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Background Studies on the Fishes of the Opossum Creek / Camp Hydaway Lake System and Effects of an Herbicide on the Lake's Aquatic Plants

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Abstract

The Opossum Creek / Camp Hydaway Lake system is a valuable asset to the Biology Department at Liberty University. This study addresses two different aspects of this system, namely the aquatic plants of Camp Hydaway Lake and the fishes of both the lake and Opossum Creek. The plants in the lake, primarily *Potamogeton foliosus*, were a problem due to their high density and were treated both by grass carp and an aquatic herbicide, diquat. The grass carp did not control the plants adequately, but following the introduction of diquat, the plants were eliminated along one transect and decreased significantly along another ($P<0.01$). The presence of Camp Hydaway Lake has resulted in a significant change in the fish community of Opossum Creek directly downstream of the lake when compared by family composition with samples taken about 2 km downstream from the dam ($P<0.01$). These differences in the fish communities of the two creek sites were apparently due to the emigration of still water species from the reservoir which were replaced by species more common to streams at a further distance from Camp Hydaway Lake. The data collected in this study may be valuable in the future in consideration of possible development and continuing recreational use in this area.

Introduction

There were two major purposes for this thesis. The first and more immediate purpose was to analyze and evaluate a perceived aquatic plant problem and potential solutions. Camp Hydaway Lake is part of an activity camp used for swimming, paddle-boating, and other recreation; as such, it should not have aquatic plant densities that interfere with these activities. The second purpose was to collect data on the fish communities of Camp Hydaway Lake and Opossum Creek, which is the major stream that flows into and out of this reservoir. Since development is likely to occur in this area, background data on the fishes present in this stream system is important because of the possible disturbances that can result.

Camp Hydaway Lake and the section of Opossum Creek studied are located about 3 km southeast of the Liberty University campus. Partly because of this proximity, the aquatic system and surrounding lands are important assets to the university, including its Biology Department. Many studies have been conducted here, such as the ongoing Saw-whet owl (*Aegolius acadicus*) project of Dr. Gene D. Sattler and the aquatic studies of Drs. Paul W. Sattler and Norm G. Reichenbach. Another segment of Opossum Creek that is part of this study belongs to Dr. Bill Massie, who contacted the Biology Department with a question regarding a possible decrease in "desirable" fish species that he thought might have resulted from development upstream of his property. The section of his property on Opossum Creek that we sampled begins approximately 2 km downstream of Camp Hydaway Lake.

The study of aquatic plants in Camp Hydaway Lake was first considered by Dr. J. Douglas Oliver after it was learned that they were at nuisance levels in this lake and that triploid (sterile) grass carp (*Cnetopharyngodon idella*) were being introduced in an attempt to control them. In 2004, the manager of Camp Hydaway (Graham Harrison) had 30 triploid grass carp added to the lake to try to reduce these aquatic plants by consumption (see Literature Review below). Ten more grass carp were added in 2005 and another 40 were added in 2006, bringing the total number that had been introduced into the lake to 80 by the beginning of the present study in June, 2006. Camp Hydaway Lake covers approximately 2.8 hectares (ha, 7 acres); accordingly, there were approximately 29 grass carp per ha. (However, it is possible that the surviving density could have been significantly lower than this because of mortality or migration to the stream.) Graham Harrison was dissatisfied with the very limited amount of aquatic plant control achieved by the grass carp by June 2006. Therefore, at the recommendation of Dan Wilson of the Virginia Department of Game and Inland Fisheries (VDGIF), diquat dibromide was also added, at a standard recommended rate within Camp Hydaway Lake.

