
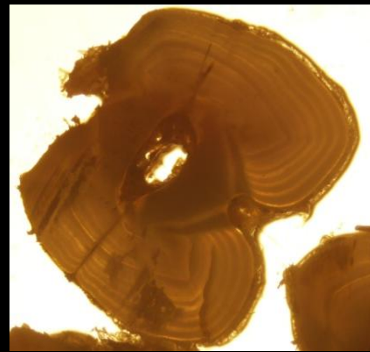


# Population Densities, Biomass, and Age-growth of Common Carp and Black Bullheads in Clear Lake and Ventura Marsh

**Study 7026 Completion Report**
**Federal Aid to Fish Restoration**
**Fisheries Research Project No. F-160-R**




**Jonathan R. Meerbeek**

**Period Covered: 1 July 2003 – 30 June 2013**
**Iowa Department of Natural Resources**
**Chuck Gipp, Director**

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# COMPLETION REPORT

# NATURAL LAKES INVESTIGATIONS

# PROJECT NO. F-160-R

**Study 7026. Population Densities, Biomass, and Age-growth of Common Carp and Black Bullheads in Clear Lake and Ventura Marsh**

Job 1. Population densities and biomass of Common Carp and Black Bullheads in Clear Lake and relative densities of Common Carp and bullheads in Ventura Marsh

Job 2. Age-growth of Common Carp and Black Bullheads in Clear Lake and Ventura Marsh

Job 3. Critical densities and biomasses of Common Carp and Black Bullheads in Clear Lake

Job 4. Completion report and management guidelines

**Period Covered:** 1 July 2003 – 30 June 2013

**Prepared by:** Jonathan Meerbeek — **Fisheries Research Biologist** — June 30, 2013 **Date**

**Approved by:** George Scholten — **Fisheries Research Supervisor** — June 30, 2013 **Date**

**CONSERVATION AND RECREATION DIVISION**
**Iowa Department of Natural Resources**
**Chuck Gipp, Director**

## Executive Summary

Clear Lake is the third largest natural lake in Iowa and is a very popular destination area by the public for various outdoor activities (Herriges et al. 2011). Water quality has substantially deteriorated in Clear Lake since the 1970's. In fact, phosphorus concentrations have nearly tripled and water clarity has decreased nearly 3-fold during this period. In response to the deteriorating water quality, a diagnostic study was initiated to determine the causes of the decline and recommend management guidelines to improve water quality in the lake. One conclusion from this investigation was that the impact of benthivorous fishes needs to be addressed to help ensure the successful renovation of Clear Lake (Downing et al. 2001).

Benthivorous fishes are known to deteriorate water quality in shallow, nutrient-rich lakes, a fact attributed to benthic feeding activities. This is especially true for Common Carp *Cyprinus carpio*, implicated in increasing phosphorus concentrations and turbidities in the water column of lakes and loss in macrophyte abundance. Therefore, reducing the biomass of Common Carp is one selected alternative in restoration plans to improve water quality in Clear Lake. This study was initiated in 2003 to provide baseline Black Bullhead *Ameiurus melas* and Common Carp information by: 1) determining population densities and biomass in Clear Lake and assess efforts to reduce densities; 2) determining age-growth and recruitment patterns in Clear Lake and Ventura Marsh; and 3) determine population densities and biomasses that allow a 3-fold increase in water transparency in Clear Lake. Major findings from this research were as follows:

- Black Bullhead and Common Carp biomass was removed primarily via rotenone application to Ventura Marsh. After the removal effort, water clarity within the marsh increased as a result of decreased suspended sediment and phytoplankton biomass. However, these applications only temporally reduced benthivore biomass.

- Significant changes in the benthivorous fish community were observed within Clear Lake. Most notably, Black Bullhead density and biomass decreased by ~99%. Common Carp biomass fluctuated during the study despite rotenone application in Ventura Marsh and periods of high commercial harvest. Common Carp abundance and mean size, however, did substantially change during the study.

- Spatial analysis of trawl data via GIS tools proved to be a valuable technique to identify spatial and temporal aggregations of both Black Bullhead and Common Carp.

- Significant improvements in secchi disk depth, chlorophyll a, total suspended solids, and total phosphorus were documented during the study period. However, only a few significant correlations among Common Carp or Black Bullhead density or biomass with any water quality parameters were detected.

- Multiple biotic and abiotic changes occurred within Clear Lake during the study period. One of those significant changes was the establishment of a viable population of invasive zebra mussels *Dreissena polymorpha*. Water clarity in Clear Lake improved substantially in 2007 and became less variable, immediately following zebra mussel colonization. In

addition, the Clear Lake Dredging Project began in 2008 and was completed in 2009. This dredging project removed 2.4 million cubic yds of sediment from the Little Lake.

- The improvements in water quality observed were multi-faceted and cannot be thoroughly understood because of the dynamic nature of the processes involved and the suite of management activities currently employed. The interactions of Black Bullhead and Common Carp within the fish community and its cascading effects were at least partially responsible for water quality improvements. The infestation of zebra mussels in 2005 in conjunction with watershed and in lake (e.g. dredging) improvements may have contributed more to the improvements in water quality than that of fish population changes.

- Significant correlations between Common Carp otter trawl biomass estimates and mark-recapture biomass estimates were detected. Trends in Common Carp biomass can easily be monitored via annual otter trawling assessments to help managers quickly identify periods of increased abundance. This information would be beneficial to managers that wish to utilize commercial harvest subsidies for Common Carp so that densities are maintained at a lower, less destructive, level.

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# STUDY 7026

## *Population Densities, Biomass, and Age-Growth of Common Carp and Black Bullheads in Clear Lake and Ventura Marsh*

### OBJECTIVE

By the year 2013, determine population densities, biomass, and age-growth of Common Carp and Black Bullheads in Clear Lake and relate these, and watershed improvements, to changes in lake water quality.

### JOB 1

***Population densities and biomass of Common Carp and Black Bullheads in Clear Lake and relative densities of Common Carp and Black Bullheads in Ventura Marsh.***

### OBJECTIVE

Determine population densities and biomass of Common Carp and Black Bullheads in Clear Lake and, by 2013, assess efforts to reduce densities.

### JOB 2

***Age-growth of Common Carp and Black Bullheads in Clear Lake and Ventura Marsh.***

### OBJECTIVE

Determine age-growth and recruitment of Common Carp and Black Bullheads in Clear Lake and Ventura Marsh and, by 2013, associate changes with densities.

### JOB 3

***Critical densities and biomasses of Common Carp and Black Bullheads in Clear Lake.***

### OBJECTIVE

Determine, by the year 2013, population densities and biomasses of Common Carp and Black Bullheads that allow a 3-fold increase in water transparency in Clear Lake.

### JOB 4

***Completion report and management guidelines.***

### OBJECTIVE

To compile, analyze, and publish findings.

**COMPLETION REPORT**
**FISHERIES RESEARCH PROJECT # F-160-R, STUDY 7026**

**STATE**: Iowa **TITLE**: Population densities, biomass, and age-growth of Common Carp and Black Bullheads in Clear Lake and Ventura Marsh
**JOB**: 1-4

*Abstract* – Significant changes in water quality and watershed characteristics have occurred over the last century in Clear Lake. Benthivorous fish density (i.e., Common Carp and Black Bullhead) was determined to be one factor that substantially influenced these water quality changes. The objective of this study was to estimate Common Carp and Black Bullhead population density, biomass, age-growth, and recruitment patterns in Clear Lake and Ventura Marsh and relate those variables to water quality trends. Black Bullhead density and biomass decreased significantly between 1999 and 2012. Black Bullhead density was greatest in the deeper areas of the lake, but varied annually and temporally. By 2007, Black Bullheads densities were < 40 fish/ac and by 2011, no Black Bullheads were collected. Correspondingly, Black Bullhead growth rates increased substantially. Common Carp biomass was more variable and did not show a substantial decreasing trend. Common Carp abundance decreased but did not result in decreased biomass because the mean weight of Common Carp increased precipitously. The application of rotenone in Ventura Marsh negatively impacted Common Carp, but shortly after each renovation, Common Carp numbers increased substantially. Periods of high commercial fishing harvest were observed but did not overly impact total Common Carp biomass. Likewise, few correlations were observed between Common Carp and Black Bullhead population density/biomass and water quality parameters, although most of these variables showed significant improvements from 2000-2012.

Despite the inability to overwhelmingly correlate water quality trends to population density of Black Bullhead or Common Carp, the interaction of these species within the fish community are likely partially responsible for water quality improvements. The infestation of zebra mussels in 2005 in conjunction with watershed and in lake (e.g. dredging) improvements may have contributed more to the improvements in water quality than that of fish population changes in density. However, the drastic reduction of Black Bullheads biomass and reduced Common Carp densities observed over the study may have contributed to increased water quality in Clear Lake and periodic monitoring of these species may be required to observe population levels. This study found significant correlations between Common Carp otter trawl biomass estimates and mark-recapture biomass estimates; therefore, trends in Common Carp biomass can easily be monitored to help managers quickly identify periods of increased abundance. This information would be beneficial to managers that wish to utilize commercial harvest subsidies for Common Carp so that densities are maintained at a lower, less destructive, level.

## Introduction

Clear Lake is a shallow, hypereutrophic lake with 3,625 surface acres located in Cerro Gordo County, Iowa (Figure 1). Clear Lake has a maximum depth of 19 feet, an average depth of 9.5 feet, and watershed to lake ratio of 2.3:1. The watershed is drained by many small tributaries with 47% of the surface flow passing through a large wetland complex (i.e., Ventura Marsh) before entering the lake (Downing et al. 2001). Land use practices within the watershed consist primarily of cropland (59%), urban development (14%) and marsh (9%). These watershed characteristics provide very high nutrient loads to the lake, particularly nitrogen and phosphorus inputs (Downing et al. 2001).

