or Common Carp density or biomass ($P > 0.11$). Although other invasive species were captured in low abundance in S5 and S6, we estimate 60% and 74% reductions in mean density and biomass of all invasive species, respectively. We detected significantly lower density and biomass post-harvest for Grass Carp (S5: $F_{1,5} = 9.51$, $P = 0.0274$; $F_{1,5} = 9.98$, $P = 0.0251$; S6: $F_{1,6} = 33.73$, $P = 0.0011$; $F_{1,6} = 28.94$, $P < 0.0017$; Figures 7 - 8), and Common Carp (S5: $F_{1,5} = 10.56$, $P = 0.0227$; $F_{1,5} = 24.14$, $P = 0.0044$; S6: $F_{1,6} = 54.58$, $P = 0.0003$; $F_{1,6} = 14.56$, $P = 0.0088$; Figures 7 - 8). Bighead carp were only captured in S5 but significantly lower density and biomass were detected post-harvest ($F_{1,5} = 120.44$, $P < 0.0001$; $F_{1,5} = 33.15$, $P = 0.0022$; Figure 7-8). Post-harvest fish population size structure (>300 mm TL) differed significantly in comparison to pre-harvest size structure in S3 ($KS_a = 1.87$, $D = 0.2206$, $P = 0.0018$; Figure 9), S5 ($KS_a = 2.09$, $D = 0.2520$, $P = 0.0003$; Figure 10), and S6 ($KS_a = 1.86$, $D = 0.1473$, $P = 0.0020$; Figure 11).

Herding Effect of Harvest

Comparisons of pre-harvest hydroacoustic assessments of percentage of fish density (>300 mm total length) within each zone to percentage of total CPUE of fish within each zone during harvest indicated that fish were effectively driven to the harvest zone in the study lakes. Proportional distribution of fish among zones estimated from pre-harvest hydroacoustic surveys was significantly different than proportional distribution of CPUE among zones in all lakes when data from all net types were combined (S3: $\chi^2 = 21.2$, $P < 0.0001$; S5: $\chi^2 = 31.7$, $P < 0.0001$; S6: $\chi^2 = 31.7$, $P < 0.0001$); there was a greater than four times increase in CPUE of all fish >300 mm total length captured using gill nets from zone 1 to zone 3 (Table 5). Similarly, proportional distributions of fish among lake zones estimated from hydroacoustic surveys differed significantly from proportional distributions of fish captured by 75 mm mesh gill nets among lake zones (S3: $\chi^2 = 59.7$, $P < 0.0001$; S5: $\chi^2 = 41.6$, $P < 0.0001$; S6: $\chi^2 = 30.2$, $P < 0.0001$); CPUE for all fish >300 mm total length captured by 75 mm mesh gill nets increased by >8x from zone 1 to zone 3 (Table 5). Silver Carp and other invasive species entanglement gear CPUE showed similar trends to CPUE of all fish in S5 and S6, with Silver Carp CPUE ten-fold greater in zone 3 compared to zone 1 (Table 5). Electrofishing yielded similar results to entanglement gears, with proportional distributions of fish among lake zones estimated by hydroacoustic surveys differing significantly from proportional distribution of electrofishing CPUE by lake zone in S5 (χ^2 = 15.3, P = 0.0005) and S6 (χ^2 = 17.8, P = 0.0001), but not in S3 (P > 0.0055). For all lakes, electrofishing CPUE at least doubled for all fish > 300 mm total length from zone 1 to zone 3 (Table 5). Catch per unit effort of Silver Carp and other invasive species in S5 and S6 also demonstrated similar trends in CPUE of all fish, with Silver Carp CPUE six to one-hundred times greater in zone 3 compared to zone 1 (Table 5).

DISCUSSION

Results indicated that our harvest protocol was effective at removing invasive fishes from STA study lakes, with an estimated 58-75% reduction in invasive fish biomass following harvest in lakes that contained substantial amounts of invasive fish biomass (S5 and S6). Fish biomass reductions in S5 and S6 were similar to recent research investigating similar harvest protocols to remove Silver Carp and Bighead Carp in a 202-ha Illinois River floodplain lake (50 - 80% reduction; Irons 2016). In the Illinois River, intensive commercial harvest program resulted in 64% estimated reduction in Silver Carp and Bighead Carp mean biomass following harvest in localized areas, and 40% throughout the upper river reaches (MacNamara et al. 2016). Fish were harvested in 4.25 - 6.5 hours (38.25 - 58.5 person-hours) of work for each STA study lake, whereas sampling was conducted over a two week period involving 60 individuals for the Illinois River floodplain lake (Irons 2016). Although invasive species density (estimated from

(MacNamara et al. 2016) and lake size differed greatly between this study and Irons (2016), our 7 - 14 kg of invasive species biomass removed per person-hour represent a baseline that may aid in planning future Asian carp removal studies in small lakes.

Removal of invasive species from STA lakes were reflected in changes to hydroacoustic-estimated size structures in each lake. Harvested fish size structure differed within each lake, which suggests that invasion year or growth of individuals differed among lakes. Growth of Silver Carp can differ among water bodies (Stuck et al. 2015), but given their close proximity and similar environmental characteristics and native fish demographics (Phelps and Garvey 2009), it is unlikely that Silver Carp growth rates differed substantially among STA lakes. Differences in observed sizes of Silver Carp between lakes S5 and S6 is likely due to different invasion years. Age and growth studies of Silver Carp in the Illinois and Wabash rivers suggest a large proportion of individuals were 5 - 7 years old in lake S5 and 3 - 5 years old in S6 (Stuck et al. 2015). These ages correspond to Kaskaskia River watershed flood years during 2011 (S5), and 2013 (S6; Rivergages U.S. Army Corps of Engineers), however, it is not known what size of fish invaded STA lakes. Previous research indicates large numbers of adult Asian carps do not often occupy small creeks (Hayer et al. 2014; Coulter et al. 2016) as their size may be a limiting factor in upstream movement in these systems (Hayer et al. 2014). Therefore, STA lakes were likely invaded by large cohorts of juvenile or young-of-year Asian carps from Plum Creek (Kaskaskia River tributary; STA lakes drain into Plum Creek) during flooding in 2011 and 2013. Other small flood years may have contributed to cohorts that represent other age and size classes, but Asian carps (excluding Common Carp) that attempt to reproduce would not recruit because eggs would not remain suspended in the water column (Kolar et al. 2007; Deters et al. 2013).

Driving of fish using sound and water surface disturbances during the harvest protocol was effective at herding fish from throughout the lake into the harvest area of zone 3, which was likely an important factor in our ability to remove invasive fish from STA lakes. Proportional distribution of fish among lake zones estimated from pre-harvest hydroacoustic surveys differed from CPUE distributions, and CPUE increased for all fish > 300 mm total length was two to eight times higher in zone 3 compared to zone 1, which indicates our harvest techniques altered fish distributions. Our increases in CPUE are consistent with previous research using sounds and disturbance to improve catch in entanglement gears (whip set fishing; (White Jr 1959; Erickson 1973). For example, Erickson (1973) found that whip set gill nets captured six times as much biomass of native fish than static gill net sets. White Jr (1959) also indicated that whip set trammel nets improved catch of native fish and rough fish (including Common Carp) compared to static set trammel nets. Invasive species CPUE trends were similar to all fish (> 300 mm), where increases (> six times) in CPUE in zone 3 compared to zone 1 for electrofishing and entanglement gears. Irons (2016) indicated that CPUE of bigheaded carps increased in gill and trammel nets as fish were moved closer to the harvest area; however, in the harvest area of Illinois River backwater lakes a large seine was used to capture fish rather than entanglement gears and electrofishing.

