Final Report to the State Wildlife Grant Program
Lake Christina Reclamation: Ecosystem Consequences of Biomanipulation

Project Collaborators:

Mark A. Hanson
Wetland Wildlife Populations & Research Group, MNDNR
Bemidji, MN

Joseph Allen
Department of Biological Sciences
North Dakota State University, Fargo, ND

Deborah Buitron
Department of Biological Sciences
North Dakota State University, Fargo, ND

Malcolm G. Butler
Department of Biological Sciences
North Dakota State University, Fargo, ND

Todd Call
MN DNR
Glenwood, MN

Thomas Carlson
MN DNR
Fergus Falls, MN

Nicole Hansel-Welch
MN DNR
Brainerd, MN

Katie Haws
MDNR
Bemidji, MN

Melissa Konsti
Department of Biological Sciences
North Dakota State University, Fargo, ND

Dan McEwen
Department of Biological Sciences
North Dakota State University, Fargo, ND

Gary Nuechterlein
Department of Biological Sciences
North Dakota State University, Fargo, ND

Kyle D. Zimmer
Department of Biology
University of St. Thomas, St. Paul, MN

Contents

I. Background and Project Description

Lake Christina, a 3949-acre shallow lake in Douglas County in west-central Minnesota, is nationally recognized as a critical staging area for migrating canvasbacks, and also is a breeding location for a number of unique nongame bird species. Since the 1950s, the lake has alternated between ecological extremes, sometimes characterized by favorable conditions, and at other times of little use as waterfowl habitat. Sustained high water and dense populations of undesirable fishes are believed to be associated with shifts toward high turbidity and other unfavorable limnological characteristics, along with extreme habitat deterioration for waterfowl and other wildlife. Twice previously, and following obvious trends of habitat deterioration (1965, 1987), the lake was "reclaimed" via chemical removal of fish. Extensive scientific monitoring was conducted in association with the 1987 treatment. Limnological and waterfowl-use data were gathered before and after 1987 to assess the nature and causal mechanisms associated with observed changes. Dramatic improvements in water quality features, extensive development of submerged aquatic plants, and increased fall use by migrating ducks followed the 1987 reclamation (Hanson and Butler 1994a,b). Data gathered before and after treatment contributed to improved understanding of ecology and management potential of shallow lakes in North America. Unfortunately, data gathering efforts at Lake Christina have since dwindled, more or less at the same time as habitat quality and suitability for wildlife has again declined. During 2000-2003, water clarity, distribution of submerged macrophytes, and fall use by migrating ducks all indicated that the lake had again stabilized in a deteriorated condition characterized by poor water quality, a sparse community of submerged macrophytes, and limited suitability for diving ducks and other wildlife species. In attempt to stimulate a limnological shift to more favorable habitat conditions, fish were again removed from Lake Christina using rotenone during October 2003. Here, we summarize responses of fishes, limnological features, and wildlife use during 2004-05, the first two years following the fish removal. Although this is a final project report, manuscripts for publication will be developed from these data and interpretations and synthesis here are subject to change pending further data collection and analysis.

We believe the environmental conditions observed during 2004-05 indicate that Lake Christina has entered a period of transition, and is tending back toward the clear-water state. Our results indicated presence of a persistent fish community during spring 2004, approximately 6 months after the October 2003 rotenone treatment. Data presented here also indicated that recruitment by remnant fish was very strong and that, by 2005, a diverse fish community was again present and included benthivorous, planktivorous, and piscivorous species. Disappointing, but not unexpected, was evidence of rapid recovery by populations of bullheads, carp, and fathead minnows during the 2 years immediately following the rotenone treatment.

However, data gathered during 2004-05 also contain strong signals indicating a move towards more favorable ecological conditions. Concomitant lake-wide trends towards higher water transparency during spring periods, increases in abundance of large-bodied herbivorous zooplankton (*Daphnia*), and changes in abundance and composition of submerged aquatic plants are consistent with outcomes lake managers had hoped to achieve, and with patterns observed following the 1987 rotenone treatment. We note that one of the most encouraging signals we observed following the 2003 rotenone treatment was the sharp increase in *Chara* during the 2004, first post-treatment year. Considerable evidence indicates that such increases in *Chara* often portend major ecological shifts towards a clear-water state in shallow lakes and a similar trend was also observed within a year following the 1987 rotenone treatment at Lake Christina. Finally, we emphasize that even if the over-all lake response is similar to that observed following the 1987 treatment (and triggers a distinct shift to the clear-water state), more dramatic, sustained improvements in water transparency may not be evident until 2006, or even later.

Non-target effects of rotenone in shallow lakes and wetlands may be considerable, but are rarely considered in lake rehabilitation studies. For example, Lake Christina has supported breeding western grebes since the late 1960's and a large population was observed using the lake during 2003. Availability of small prey fishes is considered crucial for successful recruitment of western grebes because adults fly infrequently other than during migration. During 2004, and following the 2003 rotenone treatment, adult western grebes returned to Lake Christina, but quickly abandoned traditional nesting areas and left the lake, presumably due to absence of fishes suitable as prey. By 2005, western grebes returned in large numbers and over 300 nests were identified and monitored. This may indicate that non-target effects of rotenone on some colonial waterbirds should be expected, but are short-term in that breeding waterbird populations return in response to recruitment of young fishes.

Comparison among historical relationships has great potential to help researchers identify signals of transition, thus indicating if and when lake-wide changes are underway. Lake managers have continuing needs to identify limnological signals useful for anticipating periods of rapid change, especially when the lake is entering transition to the turbid-water state. This would facilitate better use of less drastic measures to maintain a clear-water state. For example, since 1999, environmental signs showed evidence that the lake was probably transitioning towards the turbid state. In retrospect, we know that this was true. For example, TP:chl *a* ratios may be important indicators of the ecological state of Lake Christina, and researchers may benefit from monitoring the trends relative to the 3:1 threshold. Alternatively, based on use of indicator species analyses, concern may be justified when higher than usual counts of *Bosmina* occur. Additionally, it may be possible to use the importance values of *Chara* to monitor whether the lake is stable or in transition. If Chara shows sharp lake-wide declines (as it did during the period of 1999-2001, then perhaps the onset of a period of deterioration and a shift to the turbid state may be anticipated.

II. Fall Waterfowl Survey Summaries and Trends (contributed by Nicole Hansel-Welch and Thomas Carlson)

Management of this lake is focused on providing fall waterfowl migration habitat, thus routine fall waterfowl surveys have been conducted on Lake Christina since 1984. Fall use has been highly variable but has increased after previous fish kills. Waterfowl use of Lake Christina had been very low in the years (2000-2003) prior to the 2003 rotenone treatment. Duck use did increase during the first fall after treatment (2004) with peak waterfowl counts reaching 12,650 ducks and geese (compared to 2826 ducks and geese in 2003). In 2005, eight aerial and ground surveys were conducted from late September through mid-November. Total peak duck and geese counts remained very similar in 2005 compared to 2004 at 12,765 (Figure 1). Coot use of the lake more than doubled in 2005 compared to 2004 (Figure 2).

Some interesting comparisons can also be made between 1987 post-treatment data (1988-89) and 2003 post-treatment waterfowl data (2004-05). Diver response showed similar trends following both treatments, but dabbler response was much stronger after the 1987 treatment (Figure 3, 4). In contrast, increased use by coots was much greater following the 2003 treatment (Figure 4). Although these differences in dabbler and coot use are interesting, they are difficult to explain and may reflect regional patterns in migration, habitat features, or other factors.

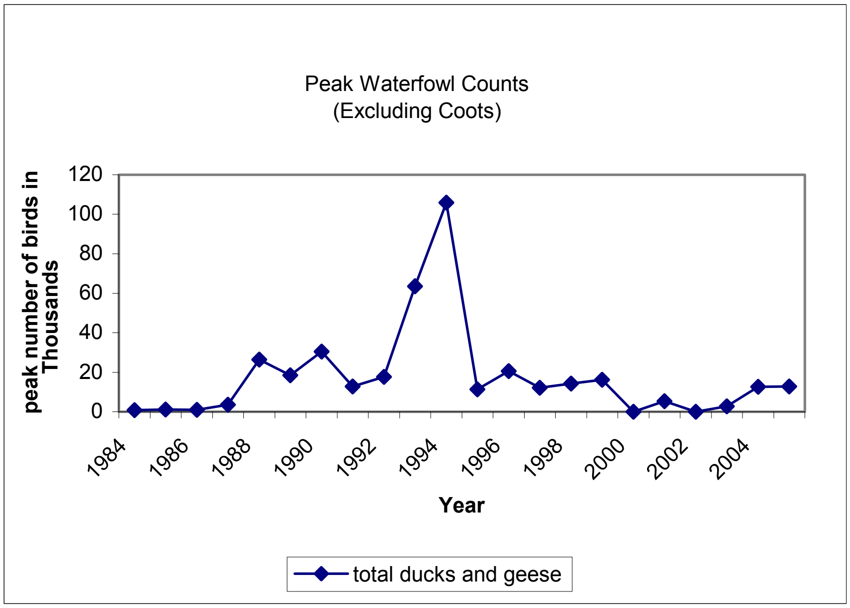


Figure 1. Annual peak waterfowl estimates for Lake Christina during 1984-2005 (plotted values do not include coots).

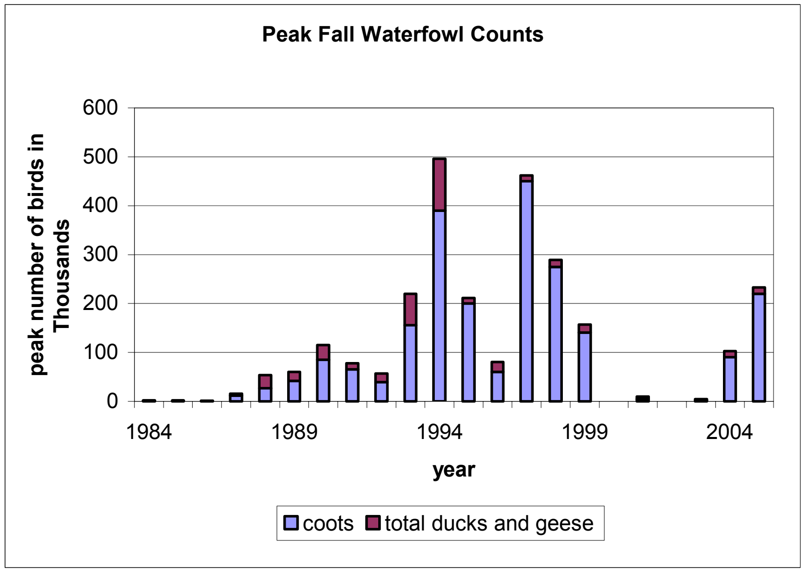


Figure 2. Annual peak waterfowl estimates for Lake Christina during 1984-2005 (plotted values do include coots).

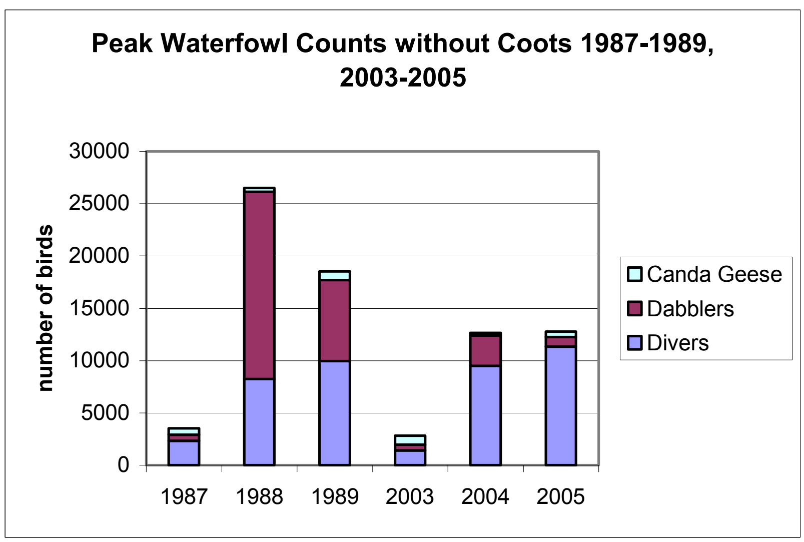


Figure 3. Annual peak water waterfowl estimates (including Canada Geese) during 3-year periods associated with two previous rotenone treatments (1987-1989, left bars, and 2003-2005, right bars). Plotted values do not include peak coot counts.

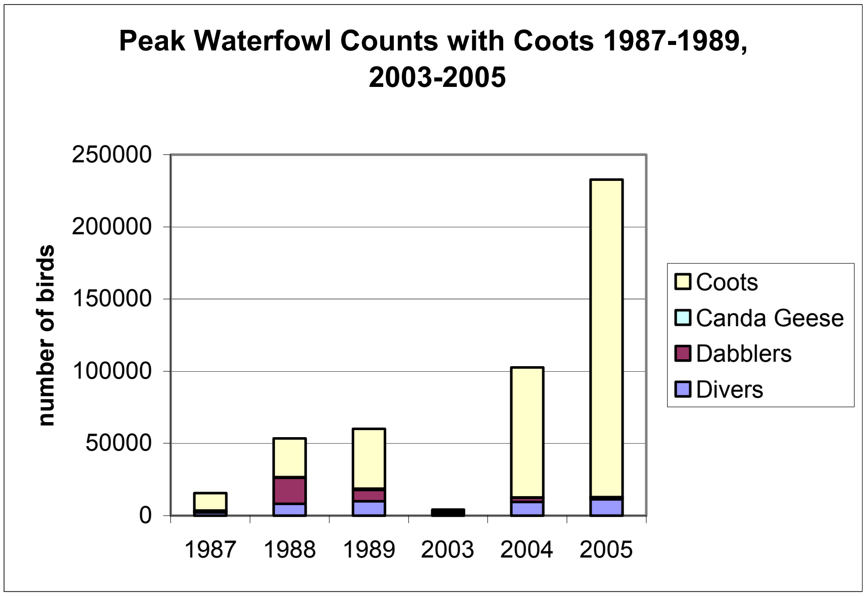


Figure 3. Annual peak water waterfowl estimates (including Canada Geese) during 3-year periods associated with two previous rotenone treatments (1987-1989, left bars, and 2003-2005, right bars). Plotted values include peak coot counts.

III. Post-Treatment Assessment of the Fish Community in Lake Christina (contributed by Melissa L. Konsti, Michelle L. Verant, Todd Call, and Kyle D. Zimmer)

INTRODUCTION

Fish populations have large influences on ecological processes and the structure of lake ecosystems (Carpenter and Kitchell 1993). Fish communities have been found to influence the structure of invertebrate communities (DeVries and Stein 1992, Hanson and Riggs 1995), phytoplankton communities (Spencer and King 1984, Vanni and Layne 1997), water clarity (Meijer *et al*. 1990, Scheffer *et al*. 1993), and nutrient cycling (Kraft 1992). One relationship that has been observed is that dense populations of planktivorous fish are commonly associated with high phytoplankton abundance, leading to high turbidity (Andersson et al. 1978, Hanson and Butler 1994).

Shallow lake ecosystems can exist in either of two alternative stable states (Scheffer *et al*. 1993). The clear-water state is characterized by an abundance of aquatic plants, while the turbid-water state is dominated by algae (Scheffer *et al*. 1993). Catastrophic shifts between these states can occur naturally and have been linked to changes the fish community. Natural winterkills causing a lake-wide fish reduction are one mechanism promoting a shift to the clear state. The resulting decrease in planktivorous fish favors an increase in large zooplankton populations, decreased algal biomass, improved water clarity, and enhanced growth of macrophytes. The vegetation then acts as a stabilizer in suppressing algal growth and maintaining the clear state (Scheffer *et al*. 2001).

Biomanipulation based on intentional fish reduction has been successful in shifting many lakes from the turbid state to the more desirable clear-water state (Meijer *et al*. 1994). Lake Christina, a 1598 ha shallow lake in Douglas County in west-central Minnesota, is nationally recognized as a critical staging area for migrating canvasbacks, and also is a breeding location for a number of unique non-game bird species. Since the 1950s, the lake has alternated between ecological extremes, sometimes characterized by favorable conditions for waterfowl habitat, and at other times characterized as degraded waterfowl habitat. Sustained high water and dense populations of undesirable fishes are believed to be associated with shifts toward high turbidity and other unfavorable limnological characteristics, resulting in extreme habitat deterioration for waterfowl and other wildlife.

Lake Christina was treated with rotenone in 1987 to induce a fish kill, and stocked with piscivores. Dramatic improvements in water clarity features, extensive development of submerged aquatic plants, and increased fall use by migrating ducks followed the 1987 reclamation. The lake had switched to the clear-water state (Hanson and Butler 1994).

Following the 1987 treatment, the response and succession of the fish community was never thoroughly assessed. The lake reverted back to the turbid state in 1999-2000, after a decade of clear water. The cause of this switch is not known because, unfortunately, data gathering efforts at Lake Christina had dwindled prior to the shift. In October of 2003, Lake Christina was treated again with rotenone to induce a fish kill. The goal of this current study was to monitor the fish community after the biomanipulation to better understand their ecological role in determining whether the lake is clear- or turbid-water state. We examined the response of Lake Christina's adult, juvenile, and larval fish community during 2004 and 2005, the two years following treatment.

METHODS

Fish Community

The adult, juvenile, and larval fish community was assessed from May through August in 2004 and 2005 using gill nets, trap nets, beach seines, minnow traps, larval fish tows, and boom electrofishing (pulsed DC). The fish species present, their densities, and growth and recruitment over the sampling period were determined for each trapping method.

Gill nets (76.2 m multifilament net with 19, 25, 32, 38, and 51-mm bar meshes) were set for 24 hours at six locations to determine the species of fish present and their relative abundance in the open water in early-June and mid-August of each year. Fish captured were identified by species and counted. In addition, total length of up to 25 randomly selected individuals was measured.

Trap nets (9.5 mm bar mesh with 4 hoops, 2 throats, 7.62 mm lead, and a 0.69 X 0.99 rectangular frame opening into the trap) were set for 24 hours, at 20 locations along the shoreline to better sample larger littoral zone fish in early-June and mid-August of each sampling year. Fish captured were identified by species and counted. In addition, total length of up to 25 randomly selected individuals was measured.

Beach seining was used to sample a 200 m^2 area at 13 shoreline stations selected in a stratified-random manner to obtain density estimates of medium- to small-sized fish. In 2004, seining occurred once every two weeks, for 12 weeks. Seining effort was reduced to once every four weeks in 2005 due increased fish abundance. Fish captured were identified by species and counted. In addition, total length of 5 randomly selected individuals was measured.

Minnow traps (154 mm X 154 mm X 459 mm, 13 mm mesh, unbaited) were set overnight at 40 stratified-random locations along the shore every two weeks in both sampling years. Fish captured were identified by species and counted. In addition, total length of 5 randomly selected individuals was measured.

Larval fish tows, filtering approximately 500 m^3 of water, were taken at 15 stratified-random shoreline locations and five open water stations to determine larval fish densities. We determined the total number of larval fish at each station.

Boom electrofishing (pulsed DC) occurred once in June, 2004 at 26 shoreline stations, for a total of 104 minutes. Similar sampling was conducted in July, 2005 at 21 shoreline stations, for a total of 94 minutes. Species present at each station were identified and counted, and total length of up to 10 randomly selected individuals was measured.

Analyses

For each sampling technique we averaged the total number of fish for each date sampled. From this we determined how the total number of fish and various species varied between years and within each year. We summarized the length data to determine frequency of length across each species between 2004 and 2005, by combining all total lengths taken from each sampling technique. From this we were able to assign how many cohorts were present for each species during each year.

RESULTS

Black bullhead was the most abundant species captured in 2004 and 2005 (Table 1). Black bullhead gill net catches averaged 239.1 fish/net in May and 124.7 fish/net in August of 2004. Black bullhead gill net catches were lower in 2005, averaging 58.3 fish/net in May and 44.2 fish/net in August. Northern pike developed a strong year class in 2004. Gill net catches increased from 0.0 fish/net in May to 8.0 fish/net in August. Gill net catches averaged 23.7 fish/net in May and 24.7 fish/net in August of 2005, after cohorts of this 2004 year class were large enough to be fully vulnerable to the sampling gear. Common carp were also relatively abundant in gill net catches. The total number of species captured in gill nets increased from six in 2004 to 10 in 2005.

Table 1. Gill net catch per unit effort (number/net) per species. Effort was six gill nets per sampling period.

Species	**May 2004**	**August 2004**	**May 2005**	**August 2005**
Bigmouth buffalo	0.3	9.8	1.8	1.5
Black bullhead	239.1	124.7	58.3	44.2
Black crappie	0	0	0	0.2
Bluegill	0	0.2	0	0.3
Common carp	0	24.5	8.0	22.7
Green sunfish	0	0	0	0.2
Northern pike	0	8.0	23.7	24.7
Pumpkinseed	0	0	0.2	2.0
White sucker	0	0	0	1.7
Yellow perch	0	0.5	0.5	2.8

Black bullhead was also the most abundant species captured in trap nets (Table 2). Black bullhead catches averaged 169.2 fish/net in May and 120.1 fish/net in August of 2004. Black bullhead trap net catches averaged 125.6 fish/net in May of 2005, but dropped to 40.5

fish/net in August of 2005. Common carp were also relatively abundant in trap net catches. Trap net catches averaged only 0.2 fish/net in May of 2004, but increased to 21.7 fish/net in August of 2004. Catch rates averaged 14.5 and 15.2 common carp/net in May and August of 2005. The total number of species captured in trap nets increased from 10 in 2004 to 14 in 2005.

Table 2. Trap net catch per unit effort (number/net) per species. Effort was twenty trap nets per sampling period.

Species	**May 2004**	**August 2004**	**May 2005**	**August 2005**
Bigmouth buffalo	<0.1	<0.1	1.1	0.6
Black bullhead	169.2	120.1	125.6	40.5
Black crappie	<0.1	0	0.1	0.2
Bluegill	0.7	0.2	1.8	6.7
Brown bullhead	0.5	0.6	0.2	1.4
Common carp	0.2	21.7	14.5	15.2
Green sunfish	0	0	0	<0.1
Hybrid sunfish	0	0	0	0.1
Largemouth bass	0	<0.1	0	0.1
Northern pike	0.2	2.7	2.5	2.2
Pumpkinseed	<0.1	0	0.2	2.7
White sucker	0	0	0	0.1
Yellow perch	0	0.1	<0.1	0.3
Walleye	0	0	0	<0.1

Beach seine results showed that fish density (fish/m^2) in the littoral zone of Lake Christina increased 26-fold in one year, increasing from 0.1 in 2004 to 2.6 in 2005 (Fig. 1). Eighteen species representing nine families were present in the lake (Table 3). The following species were consistently abundant in both sampling years: black bullhead (*Ictalurus melas*), brook stickleback (*Culaea inconstans*), fathead minnow (*Pimephales promelas*), and banded killifish (*Fundulus diaphanous*). Common carp (*Cyprinus carpio*), northern pike (*Esox lucius*), and central mudminnows (*Umbra limi*) were more abundant in 2004 than in 2005. Most cyprinids (e.g. *Lepomis macrochirus*) and percids (e.g. *Ethiostom*a sp.) were more abundant in 2005 than 2004. The remaining fish species did not show up until late in 2004 or early 2005 (e.g. *Luxilus cornutus*).

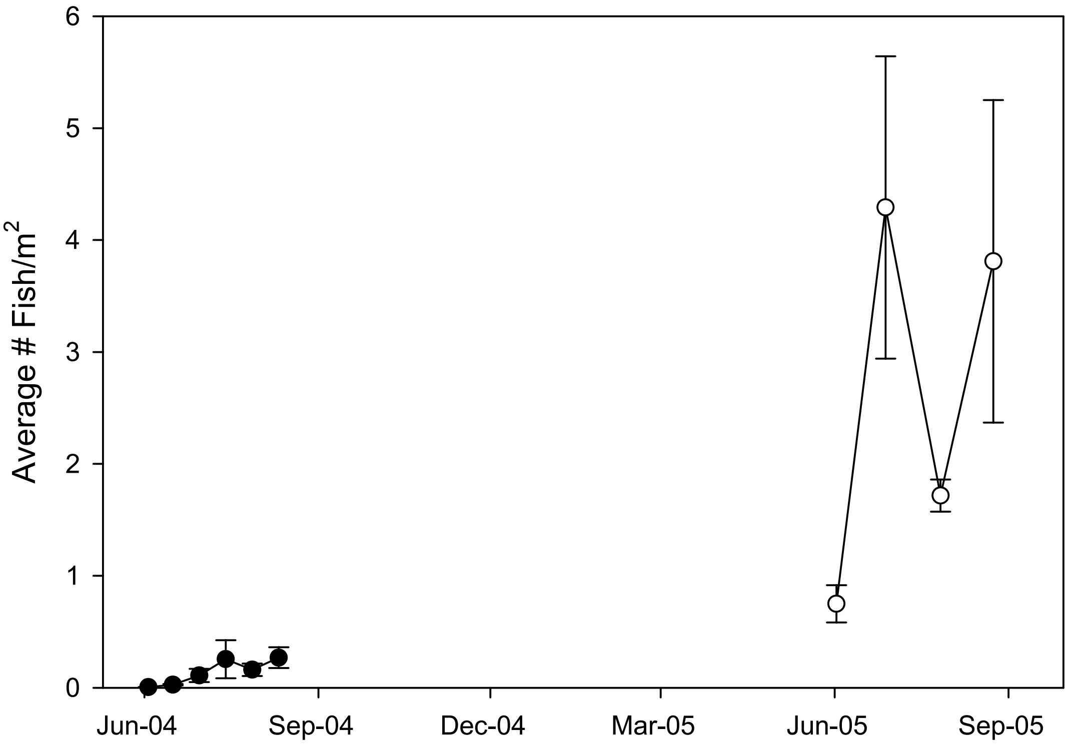


Figure 1. Beach seine results for 2004 and 2005 (average fish/m^2) (+/- 1 SE).

Table 3. Average percent fish abundance in beach seines across dates.

	2004						2005			
Species	3-Jun	16-Jun	30-Jun	14-Jul	28-Jul	11-Aug	2-Jun	28-Jun	27-Jul	24-Aug
Ictalurus melas (Rafinesque)	**33**	**24**	6	4	**18**	5	**27**	**15**	1	1
Culaea inconstans (Kirtland)	**11**	**34**	4	7	**33**	**18**	3	**59**	**36**	**11**
Pimephales promelas (Rafinesque)	**11**	**18**	**68**	**75**	**17**	**38**	**49**	**20**	**48**	**70**
Fundulus diaphanous (Lesueur)	**44**	**16**	2	2	3	**16**	**15**	2	3	5
Lepomis macrochirus (Rafinesque)	0	3	1	0	4	**19**	3	2	2	4
Cyprinus carpio (L.)	0	0	**16**	**10**	**14**	2	0	0	<1	0
Esox lucius (L.)	0	3	1	<1	0	<1	0	0	0	0
Ictiobus cyrinellus (Valenciennes)	0	0	3	0	0	<1	0	0	0	0
Umbra limi (Kirtland)	0	4	0	<1	2	<1	0	<1	0	0
Lepomis gibbosus (L.)	0	0	0	<1	0	<1	0	2	<1	<1
Lepomis cyanellus (Rafinesque)	0	0	0	0	0	0	0	<1	0	<1
Notropis hudsonius (Clinton)	0	0	1	<1	0	0	0	0	0	<1
Perca flavescens (Mitchill)	0	0	0	<1	1	<1	0	<1	1	<1
Ictalurus nebulosus (Lesueur)	0	0	0	0	3	0	0	0	0	0
Ethiostoma sp. (*nigrum* & *exile*)	0	0	0	0	4	1	<1	<1	8	2
Micropterus salmoides (Lacepède)	0	0	0	0	<1	<1	0	0	0	0
Luxilus cornutus (Mitchill)	0	0	0	0	0	0	4	1	1	6

Minnow trap results also showed an increase in abundance of fish (average fish per minnow trap) from 1.04 in 2004 to 15.20 in 2005 (Fig. 2). In 2004, the average fish per minnow trap increased during the summer. Of the nine total species present in 2004, black bullheads (57.1%), bluegills (26.7%), and fathead minnows (9.5%) comprised the majority of the fish captured in minnow traps (Table 4). Fish abundance in minnow traps decreased throughout the summer in 2005. Bluegill (34%), fathead minnow (27%), black bullhead (16%), and brook stickleback (14%) comprised the majority of fish captured in 2005. There was a total of 13 species recorded in 2005.