Significant changes in water quality and watershed characteristics have occurred over the last century in Clear Lake. From 1896 to 2000, water transparency has decreased 3-fold and phosphorus concentrations have increased 9-fold (Egertson et al. 2004). Consequently, the frequency and intensity of algae blooms has increased, thus further deteriorating water clarity to the point that the density and diversity of rooted macrophytes (i.e., vascular plants) has declined substantially. The relatively small watershed has changed from fragmented forest, prairie, and oak savannah to primarily agricultural and urban. To this end, a diagnostic and feasibility study was initiated in the late 1990s to determine the causes of the decline and to recommend management guidelines to improve water quality in the lake (Downing et al. 2001).

One of the factors determined to substantially influence water quality in Clear Lake was benthivorous fish density. Benthivorous fishes deteriorate water quality in shallow, nutrient-rich lakes by their benthic feeding habits (Andersson et al. 1978). Common Carp *Cyprinus carpio* are voracious benthic feeders and cause re-suspension of sediments while foraging resulting in increased turbidity, increased phosphorus, reduced macrophyte growth, and physical uprooting of macrophytes (Crivelli 1983; Breukelaar et al. 1994; Scheffer 1998; Chumchal et al. 2005). Common Carp substantially impact benthic invertebrate abundance through predation and habitat destruction, thus removing organisms critical in sequestering organic matter and nutrients (Egertson and Downing 2004). In shallow eutrophic lakes, Common Carp often attain extremely high densities and large quantities of nutrients are excreted (Driver et al. 2005) which promote toxic phytoplankton blooms (e.g., cyanobacteria; Parkos et al. 2003; Egertson and Downing 2004; Ibelings et al. 2005).

Because Common Carp have such deleterious effects on water quality in aquatic ecosystems, Common Carp control via commercial harvest, chemical renovations, and piscivore stockings has been attempted, yet rarely is Common Carp control achieved (Lougheed and Chow-Fraser 2001; Shrage and Downing 2004; Driver et al. 2005). In Clear Lake, the commercial fishery was used to limit the impacts of Common Carp on the ecosystem with over 2.2 million lbs of biomass removed during the 70 years prior to this study (Wahl 2001). However, despite intense commercial fishing, water quality in Clear Lake remained impaired.

Reducing benthivorous fishes in Clear Lake would likely increase water quality by reducing benthic activity. Therefore, reducing the biomass of both Common Carp and Black Bullheads *Ameiurus melas* was considered a viable management option to help renovate Clear Lake. Current and on-going biomass estimates of Common Carp and Black Bullheads were necessary during this biomanipulation experiment so that realistic and obtainable objectives could be formalized. These baseline data were critical to determine how much biomass needed to be removed to ensure a positive impact on water quality. Investigating these populations over time allowed the Iowa Department of Natural Resources (DNR) to determine how fast the exploited populations rebounded to their former levels, and how much effort was required to keep the populations within acceptable levels. Specifically, the objective was to determine population densities, biomass, and age-growth of Common Carp and Black Bullheads in Clear Lake.

## Methods

*Fish Marking*

Black Bullheads were sampled via 24-h fyke net set (2ft x 4ft x ¾ in mesh; 40 ft lead) in April of 1999, 2000 and 2002. Common Carp were captured via a commercial seining operation in April (1999-2002) or May-June (2007-2010). All Black Bullheads and Common Carp captured each year were examined for marks and marked with a unique fin clip for each year (Table 1). A representative subsample of each species was measured (total length [TL]; in) and weighed (lbs). Individually marked fish were released back into the lake and allowed to mix with the unmarked population over the summer.

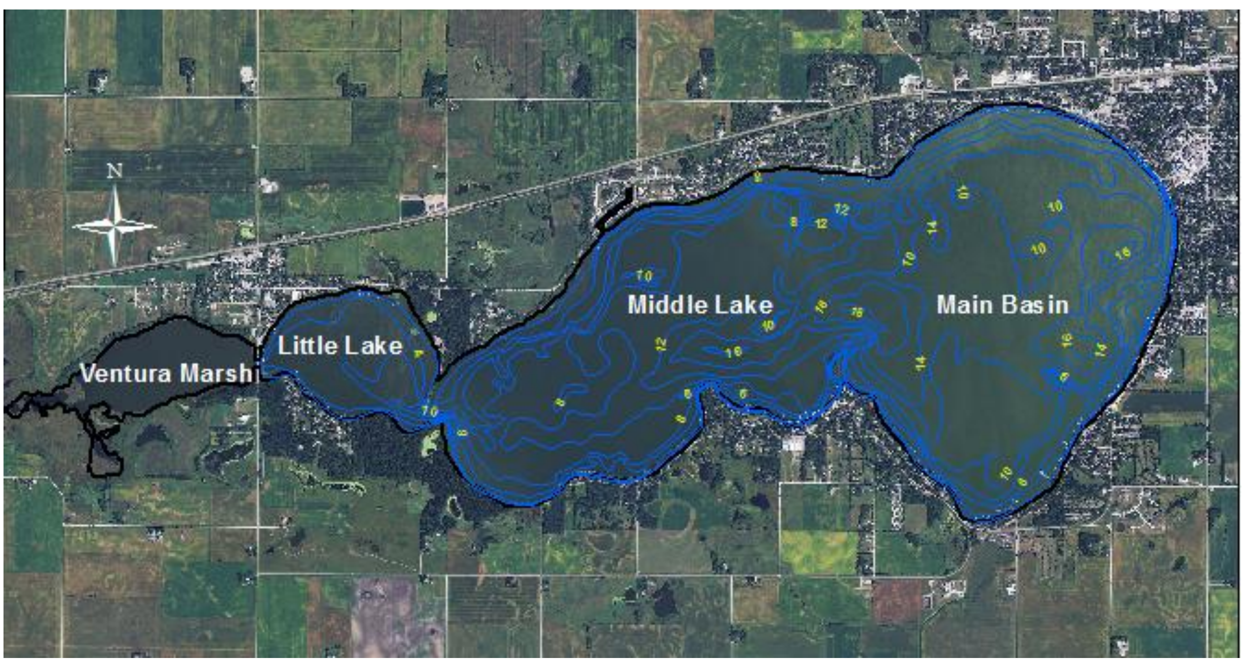


**Figure 1.** Aerial view of Clear Lake, Iowa with depth contours and designation of Ventura Marsh, Little Lake, Middle Lake, and the Main Basin.

**Table 1.** Number of Black Bullhead and Common Carp marked (M), captured (C) or recaptured (R) with biomass (lbs/ac) and density (N/ac) estimates (with 95% confidence intervals) for Clear Lake between 1999 and 2010.

| Year | Clip | M | C | R | N/ac | 95% C.I. | Mean wt | lbs/ac | 95% |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **Black bullhead** | | | | | |
| 1999 | Adipose | 22,618 | 46,281 | 374 | 739.2 | 677 - 818 | 0.38 | 280.1 | 257 - 310 |
| 2000 | NA | 16,060 | 18,246 | 275 | 286.5 | 261 - 319 | 0.41 | 118.8 | 108 - 132 |
| 2002 | NA | 11,380 | 6,333 | 67 | 287.7 | 235 - 387 | 0.47 | 135.2 | 110 - 182 |
| | | | | **Common carp** | | | | | |
| 1999 | Lower caudal | 5,075 | 298 | 22 | 17.9 | 13 - 28 | 6.22 | 111.3 | 77 - 173 |
| 2000 | Top caudal | 3,041 | 302 | 6 | 35.6 | 21 - 69 | 8.84 | 315.7 | 160 - 612 |
| 2003 | Left pectoral | 4,529 | 345 | 6 | 62.2 | 32 - 121 | 7.75 | 481.9 | 244 - 934 |
| 2004 | Left pelvic | 5,175 | 357 | 9 | 51.5 | 29 - 94 | 7.45 | 383.5 | 216 - 702 |
| 2007 | Top caudal | 3,515 | 1,387 | 136 | 9.7 | 8 - 12 | 8.38 | 80.9 | 70 - 98 |
| 2008 | Right pelvic | 2,959 | 1,702 | 89 | 15.2 | 13 - 20 | 11.46 | 174.2 | 145 - 223 |
| 2009 | Lower caudal | 3,367 | 819 | 76 | 9.7 | 8 - 13 | 12.57 | 122.2 | 101 - 160 |
| 2010 | Right pectoral | 2,840 | 2,450 | 172 | 10.9 | 10 - 13 | 12.13 | 132.4 | 116 - 156 |

*Fish Recapture*

A semi-balloon otter trawl (Hayes et al. 1996) with a 26 ft head rope, 1.5 in stretch mesh body, and ¼ in mesh cod end was used either in July (1999-2003) or September/October (2007-2012) to sample Black Bullhead and Common Carp. The trawl was towed at a speed 2.0-2.5 mph for a period between 2-5 min. All trawls were georeferenced with a Global Positioning System (GPS) unit and the linear distances sampled were recorded for each trawl (Figure 2). All Black Bullhead and Common Carp captured were enumerated and examined for marks prior to being released. Lengths and weights were taken from a representative subsample.

In November of 2007-2010, Common Carp were recaptured by seining areas of known high Common Carp density (Penne and Pierce 2008). Captured fish were enumerated and each fish was checked for prior marks.

*Mark-Recapture Population and Biomass Estimates*

A modified Lincoln-Peterson mark-recapture model (Chapman 1951) was used to estimate densities (number/ac) of Black Bullhead and Common Carp. Average weights of Black Bullheads and Common Carp were multiplied by the population estimates to derive biomass estimates.