Despite our effectiveness of herding and removing invasive fish and Silver Carp from STA lakes, refinement of harvest techniques may lead to increased harvest rates of invasive species and improved biomass removed per person-hour. Adding more harvest zones with more block nets to further concentrate fish into a smaller harvest zone would be expected to increase the efficacy of non-native fish removal. Increasing entanglement gears within each zone and adapting mesh sizes to better match size distributions of invasive fishes in each lake may also improve removal of non-native species (e.g., 75 mm mesh nets had the highest CPUE among gill nets used given the size of invasive fish present in STA lakes). Similarly, additional electrofishing boats to drive fish into nets and capture fish along shoreline snags (using electrofishing boats in tandem to create a wider electric field and increase the number of dip netters) or the use of a large seine in zone 3 to corral fish may enhance removal efficiency.

The invasive species harvest protocol was effective for the three STA study lakes that were selected for their similar physical and morphological characteristics, but applicability of this harvest approach is likely adaptable to other lakes. Lakes that have < 5 m mean depth, lake width < 152 m, and are non-dendritic such as STA lake S12 would likely yield similar harvest results as we found in STA study lakes. However, it is unknown how increasing depth or size (e.g., STA L1 and L2) and shape (e.g., wider than 152 m block nets; S11) would affect ability to herd, capture, and remove Asian carps. The lake in Irons (2016) was much larger than any STA lake and depth profiles were comparable (2.5 m average depth) to STA study lakes, but to produce similar density reductions, larger crews, more nets, and time were required. Similarly, in large Chinese lakes where this method was developed, fishermen systematically drive fish over the course of months to remove up to 90% of fish biomass (Irons 2016). Therefore, at a minimum a harvest protocol would need to be developed for each potential lake based on its characteristics and morphology. For example, STA L1 or L2 would require significantly more gill nets, and more block nets (zones) because of its size, and driving fish to a harvest location would need to be systematically done over the course of days instead of hours. Future research investigating the techniques used in this study and their effectiveness at removing invasive species in lakes that differ substantially in morphometry from our study lakes (S3, S5, and S6) should be conducted.

Regardless of the effectiveness of the invasive species harvest protocol for STA lakes, managing the potential for future invasions will be needed. We removed large proportions of invasive fish biomass from STA lakes, and application of the techniques to other STA lakes is feasible for invasive fish removal. However, we postulated that juvenile or young-of-year fish invaded STA lakes during flood years, but likelihood of in-lake reproduction is low (excluding Common Carp; Kolar et al. 2007; Deters et al. 2013). Therefore, barriers to limit upstream movement of young-of-year or juvenile Asian carps should be considered for lakes that are vulnerable to invasion, particularly those in close proximity and elevation to Plum Creek. High elevation lakes such as S2 or lakes far from Plum Creek (S7, S8, and S9) may not require barriers or other management practices to prevent Asian carp invasions because of their reduced vulnerability to invasion. Removal of invasive species using our harvest protocol coupled with management techniques to reduce vulnerability to future invasion should help mitigate the negative ecological effects of these species along with their recreational nuisance. Additional studies should investigate the efficacy of Asian carp harvest in conjunction with installation of barriers to limit potential for re-invasion as an approach for long-term control of Asian carp abundance and impacts in small lakes.

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Table 1. Physical and chemical characteristics of Sparta Training Area study lakes.

Lake	Area (hectares)	Mean Depth (m)	Max Depth (m)	Water Clarity (cm)	Water Conductivity (µms)	Water Temperature °C
S3	3.06	3.20	7.09	63	802	19.1
S5	2.52	1.95	3.22	52	897	17.8
S6	3.61	3.76	11.37	68	887	19.0

Table 2. Gear type amount and effort by zone during invasive species harvest at STA study lakes. EXP = Experimental gill net; all other gill nets are categorized by mesh size (bar measure). Electrofishing values in parentheses indicate additional time spent in each zone after nets were removed. Note: two multifilament block nets were also used at each lake.

		Monofilament Gill Net Count				Pulsed-DC EF
Lake	Zone	50 mm	75 mm	100 mm	EXP	Minutes
S3	1	1	1	1	3	25 (20)
	2	3	2	1	0	25 (20)
	3	2	2	0	0	40
S5	1	0	1	1	2	23 (20)
	2	3	2	1	0	24 (20)
	3	3	3	0	0	40
S6	1	2	2	0	2	25 (20)
	2	2	2	1	2	20 (20)
	3	2	2	1	0	40

Table 3. Total number of invasive species (Silver Carp; SCP, Bighead Carp; BHC, Grass Carp; GRC, and Common Carp; CAP) and biomass (kg) harvested from STA study lakes.

	Number Harvested					Biomass (kg) Harvested				
Lake	SCP	BHC	GRC	CAP	Invasive	SCP	BHC	GRC	CAP	Invasive
S3	0	0	8	1	9	0.00	0.00	91.58	3.15	94.73
S5	250	1	20	15	286	720.24	11.25	48.32	41.03	820.84
S6	155	0	5	14	174	272.19	0.00	17.88	26.40	316.47

Table 4. Total hours, crew members and person-hours required to sample each STA study lake, and amount of invasive species (Silver Carp, Bighead Carp, Grass Carp, and Common Carp combined) and Silver Carp biomass (kg) harvested per person-hour. Pre-harvest invasive biomass (kg) / 1000 m^3 was estimated from hydroacoustic surveys.

Lake	Sampling Hours	Crew Members	Person Hours	Invasive Biomass (kg) / 1000 m^3	Silver Carp (kg) / Person-Hour	Invasive Species (kg) / Person-Hour
S3	4.25	9	38.25	1.47 ± 0.73	0.00	2.48
S5	6.50	9	58.50	27.13 ± 2.08	12.31	14.03
S6	5.00	9	45.00	13.00 ± 0.47	6.05	7.03

Table 5. Catch per unit effort of invasive species (Silver Carp; SCP, Bighead Carp; BHC, Grass Carp; GRC, and Common Carp; CAP) and all fish (>300 mm total length) by gear type and zone within each STA study lake. Note: Catch per unit effort is fish/net/hr for netting and fish/hr for electrofishing.

			Catch Per Unit Effort					
Lake	Zone	Gear	SCP	BHC	GRC	CAP	Invasive Spp.	All Fish (>300 mm)
S3	1	All Nets	0.00	0.00	0.04	0.00	0.04	0.55
	2	All Nets	0.00	0.00	0.00	0.00	0.00	0.55
	3	All Nets	0.00	0.00	0.80	0.00	0.80	2.20
S5	1	All Nets	0.26	0.00	0.03	0.00	0.29	0.91
	2	All Nets	0.59	0.00	0.00	0.04	0.63	1.11
	3	All Nets	3.33	0.07	0.00	0.20	3.60	5.60
S6	1	All Nets	0.13	0.00	0.03	0.00	0.17	0.70
	2	All Nets	1.02	0.00	0.04	0.12	1.18	1.84
	3	All Nets	1.69	0.00	0.00	0.09	1.78	4.36
S3	1	75 mm	0.00	0.00	0.00	0.00	0.00	0.24
	2	75 mm	0.00	0.00	0.00	0.00	0.00	0.00
	3	75 mm	0.00	0.00	0.00	0.00	0.00	1.60
S5	1	75 mm	0.35	0.00	0.00	0.00	0.35	0.47
	2	75 mm	1.11	0.00	0.00	0.00	1.11	1.67
	3	75 mm	5.87	0.00	0.00	0.40	6.27	8.13
S6	1	75 mm	0.30	0.00	0.00	0.00	0.30	0.90
	2	75 mm	1.71	0.00	0.00	0.29	2.00	2.43
	3	75 mm	4.00	0.00	0.00	0.22	4.22	8.00
S3	1	EF	0.00	0.00	0.00	0.00	0.00	16.00
	2	EF	0.00	0.00	0.00	0.00	0.00	25.33
	3	EF	0.00	0.00	4.50	1.50	6.00	30.00
S5	1	EF	26.51	0.00	5.58	5.58	37.67	61.40
	2	EF	50.45	0.00	0.00	2.73	53.18	73.64
	3	EF	154.50	0.00	9.00	7.50	171.00	201.00
S6	1	EF	1.33	0.00	2.67	8.00	12.00	32.00
	2	EF	9.00	0.00	1.50	4.50	15.00	43.50
	3	EF	133.50	0.00	0.00	1.50	135.00	135.00