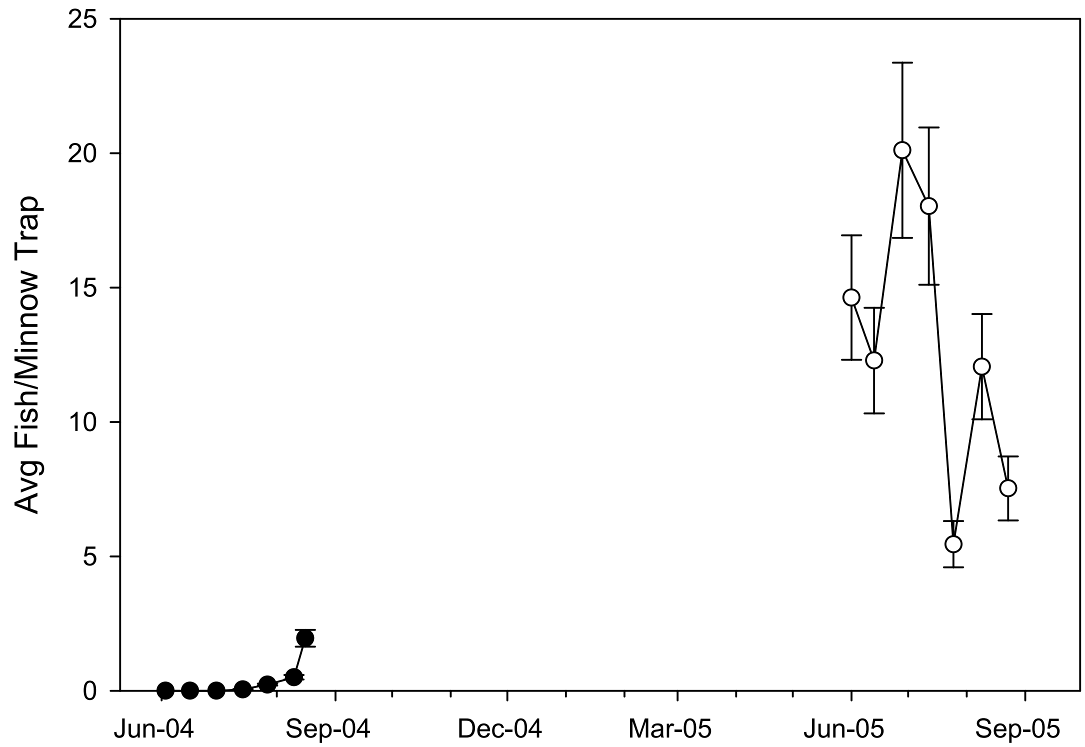


Figure 2. Average fish per minnow trap for 2004 and 2005 summer sampling (+/- 1 SE).

Table 4. Average percent abundance of all species in minnow traps in 2004 and 2005.

Common Name	**2004** (%)	**2005** (%)
black bullhead	**57**	**16**
bluegill	**27**	**34**
fathead minnow	**10**	**27**
brook stickleback	2	**14**
green sunfish	1	2
pumpkinseed	0	5
common carp	4	0
yellow perch	0	1
central mudminnow	0	<1
banded killifish	0	<1
northern pike	0	<1
johnny darter	0	<1
Iowa darter	0	<1

Larval fish densities (average number of fish/m^3) increased from June 2004 to August 2004 (Fig. 3). In 2005, larval fish densities started low in early-June, increased in late-June, and decreased again in mid-July. The rest of the July and August samples still need to be processed for further results in 2005, but there appears to be a similar trend.

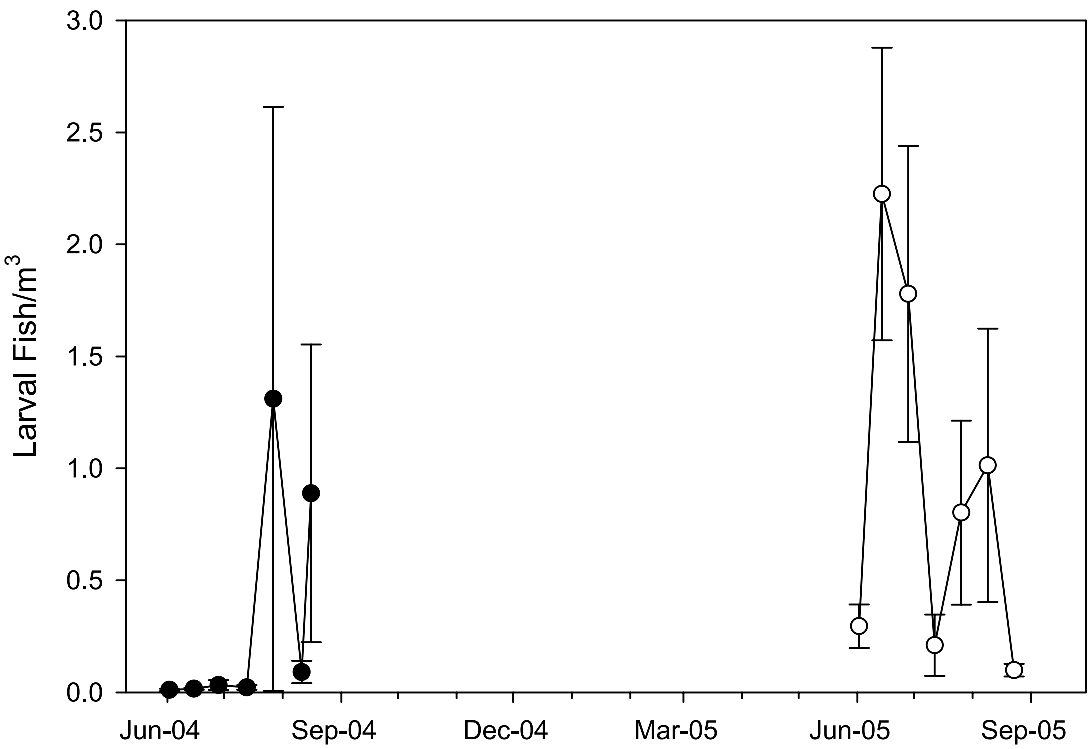


Figure 3. Larval fish tow results for 2004 and 2005 (average larval fish/m^3) (+/- 1 SE).

Electrofishing results showed a significant increase in average number of fish caught per minute of shocking from 4.5 in 2004 to 13.7 in 2005 (Fig 4.). There were only six species of fish captured in 2004, with the black bullhead (4.4) being the most abundant species (Table 5). There were a total of 15 species in 2005, with black bullheads (6.8), fathead minnows (2.7), central mudminnows (1.3), yellow perch (0.7), and bluegill (0.7) being the most dominant species captured.

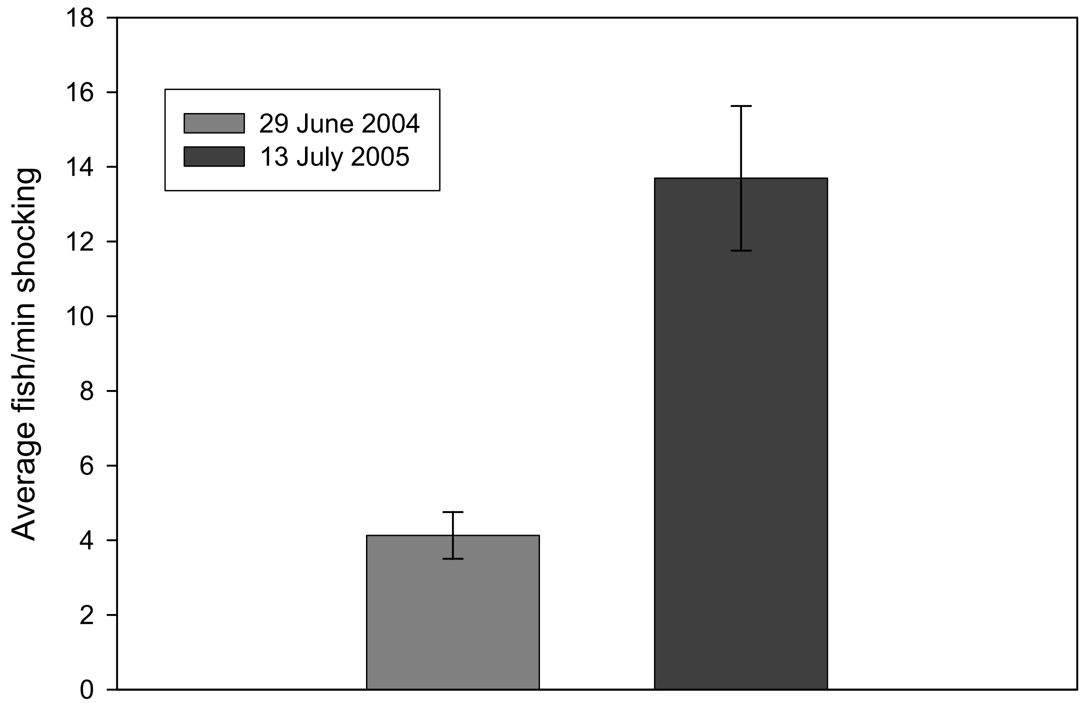


Figure 4. Average fish per minute of shocking for 2004 and 2005 summer sampling (+/- 1 SE).

Table 5. Average number of fish per minute shocking for each species present in Lake Christina in 2004 and 2005.

Fish Species	**June 29, 2004**	**July 13, 2005**
Black Bullhead	**4.4**	**6.8**
Pumpkinseed	<0.1	0.4
Bluegill	<0.1	**0.7**
Northern Pike	<0.1	<0.1
Fathead Minnow	<0.1	**2.7**
Common Carp	<0.1	0.1
Yellow Perch	0	**0.7**
Largemouth Bass	0	<0.1
Central Mudminnow	0	**1.3**
Common Shiner	0	0.3
Green Sunfish	0	0.1
Brook Stickleback	0	0.3
Banded Killifish	0	0.1
Iowa Darter	0	<0.1
White Sucker	0	<0.1
TOTAL	**4.5**	**13.7**

Length data for the black bullhead (Fig. 5) showed two cohorts (age groups) in 2004 and 2005. This trend was also evident for fathead minnows, but the two cohorts were not sharply different in 2005 (Fig. 6). Northern pike had one strong cohort around 250 mm in length in 2004 with some large fish 400-600 mm (Fig. 7). In 2005, the cohort had grown to center around 450 mm. The common carp appeared to have two cohorts in 2004, very close to one another in length (Fig. 8). In 2005, the fish were larger but the two cohorts appeared to have melded to one. The bluegill have one strong young group and a few older individuals (Fig. 9). Banded killifish appeared to have good growth from 2004 to 2005 (Fig. 10).

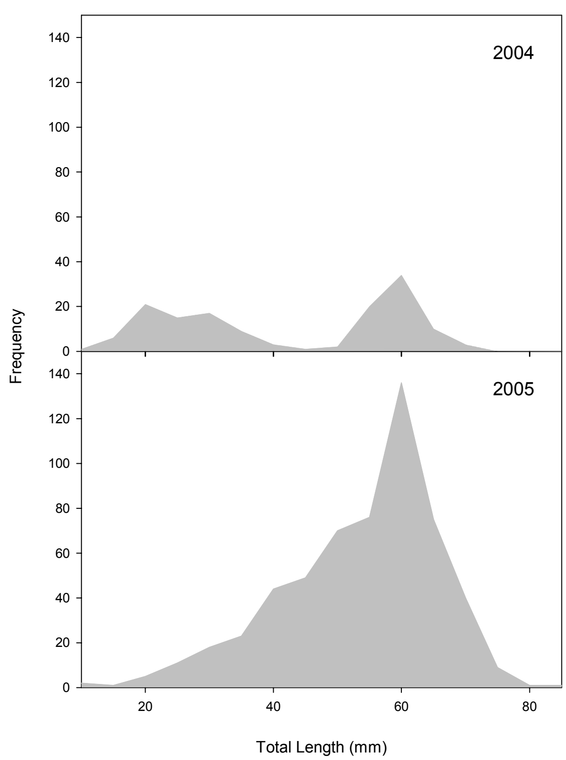


Figure 5. Length distribution of fathead minnow.

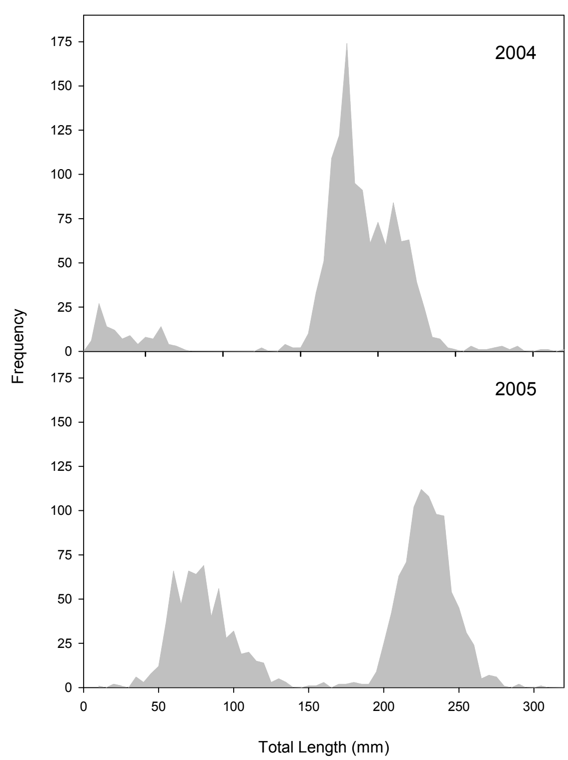


Figure 6. Length distribution of black bullhead.

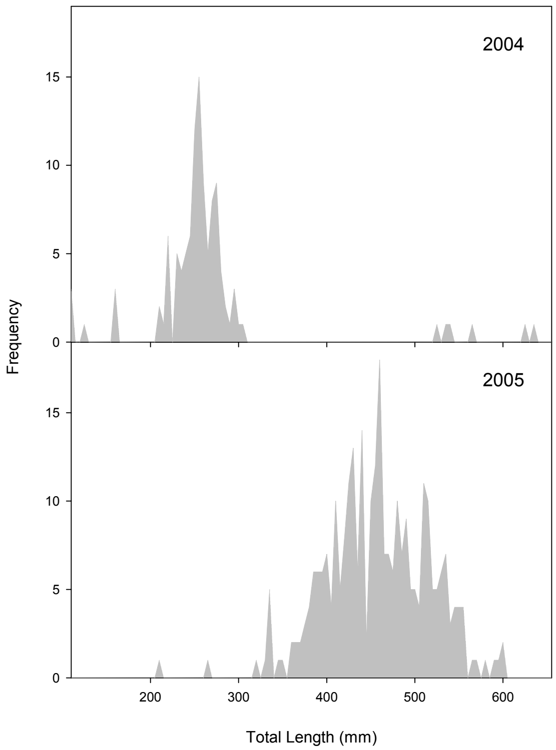


Figure 7. Length distribution of northern pike.

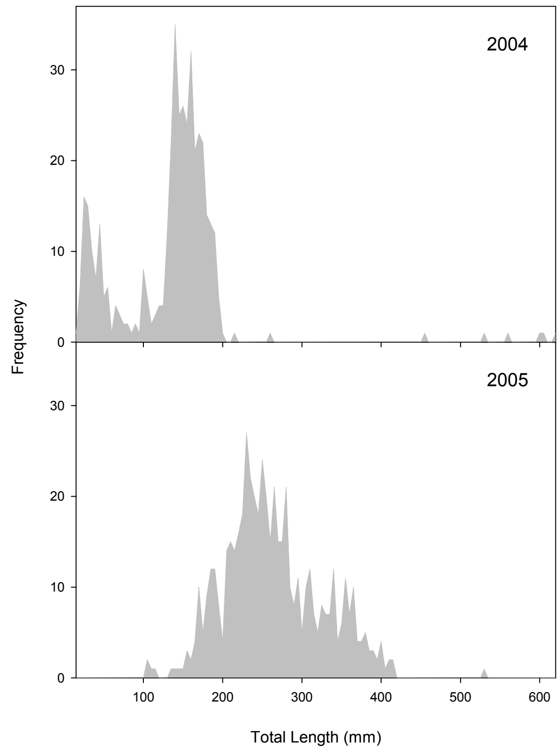


Figure 8. Length distribution of common carp.

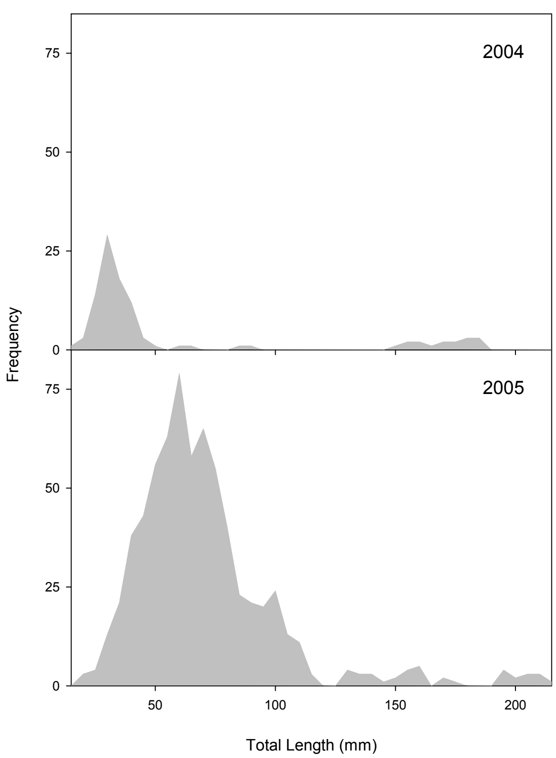


Figure 9. Length distribution of bluegill.

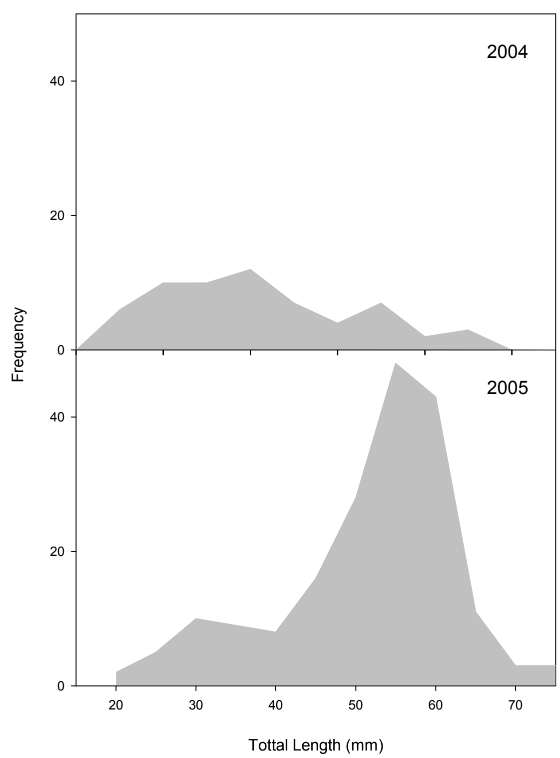


Figure 10. Length distribution of banded killifish

DISCUSSION

Fish Abundance

The results of the biomanipulation were as anticipated. We did not expect the rotenone treatment to remove 100% of the fish, but results indicated the biomanipulation did dramatically reduce fish abundance in Lake Christina. Fish abundance was low in 2004 (first summer following treatment), specifically in the early summer (June), but increased by August. In 2005, we observed a substantial increase in overall fish abundance. We expected to see this type of response in fish abundance. Fish populations in finite environments such as lakes are usually limited by competition for resources, such as food (Romare 2000). When density of fish is reduced, competition pressure is lowered and the recruitment of year class improves (Hansson *et al*. 1998). Following the treatment, fish density was low, but increased throughout the summer with recruitment. The next summer population growth increased even more, as again numbers are relatively low and space and resources are available for more fish. Very few young-of-the-year fish were recorded in 2004, indicating that recruitment following the treatment was minimal for most fish. In 2005, these larval fish increased in abundance, indicating that more fish were reproducing.

Fish Species Present

Overall, the species that were most persistent following the treatment were black bullhead, fathead minnow, bluegill, and brook stickleback. We expected the black bullhead to be the most numerous due to its ability to survive in low oxygen conditions, and its high reproductive rate. Fathead minnows reproduce multiple times during the year with large numbers of offspring, therefore, they were able to increase and thrive post-treatment. Bluegill are aggressive fish and are able to out-compete other fish species when resources are limiting

(Polis *et al.*1989). They are also omnivorous, therefore, can survive on whatever food resource is available. Brook sticklebacks are also very hardy fish and can survive in the murky, low oxygenated, water that was observed in 2004.

The community assemblage shifted from benthivore dominance in early 2004, to a more diverse community of benthivores, piscivores, and planktivores later in 2004 and 2005. In 2005, the number of fish caught in the minnow traps increased from nine (in 2004) to 13. The number of fish species caught increased from 2004 to 2005, probably because some of the fish in 2004 were not yet large enough to be trapped. Beach seining was more effective in catching all species present since 16 species were caught in 2004, and 18 species in 2005. The beach seine has a smaller size mesh than the minnow traps, and was therefore able to catch the smaller/younger fish in 2004. We think that all fish species seen in 2005 were present in 2004, but at very low numbers and small size, making them difficult to catch.

Length Distribution of Fish

For many species, we found there to be two cohorts persisting throughout 2004 and 2005. This indicates that adults were able to survive the treatment and reproduce the following year (2004). Northern pike and common carp were two species that appeared to have only one cohort in both 2004 and 2005. These fish may not have reached sexually maturity by the summer, or were more focused on growing versus reproducing. Their sizes in 2004 seemed to be in between young fish and adults. Both species (pike and carp) grew dramatically between years, and may begin allotting energy towards reproduction in the following years.

The fish community within a lake plays a large role in determining whether the lake will be in a clear- or turbid-water state. Spencer and King (1984) found that ponds with fathead minnows and brook sticklebacks were dominated by intense algal blooms and had very low zooplankton biomass. A pond without fish and a pond with a dense population of large largemouth bass (piscivore) had very low phytoplankton biomass, but supported dense populations of submerged macrophytes due to the high water transparency. Since the fish community in Lake Christina dominated by fatheads and bullheads immediately after the treatment (survey conducted by SDSU), we assume fathead minnows played a large role in keeping this lake in the turbid state (allowing phytoplankton to dominate), while the bullheads were associated with digging in the sediment, and uprooting macrophytes.

The results of this study corroborate those of other biomanipulation studies. Other studies have found that rotenone was successful in reducing or eradicating fish populations (Hanson and Butler 1994, Rowe and Champion 1994). Black bullhead and fathead minnow are the most tolerant species to rotenone toxicity. Various combinations of nets, electro-fishing, and lake de-watering have also been used to reduce fish in successful biomanipulation projects (Van Donk *et al*. 1989, Meijer *et al*. 1990). It is difficult to compare our results to other studies, since the fish community in each individual lake varies, as does the method used to remove fish. Also, many biomanipulation studies included stocking the lake with piscivores after the chemical treatment (Shapiro and Wright 1984), which was not feasible in this study, but was done after the 1987 Lake Christina treatment.

Our results have important implications for managing these shallow lakes in the clear-water state. The fish community in Lake Christina plays a large role in the abundance of invertebrates and zooplankton, which in turn controls the phytoplankton biomass, and overall water clarity (Hanson & Butler, 1994). Having a better understanding of how to manipulate a fish community in a specific lake is necessary to manage these shallow lakes.

LITERATURE CITED

Andersson, G., H. Berggren, G. Cronberg, and C. Gelin. 1978. Effects of planktivorous and benthivorous fish on organisms and water chemistry in eutrophic lakes. Hydrobiologia **59**:9-15.

Carpenter, S. R., and J. F. Kitchell. 1993. The trophic cascade in lakes. Cambridge University Press, Cambridge, England.

DeVries, D. R., and R. A. Stein. 1992. Complex interactions between fish and zooplankton: quantifying the role of an open-water planktivore. Canadian Journal of Fisheries and Aquatic Sciences:1216-1227.

Hanson, M. A., and M. G. Butler. 1994. Responses of plankton, turbidity, and macrophytes to biomanipulation in a shallow prairie lake. Canadian Journal of Fisheries and Aquatic Sciences **51**:1180-1188.

Hanson, M. A., and M. R. Riggs. 1995. Effects of fish predation on wetland invertebrates: a comparison of wetlands with and without fathead minnows. Wetlands **15**:167-175.

Hansson, L. A., H. Annadotter, E. Bergman, S. F. Hamrin, E. Jeppesen, T. Kairesalo, E. Luokkanen, P. Nilsson, M. Søndergaard, and J. Strand. 1998. Biomanipulation as an application of food-chain theory: constraints, synthesis, and recommendations for temperate lakes. Ecosystems **1**:558-574.

Kraft, C. E. 1992. Estimates of phosphorus and nitrogen cycling by fish using a bioenergetics approach. Canadian Journal of Fisheries and Aquatic Sciences **49**:2596-2604.

Meijer, J. L., M. W. De Han, A. W. Breukelaar, and H. Buiteveld. 1990. Is reduction of the benthivorous fish an important cause of light transparency following biomanipulation in shallow lakes? Hydrobiologia **200/201**:303-315.

Meijer, M.-L., E. Jeppesen, E. Van Donk, and B. Moss. 1994. Long-term responses to fish-stock reduction in small shallow lakes: Interpretation of five-year results of four biomanipulation cases in the Netherlands and Denmark. Hydrobiologia **276**:457-466.

Polis, G. A., C. A. Myers, R. D. Holt. 1989. The ecology and evolution of intraguild predation: potential predators that eat each other. Annu. Rev. Ecol. Sys. **20**:297-230.

Romare, P. 2000. Growth of larval and juvenile perch: the importance of diet and fish density. Journal of Fish Biology **56**:876-889.

Rowe, D. K., and P. D. Champion. 1994. Biomanipulation of plants and fish to restore Lake Parkinson: a case study of its implications. *in* K. J. Collier, editor. Restoration of Aquatic Ecosystems. Science and Research Series, Department of Conservation, New Zealand.

Scheffer, M. H., S. R. Carpenter, F. Jonathan, C. Folkes, and B. Walker. 2001. Catastrophic shifts in ecosystems. Nature **413**.

Scheffer, M. H., S. H. Hosper, M.-L. Meijer, B. Moss, and E. Jeppesen. 1993. Alternative equilibria in shallow lakes. Trends in Ecology and Evolution **8**:275-279.

Shapiro, J., and D. I. Wright. 1984. Lake restoration by biomanipulation, Round Lake, Minnesota - the first two years. Freshwater Biology **14**:371-383.

Spencer, C. N., and D. L. King. 1984. Role of fish in regulation of plant and animal communities in eutrophic ponds. Canadian Journal of Fisheries and Aquatic Sciences **41**:1851-1855.

Van Donk, E., R. D. Gulati, and M. P. Grimm. 1989. Food web manipulation in Lake Zwemlust: Positive and negative effects during the first two years. Hydrobiological Bulletin **23**:19-34.

Vanni, M. J., and C. D. Layne. 1997. Nutrient recycling and herbivory as mechanisms in the "top-down" effect of algae on lakes. Ecology **78**:21-40.