Literature Review

Cudmore and Mandrak (2004) wrote that grass carp (*C. idella*) are native to temperate to sub-tropical climates in Eastern Asia, inhabiting both lakes and rivers. The temperature range in which this species of Asiatic carp can survive is very wide, from a mean air temperature of 25°C in the southern portion of its native range down to -6°C in the northern part. Grass carp have been introduced in large numbers throughout the world, including the United States, for aquatic plant control and occasionally as a food source. The nonsterile, diploid form has become established in a wide range of habitats through various introductions and is considered to be a harmful invasive species because of competition with native herbivorous fishes (Cudmore 2004). For this reason a triploid, sterile form was developed (Chilton 1992) so that it could be introduced widely to control aquatic plants without becoming established in nonnative environments such as the U. S. Many studies have concluded that grass carp can be a successful means of controlling aquatic vegetation, although their feeding preferences make the control of submerged, soft-bodied vegetation, such as the pondweed (*Potamogeton sp.*) found in Camp Hydaway Lake, easier to attain (Van Dyke *et al.* 1984, Stott 1977, Sutton 1977**,** Mitchell 1980). Grass carp have been shown to choose certain plants, even when non-preferred types of vegetation are present in higher numbers (Opuszinski 1979**,** Van Dyke 1984). The daily rate of consumption by grass carp is another important factor when one is considering whether an introduction into an area will be successful as these rates may vary with age, size, temperature, and plant type (Cudmore 2004, Hickling 1966, Blackburn 1971, Kilgen 1971). Due to these differences, the recommended stocking densities and sizes of the fish depend upon the locale and the plant densities, with 30 grass carp per ha recommended in Japan (Kuronuma 1957) and grass carp of size 250 to 400 grams at a density of 150 to 250 kg per ha (i.e. about 60 grass carp per ha) in temperate zones (van Zon 1977). Colle *et al.* (1978) concluded that grass carp do not prefer Illinois pondweed (*P. illinoensis*), a plant which is similar to *P. foliosus*, until the carp reach 174 mm in total length.

The effects of grass carp on the biotic communities and the water quality of a lake are not consistent. In Arkansas lakes, grass carp were shown to neither improve nor harm the fish community in 31 lakes (Bailey 1978). However, the presence of dense aquatic plant beds often results in stunting and decreased production of some species (Surber 1961, Blackburn 1975); thus, it seems plausible that increases in fish production could become visible upon dense plant bed removal. In regard to general effects of grass carp upon water quality, turbidity can increase, and dissolved oxygen levels can decrease after introduction of grass carp and subsequent plant removal (NatureServe 2003, Rose 1972), though this is not always the case (Opuszinski 1995). Generally, any effects, both on the water quality and fish communities of a lake, are secondary and are more closely related to the removal of plants and the nutrients that result from this removal (Fedorenko 1978, Lembi 1978). No studies were found on the possible secondary effects of grass carp on a stream or river, such as Opossum Creek, that flows out of a reservoir being treated by the carp.

Although a combination of chemical, mechanical, and biological approaches is recommended (Masser 2001), herbicides can be an effective and economic method of controlling aquatic plants when unaccompanied by other methods. Diquat dibromide, the herbicide which was applied in Camp Hydaway Lake, does not have serious toxicological concerns for humans (Pastoor 1994), which is important when considering its use in this lake where swimming is common. However, physical parameters such as temperature (Netherland 2000) and inorganic turbidity due to clay can interfere with the efficacy of diquat dibromide (Poovey 2002). Furthermore, this herbicide breaks down rapidly after application due to reactions with sediments and macrophytes (Pastoor 1994, Ritter 1999); thus, it does not pose a serious long-term environmental threat. Some negative effects may include various indirect effects due to the rapid removal of macrophytes from a system, such as changes to the oxygen-carbon dioxide balance which can lead to a sharp rise in plant growth following removal (Brooker 1975). Although non-target plants may generally recover with time, herbicides are not usually species selective and generally result in almost complete removal of all species in the application area (Tasker 2001).