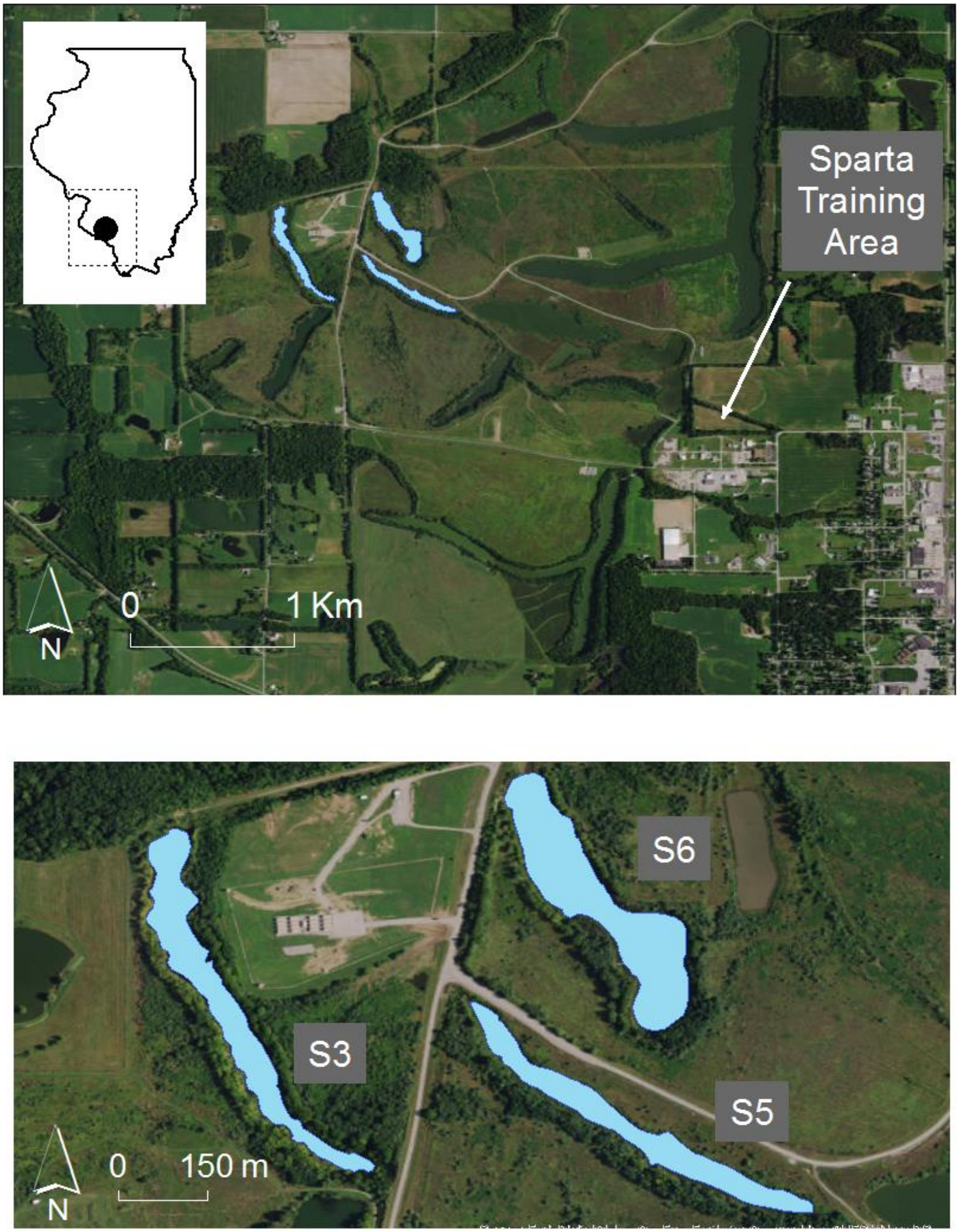

Figure 1. Map of Sparta Training Area and location of the three study lakes.