IV. Limnological Monitoring of Lake Christina, 2004-2005 (Contributed by Malcolm G. Butler and Daniel C. McEwen)

Background and Approach

Limnological monitoring of Lake Christina during 2004-2005 was intended to document changes in physical, chemical, and biological characteristics of the lake in the two years following the October 2003 rotenone treatment. Many of the variables measured over these two years had been monitored by NDSU or the MDNR since 1985. Given this database on past conditions, we present findings from 2004-05 as an extension of a time series spanning 21 years. Methods used were generally consistent throughout the entire time series, although the sampling effort for some variables has varied in intensity during different phases of the record. Details of sampling methodology for all variables can be found in Hanson and Butler (1994) and Hansel-Welch et al. (2003).

Following a similar rotenone treatment of Lake Christina in October of 1987, a pattern of responses was observed in water clarity, phytoplankton, zooplankton, and submersed macrophytes. Changes over the first two post-treatment years (1988-99) conformed to what has become a widely-accepted paradigm in shallow lake ecology (Scheffer 1998). In late spring and early summer each year, high densities of large *Daphnia* quickly dominated the zooplankton community. Intense grazing by these filter-feeders cleared the water and suppressed phytoplankton (as indicated by chlorophyll *a* values). By mid-summer each year, the phytoplankton became dominated by grazing-resistant forms and water clarity decreased.

Improved growing conditions for macrophytes early each year, when light penetration was high, permitted the plants to re-establish across the lake basin. By August of 1989, the three dominant macrophytes (*Chara*, milfoil, and sago pondweed) had formed a protective carpet of vegetation that protected the sediments from resuspension by waves. The result was a stable, clear-water state that persisted for a decade before a return to turbid state in 2000. Here, data from 2004-05, the two years following the 2003 treatment, are compared to responses during the corresponding period (1988-89) after the 1987 treatment.

Water clarity

Water clarity improved over the two years following the 2003 treatment, based on measurements of both secchi depth and light attenuation (LA). Throughout 2004 the lake was still turbid, but deeper secchi readings were seen in the first half of that summer than at any time in the previous four years. Similarly, light attenuation coefficients in early summer 2004 dropped below 2.0 (the 21-year average) for the first time since 1999. Both secchi depth and LA values show a return of high turbidity in late summer of 2004. The summer of 2005 began with clear water that persisted for the entire open-water season, as values of both indicators dropped well below their long term averages.

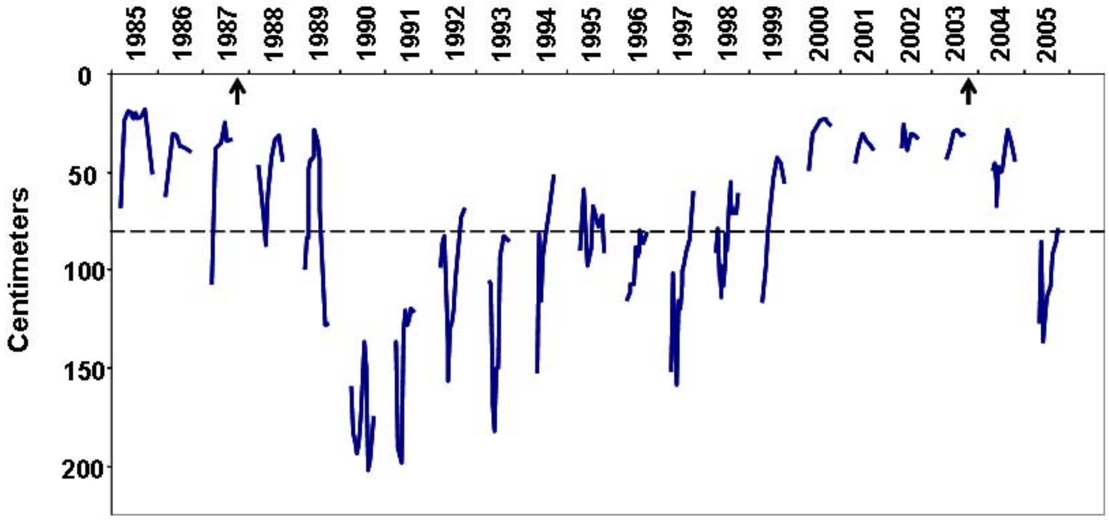


Figure 1. Mean lake-wide secchi depth (in cm) in Lake Christina, 1985-2005. Arrows indicate rotenone treatments in October of 1987 and 2003. Dashed line indicates long-term mean over the 21-year record.

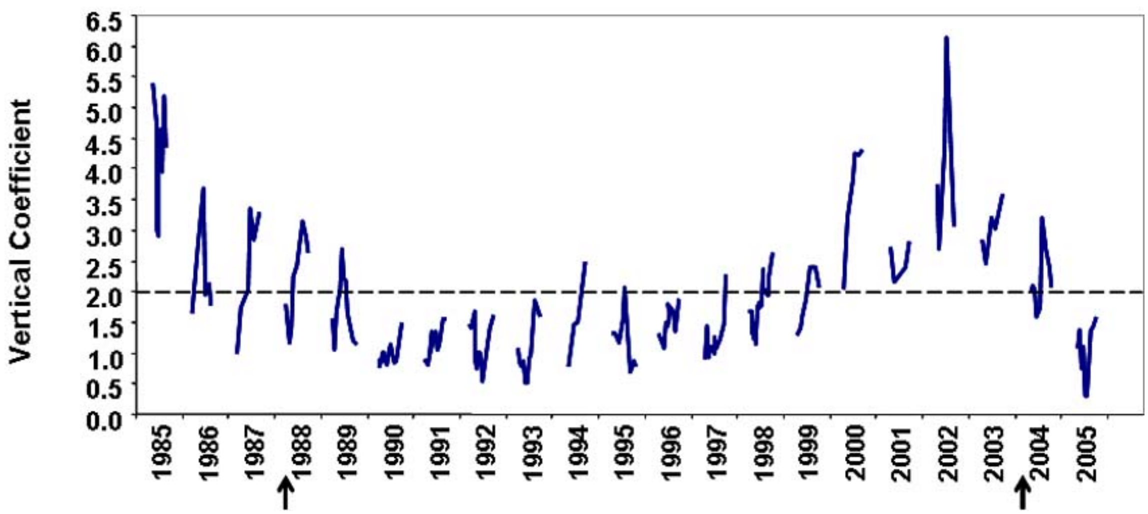


Figure 2. Mean lake-wide light attenuation coefficient (per m) in Lake Christina, 1985-2005. Arrows indicate rotenone treatments in October of 1987 and 2003. Dashed line indicates long-term mean over the 21-year record.

Daphnia abundance

A positive response by *Daphnia* is considered key to a successful biomanipulation treatment (Hanson and Butler 1994, Scheffer 1998). High densities of these important filter-feeding zooplankters were seen lake wide throughout most of 2004, initially mimicking the

Daphnia response in 1988 – one year after the 1987 rotenone treatment. *Daphnia* abundance was again high in spring of 2005, but dropped sharply in mid-June and remained at very low levels for the rest of that summer.

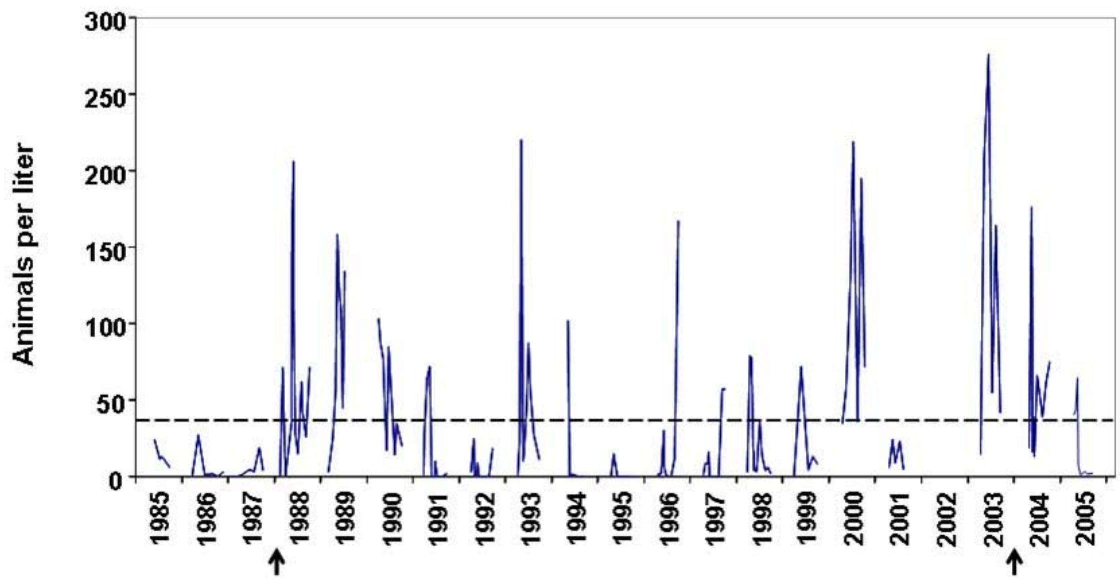


Figure 3. Mean lake-wide *Daphnia* density (number per liter) in Lake Christina, 1985-2005. Arrows indicate rotenone treatments in October of 1987 and 2003. Dashed line indicates long-term mean over the 21-year record.

The overall pattern of *Daphnia* response during these two post-treatment years (2004-05) differs somewhat from observations following the 1987 rotenone treatment. After that earlier biomanipulation, *Daphnia* exceeded 50 ind/l (and often much higher) for most of the summer, well into the fourth post-treatment year (1991). As important as abundant *Daphnia* appear to be in triggering a shift from the turbid to the clear-water state, it seems that persistence of these animals is not a prerequisite for a sustained response by the lake to the treatment once macrophytes themselves respond (see below).

It is also notable that very high abundances of *Daphnia* have been observed during both turbid and clear conditions in this lake. Monthly sampling by the MDNR in 2000 and 2003, the first and last years of the most recent turbid-water period in Lake Christina, showed the highest season-long densities of *Daphnia* seem in the entire 21 year record. These archived samples have been double-checked for accuracy, and clearly indicate that high abundance of *Daphnia* alone is insufficient to guarantee a transition to clear water. These parthenogenetic zooplankters can respond rapidly to high food levels provided by algal blooms, and their populations can crash quickly in response to either food limitation or intense planktivory. Additional data on food quantity and quality, predation mortality, and recycling of nutrients within the planktonic food web are needed to fully explain these observed patterns.

Submersed Macrophytes

The macrophyte community response to the rotenone application was very similar to that observed following the 1987 treatment. The macroalga *Chara* (stonewort) is the most sensitive macrophyte to changes in light conditions (Hansel-Welch et al. 2003). This "meadow-forming" plant (James et al. 2004) virtually disappears from the lake survey during turbid conditions, but returns rapidly once light attenuation decreases. *Chara* was found at all of the 35 sampling stations in August of 2004 and at 31 stations in 2005. During 2004 and 2005 surveys, this macrophyte had the highest abundance scores seen over the 21 year record (ranking 3.7 on a 5-point scale). In contrast, scores for both frequency of occurrence and abundance were at or near zero during the most turbid years (1985-87, 2001-2003). The rapid response of this plant to improved light conditions permits it to quickly form a carpet over the sediments. The resulting suppression of sediment resuspension by wind-generated waves thus creates a positive feedback, leading to even greater water clarity and further growth by macrophytes.

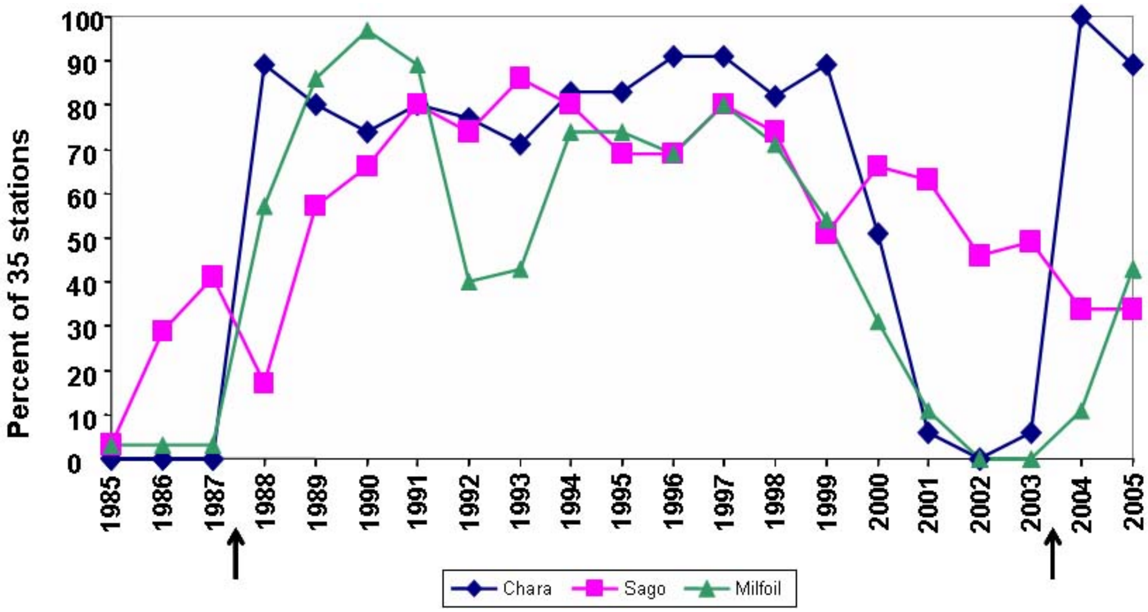


Figure 4. Percent occurrence of three macrophyte species in Lake Christina, 1985-2005. Arrows indicate rotenone treatments in October of 1987 and 2003.

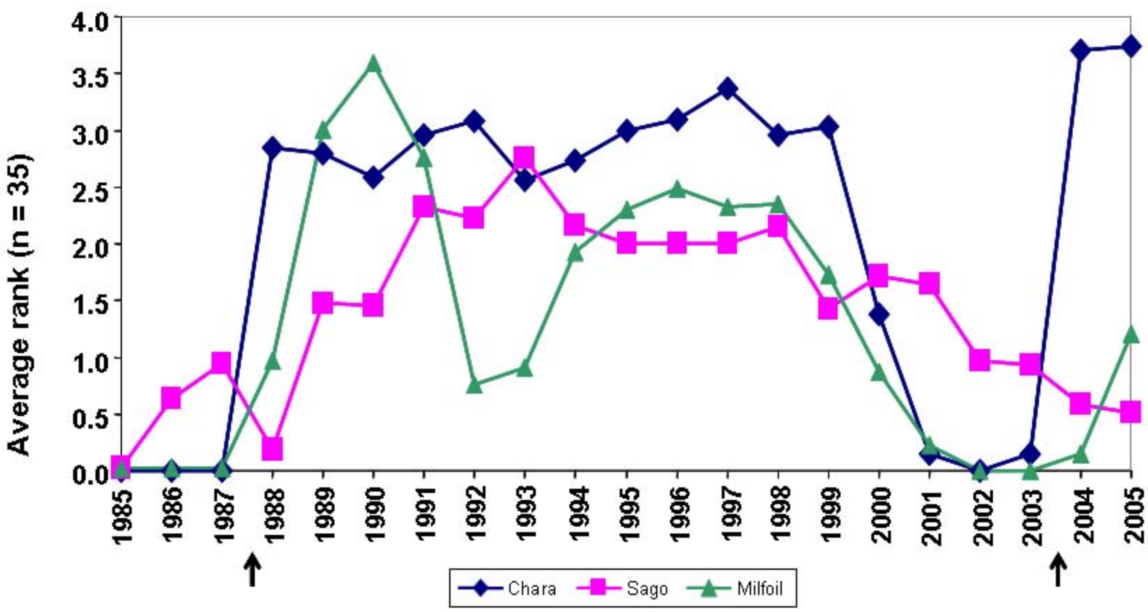


Figure 5. Relative abundance of three macrophyte species in Lake Christina, 1985-2005. Arrows indicate rotenone treatments in October of 1987 and 2003.

Myriophyllum sibiricum (northern milfoil) is a “canopy-forming” vascular plant that has also been shown to protect sediments from resuspension during high winds (James et al. 2004). Milfoil responded positively to the 2003 rotenone treatment, in a manner virtually identical to the pattern seen in 1988-89, showing an exponential increase in both frequency of occurrence and abundance ranking. For four years following the 1987 treatment, milfoil became co-dominant with *Chara* (1988-1993), but declined in years with abundant filamentous algae (Hansel-Welch et al. 2003), and when turbidity increased markedly (1999-2003). It is likely that milfoil will remain an important component of a "pioneer plant community" for several years, as documented for the "early post-treatment years" 1988-1991 (Hansel-Welch et al. 2003). Although milfoil continued to persist in Lake Christina through the 1990s, other plant species increased in importance until the return of persistent high turbidity in 2000 led to a decline in all macrophyte species.

Stuckenia pectinata (sago pondweed) is the macrophyte most desired by waterfowl managers. This plant has shown the most muted response to changing light conditions in Lake Christina as turbidity has both increased and decreased. Lack of an improvement in either frequency of occurrence or abundance scores for sago during 2004-05 could be expected, given the pattern of response seen after the 1987 treatment. Sago decreased in 1988 as *Chara* and milfoil increased, but eventually became a dominant member of the late post-treatment plant community (Hansel-Welch et al. 2003), persisting during nearly a decade of high waterfowl use of Lake Christina.

Chlorophyll, phosphorus, and turbidity in shallow lakes and Lake Christina

Many shallow lakes worldwide have been observed to exhibit "alternative stable states", shifting between clear and turbid water conditions with the loss, or recovery, of submersed macrophytes and associated ecological values (Scheffer 1998). Although some mechanisms controlling such shifts have been hypothesized and documented, causes remain unclear in many cases. A commonly assumed mechanism for a "forward shift" from clear to turbid water is eutrophication (Moss et al. 1996), generally resulting from increased loading of phosphorus that promotes higher turbidity by increasing the biomass of phytoplankton. Algal biomass is typically monitored by measuring the pigment chlorophyll *a* in water samples. Although the relationship between total phosphorus and algal turbidity is well-established in many stratified lakes throughout the temperate zone, shallow lakes may deviate from this generalization for two reasons. When submerged macrophysics are abundant, phytoplankton populations may be suppressed by a variety of mechanisms including shading, reduction of turbulence, facilitation of zooplankton grazers, and possibly allelopathy (Scheffer et al. 1993, Scheffer 1998). These suppressions can uncouple the linkage between phytoplankton biomass (as measured by chlorophyll *a*) and the total phosphorus that may be potentially available in the water column. When there is a substantial non-algal component to turbidity such as suspended inorganic material, phytoplankton may be light-limited and unable to transform available nutrients into biomass at the expected rate.

In a recent empirical analysis involving a large number of lakes worldwide, Dokulil and Teubner (2003) identified a ratio of 3 micrograms total phosphorus to 1 microgram chlorophyll a as a transition point between two types of response to phosphorus loading. Lakes with TP:chl *a* ratios less than 3:1 included both deep oligotropic lakes as well as shallow lakes dominated by algal turbidity. Here added phosphorus is efficiently converted to algal biomass, contributing to an expected increase in turbidity. Lakes with TP:chl *a* exceeding 3:1 included both macrophyte-dominated shallow lakes and lakes with high inorganic turbidity. In both cases, but for different reasons, the phytoplankton in such lakes was unable to make full use of the available phosphorus.

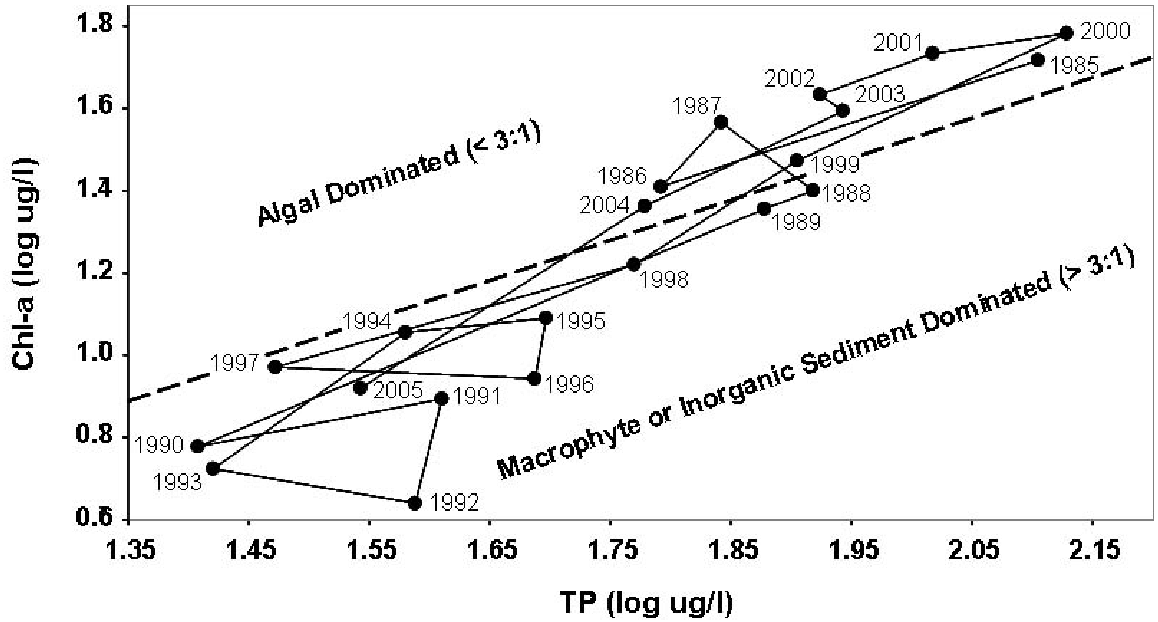


Figure 6. Trajectory of chlorophyll *a* relative to total phosphorus in Lake Christina, 1985-2005. Dashed line indicates 3:1 ratio of TP:chl *a*.

Total phosphorus and chlorophyll *a* data from Lake Christina over the past 21 years conform to the empirical generalization described by Dokulil and Teubner (2003). When annual mean values of these two variables are graphed on a log-log plot, the predicted trajectory is observed over a complete cycle of the alternative state model. Beginning in the turbid years of 1985-97, values fall in the "algal-dominated" region (TP:chl *a* <3:1 – above the dashed line). Immediately following the 1987 treatment, the line shifts to the other side of this threshold, typical of macrophyte domination or high inorganic turbidity. Both TP and chl *a* values dropped greatly between 1988-89 and the early 1990s as the lake transitioned from the early-recovery phase to a stable state of macrophyte domination. Despite the wide range of phosphorus and chlorophyll values, plotted ratios remained within the lower region characterized by TP:chl *a* >3:1. When the lake shifted back to the turbid state in 1999, the ratio again crossed into the alternative domain, where it remained throughout the recent turbid-water period. In contrast to the immediate transition following the 1987 rotenone treatment, after the 2003 treatment an additional year passed before the ratio shifted back to the macrophyte/clear water domain in 2005.

The Dokulil-Teubner model is complex because it portrays the response of phytoplankton (chlorophyll) to both nutrients and light, with the latter potentially influenced by both plants and inorganic turbidity. The concordance of Lake Christina's data with this empirical model suggests that this shallow lake is not simply responding to changes in phosphorus availability with higher or lower algal turbidity. There are likely complex interactions of phytoplankton with nutrient availability, grazing pressure by zooplankton, and the light environment, which is in turn influenced at different times by resuspended sediment, macrophyte abundance, and phytoplankton biomass itself.

Literature Cited

Dokulil, M, and K. Teubner. 2003. Eutrophication and restoration of shallow lakes – the concept of stable equilibria revisited. *Hydrobiologia* 506–509: 29–35.

Hansel-Welch, N., M.G. Butler, T.A. Carlson, and M.A.Hanson. 2003. Changes in macrophyte community structure in Lake Christina (Minnesota), a large shallow lake, following biomanipulation. Aquatic Botany 75:323-337.

Hanson, M.A., and M.G. Butler. 1994. Responses of plankton, turbidity, and macrophytes to biomanipulation in a shallow prairie lake. Can. J. Fish. Aquat. Sci. 51:1180-1188.

Hansel-Welch, N., M.G. Butler, T.A. Carlson, and M.A.Hanson. 2003. Changes in macrophyte community structure in Lake Christina (Minnesota), a large shallow lake, following biomanipulation. Aquatic Botany 75:323-337.

James, W.F., J.W. Barko, and M.G. Butler. 2004. Shear stress and sediment resuspension in relation to submersed macrophyte biomass. Hydrobiologia 515:181-191.

Moss, B., J. Madgwick, and G. Phillips. 1996. A guide to the restoration of nutrient-enriched shallow lakes. Broads Authority/Environment Agency, Norwich, Norfolk. 180pp.

Scheffer, M. 1998. The ecology of shallow lakes. Chapman and Hall, London. 357pp.

V. Submerged Aquatic Plants: Status and Trends (contributed by Thomas Carlson and Nicole Hansel-Welch)

Plants continued to increase during summer 2005 and following the 2003 rotenone treatment. Submerged macrophytes were collected at all (35) sampling stations during both 2004 and 2005, whereas prior to treatment in 2003, plants were sampled at approximately half of the locations sampled (Figure 1). These trends are very similar to what was observed in association with the rotenone treatment conducted during October 1987. Following the 2003 rotenone treatment, *Chara spp.* increased to 100% occurrence in 2004, and remained very abundant (present at 89% of sampling locations) in 2005. This reflects a dramatic increase from levels observed in 2003 (6 %). A similar response by *Chara spp*. also was evident following the 1987 rotenone treatment. During 2005, *Stuckenia pectinata* was again sampled at 34% of our sampling stations (same as in 2004, Figure 2). Based on previous experiences at Lake Christina, we expect that *Stuckenia pectinata* will continue to increase in future years, replacing some pioneering plant species. *Najas flexilis* and *Najas marina* declined in abundance from 2004, as they did in the second year following treatment in 1987. Again, the latter are pioneering species that also increased dramatically following treatments, then gradually decreased in abundance, likely due to competition with other species such as *Myriophyllum spp. which increased and was collected at* 43% of sampling stations occurrence in 2005 (up from 11% in 2004).

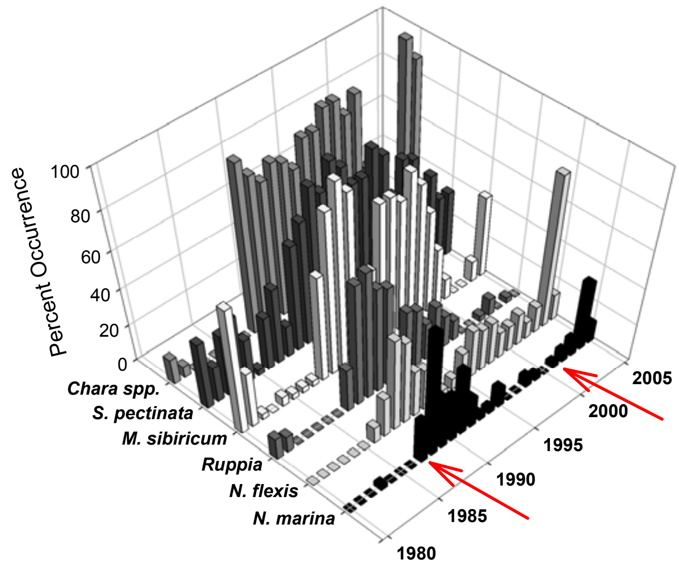


Figure 1. Percent occurrence of selected taxa of submerged vascular plants collected during annual surveys from 1980-2005. Arrows indicate timing of rotenone treatments (1987. 2003).