Development has and will likely continue to occur along stretches of Opossum Creek, which could make the data collected in this study valuable in the assessment of impacts on the fish community in the future. The effects of development on streams have been widely studied due to the importance of this topic to human water supplies and species conservation. One of the main effects of development is an increase in silt levels in the stream, which can result in a decrease in the abundance of fish immediately downstream of a construction site (Barton 1977) or can alter the abundances of certain reproductive and feeding guilds in a fish community (Berkman 1987). Benthic macroinvertebrates, which are very important as a food source for many stream fishes, may not always decrease in number but almost always change significantly in community structure, as more tolerant species become prevalent (Ehrhart 2002, Barton 1977). The affects are usually most dramatic on riffle communities close to the construction site and less dramatic in pools, which allow silts to settle out of the stream (Gregory, 1991). Streamside vegetation is important to the integrity of a river system by acting as a buffer zone which helps keep sediment from a construction site from entering a stream (Roth 1996, Gregory 1991). As development occurs along a stream and the riparian community is removed, the stream generally loses organic input and the fish and macroinvertebrate communities may be impacted (Roth 1996).

The presence of a reservoir such as Camp Hydaway Lake can also have an effect on a stream environment. Studies have shown that by filtering sediments from the stream system, a reservoir can cause changes in downstream biotic communities (Casado 1989, Garcia de Jalon 1994) and can cause erosion of the channel bed and banks as the downstream flow becomes low in sediment (Kondolf 1997). Temperature and other water quality parameters, which are often changed by the presence of a reservoir, can cause a decrease in the diversity of fishes, mainly by native species removal (Roberts 1978). Another more direct effect, which this study examines, is the abundance of still-water fishes in the downstream reaches of a stream that apparently occurs through emigration from the reservoir. For example, non-native fishes comprised roughly 80% of the downstream fish community after the construction of a dam on the White River in Colorado (Martinez 1994). However, the effects of a reservoir on both the abiotic and biotic properties of a downstream environment have been shown to gradually decrease with increased distance from the reservoir (Camargo 1990).

Choice of Sampling Site

Figure 1 is a map showing a broad view of Camp Hydaway Lake and Opossum Creek, along with the location of fish sampling sites. In order to choose Opossum Creek sites that might show possible outside effects on the stream's fish community, a ground search was done. Although it appeared that no major development was occurring there during this study, an area where light bulldozing had occurred was found along a tributary of Opossum Creek that enters just upstream of Site F.3 (Fig. 1). Site F.2 was chosen because it was immediately downstream of Camp Hydaway Lake and because it had historically been sampled by various Biology professors at Liberty University. Figure 2 is a map showing a closer view of Camp Hydaway Lake and the location of Site W.1 where water quality was monitored and the transects where aquatic plants were monitored.

Methods

Water Quality

Temperature, conductivity, and oxygen levels were measured at Site W.1 (Fig. 2) in Camp Hydaway Lake, located near the earthen outflow dam at what appears to be the deepest part of this reservoir on June 14, August 1, August 17 and September 23, 2006. Temperature and dissolved oxygen levels were measured just below the surface and at one-meter intervals below the surface until the bottom was reached, via a dissolved oxygen meter (YSI Ecosense® DO 200). In practice this meant that oxygen and temperature measurements at Site W.1 were measured to about four meters depth. Conductivity was measured at the surface at site W.1 with a conductivity meter (Model WD-35607-60, Oakton®). Secchi Disk depths were measured at various dates as a measure of water clarity for the entire study period at Site W.1.

Aquatic Plants

To monitor the plant cover in Camp Hydaway Lake, transects were formed by stretching a nylon cord with markings at every meter between two fixed points, a method similar to that described by Van Dyke *et. al.* (1984). Percent plant coverage along each transect was estimated as the percent of visible vegetation in a 0.5 x 0.5 m quadrat at five-meter intervals. Natural markers such as trees, previously installed poles located around the swim area, and the end of a man-made dock were used to mark the transect ends so that the study would not disturb activities such as swimming that were taking place on the lake (Fig. 2). Transect 1 reached across the sandy-bottomed small swim area (which was itself delineated with poles and rope) located on the eastern shore of the lake. Transect 2 reached from the northwest pole of the swim area to a prominent dead tree located directly across the lake on the western shore; this transect also passed along the edge of a recreational part of the lake with floating docks and under the end of a recently installed water slide. Transect 3 stretched from the southwest corner of the swim area across the lake to a prominent sycamore tree, which was a good marker because of its white top that leaned over the water on the southwestern shore. Sampling along Transects 1 and 3 occurred on July 3, August 1, August 17 and September 23, 2006; samples were taken on June 30, August 1, August 17 and September 23, 2006 for Transect 2. Sampling began at the western side of each transect and continued along each transect toward the east. A t-test was performed using Microsoft Excel® to compare the pre-herbicide and post-herbicide levels of aquatic plants along Transect 3.