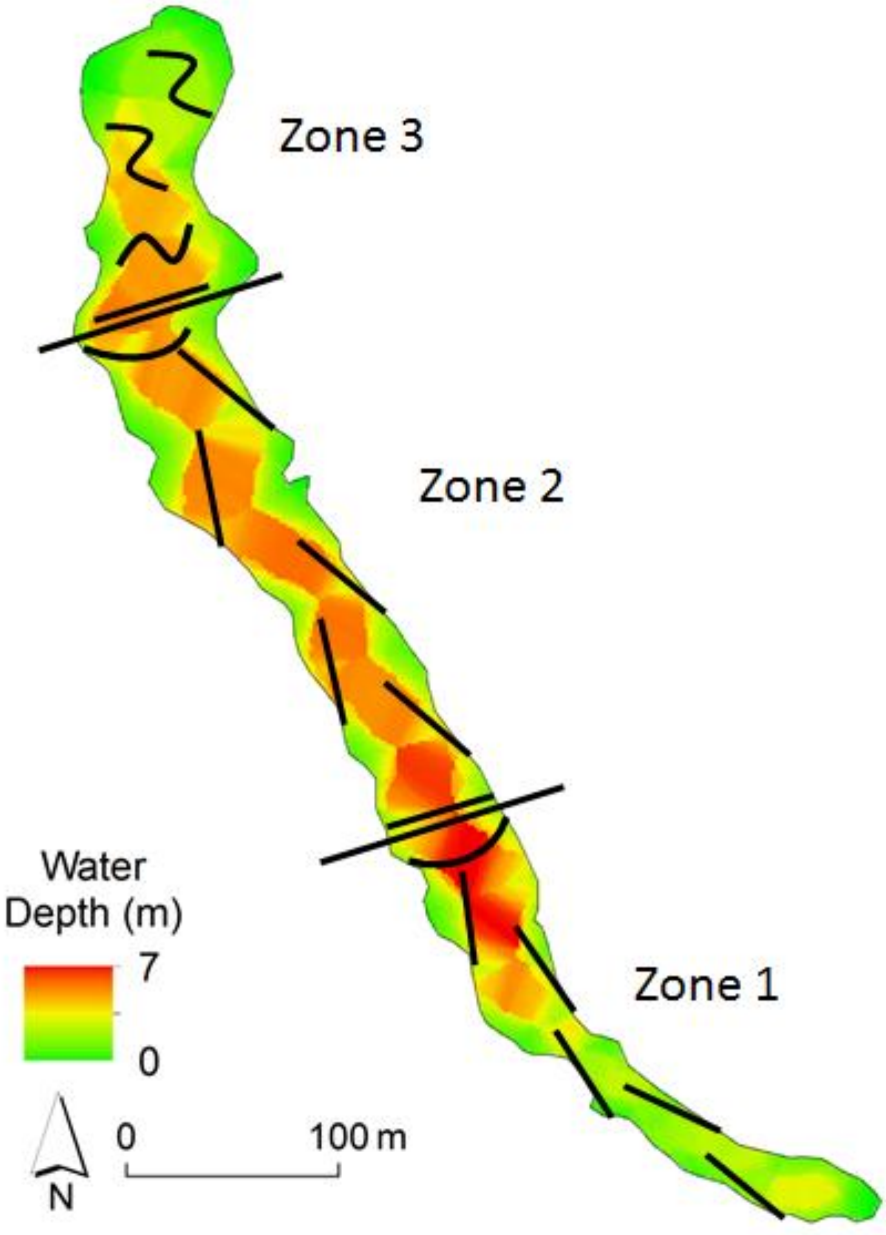

Figure 2. Bathymetric map from hydroacoustic surveys and location of net sets during invasive species harvest in lake S3. Note: fish were driven from zone 1 to zone 3.

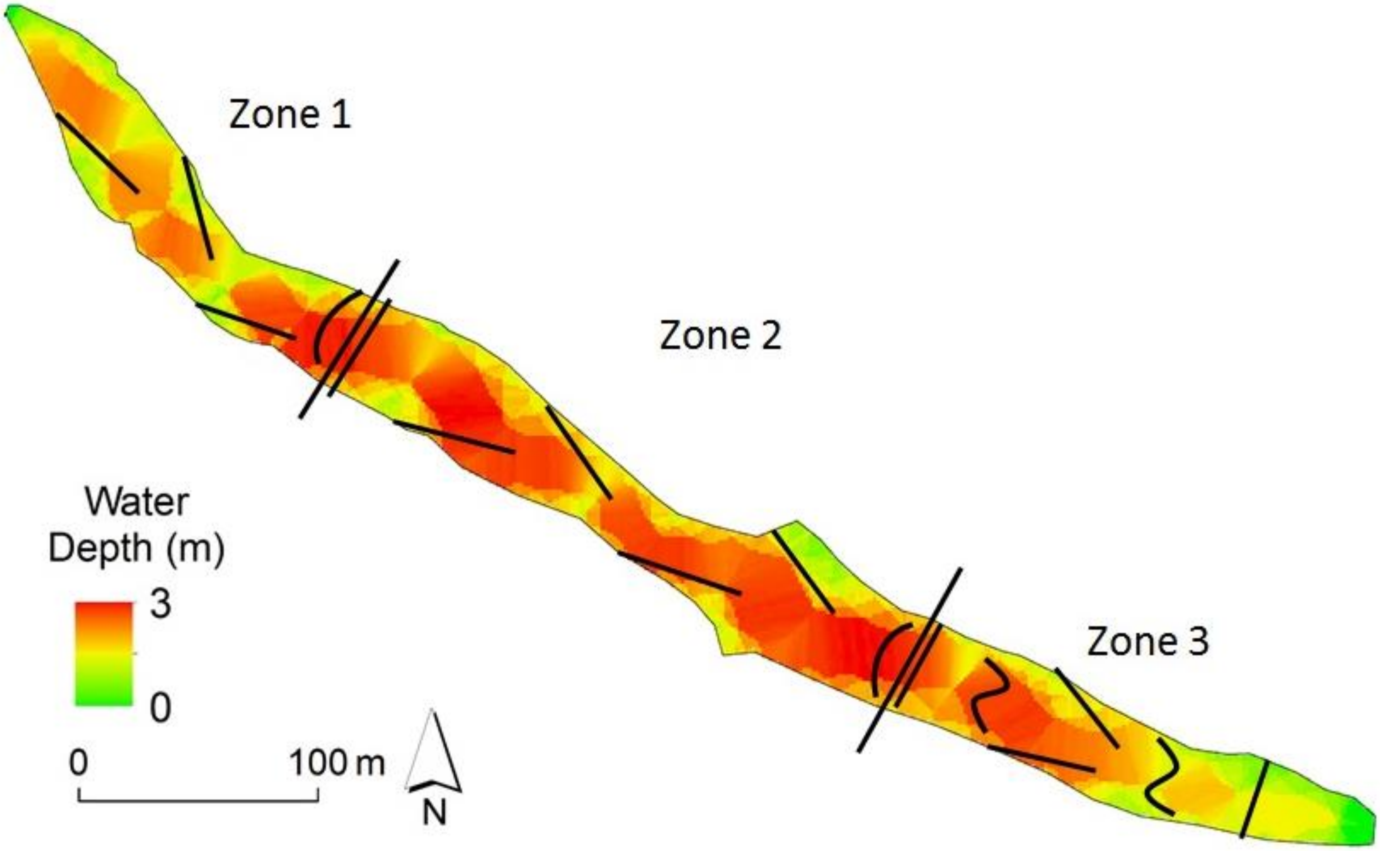

Figure 3. Bathymetric map from hydroacoustic surveys and location of net sets during invasive species harvest in lake S5. Note: fish were driven from zone 1 to zone 3.