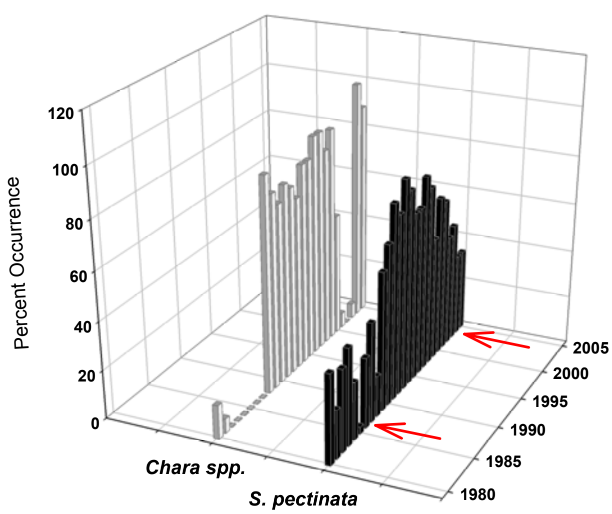


Figure 1. Percent occurrence of *Stuckenia pectinata* and *Chara spp.* collected during annual surveys from 1980-2005. Arrows indicate timing of rotenone treatments (1987, 2003).

V. Consequences of Biomanipulation on Use by Nongame Waterbirds (contributed by: J. H. Allen, G. L. Nuechterlein, and D. Buitron)

This project is a cooperative venture between the Department of Natural Resources, Nongame Wildlife Program, and the North Dakota State University Dept. of Biological Sciences.

ABSTRACT

We examined the use of Lake Christina, Minnesota, by nongame waterbirds, following an application of rotenone to eliminate its fish base in the fall of 2003. During weekly shoreline surveys conducted during the open water seasons of 2004 and 2005, individuals of 17 species of nongame waterbirds were counted. Migrant flocks of up to 95 double-crested cormorants (*Phalacrocorax penicillatus*), 74 pied-billed grebes (*Podilymbus podiceps*) and 2,100 ring-billed gulls (*Larus delawarensis*) were seen briefly during spring or fall counts. The most common summer residents were western grebes (*Aechmophorus occidentalis*), American white pelicans (*Pelecanus erythrorhynchos*), great egrets (*Ardea alba*) and black terns (*Chlidonias niger*). Western grebes were the most numerous nesting waterbird on the lake. Although over 240 western grebes were counted on Lake Christina in the spring of 2004, by the middle of June most had left the lake and no successful nesting occurred. During this same period, very few fish of the appropriate size for grebes were being trapped in the lake, and we suggest that although the emergent vegetation (bulrush, *Scirpus spp*.) was suitable for nesting, the lack of food prevented all but a few attempts. Shoreline counts of western grebes on neighboring Pelican Lake suggest that many western grebes originally on Lake Christina temporarily moved to this fish-rich lake in June and July. The only non-game waterbirds observed attempting to nest in 2004 were black terns, but they failed to hatch any young.

In 2005, minnow numbers were much higher throughout the spring and summer, and over 200 western grebes were counted on the lake by early June. Western grebes began nesting on 15 June, with over 100 nests initiated during the next 4 days. We located a total of 315 western grebe nests, of which 198 hatched at least one young (63% of all attempts).

Complete clutches averaged 3.1 eggs, and all but one nest had hatched by August 10. Over 50 black terns were counted on Lake Christina in the spring of 2005. Of the 10 black tern nests located, three hatched young. Three additional nongame waterbirds nested successfully during 2005: Clark's grebe (*A. clarkii*), red-necked grebe (*Podiceps grisegena*), and pied-billed grebe.

In addition to the variety of nongame waterbirds observed using lake Christina, 16 species of ducks, geese and coots were also observed, primarily during migration. By far the most numerous species of all was the American coot (*Fulica americana*), with over 41.000 seen in the fall of 2004 and over 132,000 in the fall of 2005. Over 300 blue-winged teal (*Anas discors*), Canada geese (*Branta candensis*), wood ducks (*Aix sponsa*) and ring-necked ducks (*Aythya fuligula*) were also counted within single surveys during spring and fall migrations.

The presence of minnows was critical to the successful breeding of western grebes on Lake Christina. Sufficient emergent vegetation existed to support a large colony of western grebes, with 215 simultaneously active nests in 2005. Considering that many of the 315 nests were probably second or third nesting attempts, this important colony appeared to have very high nesting success in 2005. Lake Christina is clearly an important nesting lake for the colonially nesting western grebe, as well as a major stopover for a variety of both game and nongame waterbirds during the spring and fall migrations.

INTRODUCTION

Shallow lakes in the prairie pothole region can be classified along a water clarity continuum with alternative stable states on each end. On one end is the clear state, which usually consists of macrophyte dominated clear water. At the opposite end is the turbid state, which is characterized by turbid water, few macrophytes, and abundant phytoplankton.

Scheffer (1998) provides a more detailed explanation of the alternative stable states, and showed that turbid water can severely impact the growth of aquatic macrophytes (Scheffer et. al. 2005). Lake Christina, a large, shallow lake in west-central Minnesota, has in the past 40 years fluctuated several times between these two alternative states. These changes have been correlated with major fluctuations in counts of waterfowl staging on the lake during the fall migration (Hanson & Butler 1994a).

Several factors can influence whether or not a lake is turbid. Sediment resuspension can be affected by boat traffic in shallow areas (Asplund & Cook 1999, Murphy & Eaton 1983) and by the presence of a high-density rough-fish population (Zambrano et. al 2001) or even large concentrations of feeding migrating waterfowl. Hansel-Welch et. al. (2003) showed that plant communities, especially *Potamogeton spp*. and *Chara spp*., will respond strongly to changes in water clarity. Macrophyte communities are thought to have the ability to reduce sediment resuspension, but water translucence must be high in order to establish long-term viable populations (James, Best, & Barko 2004). Nutrient inputs can also impact water quality (Post et. al. 1998), particularly algal biomass, which will tend to limit light reaching macrophytes (Lauridsen et. al. 2003). Zimmer et. al. (2001) showed that fish populations may also be important in turning small wetlands turbid.

Managers have many options on how to respond to turbid water and return the system to clear water. Biomanipulation involves various treatments such as the use of chemicals and water level manipulation, each of which has a different cost-benefit regime. Liquid rotenone has been a common, though expensive, option for removing rough-fish populations in efforts to return lakes and wetlands to macrophyte-dominated clear water (Van de Bund & Van Donk 2002, Finlayson et. al. 2000, Amey 1984), Public opinion, however, has begun to disapprove of rotenone use (see McClay 2000). In many cases, treatment with rotenone may have profound effects on the food-web dynamics of a lake system, leading to trophic cascades that result in the higher penetration of light needed for stimulating macrophyte growth (Rask et. al. 2003, Pijanowska & Prejs 1997, Prejs et. al. 1997).

Rotenone is commonly used as a piscicide because its direct toxic effects are generally nonpersistent. It kills fish through suffocation by blocking biochemical processes involved in the uptake of dissolved oxygen. Aquatic organisms that respire through gills are the most susceptible because of the rapid rate with which a lethal dose of rotenone can be absorbed through the gills. However, rotenone also affects many non-target organisms, such as aquatic invertebrates and plankton. In a series of studies on the effects of rotenone treatments in Colorado, Hoffman & Olive (1961) found significant decreases in aquatic invertebrates from pretreatment levels in 3 reservoirs, with some species abundances declining to zero. Morrison & Struthers (1975) and Morrison (1977) published similar results from a study on lochs in Scotland, but showed that most groups made rapid recoveries. In fact, populations of important grazing groups, such as *Daphnia spp*. and *Bosmina spp*., increased greatly over pre-treatment levels, both in abundance and body size. In North American similar trends were shown by Engstrom-Heg et. al. (1978) and Hanson & Butler (1994b). Such rapid recolonization could stem from a lack of predation and an abundance of organic material.

An important practical problem associated with using rotenone as a piscicide within larger lake systems is that it is seems to be less than 100% effective with most applications (M.G. Butler, K. D. Zimmer, pers. comm.). Undesirable rough fish species, such as black bullheads (*Ameiurus melas*) may be particularly likely to survive whole-lake treatments. Gilderhus (1982) found that many types of suspended solids (i.e. clay particles) at even moderate concentrations will decrease the effectiveness of rotenone and toxaphene. Soft bottoms and high concentrations of suspended solids are especially common in turbid, shallow lakes such as Lake Christina.

Nongame waterbirds are rarely considered in these types of community-wide manipulations. In a similar experiment, Hoyer & Canfield (1990, 1994) found that higher turbidity predicted greater bird species richness and abundance, and found no significant relationship between general bird species richness and macrophyte communities. Yet many nongame waterbird species are piscivorous, and so fish removal would be expected to have direct adverse effects on their use of a lake for foraging and reproduction. As part of a larger, multifaceted project, we evaluated the effect of biomanipulation on nongame waterbird usage of Lake Christina. Rotenone was used to remove the fish community dominated by rough fish, predominately bigmouth buffalo (*Ictiobus cyprinellus*), common carp (*Cyprinus carpio*), and black bullhead, and to reestablish macrophyte beds preferred by many migrating waterfowl species.

Project Goals:

The primary goal of this portion of the Lake Christina Reclamation project was to determine the effect of the rotenone application to the lake on the nongame waterbird populations. Our purpose was to determine the species and numbers of nongame waterbirds using Lake Christina for both breeding and non-breeding purposes during the open water seasons of 2004-2005. We were particularly interested in documenting any breeding attempts by western grebes (*Aechmophorus occidentalis*), Clark's grebe *(A. clarkii*), red-necked grebes (*Podiceps grisegena*), black terns (*Chlidonias niger*) and Forster's terns (*Sterna forsteri*), with special emphasis on the nesting success of western grebes.

A secondary goal was the completion of a master's thesis by JHA on the effects of wind, waves, and bulrush density on the survival of over-water nests of the western grebe, which has been an important over-water nesting species on Lake Christina.

Funding:

Support for this project was received from the Minnesota Nongame Wildlife Tax Checkoff and the U.S. Fish and Wildlife Service through the Minnesota Department of Natural Resources, Division of Ecological Services. The nongame waterbird monitoring section of the Lake Christina reclamation project cost $36, 260, which provided research funds for examining waterbird use during the open-water seasons of 2004-2005. These funds provided equipment and travel expenses, a research assistantship to JHA, 2-mo summer salary for DB, and the hiring of a full time field technician during the summer of 2005.

METHODS

Lake Christina

Lake Christina, located in Douglas and Grant counties of west-central Minnesota USA (46° 05'N, 95° 44'W, Minnesota USA), is a soft-bottomed lake that extends over 1600 ha with an average depth of only 1.5 m. To control for rough fish the lake has been treated periodically, with toxaphene in 1965 and with rotenone in 1987 and 2003. A thorough report on the treatment history of Lake Christina is available from the Minnesota DNR (Carlson & Hansel-Welch 2003)

Western grebes have regularly established breeding colonies (ranging from 6 to 177 active nests) on Lake Christiana since the late 1960s (Minnesota DNR data, unpub, D. Anderson pers. comm.). Other nongame waterbirds also reside or breed on Lake Christina including: red-necked grebes, Clark's grebes, pied-billed grebes (*Podilymbus podiceps*), black terns, Forsters' terns, double-crested cormorants (*Phalacrocorax auritus*), American white pelicans (*Pelecanus erythrorhynchos*), and great egrets (*Ardea alba*). Bald eagles (*Haliaeetus leucocephalus*) also commonly forage on Lake Christina. American white pelicans, Forster's terns, and bald eagles are listed as species of special concern in Minnesota.

Ground Surveys

Birds using Lake Christina were surveyed during the open water seasons of 2004-2005. Eight survey sites were established around the lakeshore to allow wide coverage of much of the open water surface of the lake and provide an index to the relative abundance of the most visible, open-water species. The first two survey sites (Sites 1 and 2, Figure 1) were elevated 20 m and 10 m respectively above the lake level, which allowed for extensive coverage of the large southern bay. We conducted weekly count surveys using binoculars and a 15-60x spotting scope during the first four hours of daylight, with the stipulation that visibility was good and that winds were 15 kph or less. Surveys were initiated at Sites 1 and 2 because calm surface waters were especially critical for counting and identifying distant waterbirds. Special care was taken to avoid counting flocks twice.

Nest Surveys

Kayaks were used to conduct weekly over-water nest surveys during the spring and summer of both years. Any nests found were marked with small, 3-cm colored tape flags attached to stems of bulrush. A Garmin ETrex GPS unit was also used to mark the location. Species, clutch size, and fate were monitored until the nest was abandoned, destroyed, or successful. Successful pairs were defined as those hatching at least 1 egg. After the colony completed nesting white plastic bags were attached to the nests. A series of aerial photos were then taken to facilitate spatial analysis of colony formation and nesting success, which will comprise a portion of JHA's master's thesis (Figure 2). The plane was a Cessna 172 rented from Alexandria Aviation, Alexandria MN, and was piloted by JHA. Aerial photos were taken by GLN and by our field assistant, Jessie Stegmeier. Weather data, including peak gust and average wind speed, were also obtained from the Alexandria airport weather station and were locally verified using an anemometer mounted on the shore of Lake Christina.

Other Data

As part of this multi-organizational project, fish communities were studied by Kyle Zimmer and students from the University of St. Thomas, St. Paul, MN. Water chemistry and aquatic invertebrate communities were examined by Malcolm Butler and students from North Dakota State University, Fargo, ND. Aquatic macrophytes and waterfowl were examined by Nicole Hansel-Welch and Tom Carlson of the Minnesota Department of Natural Resources, Bemidji, MN. This report will focus on the nongame waterbird response to the biomanipulation.

Data was analyzed using EXCEL (Microsoft Office XP Standard, Version 2002) and JMP (Version 6. SAS Institute Inc., Cary, NC, 1989-2005). Maps were created with ESRI ArcGIS 9.1 (2005).

RESULTS

Nongame Waterbird Surveys

To facilitate comparisons between game and nongame waterbird species, we counted both groups during ground surveys. Abbreviations in this report follow the USFWS Bird Banding Laboratory alpha coding system (Table 1). During the regular surveys, 32 waterbird species were counted. Table 2 lists all species and their peak counts during each open water season. Fifteen game species were observed using Lake Christina in 2004 and 14 species in 2005. Twelve nongame waterbird species were observed using Lake Christina in 2004 and 16 species in 2005. Figures 3-8 show overall changes in species abundance trends from 2004 to 2005 for various groups, including dabbling ducks and geese, diving ducks, nongame divers (loons, cormorants, and grebes), waders, and other waterbirds. The survey data from which these figures were derived are given in Appendix I.

Canada geese (*Branta candensis*) numbers were relatively high during both years, peaking in October. Wood ducks (*Aix sponsa*) and blue-winged teal (*Anas discors*) numbers peaked earlier in the fall, and were much more numerous during 2004 (Figure 3a, b). Several wood duck broods were also seen during daily work both years. American coots (*Fulica americana*) were by far the most abundant waterbird counted on Lake Christina, with a maximum count of over 141,000 birds. American coot counts peaked in late October and were much higher in 2005 than 2004 (Figure 4a, b). Most diving ducks were less abundant during 2005, except ring-necked ducks (*Aythya fuligula*), which increased greatly during the spring of 2005 (Figure 5a, b). All dabbling and diving ducks peaked in either spring or fall and were seen only in small numbers during the summer. Nongame divers and waders increased in 2005 (Figures 6a, b and 7a, b). Most other waterbirds increased in 2005, except ring-billed gulls (*Larus delawarensis*), which were much less abundant in 2004 (Figure 8). Overall, from 2004-2005 Lake Christina lost 2 species (NOPI, HOME), but gained 5 others (COME, CLGR, CAEG, TRUS, BAEA). In addition to these species counted during surveys, waterbird species seen at other times on Lake Christina included: horned grebe (*Podiceps auritus*), Franklin's gull (*Larus pipixcan*), Bonaparte's gull (*Larus philadelphia*), northern shoveler (*Anas clypeata*), red-breasted merganser (*Mergus serrator*), black crowned night heron (*Nycticorax nycticorax*), American bittern (*Botaurus lentiginosus*), least bittern (*Lxobrychus exilis*), and belted kingfisher (*Ceryle alcyon*).

In early May 2004 large numbers of western grebes began arriving on Lake Christina, but by early June their numbers started declining precipitously. During this same period western grebes began showing up on Pelican Lake, a fishing lake located immediately southwest of Lake Christina. Lake resort owners reported seeing much larger numbers of western grebes than in previous years, and we suspected that birds from Lake Christina were moving over to Pelican Lake. On 19 May, we established four survey points on the major bays of Pelican Lake. Throughout June, western grebes declined on Lake Christina until they stabilized at less than 50 birds through most of August (Figure 9a). During June and July, our counts on the open bays of Pelican Lake showed increasing numbers of western grebes, with a peak number of 165 birds on July 21. In late August western grebe numbers on both Lake Christina and Pelican Lake increased.

Minnow and small fish densities were extremely low on Lake Christina throughout the summer of 2004, with a mean catch of less than 0.5 fish per trap station throughout the breeding season (Figure 9b, fish data provided by Melissa Konsti.). Fish densities during 2005 were much higher, with mean catch rates of over 15 fish per trap throughout June and July (Figure 10b). In 2005 western grebes arrived at Lake Christina and stayed for the breeding season, while less than two dozen were observed on Pelican Lake during the spring and summer (Figure 10a).

Lake Christina hosts a variety of waterbird species throughout the year, and its use by game versus nongame species varied seasonally. Game species mainly occurred during the spring and fall migration months, while many nongame waterbird species arrive in the spring, spend the summer feeding or breeding, and then depart early in the fall (Figure 11a, b).

Monitoring of Over-water Nests

In 2004, black terns were the only waterbird species observed attempting to nest in the emergent beds of Lake Christina. Four nests with eggs were found in late July, but these were destroyed by a storm less than a week after they were located.

In 2005, 7 waterbird species nested in the emergent stands on Lake Christina: western grebe, red-necked grebe, pied-billed grebe, Clark's grebe, black tern, American coot, and canvasback (*Aythya valisineria*) (Figure 12). The only Clark's grebe that used the lake in 2005 was seen paired with a western grebe, though its nest location was undetermined, because their nests and eggs cannot be distinguished from those of western grebes. Successful breeding of the Clark's grebe, however, was confirmed in August when it was observed feeding a chick (Robert Jansen, pers. comm.). Total nest numbers found and monitored for nesting success were: 315 western grebe, 3 red-necked grebe, 3 pied-billed grebe, 10 black tern, 1 canvasback, and 1 American coot. The colony area was fairly well defined, and nests that were destroyed tended to be located at the outer margins of small bulrush islands that compose the larger colony (Figures 12, 13). All grebe species had nest success rates of greater than 60%. Black terns had nesting success rates of 30%. The one canvasback nest also hatched, and the American coot was still incubating on 10 August 2005, the last day of the colony nest checks (Table 3, Figure 14).

Western Grebe Colony Formation and Success

Only western grebes nested in sufficient numbers for further analysis. Detailed GIS analysis of colony formation and nesting success will comprise a portion of a Master's thesis that will be submitted separately from this report. Nest initiation by western grebes began in the dense bulrush beds of southwestern Lake Christina on 15 June 2005. In the first two weeks, nearly 200 nests were established. The maximum number of active nests in the colony at any given colony check was 215 (Figure 15a), and over the 2005 season 315 nests were located (Figure 15b). Average complete clutch sizes decreased with time (from 3.7 to 2.8) with an overall average clutch size of 3.1 eggs (Table 3, Figure 16).

Most of the 315 western grebe nests on Lake Christina were initiated in mid- to late-June. Hatching success was high (60% or more) during all of the nest initiation periods (Figure 17), with an overall hatching success of 63 percent (Table 3). Nest predation rates were very low, although 10 birds were found dead in the colony area. Wind conditions during June 2005 were unusually calm (Figures 18a, b), and by the time winds picked up in July the extensive stands of bulrush surrounding the nests of the colony nests were sufficiently dense to act as wave breaks. Figure 19 shows young/adult ratios for western grebes counted during Lake Christina shoreline surveys.

DISCUSSION

Nongame Waterbird Species Counts: Richness & Abundance

The shoreline counts used in this study were designed to provide an inexpensive and non-invasive index to the relative abundance of several nongame waterbird species of interest, particularly western grebes. These counts appeared to be capable of detecting major emigrations out of the lake (2004), but should not be considered as census data. The precipitous decline in open-water counts during mid-June 2005, for example, undoubtedly reflects the moving of grebe pairs into the dense bulrushes of the colony area, where they could not be easily seen from the shore. Our tower observations revealed this to be a very intense period of nest establishment. Once nests were established, one member of each pair nearly always remained at the nest, where most could not be viewed from open water vantage points.

Lake Christina's waterbird community in the spring and fall is comprised primarily of migratory game species. During the summer, nongame waterbird species become the dominant group, using the lake for breeding and foraging. The dramatic increases in nongame waterbirds from 2004 to 2005 are likely due to increases in fish abundance. Fish density was extremely low during 2004, but quickly rebounded in 2005, not only in minnows but in larger size classes as well (Melissa Konsti, pers. comm.). All nongame waterbird species counted at Lake Christina over the course of both summers were at least partially piscivorous. The fall of 2005 was characterized by unseasonably warm temperatures followed by a quick shift to below freezing temperatures in early November, which appeared to delay the migration of many waterfowl species. This could have caused counts to be low for several species, most notably in the fall of 2005, when there also were gaps in survey dates due to poor weekend weather conditions.

Nesting Success of Nongame Waterbirds

Most nongame waterbirds attempting to nest on Lake Christina in 2005 were relatively successful. All three grebe species breeding on the lake had over a 60% nesting success rate, although sample sizes are small for pied-billed grebes and red-necked grebes. Both of these species nested in the same general area as western grebes, and their nests were found in similar habitats. Black terns also nested on the outskirts of the western grebe colony, in some cases taking over abandoned grebe nests. Their smaller nests appeared to be more vulnerable to wind and wave action, and only 3 of the 10 nests were known to have hatched.

Nesting success of western grebes was very high in 2005, due mainly to relatively mild weather and wind conditions and relatively low predation rates during July. Except for a few gusty days, the weather during the breeding season was relatively calm compared to the rest of the summer. This allowed the nesting birds to avoid major wind and wave storms typical of the region. Our best estimation of a minimum total population size for western grebes on Lake Christina is 215 pairs, the maximum number of active nests found during any nest check (Figure 15). Re-nesting is very common in most grebes, and eventually 198 pairs successfully hatched young in 2005. Possibly most pairs that attempted to nest on the lake therefore were eventually successful.

Western Grebe Colony

Western grebes were by far the most abundant nongame nesting species found using Lake Christina and were therefore a major focus of this study. Western grebes have nested regularly on the lake from the late 1960's and in record numbers during the summer of 2003 (Minnesota DNR data, unpub, D. Anderson pers. comm.). Having an abundant fish resource available within the same body of water as their nesting habitat has been thought to be critical for successful breeding in western grebes, which rarely fly except during migration (Storer and Nuechterlein 1992). The application of rotenone to the fish population of Lake Christina during fall 2003 essentially provided a whole-lake test of this prediction.

Following the application of rotenone, our spring 2004 bird counts indicated that western grebes returned in large numbers, but then began leaving the lake precipitously. The lack of forage fish in Lake Christina appeared to cause large numbers of western grebes to move from Lake Christina to Pelican Lake in 2004. On Pelican Lake, western grebes probably were unable to breed due to a lack of suitable nesting habitat, which is a common occurrence within large fishing lakes of Minnesota. This buildup of western grebes on Pelican Lake did not occur in 2005, when fish had recovered in Lake Christina. Instead, western grebes again returned to Lake Christina, and this time established a thriving nesting colony.

Such abandonment and then re-colonization of an entire marsh system has rarely been documented in any grebe species, although GLN observed a similar abandonment of a well-established breeding marsh of western grebes (The Delta Marsh, Delta, Manitoba) after a rare and nearly complete winter-kill of minnows during the winter of 1975-76. Banded birds from the Delta Marsh were found nesting on another marsh 50 km away. In that case, some re-colonization and nesting occurred very late during the same breeding season, when new carp fry hatched, providing the marsh with a fresh influx of suitably-sized fish prey.

Our Lake Christina research suggest that emergent densities sufficient to be used for nesting by western grebes (or other species that build over water nests) may be limited to a single cluster of bulrush stands located in the south western corner (Figure 2). During 2005, peak nesting counts in the Lake Christina breeding colony of western grebes did not occur until the July colony check (Figure 15), which is unusually late for the species. However, a delayed colony initiation may be typical for the Lake Christina colony because of the nature of the breeding habitat. All 315 western grebe nests were located within fresh growth of bulrush islands, most of which are typically sheered off during the spring ice melt. Located over depths of 0.7-1.3 m of water, these bulrush stands take time to reach the surface, and may be the only area on the lake providing sufficient off-shore nesting habitat to protect the over-water nests of western grebes from both wave-action and land predators. The health and re-growth of these bulrush stands therefore are critical to the breeding success of this important nongame species. Western grebes on Lake Christina arrive in early May, and then play a waiting game until late-June, feeding on the abundant fish, while regularly checking the progress of island re-growth. Throughout June, we often saw small groups of western grebes roosting on the water, just outside of the colony area. In stark contrast, western grebes on Lake Osakis, Minnesota, only 50 km to the east, already were establishing nests in late May, using the previous year's old growth of cattail (*Typha spp.*) stands.

On 16 June 2005, nearly the entire western grebe population on Lake Christina moved into the bulrush stands and began to nest. A colony check 4 days later revealed that over 100 nests had been established. During the next colony check, 8 days later, 195 pairs were actively incubating, which probably accounted for nearly all of the grebes on the lake. This extreme synchrony in nest establishment provides additional evidence that western grebes on Lake Christina were simply waiting for the bulrush stands to reach sufficient density for nesting. Once several colony founders began building their nests, other grebes of the population quickly moved in to claim their own territories. This initial colony was more synchronous than those typical of many other areas, such as Lake Osakis or the Delta Marsh, where birds arrive in early spring and, after pairing up, gradually join ongoing colonies. The decrease in numbers of western grebes counted during surveys in June and July is probably primarily due to our inability to see those birds that were working on nests or incubating eggs in the dense emergent vegetation (Fig.10a). By mid July the numbers of grebes counted during surveys increased, coinciding with the abandonment of nests once young begin hatching. Details relating to nest placement and colony formation will be analyzed separately.

Management Recommendations:

- Our shoreline surveys were specifically designed to provide a noninvasive, consistent index to the relative abundance of nongame waterbirds that roost and feed in the open water, such as the main focal species of this study. Windy conditions frequently prevented survey counts, due to the large fetch distances at Lake Christina. However, informal experimental counts of large bays before and after wind conditions deteriorated confirmed that a calm surface was critical to accurate counts made over long distances.

- If rare (< 25 individuals) nongame species are to be monitored successfully, either a more intensive survey protocol or frequent "non-survey" trips to the lake are required. Many rare species are encountered haphazardly and will not be observed on regular surveys.
- Shoreline surveys were successful at detecting the presence and relative numbers of western grebes on Lake Christina, particularly before nesting began and after its completion. When not on their nests, adult western grebes fed and roosted on the open water, especially in the large open bays.
- Timing of western grebe nesting may vary considerably between lakes and between seasons depending on ice-out conditions and type and density of emergent vegetation, which means that infrequent or single-point colony checks are unlikely to provide consistent data that are very useful in monitoring breeding populations.
- Late-July shoreline surveys could be easily used to detect and monitor lakes suspected of having breeding colonies of western grebes. Pairs with older young are usually feeding conspicuously in open water areas where they could easily be detected and counted by local birders.
- Fish re-colonization was rapid the summer following the rotenone application, but for the presence and breeding of nongame waterbird species, some desirable species of fish should be stocked after rotenone treatments to provide a minimum forage base for piscivorous birds.

ACKNOWLEDGMENTS

We must first thank Katie Haws for funding our project, providing background information and data, her boat, and much more. Tom Carlson, Nicole Hansel-Welch, Todd Call, and Mark Hanson of MNDNR all helped with various aspects of the project. The surveys would not be possible without the land-use permission of Brad Gruss, John Lindquist, Kevin Fick, and all other lakeshore landowners. Special Thanks to Brad Gruss and John Lindquist for always being friendly, encouraging, and knowledgeable. Housing was graciously provided by Duke Anderson and the Douglas County Landowner Co. for 2004, and Randy Elmer and the Lake Christina Gun Club in 2005. We would like to thank Jessie Stegmeier for all of her hard work during 2005. Jim Church and Heath Hagy were helpful during colony checks and when kayaks capsized. Emily Nuechterlein and Melissa McKay also helped with colony checks. We thank Alexandria Aviation for cooperating with our schedule.