Boat Electrofishing

In Camp Hydaway Lake, D. Wilson of the VDGIF assisted our Liberty University personnel in sampling the fish community with his Department's electrofishing boat. Two laps around the outer edge of the lake (Site F.1) had been made by other VDGIF and Liberty University workers on July 2, 2001; and one lap was made by D. Wilson, J.D. Oliver and me for this study on June 14, 2006 (following D. Wilson's recommendations). Fish were collected, identified, and measured for total length on-site before release back into the lake. During the later analysis of data, the numbers of each species of fish from the 2001 sample were divided by two to allow comparison with the 2006 sample per single lap of boat electrofishing. A chi-square (x^2) test was used to test for a significant difference between the species compositions of the two years' samples.

Backpack Electrofishing

In Opossum Creek, fish were sampled by backpack electrofishing at Site F.2 on

August 21 and October 21, 2006 and at Site F.3 on August 21, September 23 and October 21, 2006 (Fig. 1). Fish sampling methods in the creek were previously developed by other workers at Liberty University (especially Drs. P.W. Sattler and N.G. Reichenbach) to attempt to observe any changes in vertebrate abundances that occur through time and between various sites. This method employs a total shocking time of approximately 600 seconds ($\pm$ 100 seconds). The present study involved electrofishing of 50-100 meters of the creek at each sampling. Sampling of Site F.2 began approximately 100 m downstream from the dam at a small footbridge and continued upstream toward Camp Hydaway Lake. Opossum Creek flows from that site in a northeasterly direction toward the property of a local landowner, Dr. Massie, in which Site F.3 was located (Fig. 1). Sampling of Site F.3 began approximately 100 m downstream of an incoming tributary that had passed through a possible development site, as discussed in the Introduction. Site F.3 was located approximately 2 Km downstream of Camp Hydaway Lake, a distance which was anticipated to reduce any possible effects of the reservoir on the Creek fish community. Chi-square tests were used for statistical analyses of the fish samples as described below.

Results

Water Quality of Camp Hydaway Lake

Temperature and oxygen profiles are illustrated for Site W.1 near the Dam, at four sampling dates that spanned late spring to early fall (Figure 3a-d). This deeper part of the lake showed some warm season stratification, characterized by warmer temperatures near the surface than at greater depths, on all of the water sampling dates. Water temperatures reached approximately 31 °C at the surface of the lake by August 1, and approximately 18 °C at the bottom (Fig. 3b). By September 23, the lake temperatures had cooled significantly to approximately 20 °C at the surface and about 17 °C near the bottom, in what may have been the forerunner of a fall isothermal mixing period (Fig. 3d). However, the dissolved oxygen concentrations at various depths in the lake still showed a significant stratification pattern on September 23, with higher values near the surface than near the bottom; this signifies that a mixing period had not yet occurred in the lake (Fig. 3). Note also that on all of these dates dissolved oxygen levels were below 1 ppm at and below a depth of 3 meters.

Secchi disk depth measurements are usually directly correlated with water clarity and inversely correlated with the primary productivity of a typical lake. The Secchi disk depth (Figure 4) was lowest (0.76 m) in Camp Hydaway Lake at the beginning of the study period in the spring, a time in which temperate lakes typically have high primary productivity and thus low water clarity. Then on July 2 and 3, 2006, the aquatic herbicide diquat was sprayed in Camp Hydaway Lake in order to reduce the levels of pondweed (*Potamogeton sp*). Water clarity as estimated by Secchi disk was higher after the spraying on July 3, as well as on August 17 and September 23 (Fig. 4).