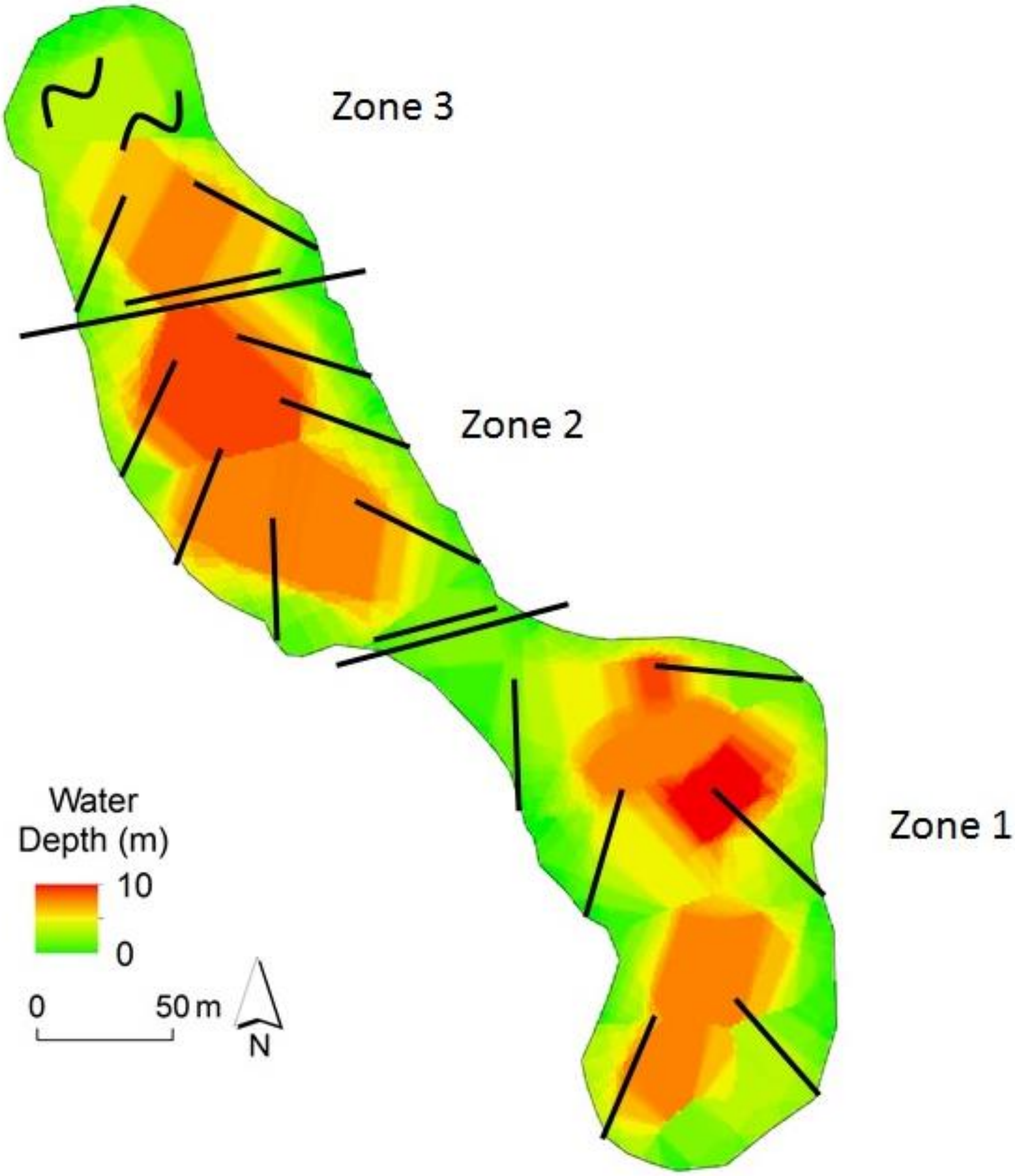

Figure 4. Bathymetric map from hydroacoustic surveys and location of net sets during invasive species harvest in lake S6. Note: fish were driven from zone 1 to zone 3

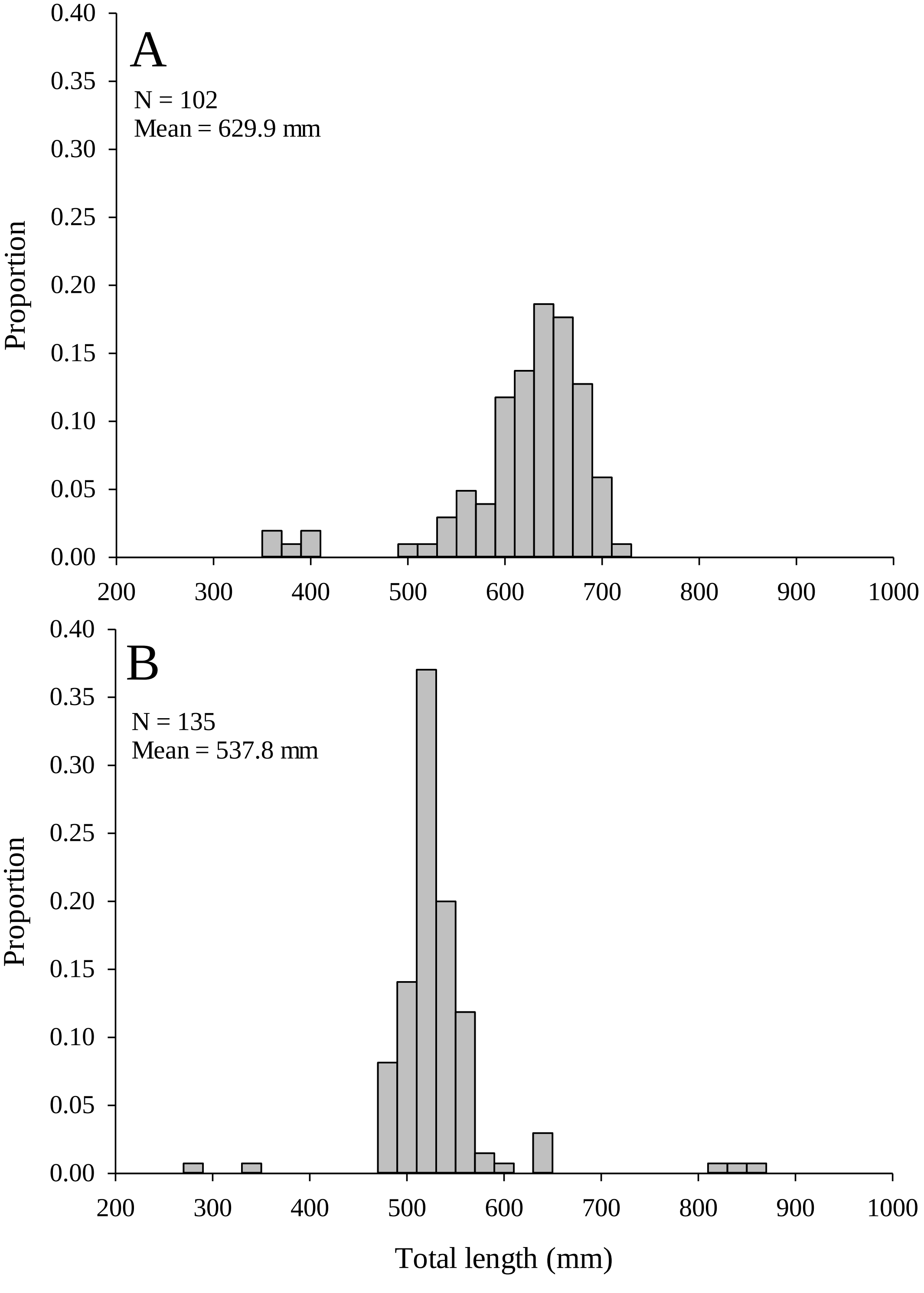

Figure 5. Length-frequency histograms of Silver Carp harvested from S5 (A), and S6 (B). Note: no Silver Carp were collected in S3.