LITERATURE CITED

Amey, M. 1984. The application of liquid Derris (5% Rotenone) to a spring-fed upland pond to eradicate perch (*Perca fluviatilis* L.)- 3 year post-application monitoring. Fisheries Management 15(2): 75.

Asplund, T., C. Cook. 1999. Can no-wake zones effectively protect littoral zone habitat from boating disturbance? LakeLine 19: 16-18, 48-52

Carlson, T., N. Hansel-Welch. 2003. Lake Christina rotenone treatment report. Minnesota Department of Natural Resources: Section of Wildlife Report.

Engstrom-Heg, R., T. Colsante, E. Silco. 1978. Rotenone tolerances of stream-bottom insects. New York Fish and Game Journal 25(1): 31-41.

Finlayson, J., R. Schnick, R. Cailteux, L. DeMong, W. Horton, W. McClay, C. Thompson, G. Tichacek. 2000. Rotenone use in fisheries management: administrative and technical guidelines manual. American Fisheries Society, Bethesda, Maryland.

Gilderhus, P. 1982. Effects of an aquatic plant and suspended clay on the activity of fish toxicants. North American Journal of Fisheries Management 2: 301-306.

Hansel-Welch, N., M.G. Butler, T.J. Carlson, M. A. Hanson. 2003. Changes in macrophyte community structure in Lake Christina (Minnesota), a large shallow lake, following biomanipulation. *Aquatic Botany* 75: 323-337.

Hanson, M., M. Butler. 1994a. Responses to food web manipulation in a shallow waterfowl lake. Hydrobiologia 279/280: 457-466.

Hanson, M., M. Butler. 1994b. Responses of plankton, turbidity, and macrophytes to biomanipulation in a shallow prairie lake. Canadian Journal of Aquatic Science 51: 1181-1188.

Hoffman, D., J. Olive. 1961. The effects of rotenone and toxaphene upon plankton of two Colorado reservoirs. Limnology and Oceanography 6(2): 219-222.

Hoyer, M., D. Canfield. 1994. Bird abundance and species richness on Florida lakes: influence of trophic status, lake morphology, and aquatic macrophytes. Hydrobiologia 297/280: 107-119.

Hoyer, M., D. Canfield. 1990. Limnological factors influencing bird abundance and species richness on Florida lakes. Lake and Reservoir Management 6(2): 133-141.

James, W., E. Best, J. Barko. 2004. Sediment resuspension and light attenuation in Peoria Lake: can macrophytes improve water quality in this shallow lake system? Hydrobiologia 515: 193-201.

James, W., J. Barko, M. Butler. 2004. Shear stress and sediment resuspension in relation to submersed macrophyte biomass. Hydrobiologia 515: 181-191.

Lauridsen, T., J. Jensen, E. Jeppesen, M. Sondergaard. 2003. Responses of submerged macrophytes in Danish lakes to nutrient loading reductions and biomanipulation. Hydrobiologia 506-509: 641-649.

McClay, W. 2000. Rotenone use in North America (1988-1997). Fisheries Management 25(5): 15-21.

Morrison, B. 1977. The effects of rotenone on the invertebrate fauna of three hill streams in Scotland. Fisheries Management 8(4): 128-139.

Morrison, B., G. Struthers. 1975. The effects of rotenone on the invertebrate fauna of three Scottish freshwater lochs. Fisheries Management 6(4): 81-91

Murphy, K., J. Eaton. 1983. Effects of pleasure-boat traffic on macrophyte growth in canals. Journal of Applied Ecology 20: 713-729.

Post, D., J. Taylor, J. Kitchell, M. Olsen, D. Schnidler, B. Herwig. 1998. The role of migratory waterfowl as nutrient vectors in a managed wetland. Conservation Biology 12(4): 910-920.

Pijanowska, J., A. Prejs. 1997. Food-web manipulation in shallow, eutrophic lakes: Bridging the gap between the whole-lake approach and behavioural and demographic studies. Hydrobiologia 342: 305-310.

Prejs, A. J. Pijanowska, P. Koperski, A. Martyniak, S. Boron, P. Hliwa. 1997. Food-web manipulation in a small, eutrophic Lake Wirbel, Poland: Long-term changes in fish biomass and basic measures of water quality. A case study. Hydrobiologia 342: 383-386.

Rask, M., M. Olin, J. Keskitalo, A. Lehtovaara, J. Ruuhijarvi, S. Vesala. 2003. Responses of plankton and fish communities to mass removal of planktivorous fish in a two-basin lake in Southern Finland. Hydrobiologia 506-509: 451-457.

Scheffer, M. 1998. Ecology of Shallow Lakes. Chapman and Hall, London.

Scheffer, M., H. Holmgren, V. Brovkin, M. Claussen. 2005. Synergy between small- and large-scale feedbacks of vegetation on the water cycle. Global Change Biology 11 (7): 1003-1012.

Smith, J. 1946. The canvas-back in Minnesota. Auk 63: 73-81.

Storer, R.W. and G.L. Nuechterlein. 1992. Western and Clark's Grebe. *In* The Birds of North America, No. 26 (A. Poole, P. Stettenhem, and F. Gill, Eds.) Philadelphia: The Acad. of Nat. Sciences; Wash. D.C: The American Ornithologists' Union.

Van de Bund, W., E. Van Donk. 2002. Short-term and long-term effects of zooplanktivorous fish removal in a shallow lake: a synthesis of 15 years of data from Lake Zwemlust. Freshwater Biology 47: 2380-2387.

Zambrano, L., M. Scheffer, M. Martinez-Ramos. 2001. Catastrophic response of lakes to benthivorous fish introductions. Oikos 94: 344-350.

Zimmer, K., M. Hanson, M. Butler. 2001. Effects of fathead minnow colonization and removal on a prairie wetland ecosystem. Ecosystems 4: 346-357.

Table 1. Alpha codes of the U.S. Fish and Wildlife Service Bird Banding Laboratory (BBL) were used for the tables and figures within this report.

	Common Name	Scientific Name
AMCO	American Coot	*Fulica americana*
AWPE	American White Pelican	*Pelecanus erythrorhynchos*
BAEA	Bald Eagle	*Haliaeetus leucocephalus*
BLTE	Black Tern	*Chlidonias niger*
BUFF	Bufflehead	*Bucephala albeola*
BWTE	Blue-winged Teal	*Anas discors*
CAEG	Cattle Egret	*Bubulucus ibis*
CAGO	Canada Goose	*Branta candensis*
CANV	Canvasback	*Aythya valisineria*
CLGR	Clark's Grebe	*Aechmophorus clarkii*
COGO	Common Goldeneye	*Bucephala clangula*
COLO	Common Loon	*Gavia immer*
COME	Common Merganser	*Mergus merganser*
DCCO	Double-crested Cormorant	*Phalacrocorax penicillatus*
EAGR	Eared Grebe	*Podiceps nigricollis*
FOTE	Forster's Tern	*Sterna forsteri*
GADW	Gadwall	*Anas strepera*
GBHE	Great Blue Heron	*Ardea herodias*
GREG	Great Egret	*Ardea Alba*
HOME	Hooded Merganser	*Lophodytes cucullatus*
LESC	Lesser Scaup	*Aythya affinis*
MALL	Mallard	*Anas platyrhynchos*
NOPI	Northern Pintail	*Anas acuta*
PBGR	Pied-billed Grebe	*Podilymbus podiceps*
RBGU	Ring-billed Gull	*Larus delawarensis*
REDH	Red Head	*Aythya americana*
RNDU	Ring-necked Duck	*Aythya fuligula*
RNGR	Red-necked Grebe	*Podiceps grisegena*
RUDU	Ruddy Duck	*Oxyura jamaicensis*
TRUS	Trumpeter Swan	*Cygnus buccinator*
WEGR	Western Grebe	*Aechmophorus occidentalis*
WODU	Wood Duck	*Aix sponsa*

Table 2. Thirty-two waterbird species were observed on surveys of Lake Christina during 2004-2005. For each species the maximum count obtained on a survey during the open-water season is given for each survey.

	2004	2005
Dabbling Ducks/Canada Goose		
AMCO	41515	132600
BWTE	479	40
CAGO	407	300
GADW	18	30
MALL	32	53
NOPI	20	0
WODU	363	38
Diving Ducks		
BUFF	2	36
CANV	25	37
COGO	17	3
COME	0	3
HOME	1	0
LESC	32	68
REDH	1	53
RNDU	75	442
RUDU	16	1
Nongame Divers		
CLGR	0	1
COLO	2	4
DCCO	34	95
EAGR	6	3
PBGR	2	74
RNGR	1	8
WEGR	246	324
Wading Birds		
CAEG	0	1
GBHE	13	16
GREG	4	47
Other Waterbirds		
AWPE	115	320
BAEA	0	3
BLTE	31	60
FOTE	3	12
RBGU	2135	158
TRUS	0	1

Table 3. Summary of waterbird nesting success at Lake Christina, 2005.

Species	Sample Size	Ave. Clutch Size	Number (%) Hatched	Number (%) Failed	Number (%) Unknown
WEGR	315	3.1	198 (62.9)	115 (26.9)	32 (10.2)
RNGR	3	4	2 (66.7)	0 (0)	1 (33.3)
PBGR	3	6.3	2 (66.7)	1 (33.3)	0 (0)
BLTE	10	2.4	3 (30)	4 (40)	3 (30)
CANV	1	8	1 (100)	0 (0)	0 (0)
AMCO	1	9	0 (0)	0 (0)	1 (100)

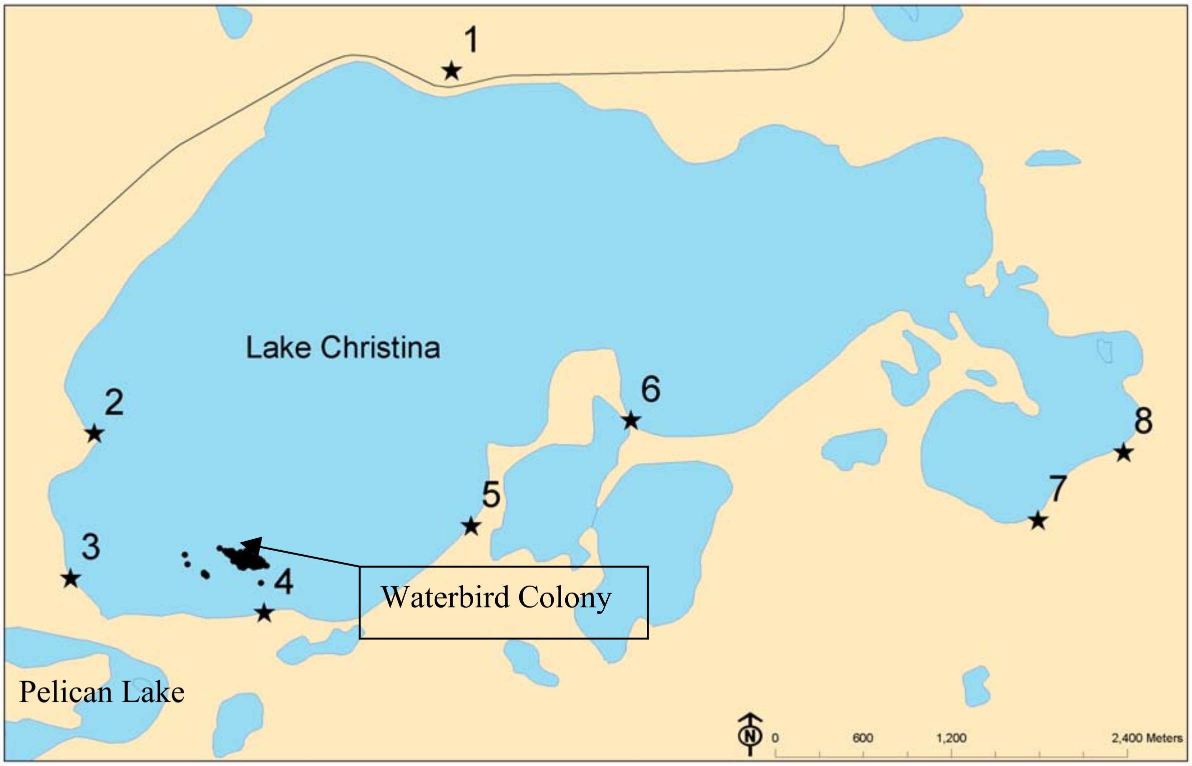


Figure 1. Waterbird survey points located around Lake Christina provided almost complete visual coverage of the lake.

Figure 2. The sequence of three aerial pictures show the dense bulrush beds in the southwest bay used for nesting by western grebes. White dots are plastic bags marking nests after the colony had completed nesting in August 2005 (GLN- photographer, JHA-Pilot).

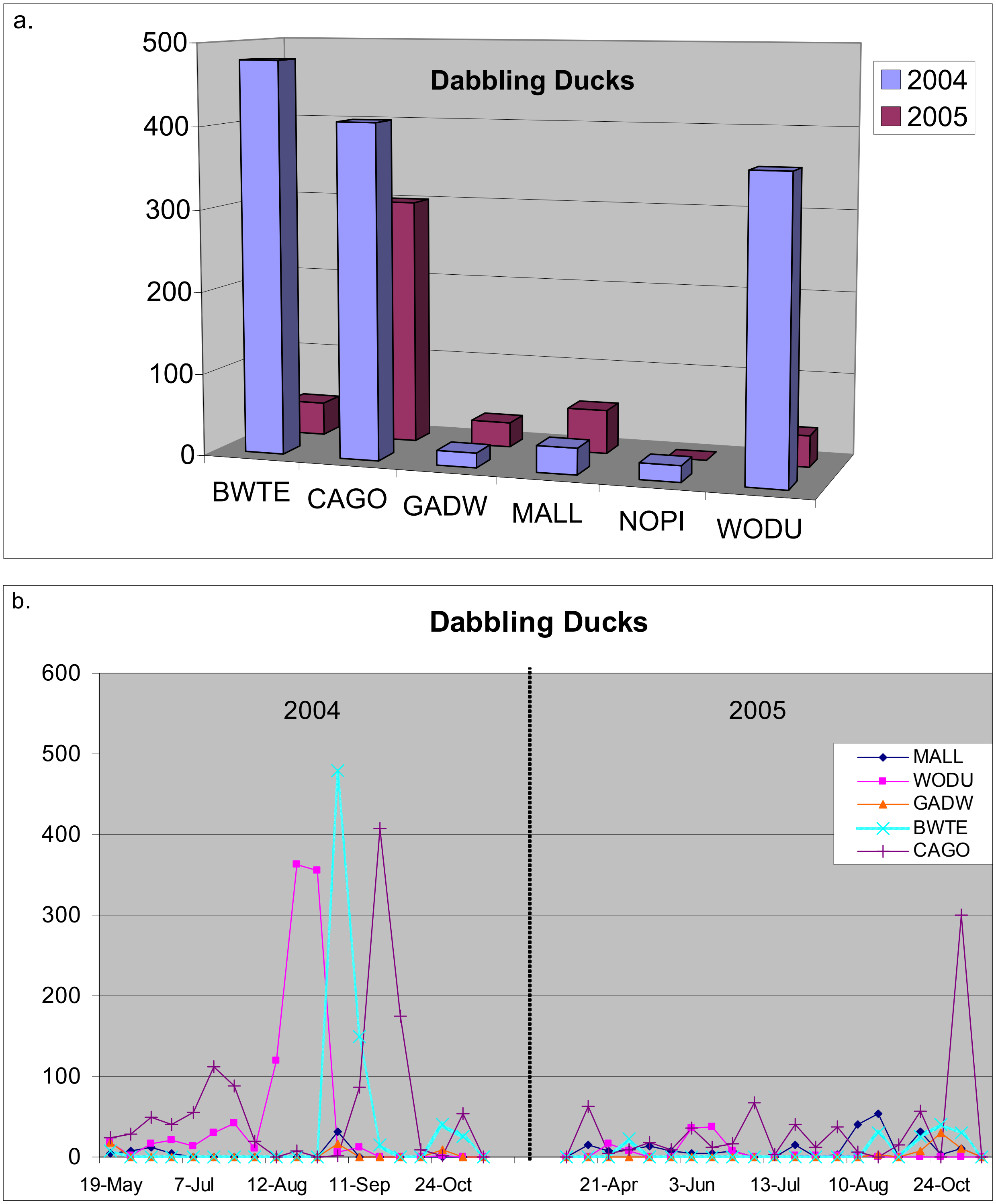
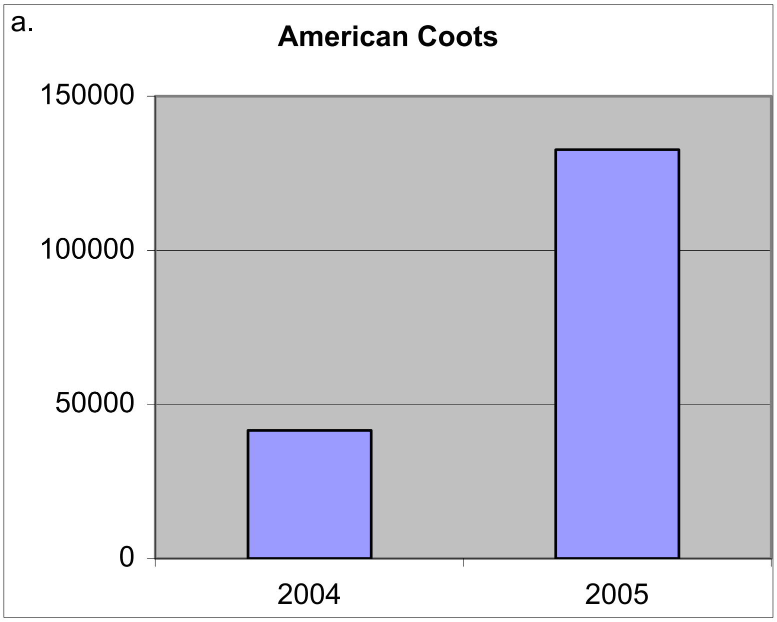


Figure 3. (a) Maximum counts of wood ducks and blue-winged teal reached a much greater abundance during the 2004 surveys compared to 2005. Canada goose counts were relatively high during both years. (b) Survey counts for these species peaked between mid-August and mid-October 2004.



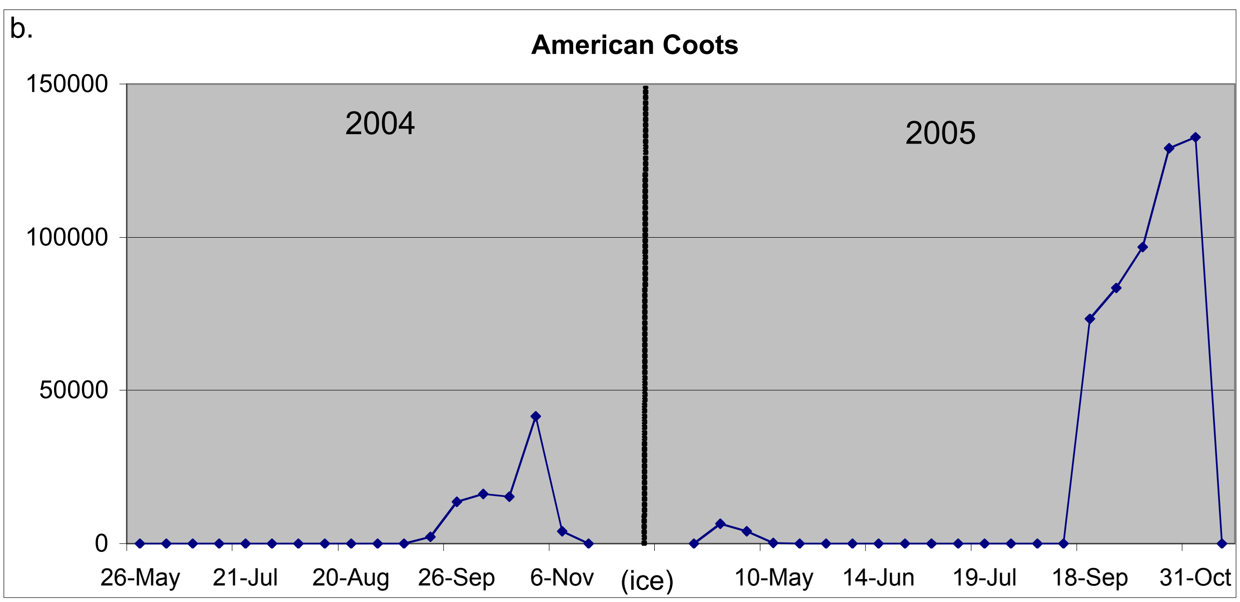
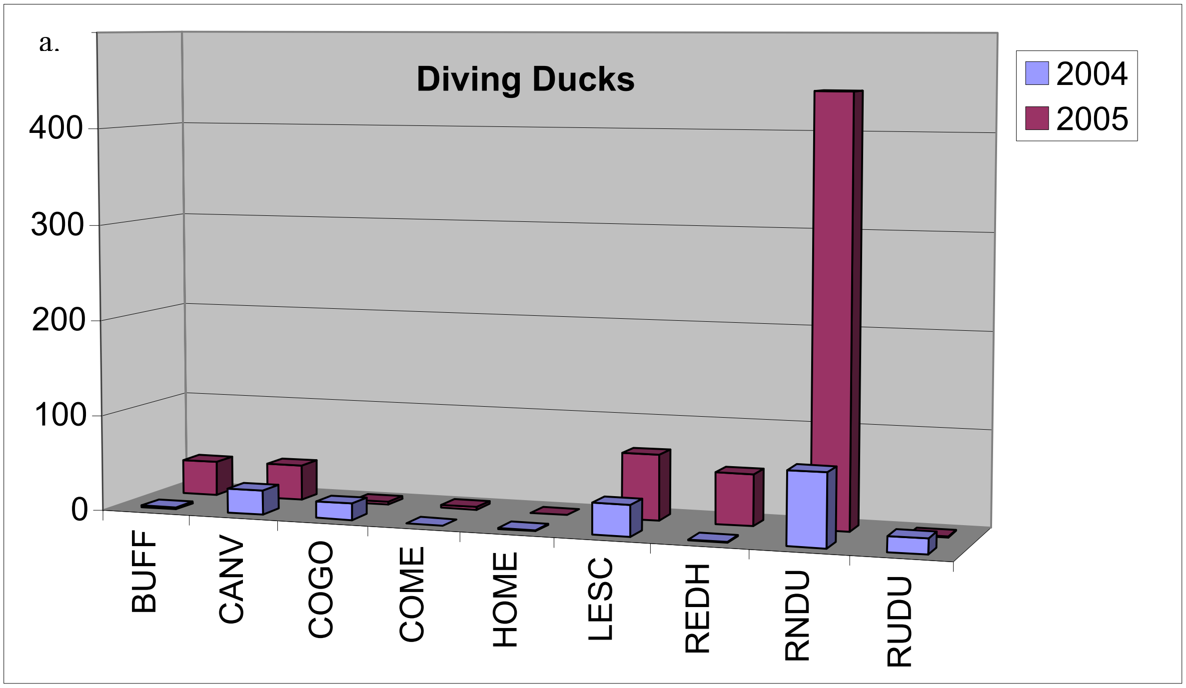


Figure 4. (a) Maximum counts of American coots showed a dramatic increase in2005 relative to 2004. (b) In both years coot numbers peaked in late October.



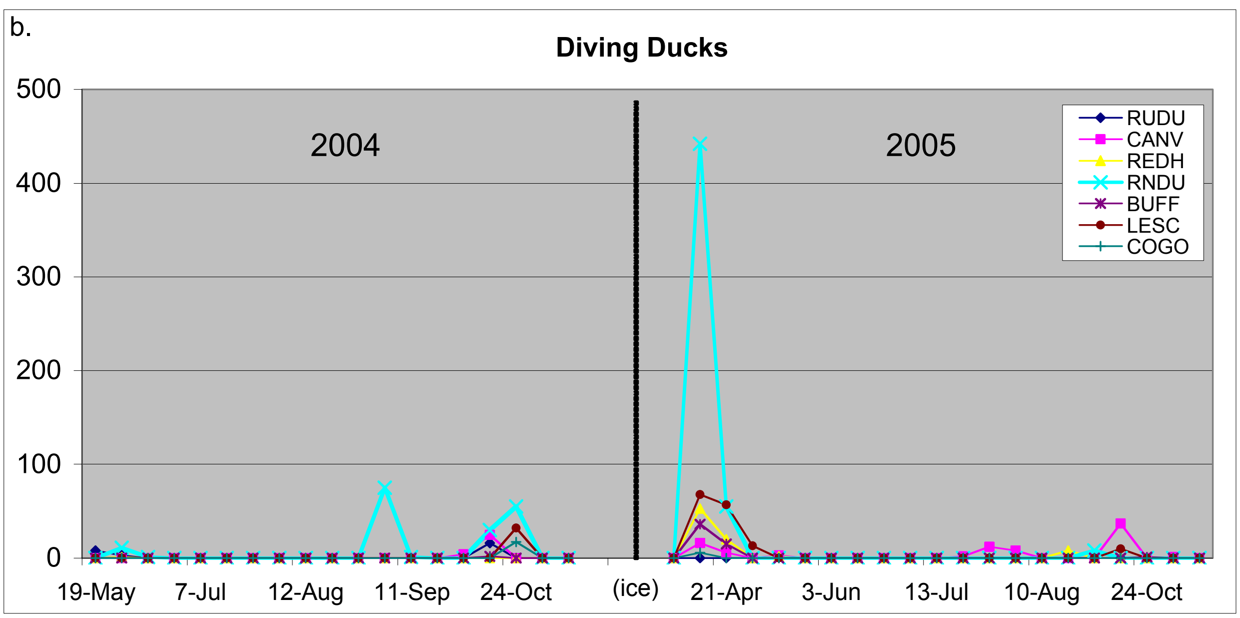
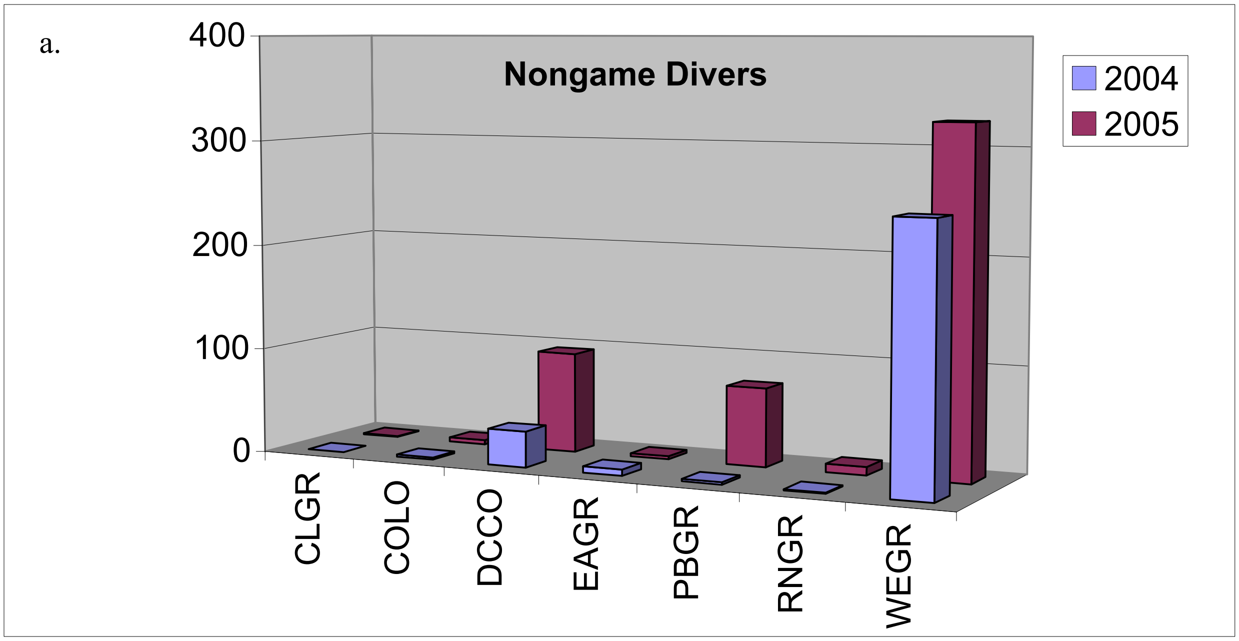


Figure 5. (a) Maximum counts for most species increased in 2005, with ring-necked ducks showing the most dramatic increase in abundance. (b) Survey counts for most divers peaked in mid-April to mid-May 2005.