Conductivity is sometimes also complexly related to lake productivity. In our case, Camp Hydaway Lake's conductivity (shown in Fig. 5) appeared to be relatively higher during the summer and relatively lower at the end of the study period in late September. In fact, the conductivity data and the Secchi disk both suggest that the lowest level of productivity had occurred at the time of the final sample (when the weather was cooler and the daytime was shorter, in late September); and also suggested that there were at least moderate levels of primary productivity during the summer. However, the conductivity level at the beginning of the study period was relatively low (Fig. 5, 6/14/2006), which did not appear to agree with the lower Secchi disk depth (i.e. high productivity assumed for this date, Fig. 4). It is possible that the conductivity levels at this time were lower due to an abundance of phytoplankton, which could have lowered the levels of dissolved solids through nutrient uptake.

Aquatic Plants of Camp Hydaway Lake

At the beginning of this study, on June 19, 2006, Dr. Oliver and I visually estimated the total plant coverage to be around 30-40% of the total surface of the lake by viewing from the shore and touring the lake in a paddleboat. In the shallowest of places near the southern end of the lake, the plant density was sufficient to impede the use of both the paddleboats and motor boats used during sampling, while in the deeper, northern part (near Site W.1, Fig. 2) of Camp Hydaway Lake, plant cover was scarce to nonexistent. According to Dr. Gwyn Ramsey of Lynchburg College, the two major plants in our samples were *Potamogeton diversifoliosus* (water-thread pondweed) and *P. foliosus* (leafy pondweed). Although these two species are similar in appearance, the vast majority of these plants were identified as *P. foliosus*.

Transect 1 reached across the small but heavily used near-shore swim area of Camp Hydaway Lake (Fig. 2). Throughout the period of our measurements of aquatic macrophyte density, from July 3 until September 23, 2006, we found no plant cover there (0% at all 5-m intervals along this transect on all sampling dates). It appeared that the macrophyte growth in this section of the lake was not significant, probably due to the sandy bottom which apparently had been occasionally augmented for the establishment of the beach area; and perhaps also by disturbance from youth swimming and boating activities.

We set up Transect 2 to run across the approximate center of Camp Hydaway Lake, through a moderately deep area that experienced some swimming and boating traffic (Fig. 2). The first sample of the visible plant growth along this transect was taken on June 30, only a few days before the addition of the herbicide on July 2-3 (Fig. 6). The average percent aquatic plant cover at this time was 40.8%, with highly variable values ranging from 0 - 80% (Fig. 6). After the herbicide was added on July 2-3, 0% visible plant cover was present along all sampling points of this transect for August 1, August 17 and September 28 (they are not shown in Fig. 6 for simplification.) As is clear from the data, the general plant cover for the first sample along this transect was unfavorably high for swimming, boating, or other recreational use, but was apparently eliminated after the addition of the herbicide.

Transect 3, which stretched across a relatively shallow southern portion of the lake (Fig. 2), appeared to maintain a higher overall density of aquatic plants throughout the study period when compared to Transects 1 and 2. Figures 7a-d show the percent cover values for the Transect 3 samples at four successive dates. The average percent plant cover along Transect 3 for the July 3 sample, which was taken on the second day of herbicide addition, was very high at 51.9% (Fig. 8). The plant densities in this first sample were higher in the first 60 meters and much lower near the swim area (Fig. 7a). After the addition of herbicide, the average percent plant cover of Transect 3 dropped greatly to remain near 20 % for the remainder of the study (Fig. 8). A t-test shows that the plant densities along Transect 3 were significantly lower after the addition of herbicide ($t=2.93$, $d.f.=34$, $P<0.01$). The plants in the central and eastern portion of Transect 3 were reduced after the addition of the herbicide, but plant density remained relatively high along the first 20 meters in the far southwestern portion of the lake, i.e. in very shallow water and away from the swim area (Fig. 7b-d).