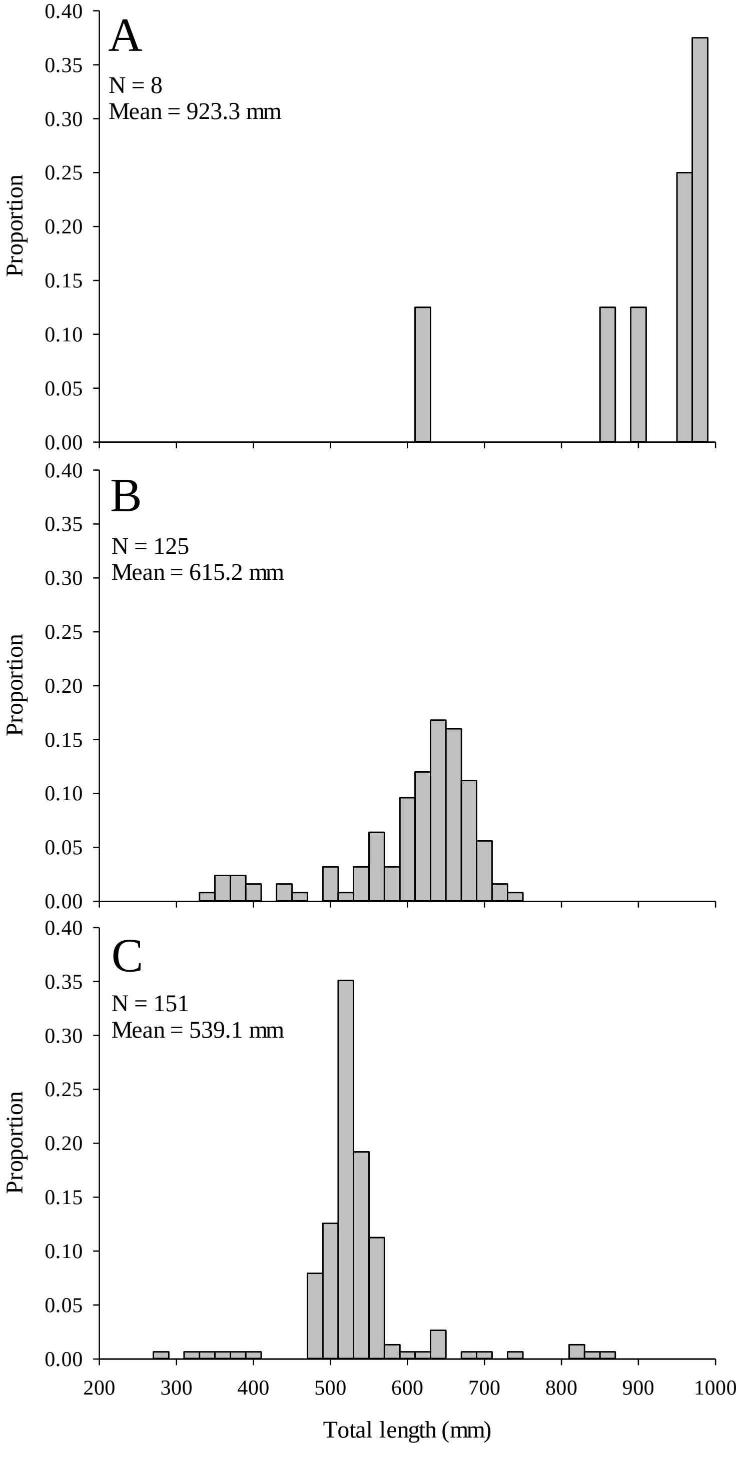

Figure 6. Length-frequency histograms of all invasive fish species (Silver Carp, Bighead Carp, Grass Carp, and Common Carp) harvested from S3 (A), S5 (B), and S6 (C).

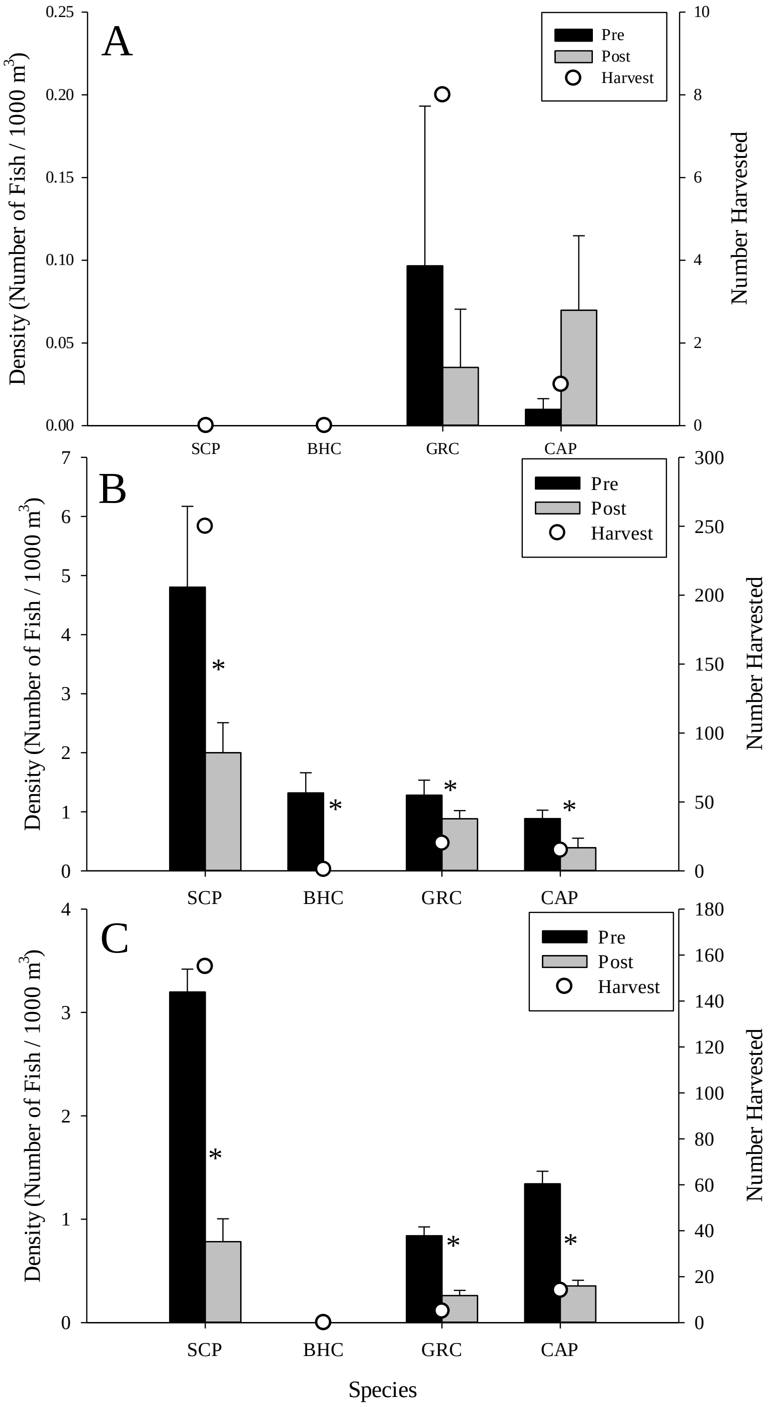

Figure 7. Pre- and post-harvest hydroacoustic estimates of invasive species (Silver Carp; SCP, Bighead Carp; BHC, Grass Carp; GRC, and Common Carp; CAP) density (number of fish / 1000 m^3; ± standard error) in S3 (A), S5 (B), and S6 (C). Black bars represent pre-harvest density, grey bars represent post-harvest density, and open circles indicate the number of individuals harvested per species (y2 axis). Species marked with asterisks indicate significant differences between pre- and post-harvest density estimates. Note: scales of y1 and y2 axes are not equal.