*Otter Trawl Population and Biomass Estimates*

Population densities per acre trawled were calculated by computing the area of lake bottom trawled (*Equation 1*) and multiplying this by the number of adult Black Bullheads or Common Carp captured in each 2-5 min trawl.

*Equation 1.*

$$\frac{\left[yds\ trawled * \frac{3\ ft}{1\ yd}\right] * \left[width\ of\ trawl\ opening\ [18.77\ ft]\right]}{\frac{43563\ ft^2}{1\ acre}}$$

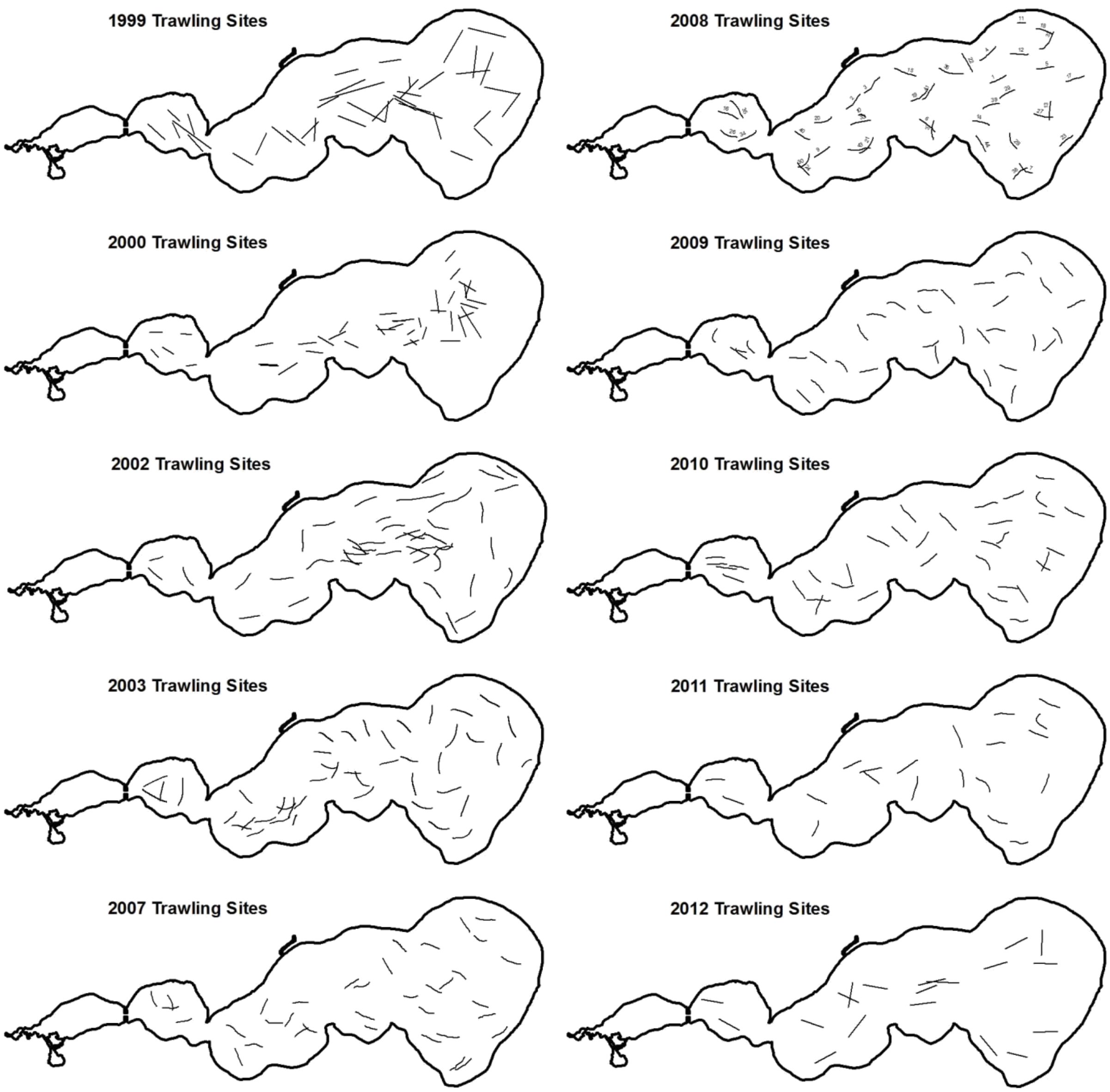


**Figure 2**. Actual otter trawling locations recorded via GPS in Clear Lake, IA from 1999-2012.

Three methods were used to estimate the distance trawled (yds) during the study. In 1999 and 2000, tow distance was measured using a General Oceanics Flowmeter (Model 2030) that was attached to the trawl frame and suspended in the net mouth. The flowmeter was calibrated by regressing known distances (measured via a laser range finder) to flowmeter units (start units minus ending units). This regression equation (*Equation 2*) was used to estimate yds trawled for each 2-5 min trawl. From 2002-2011, GPS coordinates were recorded at 30 second intervals for the trawl path and the linear distance was calculated using geometry tools via geographic information system (GIS; i.e., ESRI ® 2011 ArcMap 10.0). In 2012, waypoints were taken at the beginning and end of each trawl run. A linear regression model (*Equation 3*) was developed using georeferenced points and yards trawled (via flowmeter model) and was used to estimate total distance trawled in 2012.

*Equation 2.*

$$yds\ trawled = 0.03891 * (flowmeter\ units) + 14.10363$$

*Equation 3.*

$$yds\ trawled = 0.9768 * (georeferenced\ distance[yds]) - 32.668$$

Adult Black Bullhead and Common Carp biomass (lbs/ac) for each trawl site each year was estimated by multiplying population estimates (number/ac) by the mean weight of Black Bullhead or Common Carp. These estimates were averaged by year to estimate mean biomass (with 95% confidence intervals) for each species. The coefficient of variation (CV; standard deviation divided by mean) among otter trawling sites each year was calculated to compare variability of Black Bullheads and Common Carp densities each year. Linear regression was used to evaluate trends in otter trawl biomass estimates and mark-recapture biomass estimates ($P < 0.05$; SAS Institute 2001).

*Spatial analysis of trawls*

A concerted effort was made each year to distribute otter trawls samples evenly throughout Clear Lake (Figure 2). This coverage made it possible to analyze spatially (and temporally) the density of Black Bullheads and Common Carp. Bottom trawls were logged from beginning to end using GPS. These files were used to spatially reconstruct the trawl lines using GIS (Figure 2). The midpoint tool in GIS was used to define the middle point of the trawl run for each run each year and this point was given a density value (number/ac) for Black Bullhead and Common Carp. A variogram was constructed to view the spatial variation in fish density using Spatial Analyst Tools within GIS software. This variogram describes how spatial continuity changes as a function of distance and direction (Isaaks and Srivastava 1989). Models were visually selected that closely matched the observed spatial variation observed in the variogram. Each of the model components allow for independent specification of the anisotropy (a preferred direction, or direction of higher or lower continuity between data points which provide a ratio for distance weighting) observed in the data set (Isaaks and Srivastava 1989).

Kriging (a geostatistical gridding interpolation method) was used to interpolate a fish density surface for the entire lake. Kriging is a popular gridding method, which has the ability to be custom fit to data sets by specifying the appropriate variogram model. By using the variogram model fit to each data set it incorporates anisotropy and underlying trends in an efficient and natural matter. Variogram model components for each fish species and each year were created and these components were used in the Kriging interpolation routines to create a lake surface based on fish density for each year and fish species. Specifically, ordinary Kriging methods using the exponential semivariogram model were used to spatially estimate fish densities each year in Clear Lake. Temporal differences in fish distribution were also examined via Kriging techniques by pooling July and September/October trawling sampling data. Kriging was also performed on all trawling data (e.g., 10 years of summer trawling data) to observe overall trends in fish distribution.

*Age-growth of bullheads and carp*

In April 1999, anal spines were taken from a representative sample of Common Carp by cutting the spine as close to the base as possible with side cutters. In April of 1999 and 2003, pectoral spines were taken from a subsample of Black Bullheads by rotating the spine dorsally until the articulating process separated from the joint. All spines were placed in coin envelopes and allowed to dry.

Spines were sectioned in approximately 1/4 inch sections using a homemade saw fitted with a Dremel saw blade (Margenau 1982). Spine sections were placed on a glass slide, cleared with glycerin and viewed with an Olympus SZ6045 microscope (30x) using reflected light. Digital images were captured using an Olympus DP70 camera mounted on the microscope and cross-sections were viewed using Optimas image analysis system (Biosonics inc., Seattle WA). The reader identified the focus and measured the distance from the focus to each annuli and the spine edge along the horizontal compressed transect (Borkholder and Edwards 2001). Age-growth information was extracted to an excel spreadsheet for summary and analysis. Temporal changes in growth due to changes in biomass were also compared using age-growth data from this study and a concurrent study (Colvin et al. 2010).

*Ventura marsh monitoring*

Prior to 2010, the outflow structure at Ventura Marsh limited seasonal and yearly water level fluctuations and provided optimal habitat for benthivorus fishes (Downing et al. 2001). To reduce or eliminate benthic fish populations, rotenone was aerially applied to Ventura Marsh in August 1999 and June 2000. During the winter of 1999-2000, the marsh was drawn down and rotenone was applied under the ice. Winter drawdown was again used to induce fish winterkill conditions during winter 2003-2004. Three standardized gillnet (160 ft, 2.5 inch bar mesh) sites were established to assess the population status of adult Black Bullhead and Common Carp in the marsh pre, during, and post renovation efforts. Standardized gillnets were set twice in the fall of 1999 and twice in the spring of 2000, immediately pre and post rotenone application. From 2001-2010, standardized gillnet sets were used in May to document trends in adult fish catch-per-unit-effort (CPUE). In addition, two standardized electrofishing runs (pulsed-DC) were established to monitor age-0 fishes each fall between 2000 and 2009. In 2010, the Ventura Marsh restoration project began, which included replacing the stop log outlet structure, installing a new pumping station, and dredging a flow channel to allow for de-watering of the marsh. The initial drawdown of Ventura Marsh began in the late fall of 2011; therefore adult or age-0 fish were not sampled beyond the spring of 2010.