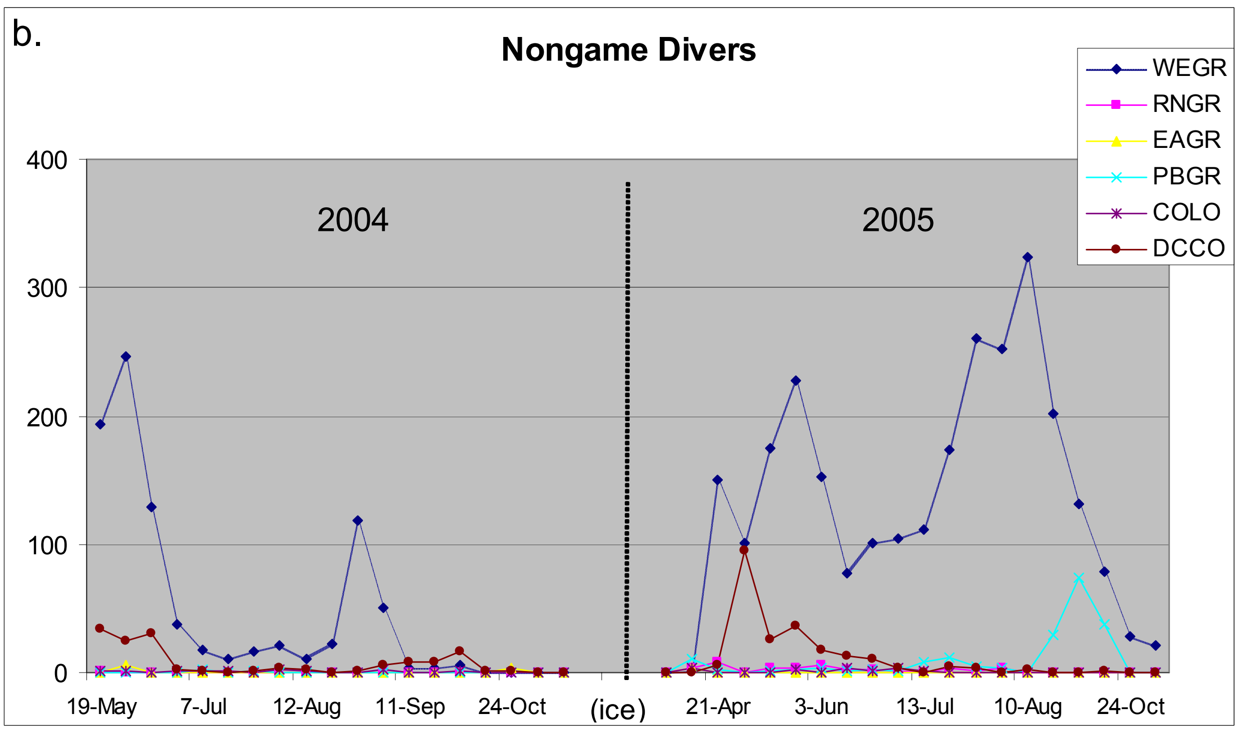


Figure 6. (a) Maximum counts of western grebes, pied-billed grebes, and double-crested cormorants increased in 2005 over 2004. (b) Throughout most of the open-water season of both years, western grebes were the most abundant nongame diver. Double-crested cormorants peaked during the spring of 2005, while the maximum counts of pied-billed grebes occurred during the fall of 2005.

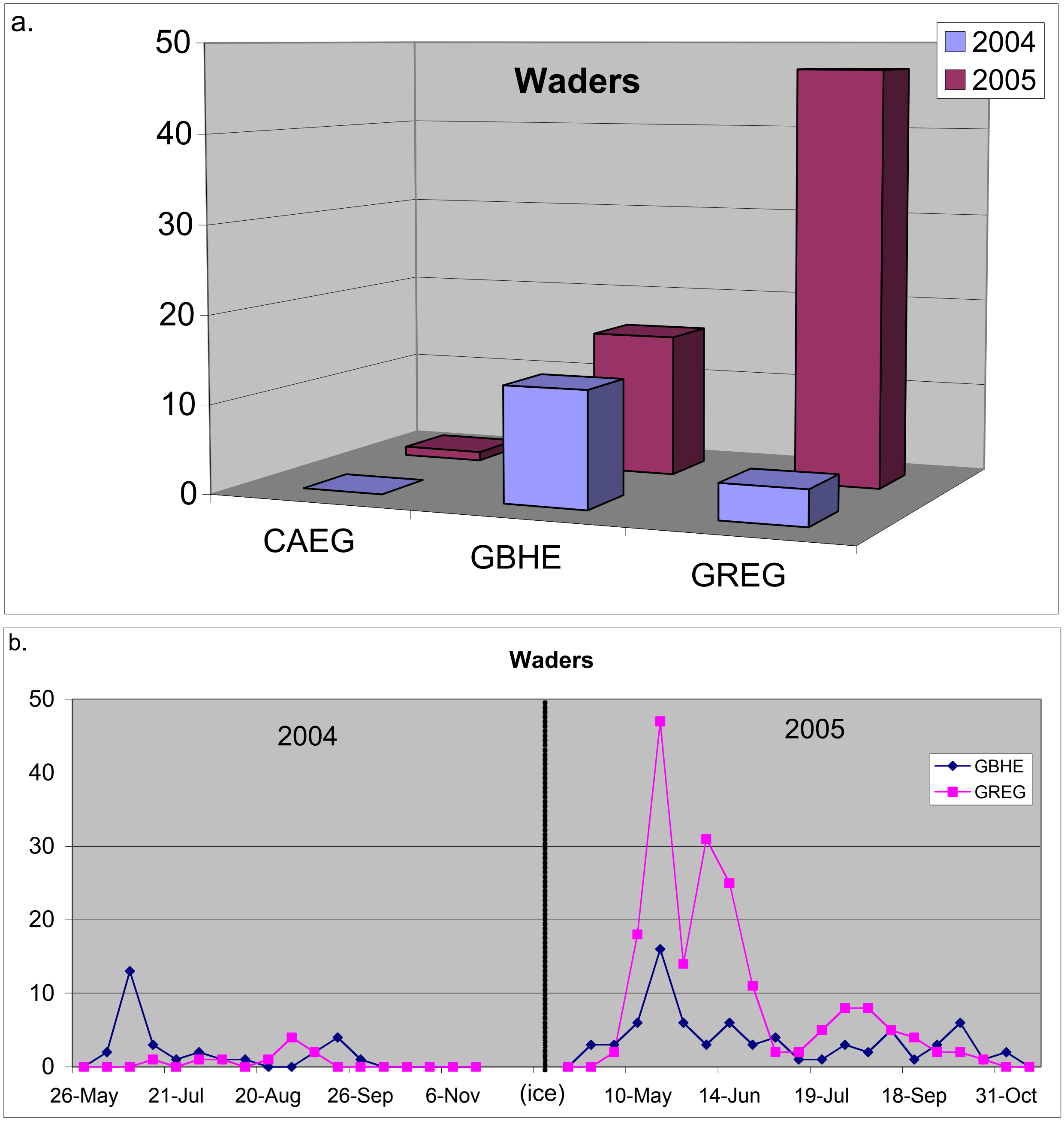
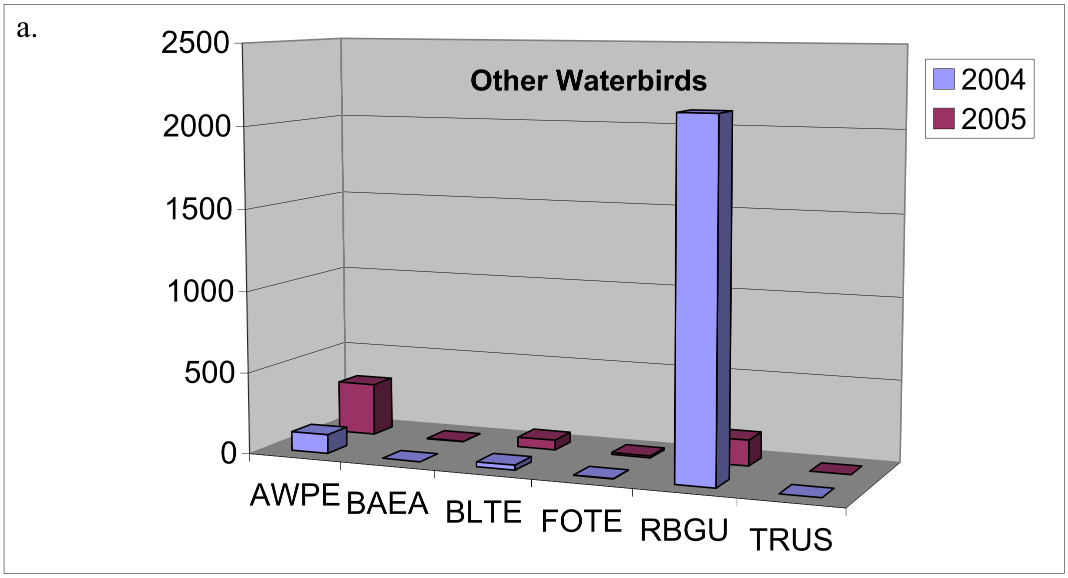
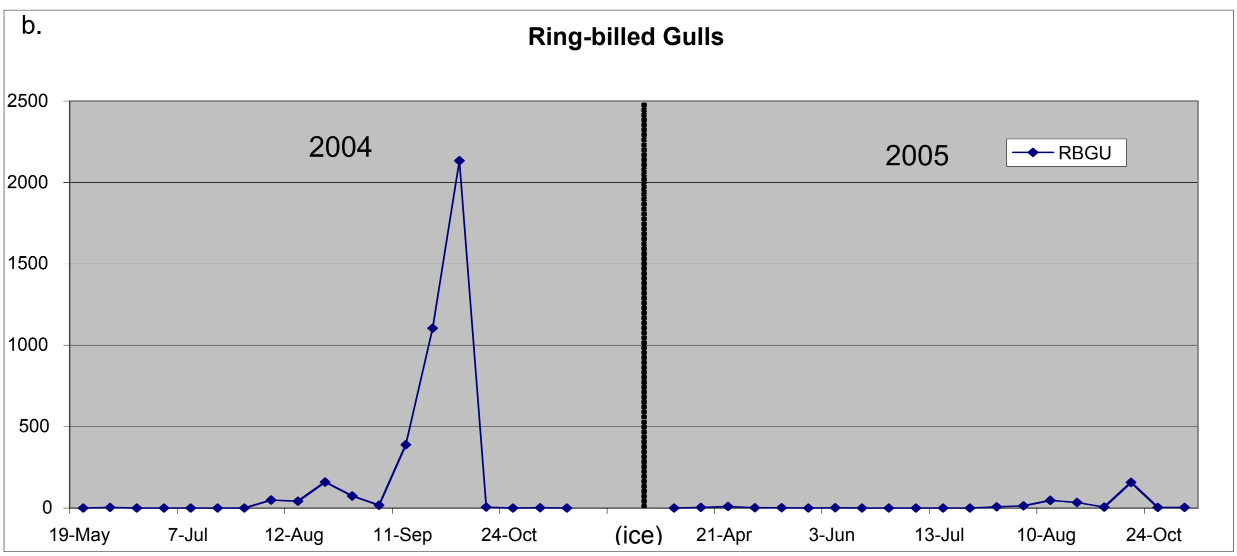


Figure 7. (a) Maximum counts of great egrets increased dramatically in 2005. (b) Survey counts of great blue herons and great egrets peaked during spring counts.





(Figure 8 continued on next page)

(Figure 8 continued)

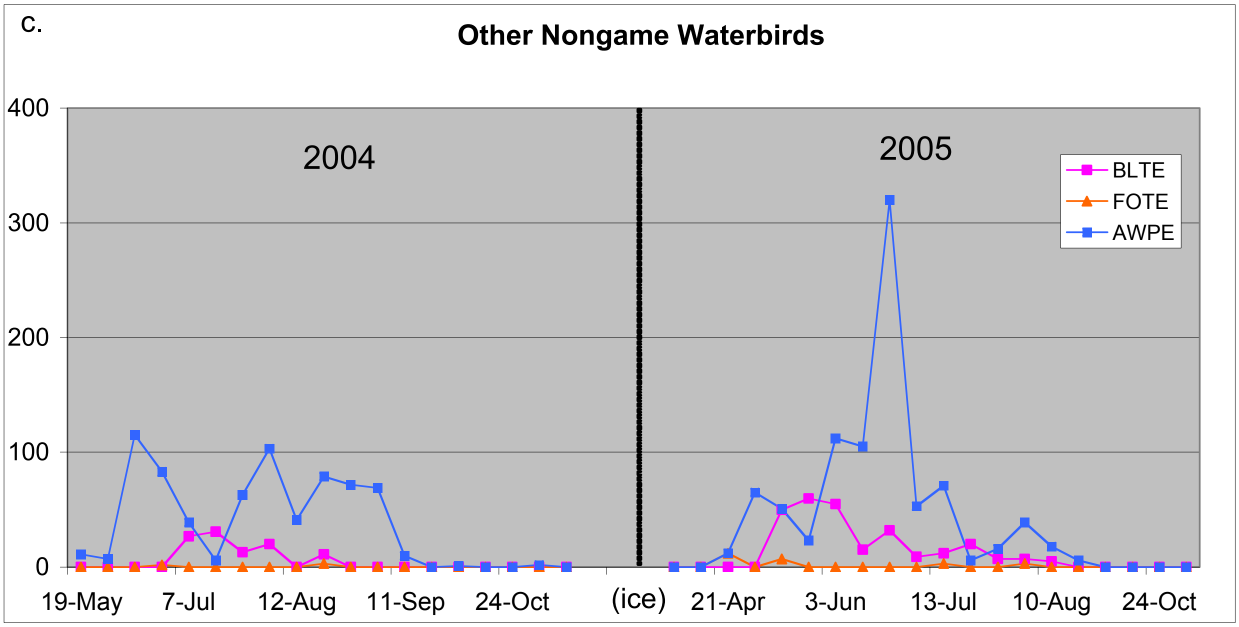


Figure 8. The biggest difference in years for all other waterbird species occurred with RBGU, which were much less abundant in 2005. TRUS was a new species in 2005. BAEA occurred both years, however not seen on survey days in 2004, but still more abundant and feeding with young in 2005.

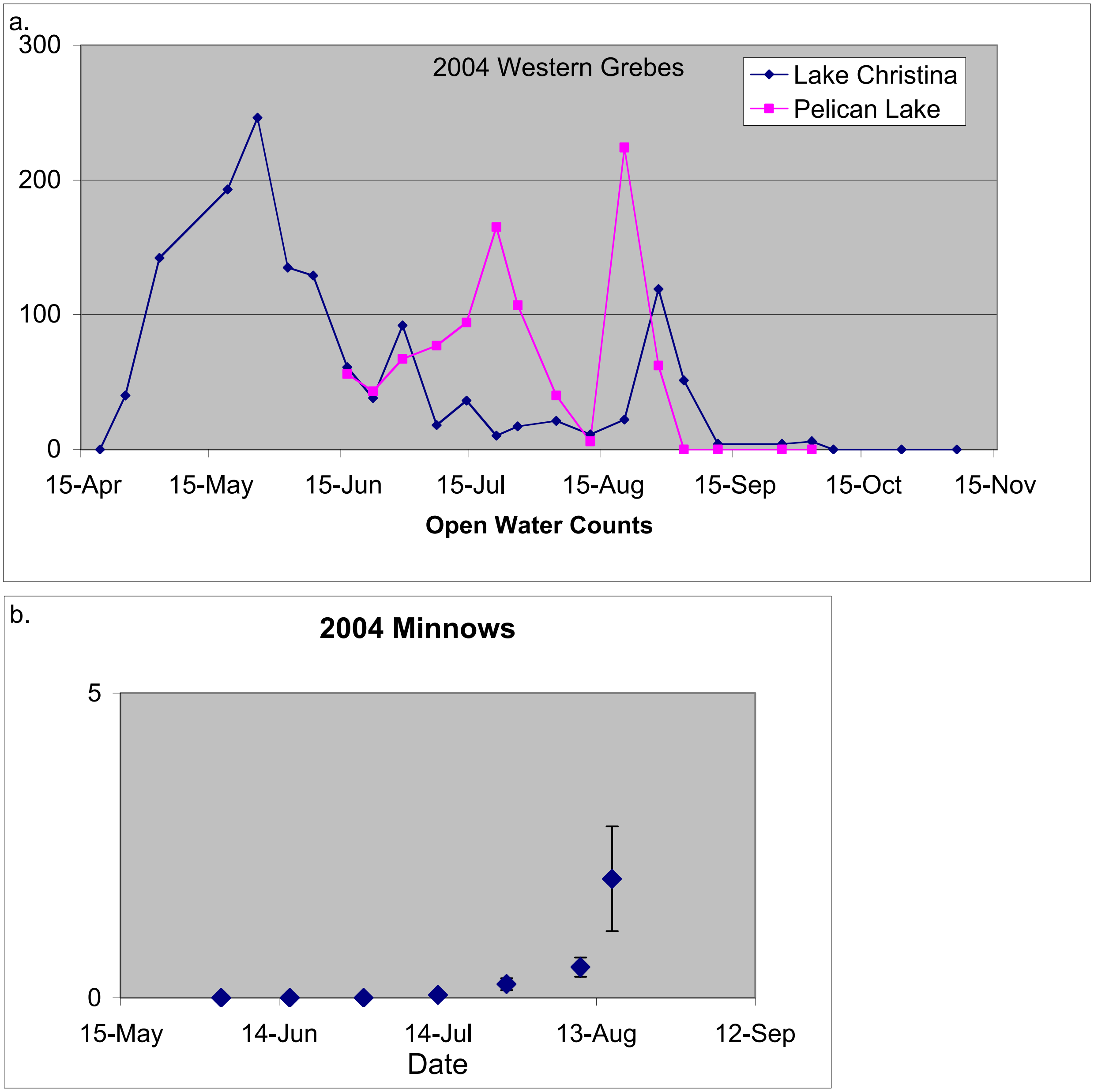
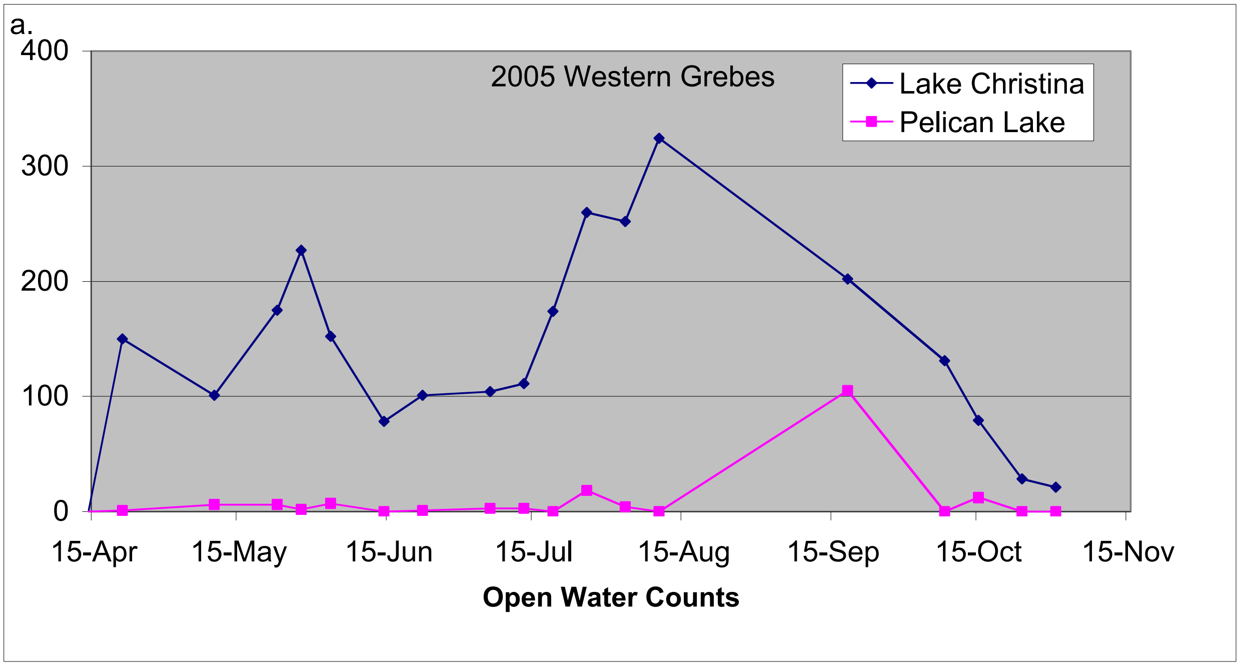


Figure 9. (a) Survey counts of western grebes on Lake Christina and Pelican Lake during 2004 showed many western grebes arriving at Lake Christina in early 2004, but then numbers decreased while Pelican Lake began hosting larger numbers of grebes. (b) trap counts for minnows on Lake Christina began increasing in Fall 2004.



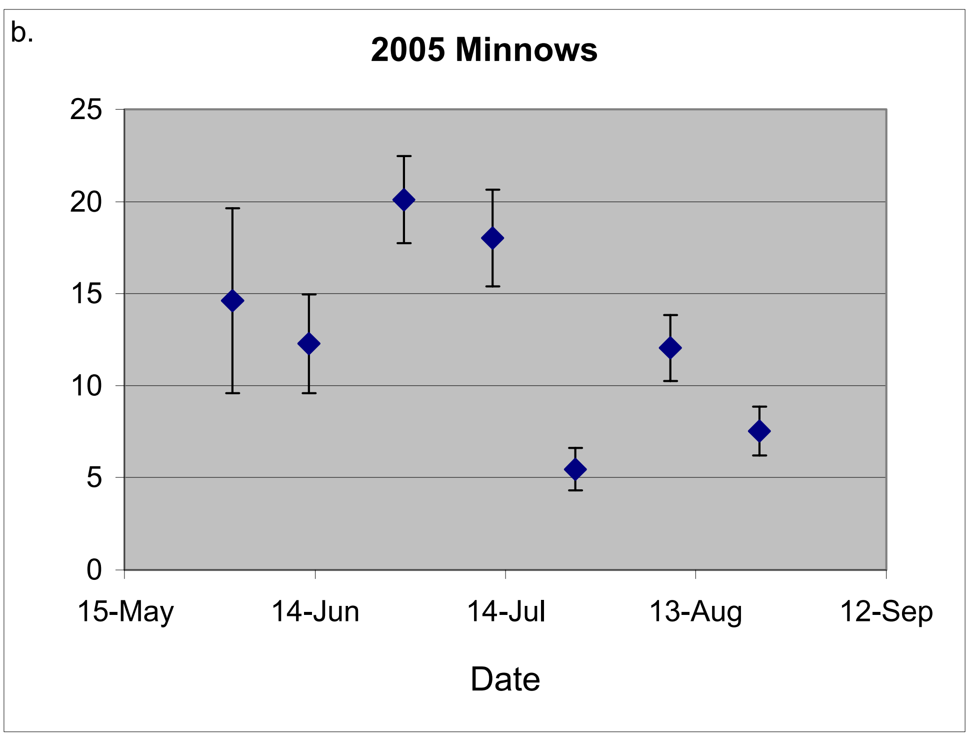


Figure 10. (a) Counts of western grebes on Lake Christina remained high throughout the open-water season of 2005. During incubation open water counts of western grebes were lower. Counts at Pelican Lake remained low throughout 2005. (b) During 2005, trap counts for minnows on Lake Christina were much higher than in 2004, with numbers peaking in the spring.

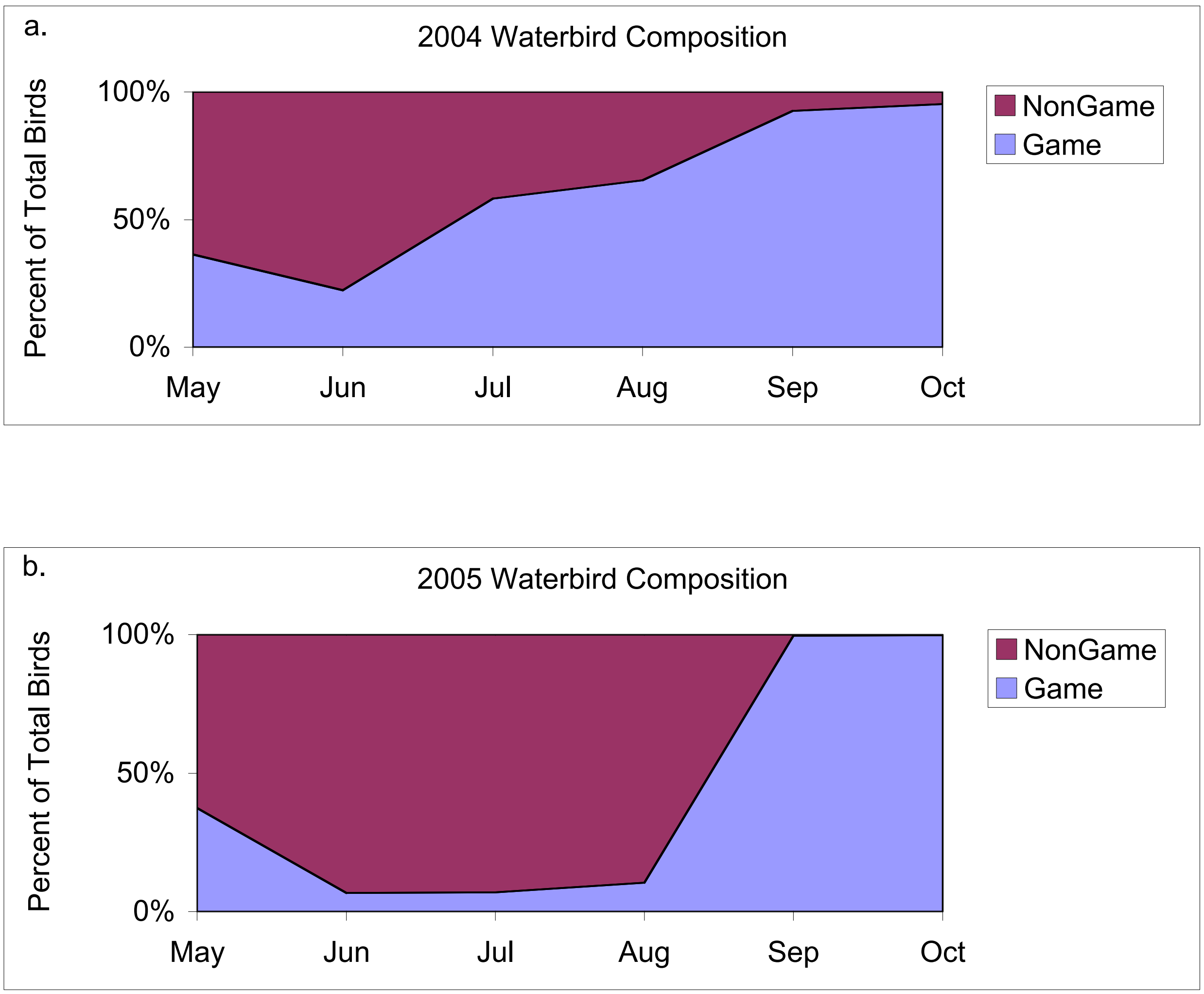


Figure 11. During the summers of both (a) 2004 and (b) 2005, Lake Christina's waterbird community was comprised mainly of nongame species, while the proportion of game species increase during spring and fall migrations.