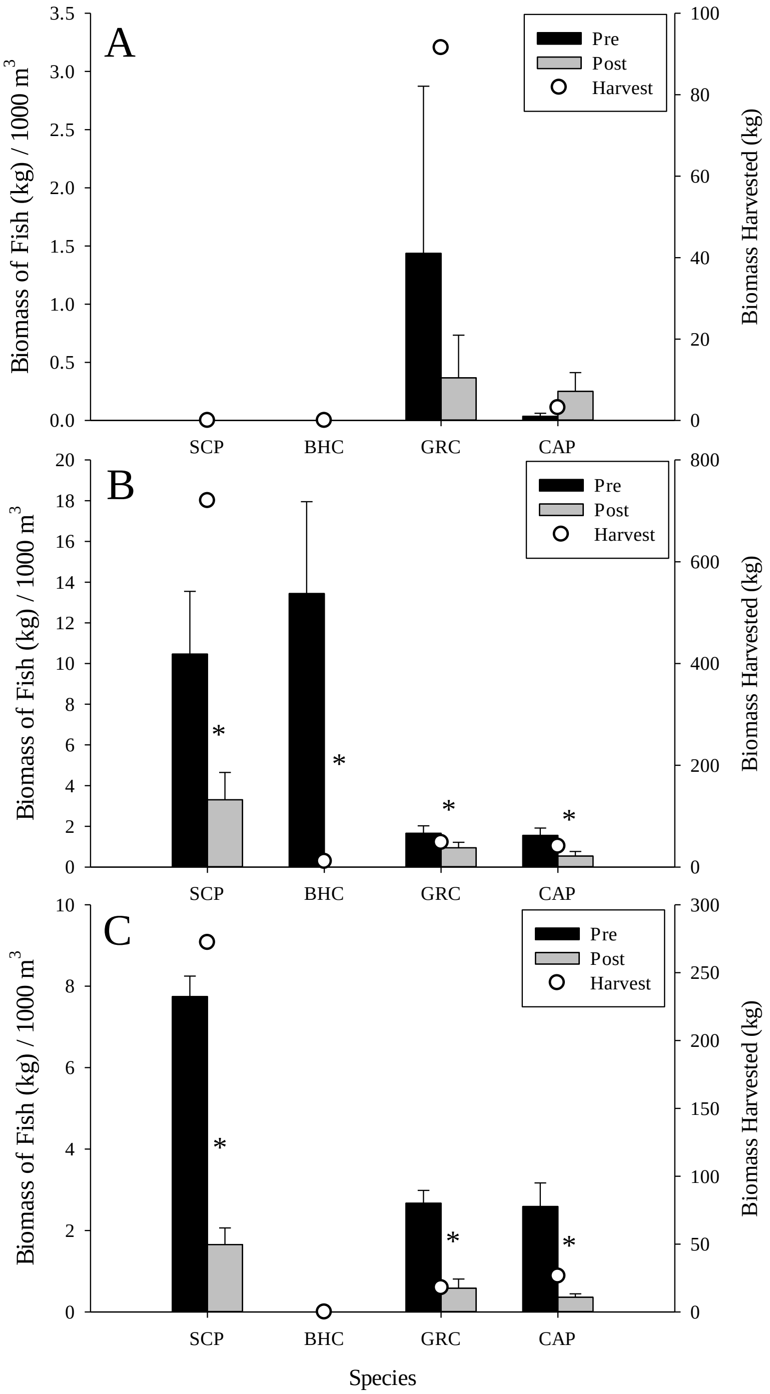

Figure 8. Pre- and post-harvest hydroacoustic estimates of invasive species (Silver Carp; SCP, Bighead Carp; BHC, Grass Carp; GRC, and Common Carp; CAP) biomass (kg of fish / 1000 m^3; ± standard error) in S3 (A), S5 (B), and S6 (C). Black bars represent pre-harvest biomass, grey bars represent post-harvest biomass, and open circles indicate the biomass (kg) harvested per species (y2 axis). Species marked with asterisks indicate significant differences between pre- and post-harvest biomass estimates. Note: scales of y1 and y2 axes are not equal.

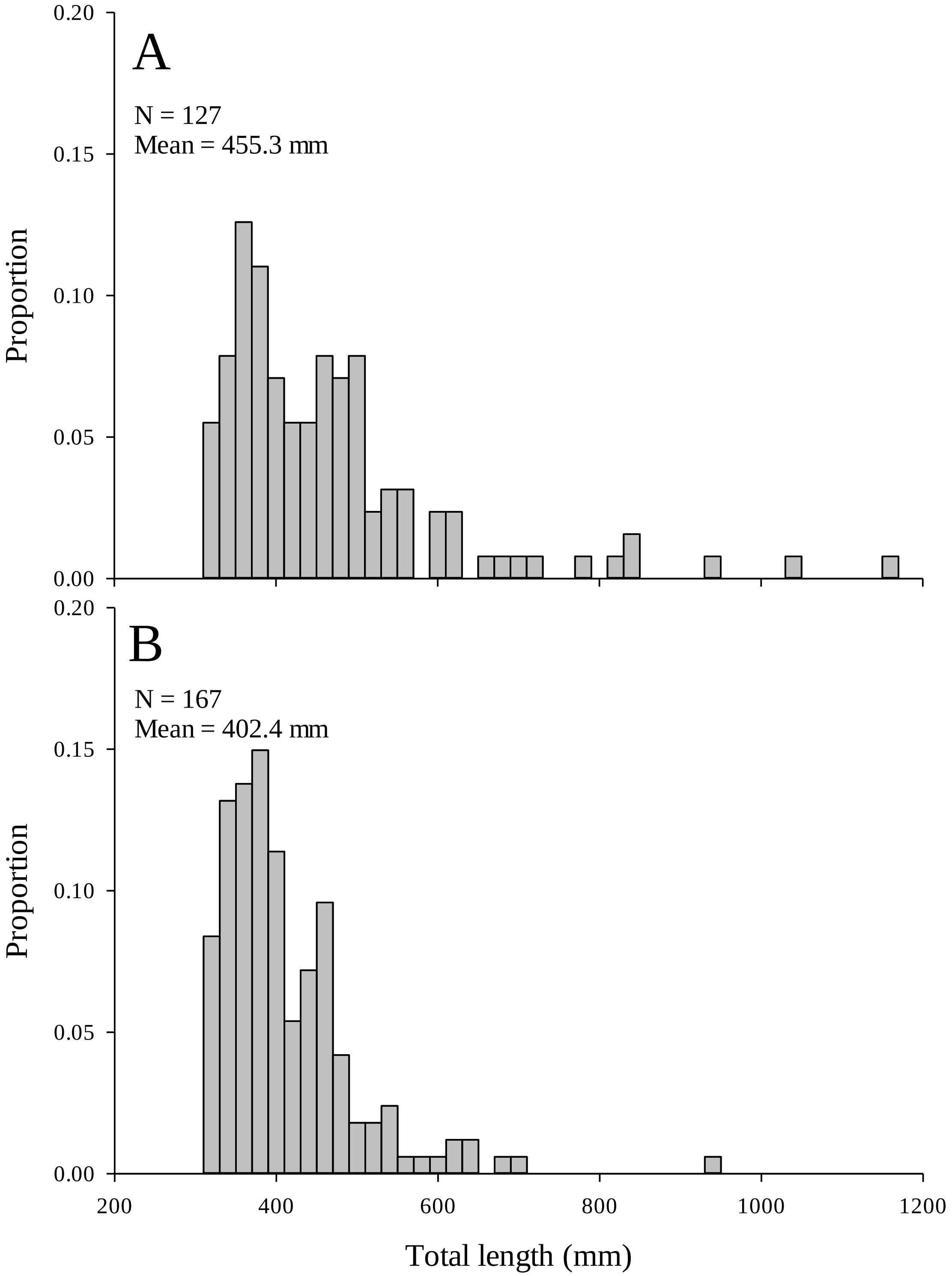

Figure 9. Length-frequency histograms of all fish (>300 mm total length) estimated by hydroacoustic surveys pre-harvest (A), and post-harvest (B) from S3.