*Commercial Fishing Operations*

All past and current commercial fishing on Clear Lake was conducted through a limited entry contract fishing procedure which involves competitive bidding and a public bid letting. Successful bids were granted to one commercial fisher and they were allowed to fish Clear Lake at their discretion within the dates allowed by the Iowa DNR. All commercial fishers were required to provide monthly harvest reports. This information was entered and trends in Common Carp harvest were examined.

*Fish Stocking*

Clear Lake has been stocked with multiple species of sport fish of varying life stages since the early 1900s. Stocking recommendations are provided by the fisheries management biologist annually; however, the number and size of fish stocked is ultimately dependent on hatchery production during any given year. Walleye *Sander vitreus*, Northern Pike *Esox lucius*, Muskellunge *Esox masquinongy*, and Channel Catfish *Ictalurus punctatus* have been stocked regularly in Clear Lake the past 20 years. Fish stocking rates or species stocked during the study was not specifically used as a biomanipulation technique, but were reported.

*Water Quality Parameters*

Water quality monitoring was conducted as part of the Clear Lake Restoration Diagnostic and Feasibility Study from 1998-2000. From 2000-2012 (except 2008), water samples were taken once per month at 3 sites between June and August and were analyzed at the Iowa State University Limnological Laboratory (ISULL; Iowa Lakes Information System 2005). As part of the Clear Lake Enhancement and Restoration Project (CLEAR; Clear Lake Enhancement and Restoration Project 2004), water samples from 3 sites on Clear Lake, 2 sites on Ventura Marsh, and 7 tributary sites within the watershed were collected bimonthly throughout the open water season and analyzed at the State Hygienic Laboratory at the University of Iowa (annually between 2004-2012). Simple linear regression was used to determine trends in mean annual secchi transparency (ft), chlorophyll a (μg/L), total suspended solids (mg/L), and total phosphorus (μg/L) for both the ISULL and CLEAR data collected only within the Clear Lake basin ($P < 0.05$; SAS Institute 2001). Relationships between standing stocks (trawl and mark-recapture estimates) of both Black Bullheads and Common Carp to water quality parameters were examined using linear regression ($P < 0.05$; SAS Institute 2001).

## Results

*Population and biomass estimates*

Black Bullhead density and biomass estimates via mark-recapture methods decreased from 1999 to 2002 (Table 1). Correspondingly, there was a substantial increase in mean weight of Black Bullheads from 1999 to 2002 in both the otter trawl and mark-recapture events (Table 1 and 2). Otter trawl Black Bullhead biomass estimates from 1999-2003 were similar, ranging from 145 to 165 lbs/ac; whereas density estimates decreased 36%. Both Black Bullhead biomass and density estimates obtained from otter trawling declined significantly by 2007 and remained very low (Table 2). No Black Bullheads were sampled in either 2011 or 2012 otter trawling samples.

Common Carp biomass was more variable throughout the study and did not show a substantial decreasing trend; however, the abundance of Common Carp has decreased (Table 1 and 2). Based off mark-recapture events, biomass ranged from 80.9 lbs/ac in 2007 to 481.9 lb/ac in 2003; whereas, abundance estimates ranged from 62.5 fish/ac in 2003 to 9.7 fish/ac in both 2007 and 2009 (Table 1). Mean weight of Common Carp captured during the spring marking efforts increased linearly from 6.2 lbs in 1999 to 12.6 lbs in 2009 (Table 1). Otter trawl samples varied from 15.7 lbs/ac in 2002 to 102.2 lbs/ac in 2003 and from 1.6 fish/ac in 2011 to 15.2 fish/ac in 2003. From 2007-2012, few differences were observed in Common Carp biomass via trawling. The abundance of Common Carp in 2010 substantially increased, but did not represent an increase in biomass due to their small average size (Table 2).

Otter trawl biomass estimates varied directly with mark-recaptures estimates for Common Carp ($P < 0.01$; $R^2 = 0.84$; Figure 3). This relationship was not observed for Black Bullheads ($P = 0.9861$).

*Spatial analysis of trawls*

Adult Black Bullheads were not uniformly distributed in Clear Lake and their distribution varied annually and temporally (Figure 4 and 5). In general, Black Bullhead density was greatest in the deeper areas located in the north-northeast basin of the main lake, middle lake, and western portion of the middle lake (Figure 4 and 5). In 1999, when biomass and population densities were at their highest, Black Bullhead aggregated in the deeper basin within the middle of Clear Lake, but also aggregated in other small areas of the lake at rather high densities (> 400 fish/ac; CV = 0.83; Figure 5). In 2000, Black Bullhead density in the north east basin was substantial (1,013 – 3,941 fish/ac), but fish also aggregated in similar locations as in 1999 at relatively high densities (400-500 fish/ac; CV = 1.85; Figure 5). Black Bullheads aggregated more in the middle of the lake in 2002 (CV = 0.75), but in 2003 (CV = 0.59), higher densities were observed in the western basin. By 2007, population densities decreased substantially and Black Bullheads were only found in a few areas of Clear Lake at densities less than 40 fish/ac (Figure 5). Population densities continued to decline and few, if any bullheads were caught at any location between 2008-2012 (Figure 5; CV ≥ 1.42).

**Table 2.** Density (N/ac) and biomass (lbs/ac) estimates of Black Bullhead and Common Carp from otter trawl techniques in Clear Lake, IA, 1999-2012.

| | N/ac | 95% C.I. | Mean wt | lbs/ac | 95% C.I. | N/ac | 95% C.I. | Mean wt | lbs/ac | 95% C.I. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Black bullhead** | | | | | **Common carp** | | |
| 1999 | 381.4 | 288 -457 | 0.38 | 144.5 | 109 - 180 | 8.8 | 6.6 - 11.3 | 6.22 | 54.9 | 41 - 69 |
| 2000 | 338.3 | 141 - 536 | 0.41 | 138.5 | 58 - 219 | 13.6 | 9.7 - 17.4 | 4.58 | 62.1 | 45 - 80 |
| 2002 | 218.8 | 168 - 269 | 0.72 | 158.3 | 122 - 195 | 4.3 | 2.2 - 6.4 | 3.66 | 15.7 | 8 - 23 |
| 2003 | 241.1 | 197 - 285 | 0.68 | 165.0 | 135 - 195 | 15.2 | 11.3 - 19.0 | 6.74 | 102.2 | 77 - 128 |
| 2007 | 7.2 | 3.7 - 10.7 | 1.01 | 7.3 | 4 - 11 | 1.7 | 0.7 - 2.6 | 13.79 | 22.8 | 10 - 36 |
| 2008 | 1.2 | 0.6 - 1.8 | 0.78 | 0.9 | 0.4 - 1.4 | 2.4 | 1.3 - 3.6 | 13.00 | 31.8 | 17 - 46 |
| 2009 | 0.1 | 0.0 - 0.2 | 0.93 | 0.1 | 0.0 - 0.2 | 2.4 | 1.3 - 3.5 | 14.17 | 33.7 | 18 - 50 |
| 2010 | 0.2 | 0.0 - 0.4 | 0.20 | 0.4 | 0.0 - 0.1 | 5.7 | 3.3 - 8.0 | 6.76 | 38.4 | 23 - 54 |
| 2011 | 0.0 | 0.0 - 0.0 | ns | 0.0 | 0.0 - 0.0 | 1.6 | 0.6 - 2.6 | 13.87 | 22.3 | 9 - 36 |
| 2012 | 0.0 | 0.0 - 0.0 | ns | 0.0 | 0.0 - 0.0 | 1.9 | 0.2 - 3.5 | 10.77 | 20.2 | 3 - 38 |

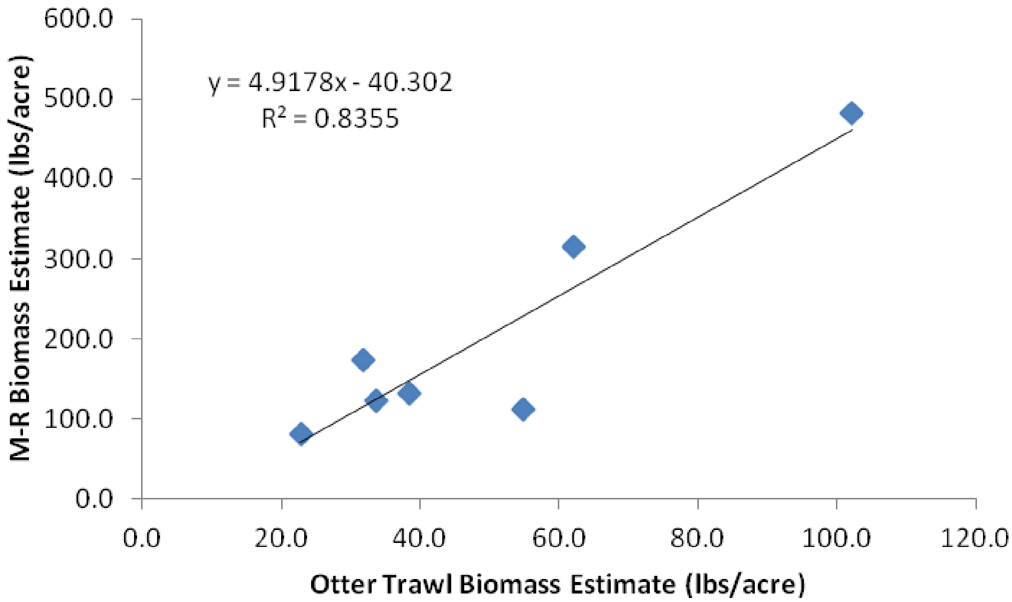


**Figure 3.** Relationship between Common Carp mark-recapture biomass (lbs/ac) estimates and trawl biomass estimates in Clear Lake, IA from 1999-2010.