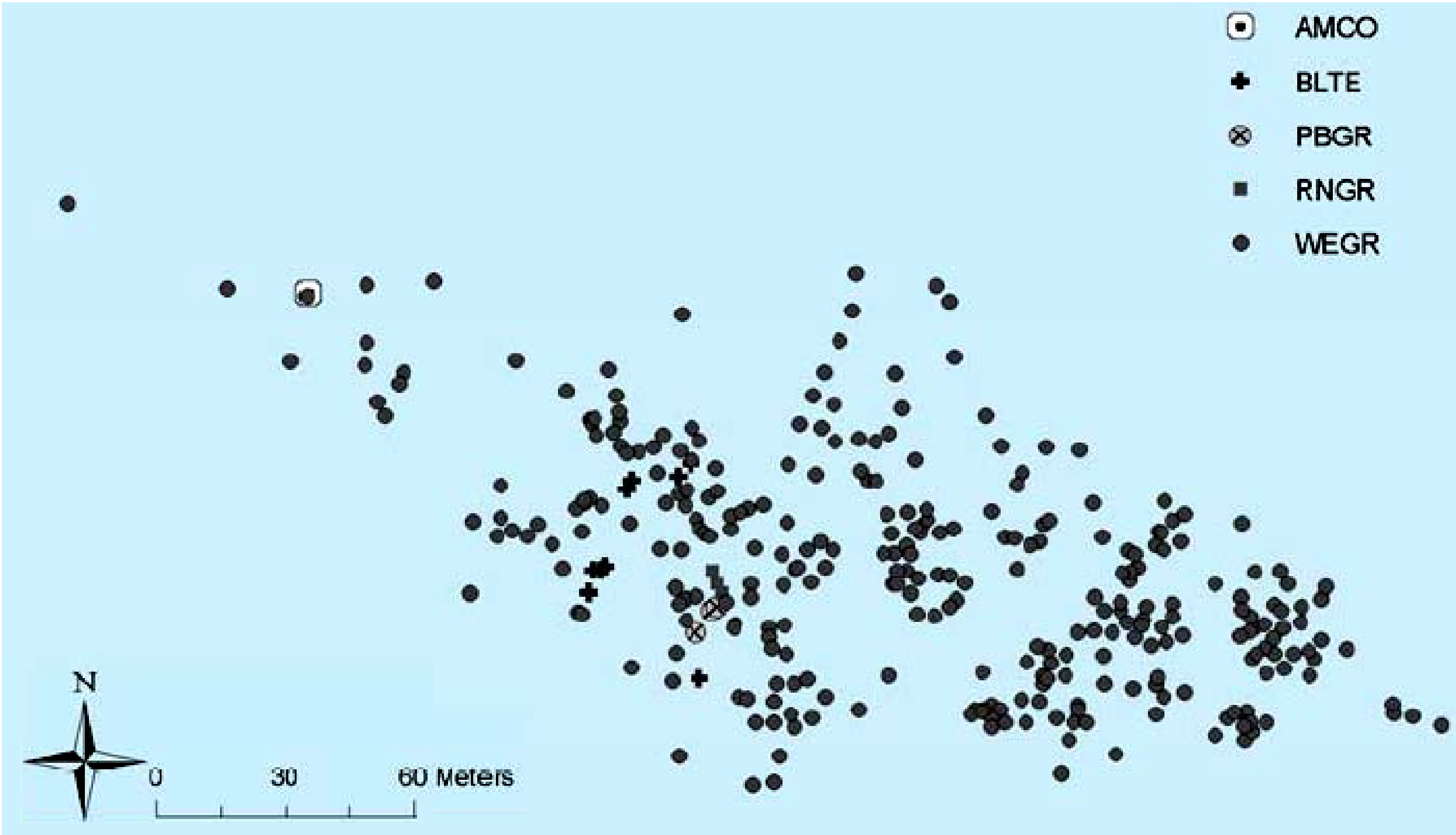


Figure 12. The waterbird nesting colony at Lake Christina was located in the thick bulrush beds in the south central portion of the large, shallow bay. The colony was predominately western grebes, but also contained red-necked grebes, pied-billed grebes, black terns, and one American coot nest.

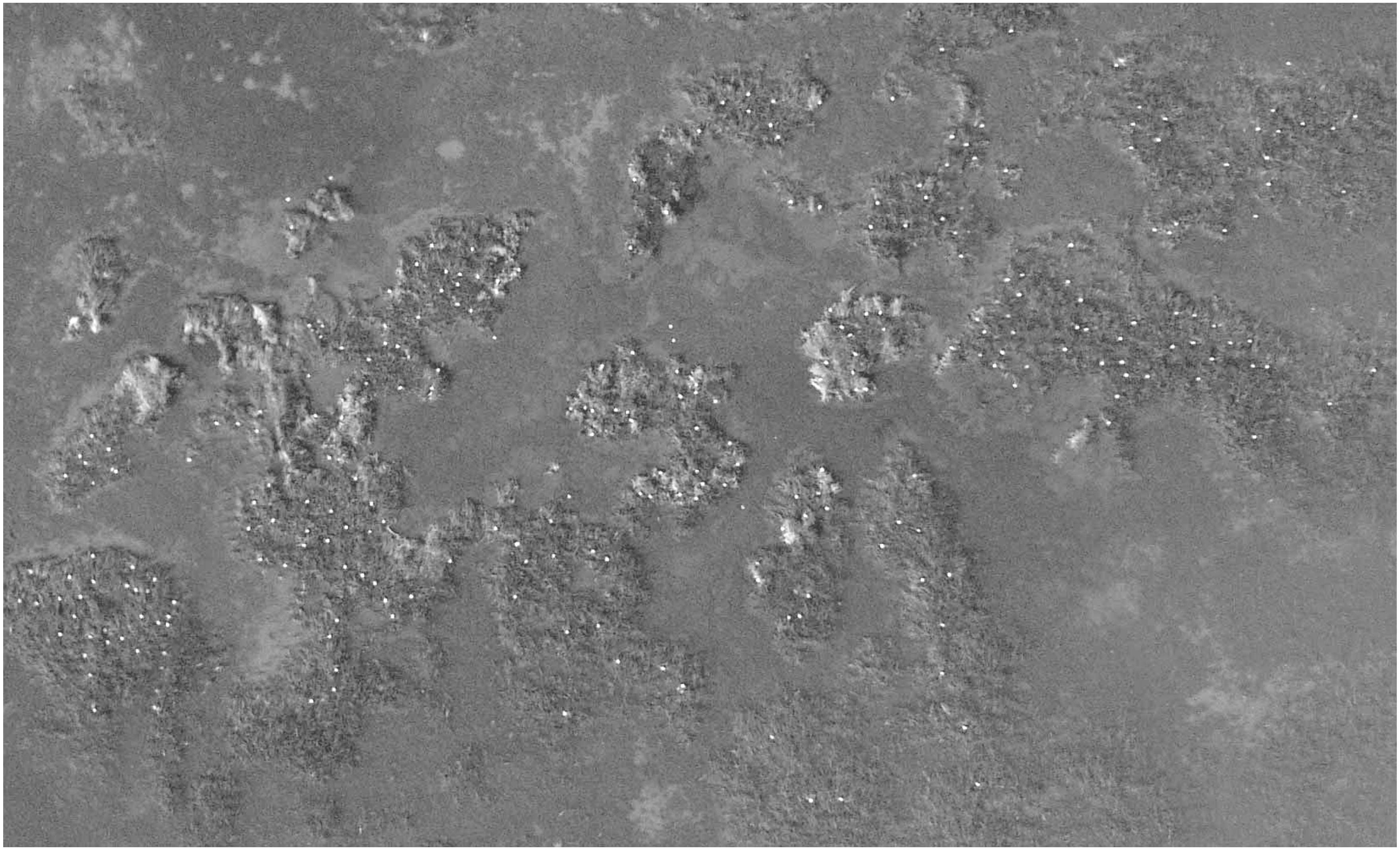


Figure 13. Aerial composite of western grebe colony located in bulrush bed clusters on Lake Christina in 2005. Nests were marked with white plastic bags. (JHA: Pilot, GLN: Photo).

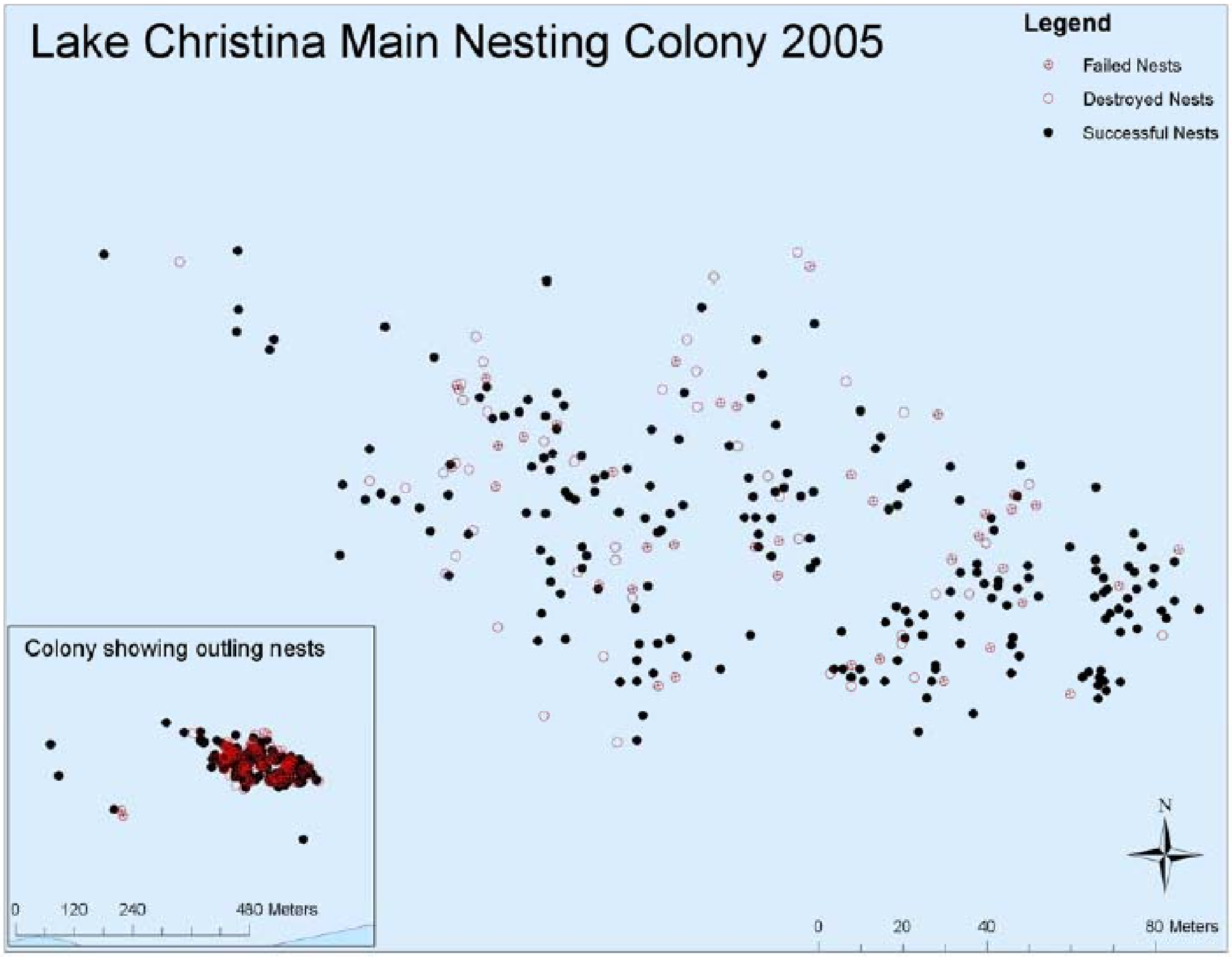


Figure 14. Lake Christina's waterbird colony had high success rates across most nesting species. Nests destroyed by wind and wave action were often located at the edges of bulrush islands (shown by clustered appearance within the main colony area).

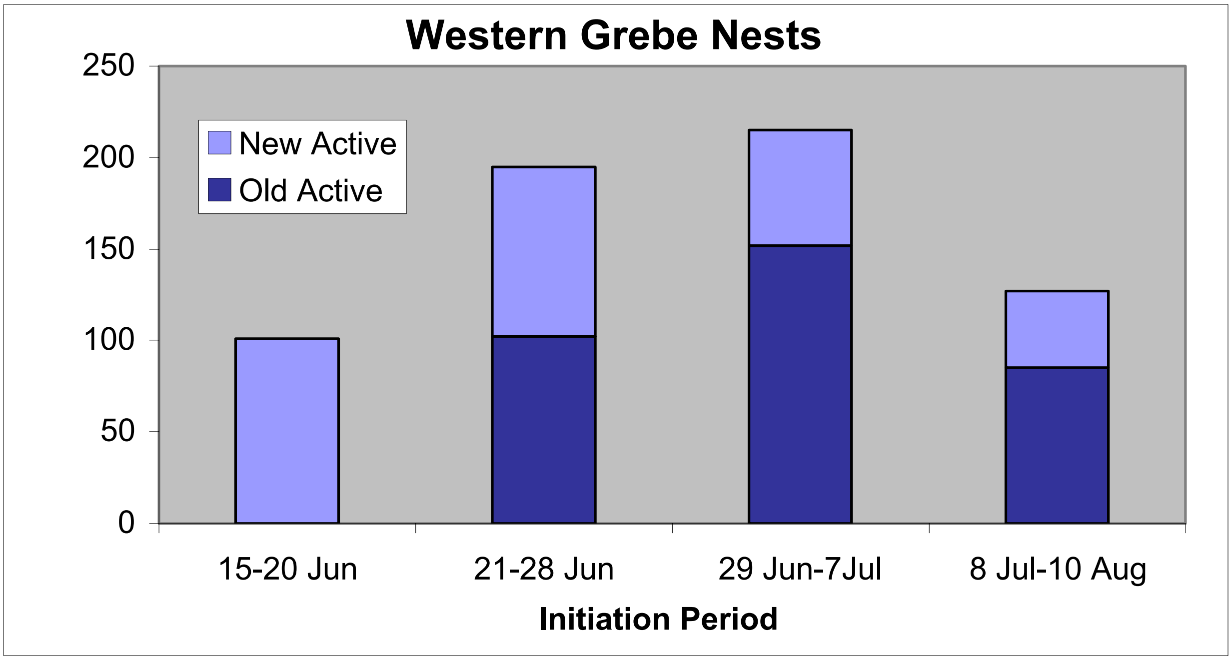


Figure 15. Nesting by western grebes at the Lake Christina colony began in mid-June. The peak number of active western grebe nests occurred in the first week of July with 215 nests.

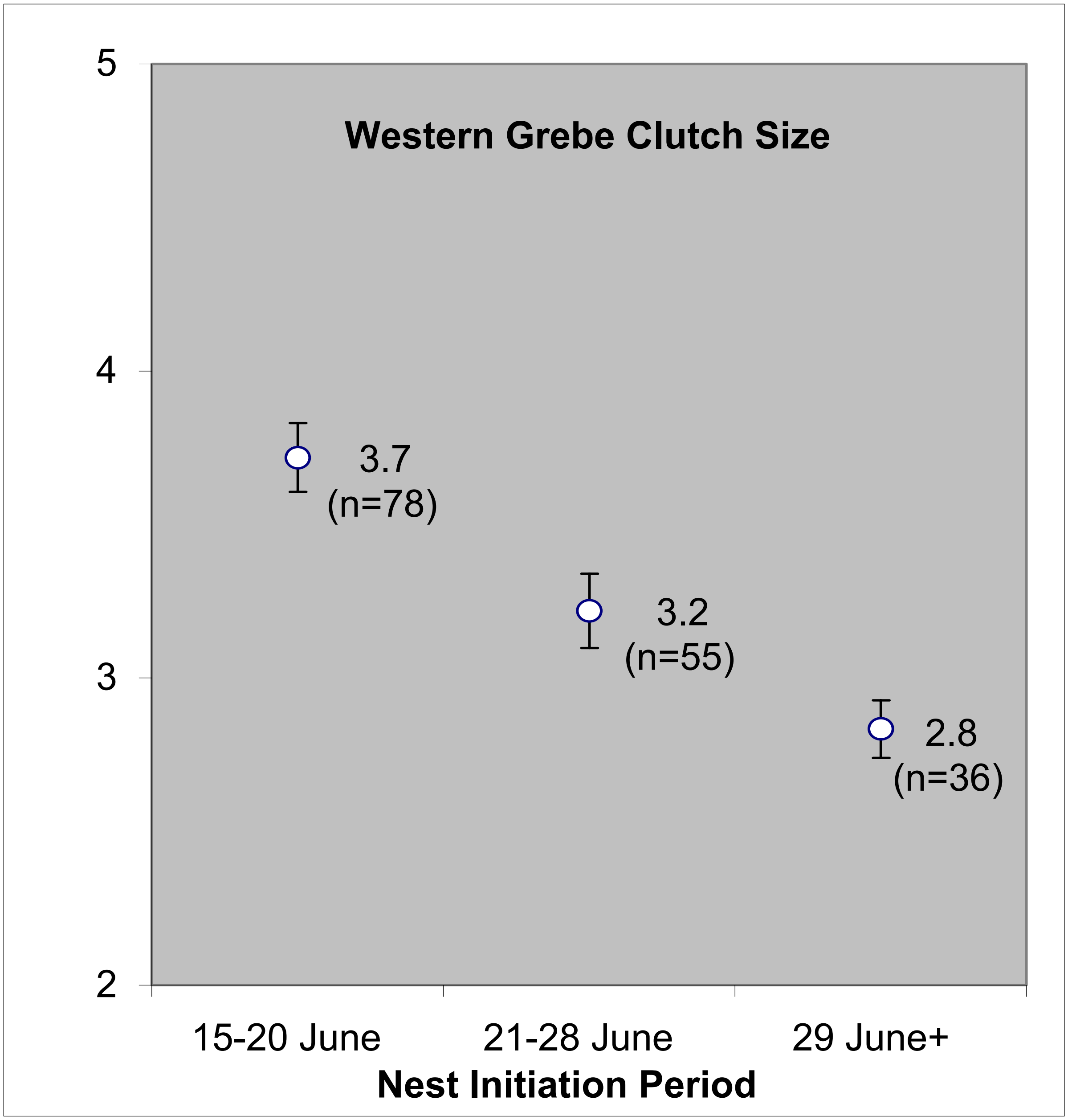


Figure 16. Average clutch size for western grebes decreased throughout the nesting season.

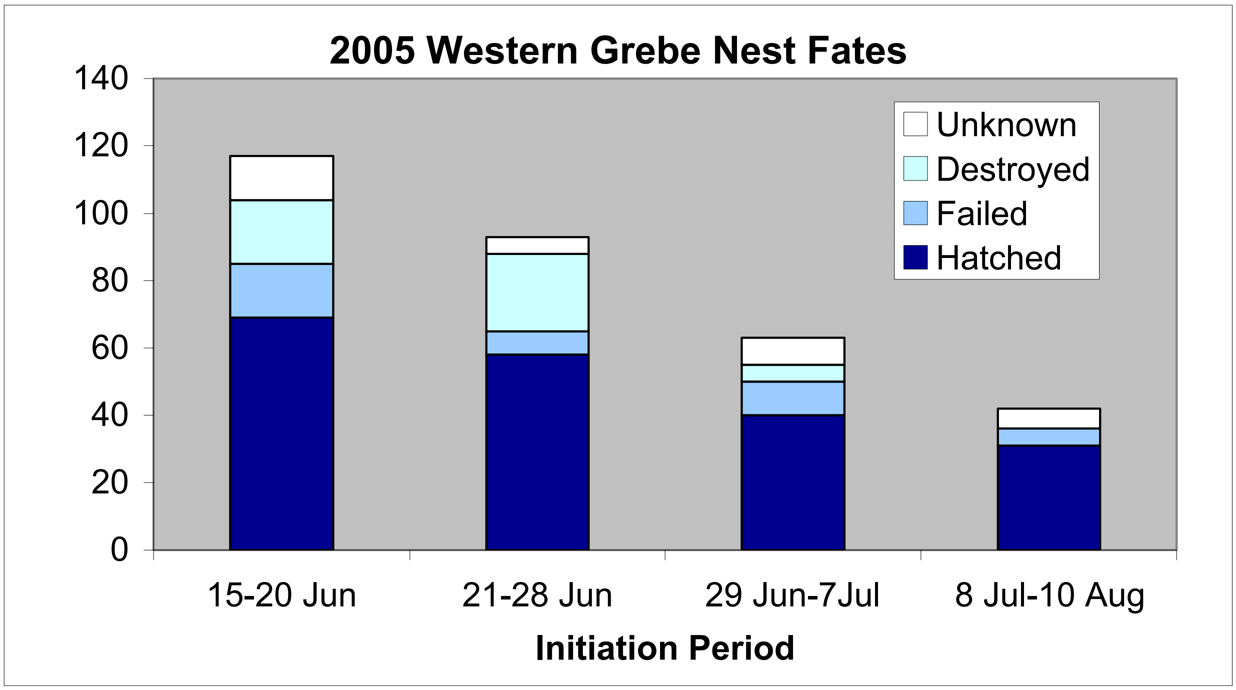


Figure 17. Most western grebe nests on Lake Christina were initiated in mid- to late-June. Hatching success was high during all of the nest initiation periods.

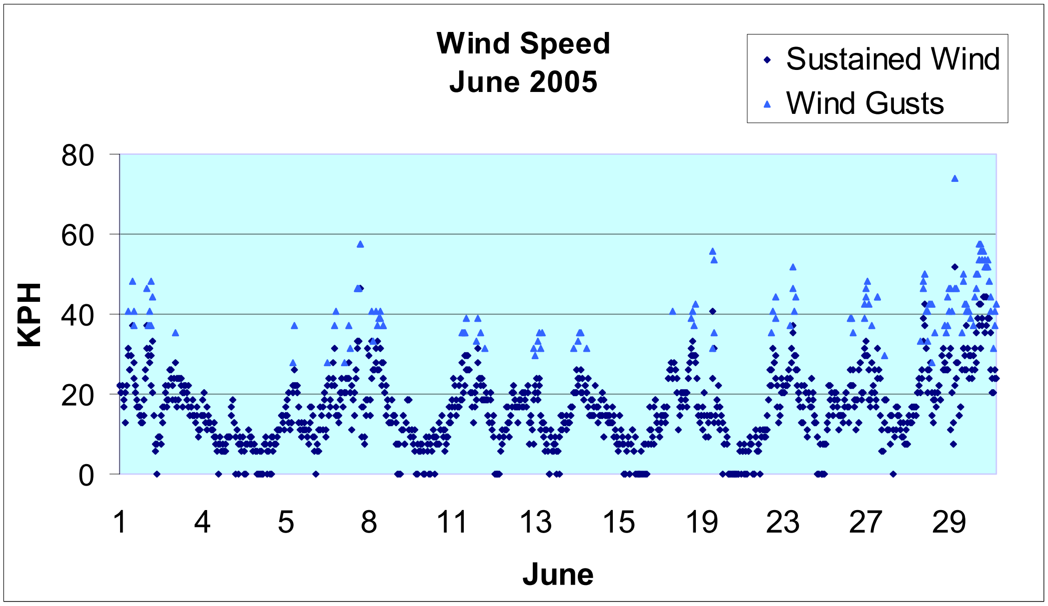


Figure 18. Hourly wind speeds recorded during June 2004 at Alexandria Aviation, MN.

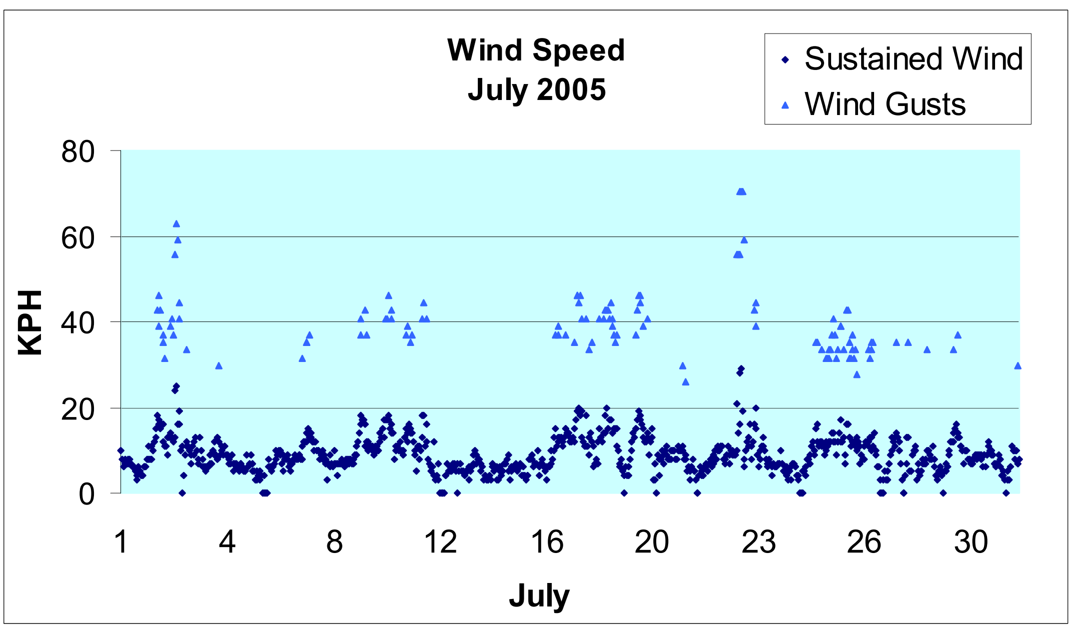


Figure 19. Hourly wind speeds recorded during July 2005 at Alexandria Aviation, MN.

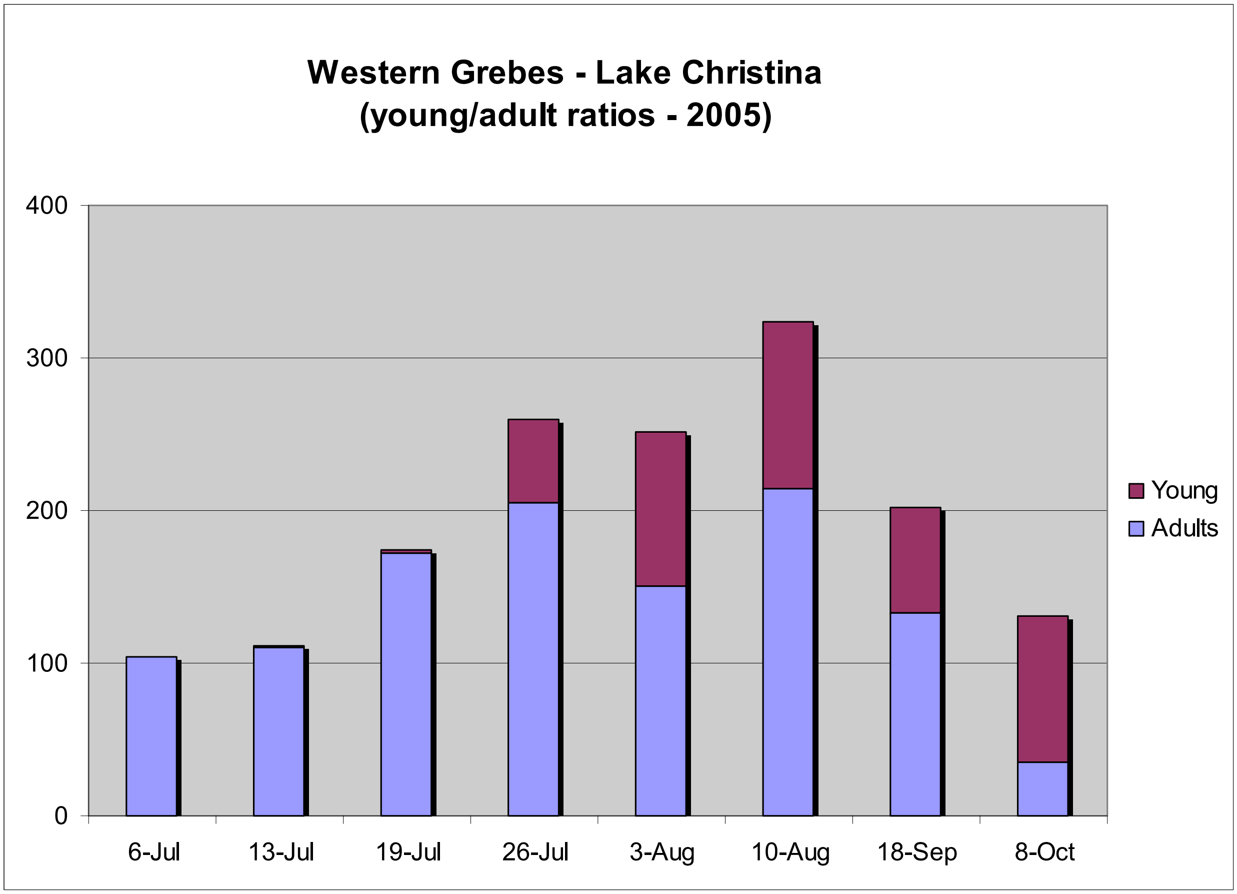


Figure 19. Ratios of young to adult western grebes counted in the Lake Christina shoreline surveys.