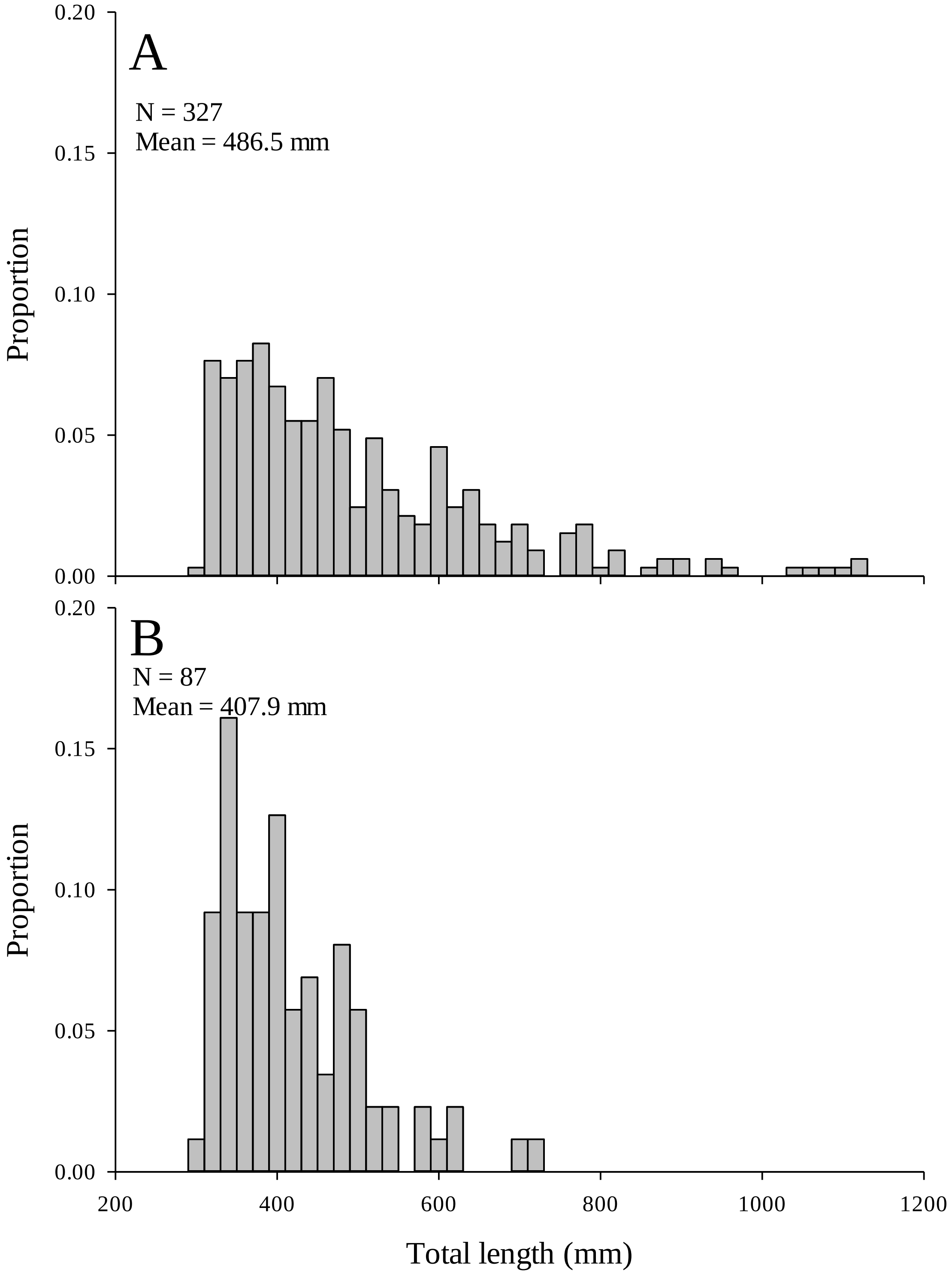

Figure 10. Length-frequency histograms of all fish (>300 mm total length) estimated by hydroacoustic surveys pre-harvest (A), and post-harvest (B) from S5.

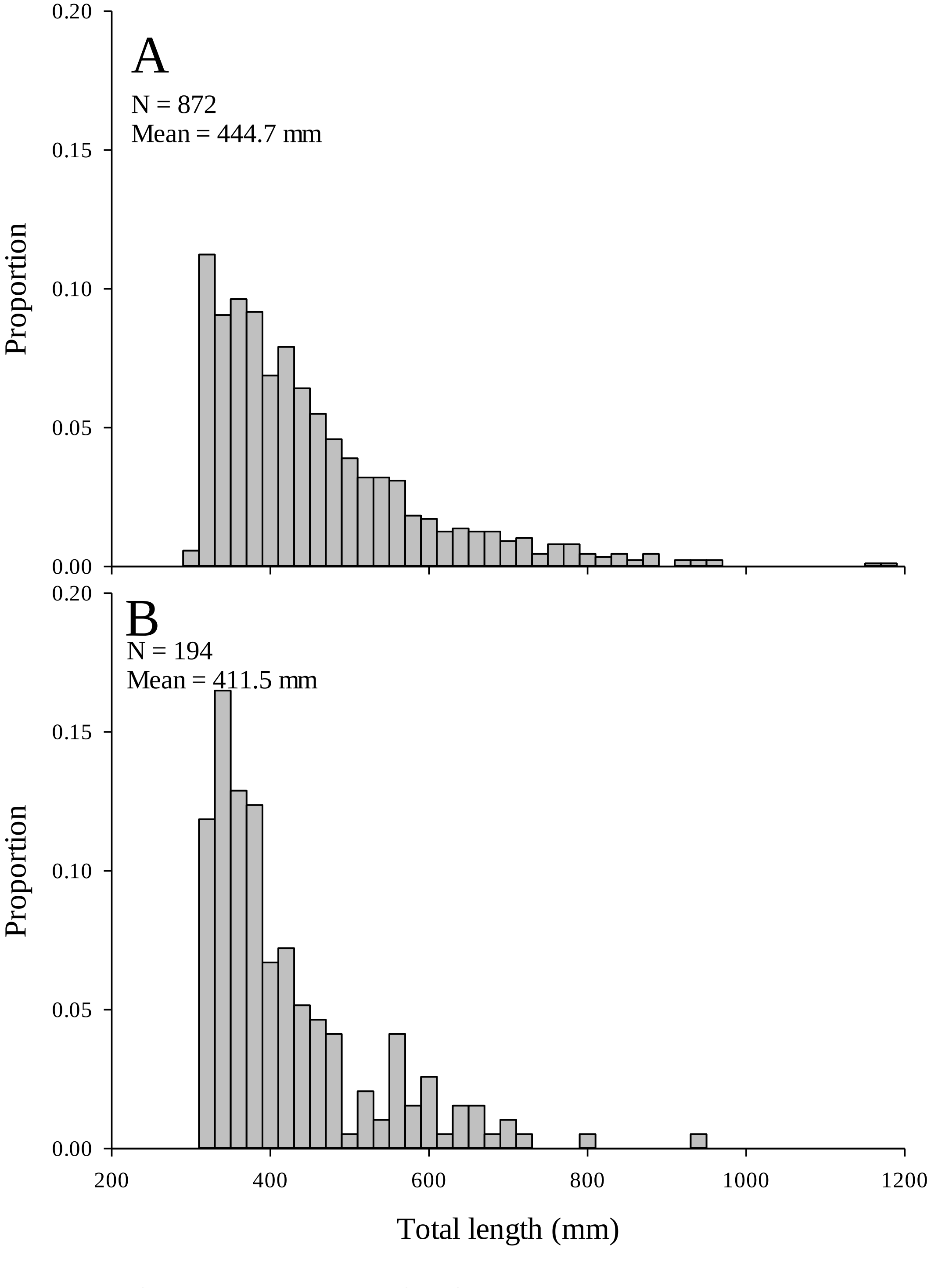

Figure 11. Length-frequency histograms of all fish (>300 mm total length) estimated by hydroacoustic surveys pre-harvest (A), and post-harvest (B) from S6.