Camp Hydaway Lake Fish Community

Figure 9 illustrates the numbers of fish obtained by boat electrofishing in Camp Hydaway Lake in 2001 and 2006. These graphed data are compared as total numbers of each species per lap of electrofishing around the entire lake. The mean number of fish per electrofishing lap in 2001 totaled 52 fish: 31 bluegill (*Lepomis macrochirus*), 14 largemouth bass (*Micropterus salmoides*), 4.5 redear sunfish (*Lepomis microlophus*), 2 black crappie (*Pomoxis negromaculatus*) and 0.5 redbreast sunfish (*Lepomis auritus*) [mean numbers over 2 laps]. The number per electrofishing lap in 2006 totaled 123 fish: 58 bluegill, 40 redear sunfish, 16 largemouth bass, 5 chain pickerel (*Esox niger*), 2 redbreast sunfish and 2 American eel (*Anguilla rostrata*) [numbers over one lap]. Within these limited samplings, the two most common fish in 2001 appeared to be bluegill and largemouth bass, but in 2006 the two most common species appeared to be bluegill and redear sunfish. A chi-square test comparing these two samples of the fish communities shows that the species composition of the fish community changed significantly between 2001 and 2006 (x^2=19.3, d.f.=5, P<0.01).

Opossum Creek Fish Community

The following results were obtained by backpack electrofishing at Sites F.2 and F.3 in Opossum Creek. At Site F.2 (Fig.1), just downstream of the Lake, bluegill predominated in number on both August 21 and October 21, 2006 (Fig. 10, which shows the common names of all fishes sampled there). Other dominant species at both sampling dates included green sunfish (*Lepomis cyanellus*) and redbreast sunfish. The data for samples obtained at Site F.3 of Opossum Creek, about 2 km downstream from Camp Hydaway Lake, are shown in Figure 11. Bluegill were common in number on all three sampling dates, August 21, September 23 and October 21, 2006 (Fig. 1 and Fig. 11). Other common species at all three sampling dates included bluehead chub (*Nocomis leptocephalus*) and rosyside dace (*Clinostomus funduloides*, Fig. 11).

It appears that there was a decrease in the total number of fish at both Sites F.2 and F.3 in Opossum Creek through time (Figs. 10 and 11), but this has not been confirmed by the current limited data. If such possible decreases were real, they might have resulted from repeated sampling causing decreased fish densities due to mortality or emigration to other areas due to disturbance. There were some differences among the species compositions of the samples taken at each site, as is common in an ecological study. These differences were not significant between the two samples obtained from Site F.2 (x^2=12.6, d.f.=12, P=0.40). The species compositions of the samples from Site F.3 were not significantly different when comparing subsequent samples, such as August 21 vs. September 23 (x^2=20.2, d.f.=15, P=0.17) and September 23 vs. October 21 (x^2=10.32, d.f.=14, P=0.74), but were significantly different between the August 21 and October 21 samples (x^2=633, d.f.=14, P<0.01).

Comparison of Fish Communities

In order to look for any notable differences or similarities in fish species composition, the 2006 fish sample from Camp Hydaway Lake (Site F.1) and the samples from Opossum Creek (Sites F.2 and F.3) were compared. The species compositions of Site F.2 was significantly different from that of Site F.3 when compared with a chi-square test (x^2=31.8, d.f.=20, P=0.045), suggesting that a notable difference existed between the two stream environments. A notable similarity between the fish communities of the lake and Site F.2 of the creek is the presence of still-water fish species such as chain pickerel and largemouth bass (Fig. 1 and Fig. 10). Perhaps not surprisingly, these still water species were not present in any of our samples at Site F.3, about 2 km downstream from the lake (Fig. 11). Other apparent differences between Sites F.2 and F.3 include higher numbers of bluegill and green sunfish, typically still-water sunfish species, at Site F.2 than at Site F.3 (Fig. 10 and 11).