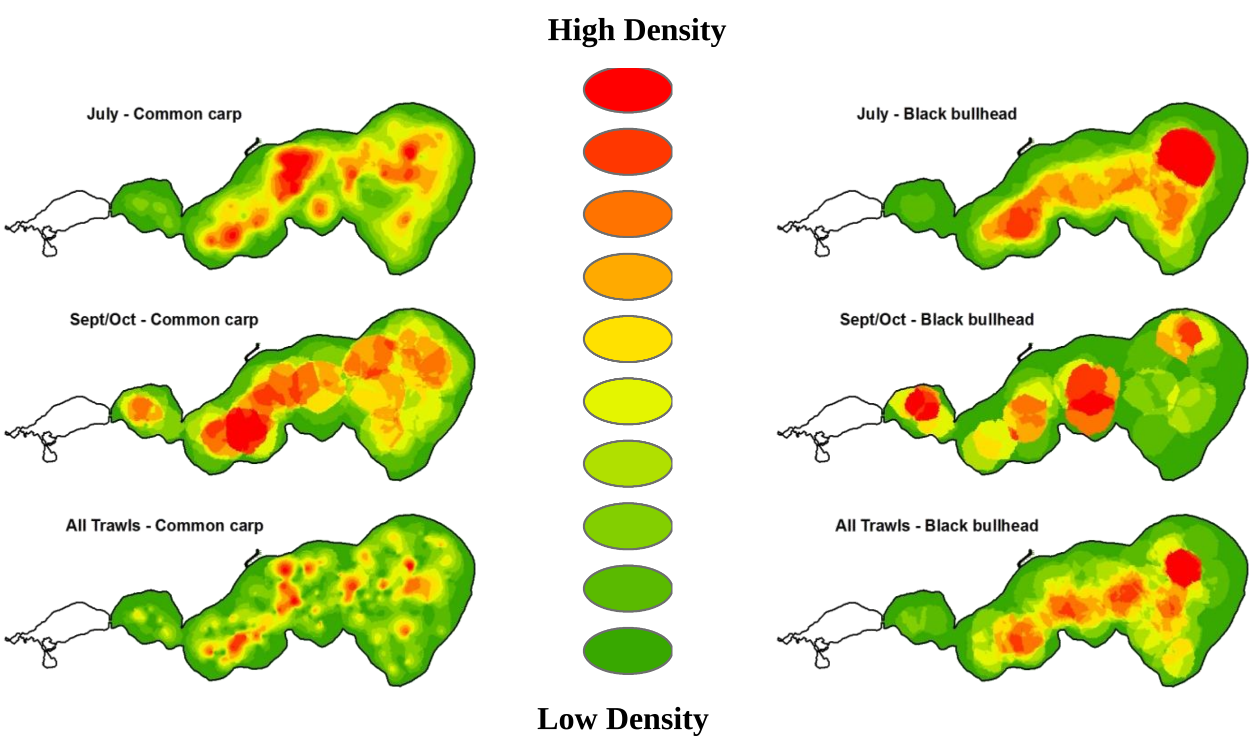


**Figure 4.** Common Carp (left) and Black Bullhead (right) densities estimated via Kriging methods during trawl events in July, September/October, and all trawls combined in Clear Lake, IA.

Adult Common Carp densities in Clear Lake were not uniform and varied annually; however, distinct areas of congregation were observed (Figure 4 and 6). Combined trawl data found few differences in spatial distribution among month trawled (Figure 4). In general, Common Carp aggregated in the deepest portions of Clear Lake. Specifically, dense aggregations (≥ 25.0 fish/ac) were found within the middle lake (southwestern and central), north of Woodford Island, and in the center of the main basin (Figure 4).

Between 1999 and 2002, Common Carp densities were highest in the main basin (Figure 6). In 2003, Common Carp densities were highest in the middle lake. Coefficient of variation of trawl data between 1999 and 2003 was ≤ 0.89, thus indicting high association to those locations in those years. Although substantially fewer Common Carp were captured in otter trawls from 2007-2012 and their CV's were much higher (range of 1.21 to 1.82), Common Carp continued to aggregate either in the main basin or the middle lake (Figure 6).

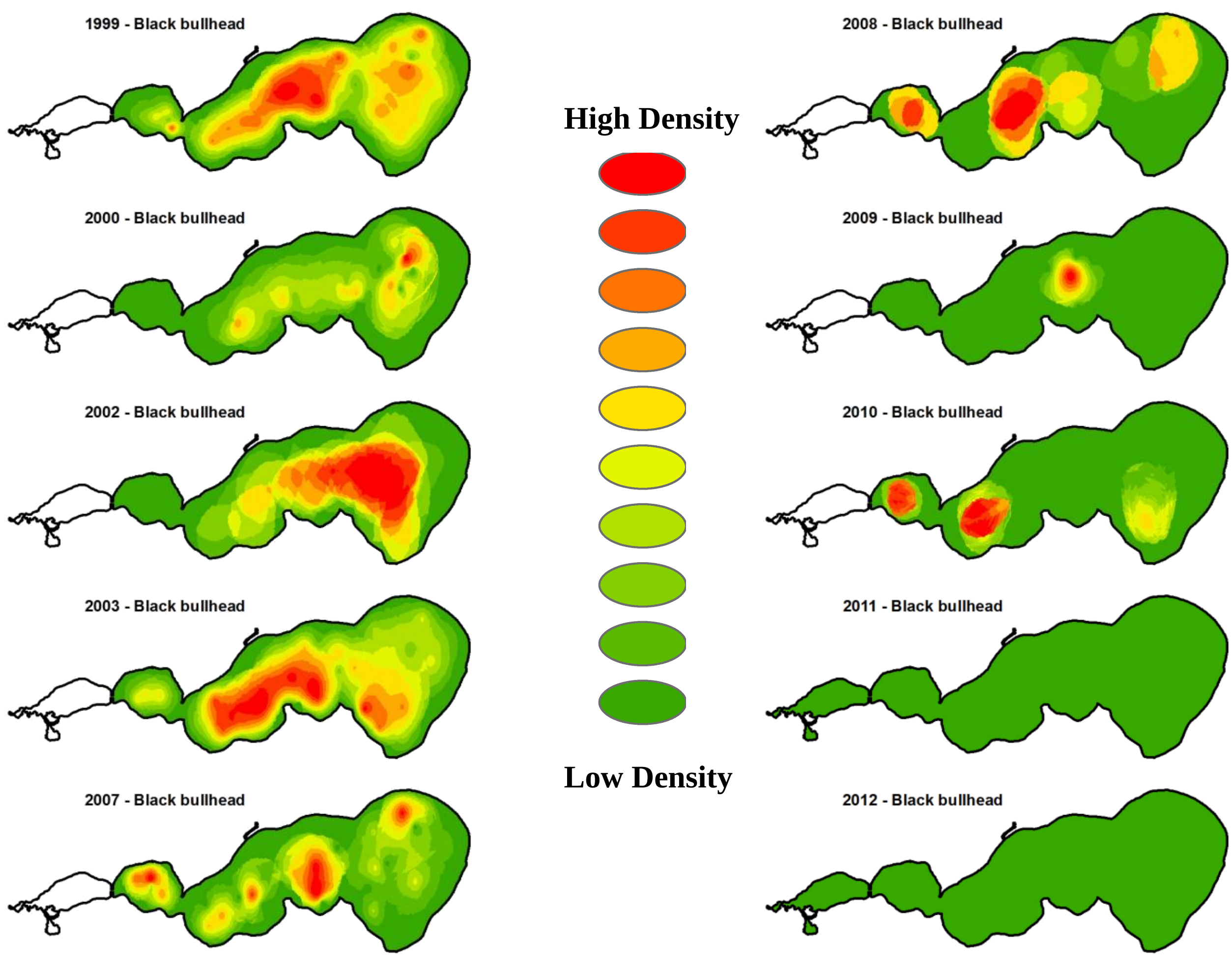


**Figure 5.** Black Bullhead density estimated via Kriging methods during summer trawling events between 1999-2012 in Clear Lake, Iowa.