APPENDIX I: Shoreline Surveys

Appendix I. Shoreline Survey Data

A. Shoreline Surveys
2004

Dabbling Ducks	19-May	26-May	8-Jun	22-Jun	7-Jul	21-Jul	26-Jul	4-Aug	12-Aug	20-Aug	28-Aug	3-Sep	11-Sep	26-Sep	3-Oct	8-Oct	24-Oct	6-Nov
MALL	5	7	12	5	0	0	0	0	0	0	0	32	0	0	0	0	0	0
WODU	18	2	16	21	13	30	42	11	120	363	355	6	12	0	0	0	1	0
GADW	18	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	9	0
BWTE	8	0	0	0	0	0	0	0	0	0	0	479	150	15	0	0	41	26
NOPI	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0
DUCKS	5	0	3	0	9	0	2	0	0	340	311	268	351	549	600	291	1380	41
CAGO	24	29	50	40	55	112	88	20	0	7	0	2	86	407	175	9	2	53

Diving Ducks	19-May	26-May	8-Jun	22-Jun	7-Jul	21-Jul	26-Jul	4-Aug	12-Aug	20-Aug	28-Aug	3-Sep	11-Sep	26-Sep	3-Oct	8-Oct	24-Oct	6-Nov
RUDU	8	3	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
CANV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	25	0	0
REDH	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HOME	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RNDU	0	11	1	0	0	0	0	0	0	0	0	75	1	0	0	30	55	0
BUFF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
LESC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0
COGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0

Nongame Divers	19-May	26-May	8-Jun	22-Jun	7-Jul	21-Jul	26-Jul	4-Aug	12-Aug	20-Aug	28-Aug	3-Sep	11-Sep	26-Sep	3-Oct	8-Oct	24-Oct	6-Nov
WEGR	193	246	129	38	18	10	17	21	11	22	119	51	4	4	6	0	0	0
RNGR	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EAGR	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
PBGR	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0
COLO	1	1	0	1	1	1	0	2	1	0	0	2	0	0	1	0	0	0
DCCO	34	25	30	2	1	0	1	4	2	0	1	6	8	8	17	1	1	0

Waders	19-May	26-May	8-Jun	22-Jun	7-Jul	21-Jul	26-Jul	4-Aug	12-Aug	20-Aug	28-Aug	3-Sep	11-Sep	26-Sep	3-Oct	8-Oct	24-Oct	6-Nov
GBHE	6	0	2	13	3	1	2	1	1	0	0	2	4	1	0	0	0	0
GREG	0	0	0	0	1	0	1	1	0	1	4	2	0	0	0	0	0	0

Other Waterbirds	19-May	26-May	8-Jun	22-Jun	7-Jul	21-Jul	26-Jul	4-Aug	12-Aug	20-Aug	28-Aug	3-Sep	11-Sep	26-Sep	3-Oct	8-Oct	24-Oct	6-Nov
RBGU	0	3	0	0	0	0	0	50	42	160	74	18	389	1104	2135	5	0	1
BLTE	0	0	0	0	27	31	13	20	0	11	0	0	0	0	0	0	0	0
FOTE	0	0	0	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0
AWPE	11	7	115	83	39	6	63	103	41	79	72	69	10	0	1	0	0	2

B. Shoreline Surveys 2005

Dabbling Ducks	14-Apr	21-Apr	10-May	23-May	28-May	3-Jun	14-Jun	22-Jun	6-Jul	13-Jul	19-Jul	26-Jul	3-Aug	10-Aug	18-Sep	8-Oct	15-Oct	24-Oct	31-Oct
MALL	15	8	9	13	7	5	4	7	0	0	15	0	3	41	53	0	32	3	11
WODU	0	16	8	0	0	36	38	7	0	0	1	1	1	1	0	0	0	0	0
GADW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7	30	11
BWTE	0	0	22	0	0	0	0	0	0	0	0	0	0	0	30	0	25	40	30
CAGO	63	5	9	18	9	36	12	16	67	3	41	12	38	6	0	15	56	0	300

Diving Ducks	14-Apr	21-Apr	10-May	23-May	28-May	3-Jun	14-Jun	22-Jun	6-Jul	13-Jul	19-Jul	26-Jul	3-Aug	10-Aug	18-Sep	8-Oct	15-Oct	24-Oct	31-Oct
RUDU	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CANV	16	6	0	3	0	0	0	0	0	0	2	12	8	0	0	0	37	0	1
REDH	53	20	0	2	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0
HOME	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COME	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RNDU	442	55	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
BUFF	36	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
LESC	68	57	13	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
COGO	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Nongame Divers	14-Apr	21-Apr	10-May	23-May	28-May	3-Jun	14-Jun	22-Jun	6-Jul	13-Jul	19-Jul	26-Jul	3-Aug	10-Aug	18-Sep	8-Oct	15-Oct	24-Oct	31-Oct
WEGR	1	150	101	175	227	152	78	101	104	111	174	260	252	324	202	131	79	28	21
CLGR	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
RNGR	3	8	0	4	4	6	2	2	1	0	3	1	4	0	0	0	0	0	0
EAGR	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBGR	10	2	0	1	2	3	1	2	1	8	12	5	4	0	29	74	38	0	0
COLO	3	0	0	0	2	0	3	1	4	1	0	0	0	0	0	0	0	0	0
DCCO	0	6	95	26	36	18	13	11	4	0	5	4	0	2	0	0	1	0	0

Waders	14-Apr	21-Apr	10-May	23-May	28-May	3-Jun	14-Jun	22-Jun	6-Jul	13-Jul	19-Jul	26-Jul	3-Aug	10-Aug	18-Sep	8-Oct	15-Oct	24-Oct	31-Oct
GBHE	3	3	6	16	6	3	6	3	4	1	1	3	2	5	1	3	6	1	2
GREG	0	2	18	47	14	31	25	11	2	2	5	8	8	5	4	2	2	1	0
CAEG	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0

Other Waterbirds	14-Apr	21-Apr	10-May	23-May	28-May	3-Jun	14-Jun	22-Jun	6-Jul	13-Jul	19-Jul	26-Jul	3-Aug	10-Aug	18-Sep	8-Oct	15-Oct	24-Oct	31-Oct
RBGU	4	9	1	1	0	2	0	0	0	0	0	8	14	47	35	5	158	4	3
BLTE	0	0	0	50	60	55	15	32	9	12	20	7	7	5	0	0	0	0	0
FOTE	0	12	0	7	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0
AWPE	0	12	65	51	23	112	105	320	53	71	6	16	39	18	6	0	0	0	0
BAEA	0	0	0	3	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0
TRUS	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Appendix II. Nesting Survey Data

Date found	*Nest ID*	*Species*	*#Eggs**	*Clutch**	*Fate**
20-Jul	504	AMCO	9	.	U
20-Jun	153	BLTE	3	.	H
28-Jun	204	BLTE	2	.	FG
28-Jun	267	BLTE	3	.	U
28-Jun	285	BLTE	3	.	FL
28-Jun	287	BLTE	3	.	H
28-Jun	291	BLTE	2	.	U
28-Jun	297	BLTE	2	.	FG
28-Jun	300	BLTE	2	.	U
7-Jul	405	BLTE	3	.	FG
20-Jul	500	BLTE	1	.	H
20-Jun	110	PBGR	8	.	H
20-Jun	125	PBGR	8	.	FD
20-Jul	506	PBGR	3	.	H
20-Jun	130	RNGR	5	.	H
20-Jun	148	RNGR	4	.	H
28-Jun	200	RNGR	3	.	U
20-Jun	1	WEGR	5	IP	U
20-Jun	2	WEGR	2	I	FG
20-Jun	3	WEGR	4	I	FG
20-Jun	4	WEGR	3	C	FI
20-Jun	5	WEGR	3	I	FL
20-Jun	6	WEGR	3	C	FG
20-Jun	7	WEGR	4	C	U
20-Jun	8	WEGR	5	C	H
20-Jun	9	WEGR	3	I	H
20-Jun	10	WEGR	3	I	FG
20-Jun	11	WEGR	5	C	H
20-Jun	12	WEGR	4	C	H
20-Jun	13	WEGR	5	IP	FI
20-Jun	14	WEGR	5	C	H
20-Jun	15	WEGR	5	C	H
20-Jun	16	WEGR	4	C	H
20-Jun	17	WEGR	4	C	H
20-Jun	18	WEGR	3	C	FI
20-Jun	19	WEGR	3	C	H
20-Jun	20	WEGR	4	C	H
20-Jun	21	WEGR	6	IP	H
20-Jun	22	WEGR	4	C	H
20-Jun	23	WEGR	5	C	FI
20-Jun	24	WEGR	4	C	H
20-Jun	25	WEGR	4	C	H
20-Jun	26	WEGR	4	C	H
20-Jun	27	WEGR	3	I	FG
20-Jun	28	WEGR	4	I	FG
20-Jun	29	WEGR	4	C	H
20-Jun	30	WEGR	5	C	H

Code	Fate of Nest
H	Hatched
FI	Failed with nest intact
FD	Failed with nest destroyed
FG	Failed with nest gone
FL	Failed with nest lost to other species
U	Unknown (fate of nest not known)
C	Complete clutch
I	Incomplete clutch
IP	Intraspecific parasitism

20-Jun	31	WEGR	4	C	H
20-Jun	32	WEGR	3	I	FG
20-Jun	33	WEGR	5	IP	FG
20-Jun	34	WEGR	5	C	H
20-Jun	35	WEGR	3	C	H
20-Jun	36	WEGR	4	C	H
20-Jun	37	WEGR	4	C	H
20-Jun	38	WEGR	4	IP	FI
20-Jun	39	WEGR	4	C	H
20-Jun	40	WEGR	2	I	FG
20-Jun	41	WEGR	4	C	H
20-Jun	42	WEGR	4	C	FI
20-Jun	43	WEGR	4	C	H
20-Jun	44	WEGR	4	C	U
20-Jun	45	WEGR	4	C	FI
20-Jun	46	WEGR	5	C	H
20-Jun	47	WEGR	4	C	H
20-Jun	48	WEGR	4	C	H
20-Jun	49	WEGR	2	I	FG
20-Jun	50	WEGR	4	C	FG
20-Jun	51	WEGR	4	C	FI
20-Jun	52	WEGR	4	C	FI
20-Jun	53	WEGR	2	C	H
20-Jun	54	WEGR	4	C	H
20-Jun	55	WEGR	4	C	H
20-Jun	56	WEGR	4	C	U
20-Jun	57	WEGR	5	C	H
20-Jun	58	WEGR	4	C	H
20-Jun	59	WEGR	3	C	H
20-Jun	60	WEGR	3	C	H
20-Jun	61	WEGR	2	C	H
20-Jun	62	WEGR	3	IP	H
20-Jun	63	WEGR	3	C	U
20-Jun	64	WEGR	2	I	U
20-Jun	65	WEGR	3	C	H
20-Jun	101	WEGR	4	C	FG
20-Jun	102	WEGR	4	C	FI
20-Jun	103	WEGR	5	C	U
20-Jun	104	WEGR	4	IP	H
20-Jun	105	WEGR	4	C	H
20-Jun	106	WEGR	3	C	FG
20-Jun	107	WEGR	4	IP	H
20-Jun	108	WEGR	6	IP	U
20-Jun	109	WEGR	4	C	H
20-Jun	111	WEGR	4	C	H
20-Jun	112	WEGR	2	I	U
20-Jun	113	WEGR	4	C	H
20-Jun	114	WEGR	3	IP	U
20-Jun	115	WEGR	2	C	H
20-Jun	116	WEGR	2	C	FI

20-Jun	117	WEGR	6	C	H
20-Jun	118	WEGR	4	C	H
20-Jun	119	WEGR	2	I	FL
20-Jun	120	WEGR	2		U
20-Jun	121	WEGR	4	C	H
20-Jun	122	WEGR	4	C	H
20-Jun	123	WEGR	4	IP	H
20-Jun	124	WEGR	4	I	FG
20-Jun	126	WEGR	3	C	H
20-Jun	127	WEGR	4	IP	FL
20-Jun	128	WEGR	2	IP	FL
20-Jun	129	WEGR	2	IP	FL
20-Jun	131	WEGR	3	IP	H
20-Jun	132	WEGR	4	C	H
20-Jun	133	WEGR	4	C	FG
20-Jun	134	WEGR	4	C	H
20-Jun	135	WEGR	4	C	FG
20-Jun	136	WEGR	5	IP	H
20-Jun	137	WEGR	3	C	H
20-Jun	138	WEGR	4	C	U
20-Jun	139	WEGR	5	C	H
20-Jun	140	WEGR	5	IP	H
20-Jun	141	WEGR	2	IP	H
20-Jun	142	WEGR	4	IP	H
20-Jun	143	WEGR	3	C	H
20-Jun	144	WEGR	3	C	H
20-Jun	145	WEGR	5	IP	H
20-Jun	146	WEGR	3	C	FD
20-Jun	147	WEGR	4	C	H
20-Jun	150	WEGR	3	C	U
20-Jun	152	WEGR	3	C	H
20-Jun	154	WEGR	4	C	H
20-Jun	155	WEGR	4	C	H
20-Jun	156	WEGR	1	IP	FG
20-Jun	157	WEGR	3	IP	H
20-Jun	158	WEGR	4	C	H
20-Jun	159	WEGR	4	C	FG
28-Jun	201	WEGR	3	C	H
28-Jun	202	WEGR	3	C	H
28-Jun	203	WEGR	3	C	H
28-Jun	205	WEGR	3	IP	FG
28-Jun	206	WEGR	1	I	H
28-Jun	207	WEGR	3	I	H
28-Jun	208	WEGR	3	C	FD
28-Jun	209	WEGR	1	I	H
28-Jun	210	WEGR	3	C	FG
28-Jun	211	WEGR	2	C	H
28-Jun	212	WEGR	4	I	FG
28-Jun	213	WEGR	4	I	FG
28-Jun	214	WEGR	3	I	H

28-Jun	215	WEGR	3	IP	FL
28-Jun	216	WEGR	6	IP	FI
28-Jun	217	WEGR	4	C	FI
28-Jun	218	WEGR	3	C	FG
28-Jun	219	WEGR	3	C	FG
28-Jun	220	WEGR	3	C	H
28-Jun	221	WEGR	4	IP	H
28-Jun	222	WEGR	4	C	H
28-Jun	223	WEGR	2	I	FD
28-Jun	224	WEGR	2	C	H
28-Jun	225	WEGR	3	C	H
28-Jun	226	WEGR	5	C	H
28-Jun	227	WEGR	3	C	H
28-Jun	228	WEGR	3	C	H
28-Jun	229	WEGR	3	C	H
28-Jun	230	WEGR	3	C	H
28-Jun	231	WEGR	2	C	H
28-Jun	232	WEGR	2	C	H
28-Jun	233	WEGR	4	C	FD
28-Jun	234	WEGR	1	I	FG
28-Jun	235	WEGR	3	IP	FG
28-Jun	236	WEGR	3	C	H
28-Jun	237	WEGR	3	C	H
28-Jun	238	WEGR	3	I	FG
28-Jun	239	WEGR	4	I	FG
28-Jun	240	WEGR	1	I	FG
28-Jun	241	WEGR	3	I	FG
28-Jun	242	WEGR	3	I	FG
28-Jun	243	WEGR	1	I	U
28-Jun	244	WEGR	3	C	H
28-Jun	245	WEGR	2	C	H
28-Jun	246	WEGR	4	C	H
28-Jun	247	WEGR	4	C	H
28-Jun	248	WEGR	6	IP	FD
28-Jun	249	WEGR	3	C	H
28-Jun	250	WEGR	3	C	FD
28-Jun	251	WEGR	1	IP	FD
28-Jun	252	WEGR	2	C	H
28-Jun	253	WEGR	2	C	H
28-Jun	254	WEGR	1	I	H
28-Jun	255	WEGR	3	C	H
28-Jun	256	WEGR	5	C	FG
28-Jun	257	WEGR	3	C	FI
28-Jun	258	WEGR	3	C	H
28-Jun	259	WEGR	3	C	H
28-Jun	260	WEGR	4	C	H
28-Jun	261	WEGR	2	C	H
28-Jun	262	WEGR	3	C	H
28-Jun	263	WEGR	3	IP	FL
28-Jun	264	WEGR	3	C	H

28-Jun	265	WEGR	2	C	H
28-Jun	266	WEGR	4	C	H
28-Jun	268	WEGR	5	C	H
28-Jun	269	WEGR	3	I	FI
28-Jun	270	WEGR	5	C	H
28-Jun	271	WEGR	4	C	H
28-Jun	272	WEGR	2	C	H
28-Jun	273	WEGR	3	I	FI
28-Jun	274	WEGR	4	C	FI
28-Jun	275	WEGR	2	I	FG
28-Jun	276	WEGR	2	I	U
28-Jun	277	WEGR	4	C	H
28-Jun	279	WEGR	3	C	U
28-Jun	280	WEGR	3	I	H
28-Jun	281	WEGR	3	C	FI
28-Jun	282	WEGR	2	IP	H
28-Jun	283	WEGR	1	I	H
28-Jun	284	WEGR	3	C	H
28-Jun	286	WEGR	2	C	H
28-Jun	288	WEGR	3	C	H
28-Jun	289	WEGR	2	C	H
28-Jun	290	WEGR	4	C	H
28-Jun	292	WEGR	4	C	U
28-Jun	293	WEGR	4	C	H
28-Jun	294	WEGR	3	C	H
28-Jun	295	WEGR	4	C	H
28-Jun	296	WEGR	3	I	U
28-Jun	298	WEGR	4	C	H
28-Jun	299	WEGR	2	C	H
28-Jun	301	WEGR	3	C	H
7-Jul	350	WEGR	3	I	H
7-Jul	351	WEGR	3	I	FI
7-Jul	352	WEGR	3	C	H
7-Jul	353	WEGR	3	C	FG
7-Jul	354	WEGR	3	C	H
7-Jul	355	WEGR	2	C	H
7-Jul	356	WEGR	3	C	H
7-Jul	357	WEGR	3	C	U
7-Jul	358	WEGR	2	C	FI
7-Jul	359	WEGR	3	I	U
7-Jul	360	WEGR	2	C	H
7-Jul	361	WEGR	4	C	H
7-Jul	362	WEGR	1	I	H
7-Jul	363	WEGR	3	C	H
7-Jul	364	WEGR	1	I	U
7-Jul	365	WEGR	3	I	U
7-Jul	366	WEGR	4	IP	FD
7-Jul	367	WEGR	2	I	H
7-Jul	368	WEGR	2	I	H
7-Jul	369	WEGR	3	C	H

7-Jul	370	WEGR	2	I	U
7-Jul	371	WEGR	3	I	H
7-Jul	372	WEGR	3	I	FI
7-Jul	373	WEGR	3	I	FG
7-Jul	374	WEGR	3	C	H
7-Jul	375	WEGR	3	I	H
7-Jul	376	WEGR	3	C	H
7-Jul	377	WEGR	3	C	H
7-Jul	378	WEGR	1	I	FD
7-Jul	379	WEGR	2	IP	FL
7-Jul	380	WEGR	3	C	FI
7-Jul	381	WEGR	3	I	U
7-Jul	382	WEGR	3	C	FI
7-Jul	383	WEGR	3	C	H
7-Jul	384	WEGR	3	I	U
7-Jul	385	WEGR	3	C	H
7-Jul	386	WEGR	3	C	H
7-Jul	387	WEGR	3	C	H
7-Jul	388	WEGR	1	I	H
7-Jul	389	WEGR	1	I	H
7-Jul	390	WEGR	3	C	H
7-Jul	391	WEGR	3	I	H
7-Jul	392	WEGR	2	C	H
7-Jul	393	WEGR	2	C	FI
7-Jul	394	WEGR	3	C	H
7-Jul	395	WEGR	2	I	H
7-Jul	396	WEGR	3	C	H
7-Jul	397	WEGR	3	C	H
7-Jul	398	WEGR	3	C	H
7-Jul	399	WEGR	1	I	H
7-Jul	400	WEGR	3	I	H
7-Jul	401	WEGR	2	C	H
7-Jul	402	WEGR	3	C	H
7-Jul	403	WEGR	3	C	FI
7-Jul	404	WEGR	2	C	H
7-Jul	406	WEGR	2	C	FG
7-Jul	407	WEGR	3	C	FI
7-Jul	408	WEGR	4	C	FI
7-Jul	409	WEGR	3	C	H
7-Jul	410	WEGR	3	C	H
7-Jul	411	WEGR	1	I	H
7-Jul	412	WEGR	4	I	H
7-Jul	413	WEGR	3	I	U
20-Jul	501	WEGR	2	I	U
20-Jul	502	WEGR	2	I	U
20-Jul	503	WEGR	2	I	U
20-Jul	505	WEGR	2	I	U
20-Jul	507	WEGR	2	I	H
20-Jul	508	WEGR	4	I	H
20-Jul	509	WEGR	2	I	H

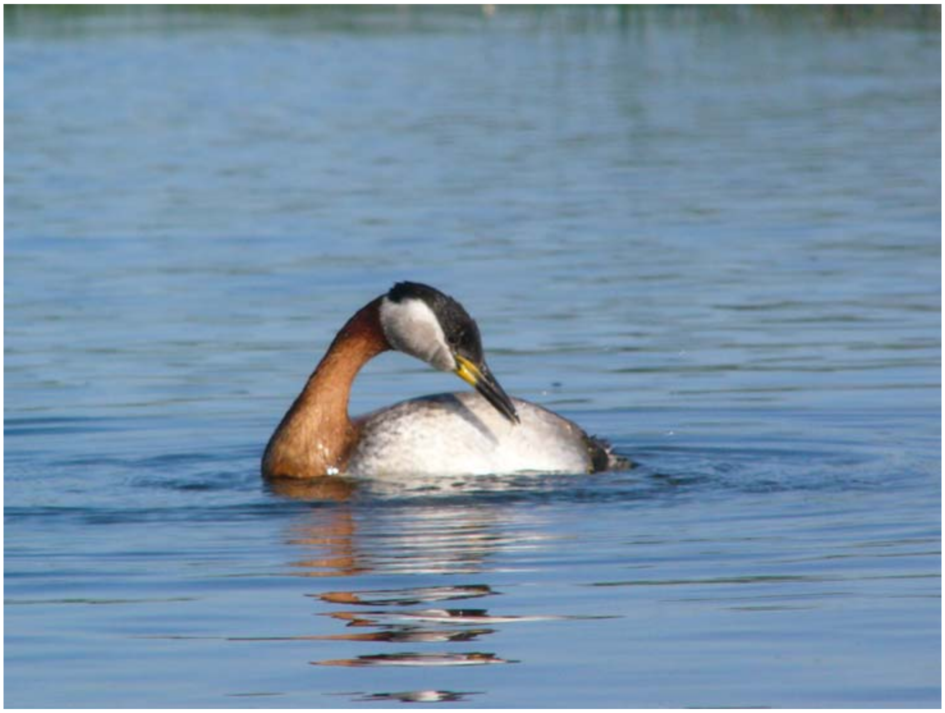
20-Jul	510	WEGR	2	I	U
20-Jul	511	WEGR	2	I	FI
20-Jul	512	WEGR	2	I	H
20-Jul	513	WEGR	3	I	H
20-Jul	514	WEGR	3	I	H
20-Jul	515	WEGR	2	I	H
20-Jul	516	WEGR	2	I	H
20-Jul	517	WEGR	1	I	H
20-Jul	518	WEGR	3	I	H
20-Jul	519	WEGR	1	I	H
20-Jul	520	WEGR	2	I	H
20-Jul	521	WEGR	2	I	U
20-Jul	522	WEGR	3	I	FI
20-Jul	538	WEGR	3	I	H
20-Jul	539	WEGR	3	I	H
20-Jul	540	WEGR	3	I	H
20-Jul	541	WEGR	3	I	H
20-Jul	542	WEGR	3	I	H
20-Jul	543	WEGR	2	I	H
20-Jul	544	WEGR	4	I	FI

APPENDIX III: Photos

A. JHA conducting bulrush stem density transects for his thesis.

B. JHA (left) and GLN (right) preparing and testing the tower blind.

C. Western grebe nesting at Lake Christina, 2005 (JHA).



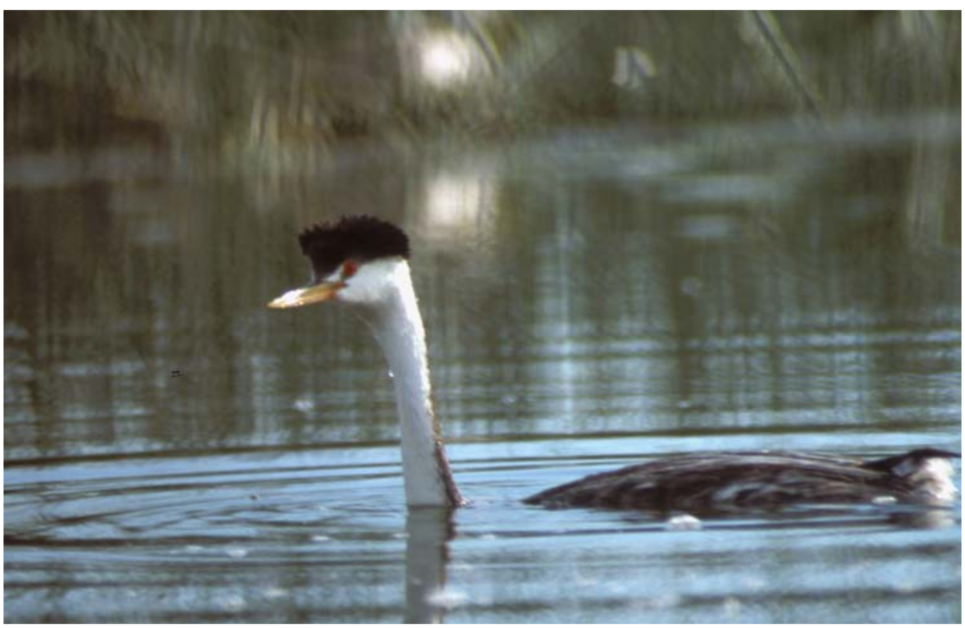
D. Red-necked grebe at Lake Christina (GLN).

E. American white pelican in the colony at Lake Christina (GLN).

F. Two Forster's terns resting in the colony at Lake Christina (GLN).

G. Black tern incubating eggs at Lake Christina (GLN).

H. Canvasback nest at Lake Christina (JHA).



I. Clark's grebe at Lake Christina.