This trend is even more obvious when these three fish communities are compared by their abundances according to fish Families (Fig. 12). The data shown for the Camp Hydaway Lake fish community is the percentage of each Family of fish for the 2006 sample, while the data from the stream sites are shown as the percent composition of each fish Family for the total number of fish sampled on all dates at each of the sites. The apparent effects of the reservoir on the fish community of Opossum Creek are clearly seen in this chart, with the sunfish Family (*Centrarchidae*) comprising 96% of the fish community in the lake, 77% in Site F.2 and only 20% at Site F.3. On the other hand, *Cyprinidae*, the minnow Family, was not observed in the lake sample but comprised approximately 8% of the fish community at Site F.2 and 54% at Site F.3 of Opossum Creek. The sucker family (*Catostomidae*) was also not present in the lake (Site F.1), yet comprised approximately 6% at Site F.2 and 13% at Site F.3 of Opossum Creek (Fig. 12). The differences in family compositions between Site F.1 and F.2 (x^2=26.0, d.f.=6, P<0.01), Sites F.2 and F.3 (x^2=26.9, d.f.=8, P<0.01) and Sites F.1 and F.3 (x^2=121.5, d.f.=7, P<0.01) are all significant. However, the differences between Camp Hydaway Lake (Site F.1) and Site F.3 of Opossum Creek are greater (notice the much higher chi-square value) due to the higher abundance of more typical stream fishes at Site F.3 than at Site F.2.

Discussion

Diquat aquatic herbicide appeared to be an effective way to control the aquatic plants of Camp Hydaway Lake, as noted in the literature (e.g. Tasker, 2001). It did not appear that grass carp were responsible for any significant decrease in plant cover, since the introduction of the fish were not observed to cause a reduction prior to this study, and the plants remained dense in the shallowest portion of the lake (Fig. 7b-d). Furthermore, some grass carp had been present for up to three years in the lake and there were still significant weed beds, while other studies have shown that grass carp effectively remove vegetation within the first few years (Van Dyke *et al.* 1984, Sutton 1977). Other studies (Kuronoma 1957, van Zon 1977) have suggested that the stocking density should have been adequate to have resulted in at least a minor decrease in the aquatic plant densities and have also suggested that the dominant aquatic macrophyte (*P. foliosus*) is a preferred food for this fish. Hence, the reason for the lack of aquatic plant control through the introduction of grass carp is unknown for this system. One possible explanation is that the grass carp that were introduced have moved out of the reservoir and into Opossum Creek, perhaps due to a paucity of retaining barriers.

The fish samples suggest that Opossum Creek received significant numbers of fish through emigration from Camp Hydaway Lake, and that these fish, which were primarily of the sunfish (*Centrarchidae*) family, somewhat displaced the native fishes downstream, which were largely of the minnow (*Cyprinidae*) family. Martinez *et al.* (1994) found a similar trend in the displacement of native species in a study which monitored the fish community of the White River in Colorado before and after the construction of a large reservoir. At a further distance downstream from Camp Hydaway Lake, this effect appeared to be less noticeable and the samples of the fish community increased in both native creek species and diversity of species, as noted by Camargo and de Jalon (1990) in a study of a large reservoir/river system in Spain. This distance-from-dam difference between Sites F.2 and F.3 could make analysis of any possible impacts of development in the stream somewhat complicated.

The results of this study suggest that most of the nuisance aquatic plant population in Camp Hydaway Lake was efficiently controlled through the use of the aquatic herbicide, diquat dibromide, and supports its use in the future when needed. However, the author also suggests that the use of triploid grass carp might be continued if efficient retaining barriers are installed at the reservoir's entrance and exit streams. While herbicide must be added on a yearly basis, grass carp can be effective for up to 10 years when there are present in sufficient numbers. It is also important to remember that secondary effects on water quality resulting from plant removal, such as decreased water clarity, may be seen in the lake as a result of continued plant control. Such effects from plant control might result in a decreased aesthetic appeal to Camp Hydaway visitors. The author therefore recommends continued water quality monitoring in this reservoir so that the best method for plant control might be chosen. This would allow for any possible effects of aquatic plant control or development to be observed, especially in relation to water clarity. If future studies involving the fish communities of the Camp Hydaway Lake / Opossum Creek System should continue, the possible impact of the Camp Hydaway Lake / Reservoir on the neighboring fish communities of Opossum Creek should also be considered. A study focused on determining land development effects upon Opossum Creek would probably be able to take into account this impact on the creek if sampling sites are located a significant distance downstream from the lake (e. g. approximately 2 km downstream from the lake or greater).