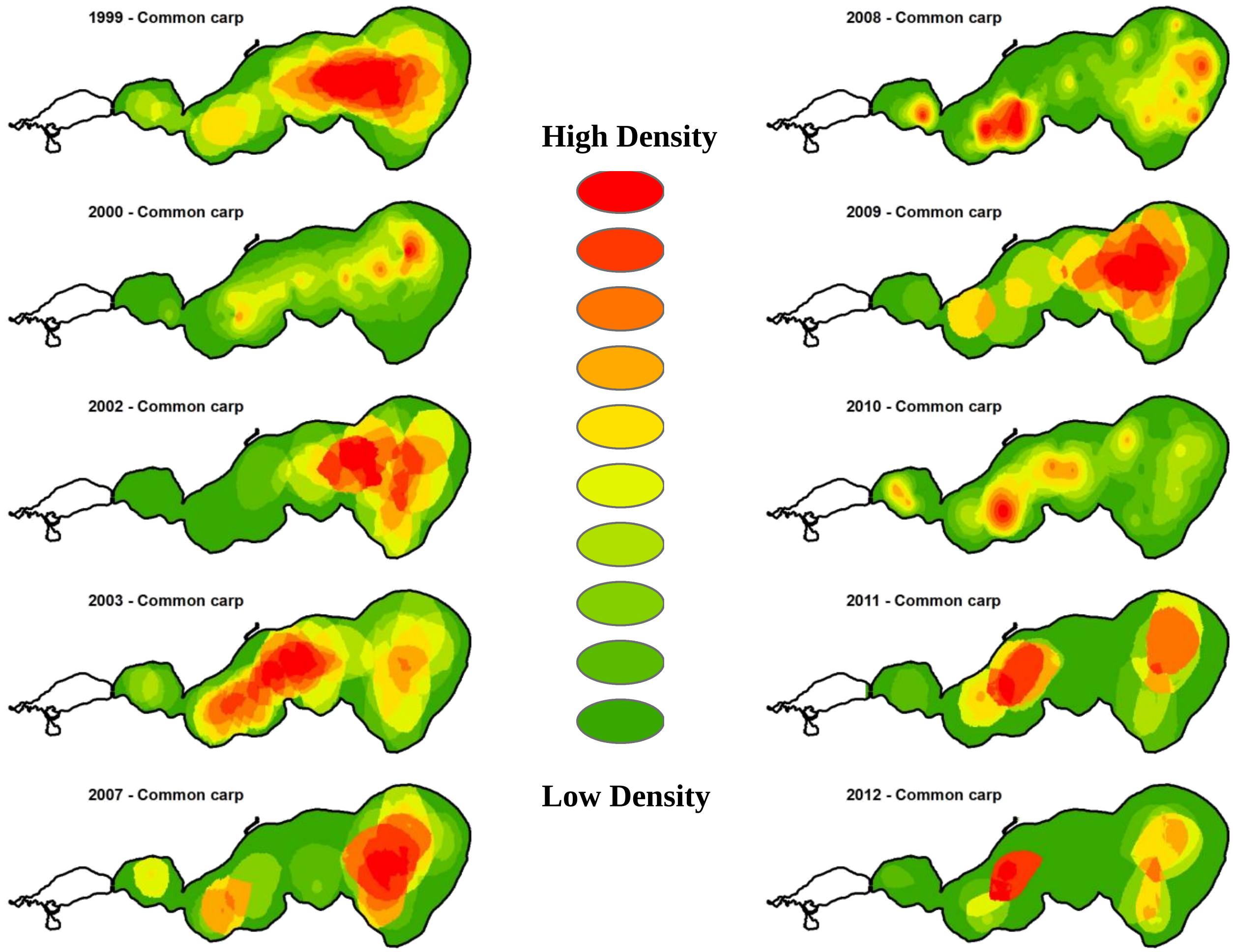


**Figure 6.** Common Carp density estimated via Kriging methods during summer trawling events between 1999-2012 in Clear Lake, Iowa.

*Age-growth of Black Bullheads and Common Carp*

A total of 29 Black Bullheads were aged in April 1999, 61 in April 2003, and 32 from 2007-2010 (Colvin et al. 2010; Table 3). On average, it took bullheads 4 years to reach eight inches in Clear Lake based on the 1999 sample. By 2003, it took only 2-3 years to reach 8 inches and this trend continued for the 2007-2010 samples (Table 3). A total of 48 Common Carp were aged in April 1999 and ages varied from 1-12 years old (Table 3). Common Carp in Clear Lake exceeded 20 inches after 4 years of growth and were nearly 30 inches after 10 years of growth (Table 3). This trend was consistent throughout the study period (Colvin 2010).

*Ventura marsh monitoring*

Only 196 adult Black Bullheads were sampled in Ventura Marsh via gillnets and most (96%) of these were sampled from 1999-2002 (Table 4). Less than 3 Black Bullheads were sampled any year following 2003. Adult Common Carp numbers were negatively impacted by the multiple applications of rotenone in Ventura marsh (Table 4). Numbers of adult carp decreased

**Table 3.** Black Bullhead (left) and Common Carp (right) back-calculated length at age estimated via spines from 1999-2010 (n = number; SD = standard deviation; Min = minimum; Max = maximum). An asterisk indicates values taken from Colvin et al. (2010).

| | | Back calculated length (in) | | | |
|---|---|---|---|---|---|
| Age | n | Mean | SD | Min | Max |
| | | **1999** | | | |
| 1 | 29 | 3.0 | 0.6 | 2.1 | 4.2 |
| 2 | 29 | 5.3 | 0.5 | 4.4 | 6.1 |
| 3 | 20 | 7.0 | 0.3 | 6.4 | 7.8 |
| 4 | 20 | 8.4 | 0.4 | 7.0 | 8.9 |
| 5 | 1 | 8.3 | | 8.3 | 8.3 |
| | | **2003** | | | |
| 1 | 61 | 4.8 | 1.2 | 2.4 | 8.4 |
| 2 | 61 | 7.1 | 1.3 | 4.1 | 10.6 |
| 3 | 59 | 9.2 | 1.3 | 6.6 | 12.2 |
| 4 | 48 | 10.5 | 1.4 | 7.4 | 14.5 |
| 5 | 13 | 10.9 | 0.7 | 9.3 | 12.0 |
| 6 | 2 | 11.3 | 0.5 | 10.9 | 11.6 |
| | | **2007-10*** | | | |
| 1 | 32 | 2.9 | 0.4 | 2.0 | 3.7 |
| 2 | 32 | 6.1 | 1.0 | 4.3 | 7.9 |
| 3 | 21 | 7.7 | 1.2 | 5.5 | 9.8 |
| 4 | 21 | 9.4 | 0.8 | 7.7 | 10.7 |
| 5 | 17 | 10.1 | 0.9 | 8.9 | 11.7 |
| 6 | 11 | 10.3 | 0.4 | 9.7 | 10.9 |
| 7 | 9 | 11.3 | 0.5 | 10.4 | 11.8 |

| | | Back calculated length (in) | | | |
|---|---|---|---|---|---|
| Age | n | Mean | SD | Min | Max |
| | | **1999** | | | |
| 1 | 48 | 5.4 | 1.0 | 4.1 | 8.3 |
| 2 | 48 | 13.3 | 1.9 | 8.4 | 16.5 |
| 3 | 48 | 18.1 | 1.9 | 13.0 | 23.3 |
| 4 | 36 | 21.1 | 1.5 | 16.8 | 24.0 |
| 5 | 14 | 23.1 | 1.6 | 20.6 | 25.4 |
| 6 | 14 | 24.6 | 1.7 | 22.1 | 27.7 |
| 7 | 12 | 25.6 | 1.7 | 23.5 | 29.7 |
| 8 | 4 | 25.5 | 0.5 | 25.0 | 26.2 |
| 9 | 4 | 26.9 | 0.1 | 26.8 | 27.1 |
| 10 | 4 | 28.3 | 0.3 | 28.1 | 28.8 |
| 11 | 3 | 29.6 | 0.0 | 29.5 | 29.6 |
| 12 | 3 | 30.9 | 0.3 | 30.6 | 31.2 |
| | | **2007-10*** | | | |
| 1 | 467 | 5.7 | 3.1 | 1.2 | 16.2 |
| 2 | 438 | 13.2 | 3.3 | 3.2 | 26.2 |
| 3 | 409 | 17.6 | 3.3 | 4.0 | 25.0 |
| 4 | 379 | 20.7 | 3.3 | 4.6 | 28.4 |
| 5 | 365 | 23.2 | 3.0 | 5.8 | 30.0 |
| 6 | 322 | 25.0 | 2.9 | 15.2 | 32.0 |
| 7 | 260 | 26.5 | 2.5 | 15.9 | 33.4 |
| 8 | 170 | 27.6 | 2.6 | 16.7 | 34.0 |
| 9 | 93 | 28.5 | 2.8 | 17.5 | 33.8 |
| 10 | 49 | 29.0 | 3.2 | 18.7 | 34.4 |
| 11 | 24 | 28.8 | 3.0 | 19.7 | 32.9 |
| 12 | 12 | 28.0 | 2.9 | 20.7 | 32.9 |
| 13 | 7 | 27.2 | 0.8 | 21.1 | 31.6 |

from a total 170 carp caught in 1999 (prior to the first application of rotenone) to only 2 carp following the third rotenone application. However, adult, yearling, and age-0 Common Carp numbers steadily increased from the last rotenone application to spring of 2003. Following a winter drawdown in 2003-2004, adult Common Carp numbers decreased substantially in the marsh, but by the fall of 2004, significant numbers of age-0 Common Carp were captured. Consequently, adult Common Carp abundance from 2004 to 2010 increased (Table 4).

*Commercial Fishing Trends and Fish Stocking*

Common Carp commercial harvest has been extremely variable since 1980, ranging from zero to 187,864 pounds harvested annually (Figure 7). Since 1999, an average of 71,226 lbs of Common Carp was harvested annually in Clear Lake. Much (61%) of this harvest occurred from 2003-2004 and 2007-2008.

Channel Catfish and Northern Pike fingerlings, Muskellunge yearlings, and various sizes of Walleye have been stocked in Clear Lake since 1999 (Table 5). The number of fingerling channel catfish stocked annually since 1999 has decreased; however stocking rates for all other species have remained relatively stable from 1999-2012 (Table 5).

*Water Quality Parameters*

Mean annual secchi disk depth ranged from 1.3 ft in 2000 to 4.6 ft in 2003 (Table 6). There was no significant change in mean secchi disk depth for data collected by ISULL ($P = 0.90$); however, significant improvements were documented through samples collected for the CLEAR project from 2004-2011 ($P = 0.02$). Mean annual chlorophyll a ranged from 82 μg/L to 13 μg/L and significantly improved according to the CLEAR samples ($P < 0.001$; Table 6), but no change was detected via ISULL ($P = 0.10$). Total suspended solids ranged from 47 mg/L in 2000 to 12 mg/L in both 2009 and 2011; whereas total phosphorous

**Table 4.** Catch-per-effort of standardized gill net and DC electrofishing survey's used to monitor adult Black Bullhead and adult, yearling, and age-0 Common Carp in Ventura Marsh.

| Date | Gillnet | | Electrofishing | | Comments |
|---|---|---|---|---|---|
| | Adult carp | Adult bullheads | YOY carp | Yearling carp | |
| August 3, 1999 | 170 | 0 | | | Pre-rotenone application |
| September 10, 1999 | 113 | 31 | | | Post aerial application of rotenone |
| April 12, 2000 | 84 | 0 | | | Post winter drawdown and rotenone application |
| June 21, 2000 | 2 | 0 | | | Post second aerial application of rotenone |
| September 1, 2000 | | | 68 | 0 | |
| May 3, 2001 | 4 | 124 | | | |
| October 4, 2001 | | | 302 | 31 | |
| May 17, 2002 | 20 | 33 | | | |
| October 3, 2002 | | | 201 | 90 | |
| May 23, 2003 | 275 | 1 | | | |
| October 2003 | | | | | Low water levels - no sample |
| May 4, 2004 | 2 | 0 | | | Post winter drawdown |
| September 24, 2004 | | | 376 | 0 | |
| May 11, 2005 | 42 | 1 | | | |
| October 10, 2005 | | | 3 | 95 | |
| May 2, 2006 | 85 | 1 | | | |
| October 2006 | | | | | Low water levels - no sample |
| May 7, 2007 | 123 | 1 | | | |
| October 10, 2007 | | | 13 | 39 | |
| May 9, 2008 | 190 | 2 | | | |
| October 9, 2008 | | | 1 | 1 | |
| May 15, 2009 | 162 | 0 | | | |
| September 30, 2009 | | | 8 | 11 | |
| May 14, 2010 | 139 | 2 | | | |

ranged from 114 µg/L in 2005 to 43 µg/L in 2011 (Table 6). Significant improvements in total suspended solids and total phosphorous were observed by both projects ($P < 0.02$).

Common Carp biomass estimates via mark-recapture or otter trawl procedures were not related to any of the water quality parameters investigated ($P > 0.12$).

In addition, Common Carp number per acre was not correlated to any water quality parameter ($P > 0.17$) except for mean total phosphorous estimated via ISULL ($P = 0.03$). Significant negative trends were observed for both mean annual chlorophyll a and mean annual total phosphorous from the ISULL project and Black Bullhead biomass and density ($P < 0.03$). No significant trend was detected for any other water quality parameter and Black Bullhead biomass or density ($P > 0.07$).

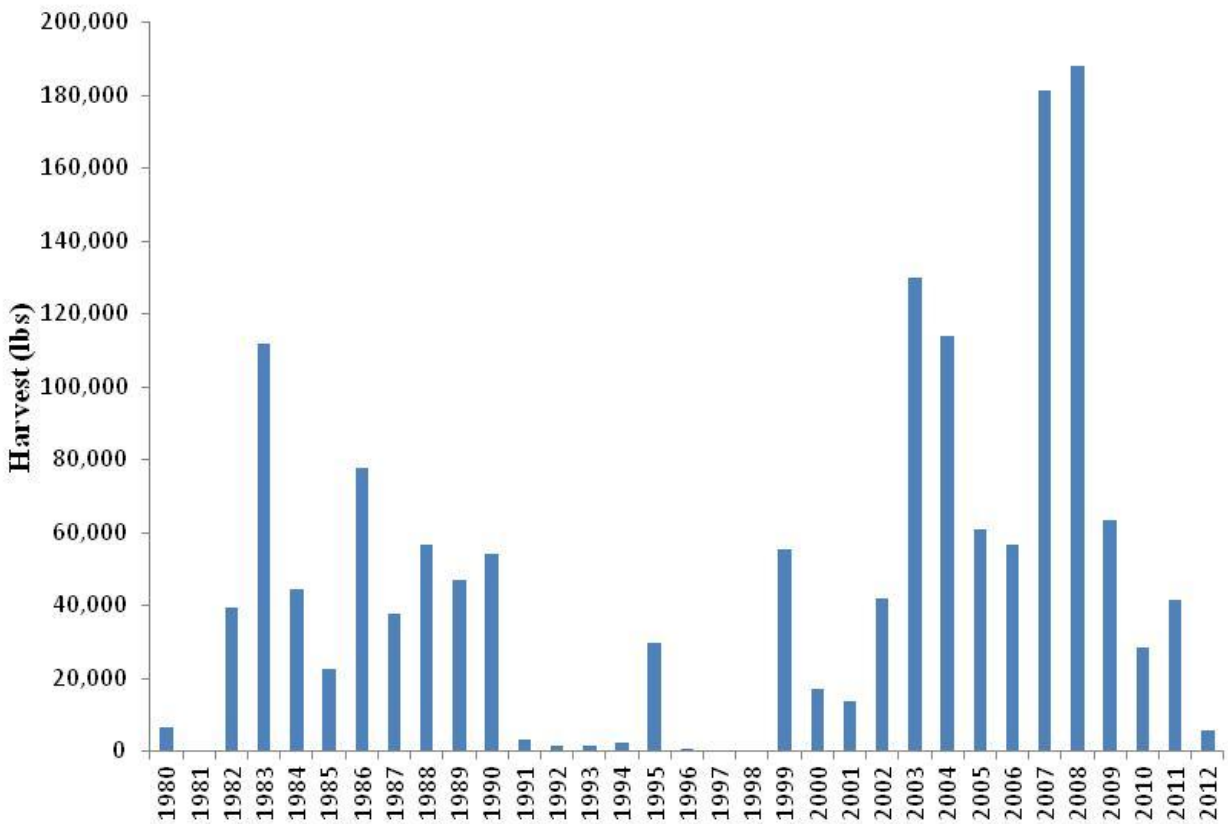


**Figure 7.** Trends in commercial harvest (lbs) of Common Carp from 1980-2012 in Clear Lake, Iowa.

**Table 5.** Number and size (FGL = fingerling) of Channel Catfish, Muskellunge, Northern Pike, and Walleye stocked into Clear Lake from 1999-2012.

| Species | Size stocked | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Channel catfish | 7-8" FGL | 21,156 | 13,210 | 11,000 | 5,502 | 24,064 | 11,000 | 7,000 | 9,309 | 5,721 | 11,282 | | 8,800 | | 7,138 |
| Muskellunge | Yearlings | 899 | | 700 | | 600 | | 408 | 192 | 600 | | 600 | | 561 | 600 |
| Northern pike | 2-3" FGL | | 18,032 | 11,016 | 11,427 | 5,565 | 18,011 | 18,126 | | | | 9,143 | 10,132 | 10,240 | 15,608 |
| Walleye | Fry (millions) | 1.2 | 1.9 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 3.2 | 1.6 | 1.6 | 1.6 | 1.9 | 1.6 | 0.8 |
| | 2-3" FGL | | | | | | | | | | | 55,076 | 55,554 | 70,569 | |
| | 5-6" FGL | 9,263 | 24,912 | 36,843 | | | 33,969 | | 18,430 | 38,198 | 14,098 | | | | |
| | 7-8" FGL | 15,900 | 9,525 | | 56,771 | 18,000 | 14,005 | 25,278 | 20,043 | 17,997 | 17,986 | 36,257 | 18,002 | 17,001 | 14,223 |

**Table 6.** Mean annual secchi disk depth (ft), chlorophyll a (CHL a; µg/L) total suspend solids (TSS; mg/L) and total phosphorus (µg/L) measured by Iowa State Limnology Laboratory (ISULL) and Clear Lake Enhancement and Restoration Project (CLEAR) within the main basin of Clear Lake from 2000-2012.

| Parameter | Project | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Secchi | ISULL | 1.3 | 2.3 | 2.6 | 4.6 | 1.6 | 1.6 | 1.6 | 3.9 | | 2.0 | 2.3 | 3.0 | 2.0 |
| | CLEAR | | | | | 1.8 | 1.7 | 1.6 | 2.7 | 2.3 | 2.9 | 2.2 | 3.0 | |
| CHL a | ISULL | 31 | 71 | 30 | 21 | 82 | 82 | 53 | 22 | | 16 | 13 | 16 | 17 |
| | CLEAR | | | | | 47 | 40 | 53 | 33 | 28 | 17 | 22 | 21 | |
| TSS | ISULL | 47 | 28 | 18 | 19 | 21 | 32 | 23 | 13 | | 15 | 16 | 13 | 14 |
| | CLEAR | | | | | 30 | 29 | 28 | 17 | 19 | 12 | 14 | 12 | |
| TP | ISULL | | 101 | 65 | 67 | 77 | 93 | 70 | 46 | | 46 | 58 | 43 | 47 |
| | CLEAR | | | | | 80 | 114 | 91 | 62 | 58 | 62 | 55 | 50 | |

## Discussion

Biomanipulation is considered to be the lynchpin for shallow lakes renovation (Scheffer 1998). Biomanipulation is simply the alteration of an extant fish community to encourage the development of a clear water, macrophyte dominated ecosystem. Biomanipulation has been successfully used to renovate shallow lakes in Europe (Faafeng and Brabrand 1990; Hosper 1989; Lauridsen et al. 1994) and in the United States (Shapiro and Wright 1984). Early biomanipulation experiments focused on “top-down” effects. This biomanipulation approach involves removal of a large quantity of planktivore and benthivore fish biomass, which consequently increases zooplankton abundance, decreases phytoplankton abundance, and improves water quality (Shapiro et al. 1975; McQueen et al. 1986). In Denmark the extent of fish removal during biomanipulation experiments in 20 lakes varied from 5-80% of the total fish biomass (Sondergaard et al. 2000). These researchers recommend removing at least 75% of the biomass of planktivorous and benthivorous fishes to help ensure a successful shallow lake renovation.

In this study, Black Bullhead and Common Carp biomass was removed primarily via rotenone application to Ventura Marsh. After the removal effort, water clarity within the marsh increased as a result of decreased suspended sediment and phytoplankton biomass. However, these applications only temporally reduced benthivore biomass and few long-term water quality improvements were achieved within the marsh (Clear Lake Enhancement and Restoration Project 2004). Within Clear Lake, however, significant changes in the benthivorous fish community were observed throughout the study period. Most notably, Black Bullhead density and biomass decreased by ~99%. This trend was also documented via annual creel surveys conducted between 1953 and 2012 (Grummer et al. 2012). From 1970 to the mid-1990s, Black Bullhead comprised on average 77% of the fish harvested in Clear Lake. By 2005, this rate decreased to 38%, and by 2012, < 0.03% of the total fish harvest was Black Bullheads (Grummer et al. 2012). Clearly, such a drastic change within the fish community could have major implications on fish community interactions and water quality characteristics. We are unsure as to the mechanisms behind such a drastic decline in Black Bullhead abundance in Clear Lake. Our efforts to reduce biomass via rotenone treatment to a marsh were not substantial enough to warrant such a decrease in abundance, thus suggesting that other factors were contributing more to the Black Bullhead demise. Interestingly, a similar trend in abundance or harvest patterns has also been observed in many other shallow natural lakes (Hawkins and Hawkins 2012; Ryan Doorenbos, MN DNR, personal communication) and large river systems (Daniel Dieterman, MN DNR, personal communications) within the Midwest. No study has evaluated the underlying mechanisms behind the demise of Black Bullhead populations. A study conducted in six Minnesota shallow lakes observed significant inverse relationship between Black Bullhead and catfish abundance in four of the lakes investigated (Schultz 2008). Channel catfish fingerlings (7-8 in) have been stocked in Clear Lake at relatively high densities (1.6-9.2 fish/ac) since 1990, yet very few anglers have targeted channel catfish (Grummer et al. 2012). Current channel catfish population levels in Clear Lake are unknown; however, considering past and recent stocking rates coupled with low harvest rates, predator-prey relationships may have been partially responsible for the decrease in Black Bullhead abundance. Black Bullheads occur in a variety of habitats but are most abundant in habitats with turbid water, a silt bottom, little water current, and low fish diversity (Pflieger 1975) and can thrive in systems that experience periodic winterkills. Regional water quality improvements have been made since the implementation of the Clean Water Act in 1972, thus potentially altering the aquatic habitat where Black Bullheads once thrived. Improvements in water clarity could substantially increase young bullhead predation (e.g., reproductive failure) because of their conspicuous nature. However, this phenomenon is likely multi-faceted and may be a result of water quality improvements, predator-prey relationships, fish pathogens or disease, agricultural chemical runoff, and/or climate change patterns.

Common Carp biomass fluctuated during the study despite rotenone application in Ventura Marsh and periods of high commercial harvest. In fact, estimated Common Carp biomass was at its highest levels immediately following the three rotenone applications. After 2007, Common Carp biomass remained relatively stable; however, the number and mean size of fish captured substantially differed from early estimates. The changes in mean size and abundance could be related to periods of pulsed high commercial harvest that occurred during 2003-2004 and 2007-2008. Colvin et al. (2012) found relatively short Common Carp doubling time in Clear Lake during periods of pulsed commercial fishing and this may explain why commercial fishing harvest in inland lakes is rarely successful (Wydoski and Wiley 1999). Most biomanipulation projects where Common Carp biomass was reduced by <75% have been unsuccessful in the long term (Meijer et al. 1998). Although we did not document a substantial decreasing trend in Common Carp biomass, there was a marked decrease (52-60%) in biomass when we compared pooled data for 1999-2004 and 2007-2012. However, these levels were still much lower than what others have documented for successful biomanipulation via Common Carp removal.

Spatial analysis of trawl data via GIS tools proved to be a valuable technique to identify spatial and temporal aggregations of both Black Bullhead and Common Carp. A concurrent radio telemetry study of adult Common Carp in Clear Lake found very similar areas of Common Carp aggregation during July and September/October as we did using georeferenced otter trawl density estimates and spatial analysis algorithms (Penne and Pierce 2008). Identification of Common Carp aggregations has led to more efficient fishing and a reduction in fishing effort (Colvin et al. 2010; Bajer et al. 2011).

Of the two water quality monitoring programs for Clear Lake, significant improvements in secchi disk depth, chlorophyll a, total suspended solids, and total phosphorus were documented by one, if not both programs during the study period. We did not document any correlations among Common Carp density or biomass with any water quality parameter and only a few significant correlations were detected among Black Bullhead density or abundance and water quality. Some of the inability to detect trends may have been attributed to the lack of trawling and mark-recapture biomass estimates between 2004 and 2006, thus reducing sample size for the analysis. Although substantial changes occurred in both water quality and benthivorous fish community dynamics, we were unable to relate the two directly. Other factors, or a combination of multiple factors were likely responsible for the drastic changes in water quality improvements within Clear Lake.

In many biomanipulation experiments, managers use adaptive management strategies and often multiple techniques are implemented shortly after each other to more quickly achieve their management goal (Sondergaurd et al. 2007). Unfortunately, these strategies make it difficult to discern the effects of any individual measure. Multiple changes within Clear Lake's biotic and abiotic environment occurred during the study period. One of those significant changes was the establishment of a viable population of invasive zebra mussels *Dreissena polymorpha*. Adult zebra mussels were discovered in Clear Lake in August of 2005 and by 2007 zebra mussels were found on all Dendy-Hester settlement samplers (Jim Wahl, IA DNR, personal communication). Zebra mussels are voracious filter feeders that can very effectively remove organic and inorganic matter from pelagic habitats (Chase and Bailey 1999; Garton et al. 2005). Soon after a zebra mussel invasion, lakes typically show increases in water clarity, benthic macroinvertebrates, macrophytes, and benthic primary production (Yu and Culver 2000; Idrisi et al. 2001), whereas phytoplankton and zooplankton biomass declines (Horgan and Mills 1999; Idrisi et al. 2001; Mayer et al. 2002). Zebra mussels are so efficient at filtering seston particles that they have been used in biomanipulation experiments to increase water clarity (Reeders and Bij de Vaate 1990). Water clarity in Clear Lake improved substantially in 2007 and became less variable, immediately following zebra mussel colonization. Correspondingly, aquatic macrophyte abundance has increased substantially (Scott Grummer, IA DNR, personal communication). Zebra mussels can have negative effects on water quality by excreting large quantities of phosphorus that can return to the water column and become available for processes such as cyanobacteria blooms (Vanderploeg et al. 2001, Conroy et al. 2005). Total phosphorus levels in Clear Lake have significantly decreased post-infestation, thus suggesting that zebra mussel densities may be too low to substantially influence total phosphorous concentration or other biological processes are sequestering these nutrients.

In addition to the invasion of zebra mussels, the Clear Lake Dredging Project began in 2008 and was completed in 2009. This dredging project removed 2.4 million cubic yds of sediment from the Little Lake to act as a sediment and nutrient trap for water flowing into the lake from Ventura Marsh. The mean depth of the Little Lake increased from 6ft to more than 20ft as a result of the dredging project. Sediment dredging has been a popular technique to combat eutrophication in Denmark, the Netherlands, and also within lakes and reservoirs across the United States (Cooke et al. 2005; Sondergaurd et al. 2007; Zhang et al. 2009). In general, sediment removal resulted in reduced phosphorous, total suspended solids, Chlorophyll a, and increased transparency in lakes (Van der Does et al. 1992; Zhang 2009), all of which were recent documented trends within Clear Lake.

The improvements in water quality observed over the course of this study are obviously multi-faceted and cannot be thoroughly understood because of the dynamic nature of the processes involved and the suite of management activities currently employed. However, despite the inability to overwhelmingly correlate water quality trends to population density of Black Bullhead or Common Carp, the interaction of these species within the fish community and its cascading effects are likely partially responsible for water quality improvements. The infestation of zebra mussels in 2005 in conjunction with watershed and in lake (e.g. dredging) improvements may have contributed more to the improvements in water quality than that of fish population changes in density. However, the fact that improvements in water quality were made suggest that Black Bullhead and Common Carp densities may have been a contributor to increased water quality in Clear Lake and periodic monitoring of these species may be required to observe population levels. Since this study found significant correlations between Common Carp otter trawl biomass estimates and mark-recapture biomass estimates, trends in Common Carp biomass can easily be monitored via annual otter trawling assessments to help managers quickly identify periods of increased abundance. This information would be beneficial to managers that wish to utilize commercial harvest subsidies for Common Carp so that densities are maintained at a lower, less destructive, level.

## Management Implications and Recommendations

The application of rotenone in Ventura Marsh was not an effective technique to control benthivore fish densities in Clear Lake. Factors other than selected fish eradication were responsible for the demise of Black Bullhead populations and Common Carp densities were not substantially impacted by any of the rotenone applications. Fish exclusion to prime reproductive habitats via fish barriers and subsidized commercial harvest may be more appropriate for large, shallow lakes with high common carp doubling rates, such as Clear Lake.

Significant correlations between Common Carp otter trawl biomass estimates and mark-recapture biomass estimates were detected. Common Carp biomass trends should be periodically monitored via otter trawling to help managers quickly identify periods of increased abundance. This information would be beneficial to managers that wish to utilize commercial harvest subsidies for Common Carp so that densities are maintained at a lower, less destructive, level.

Spatial analysis of trawl data via GIS tools proved to be a valuable technique to identify spatial and temporal aggregations of fishes. Maps from this study can be used to advise recreational and commercial anglers. This approach should be used on other systems where limited information on Common Carp temporal and spatial aggregation areas exists.

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