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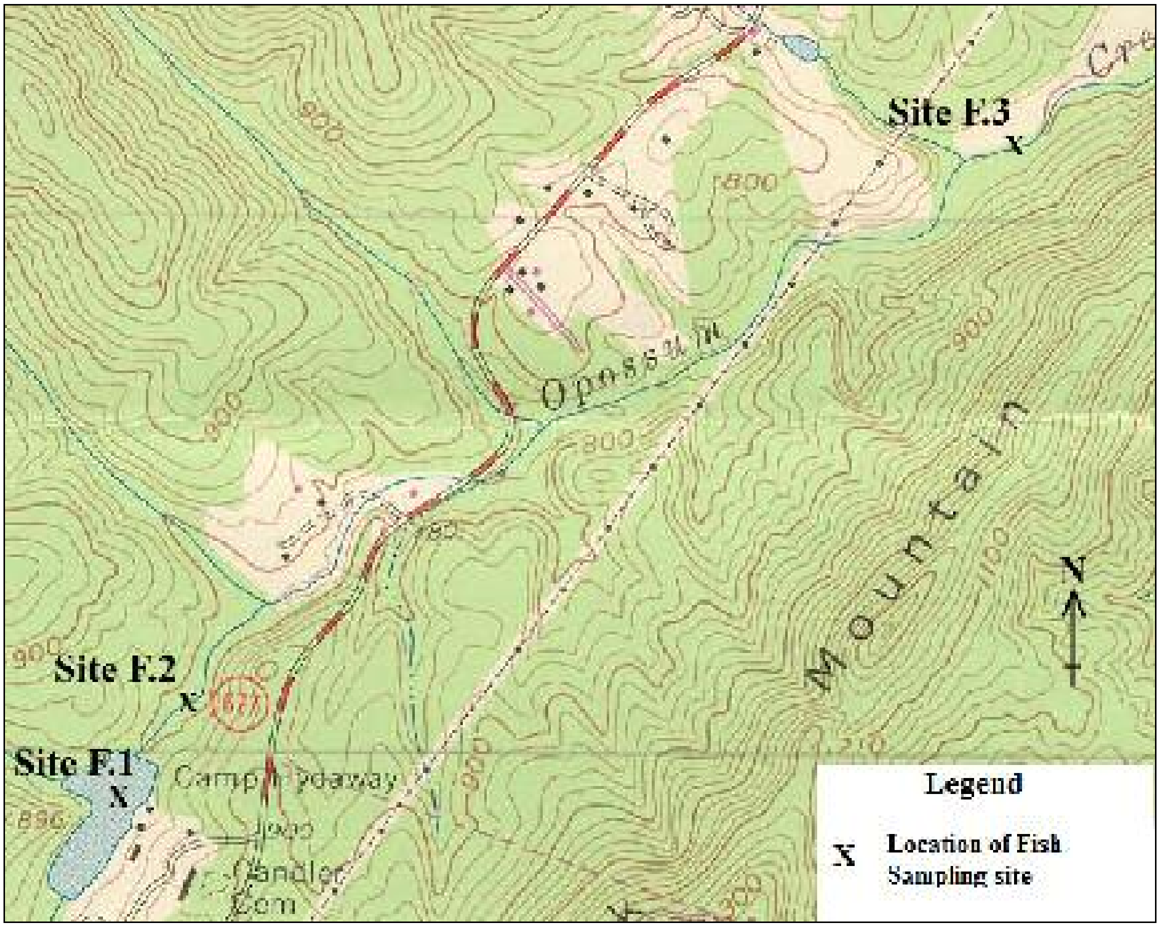


Figure 1: Map of the Camp Hydaway Lake / Opossum Creek System showing the location of Fish Sampling Sites F.1, F.2, and F.3. The distance from the lake to Site F.3 is approximately 2 km. Samples at Site F.2 begin at the location marked and continue upstream to end below the lake. Site F.3 begins at the location marked and ends at the first tributary upstream. The stream flows in a northeasterly direction from Site F.1 to Site F.2.

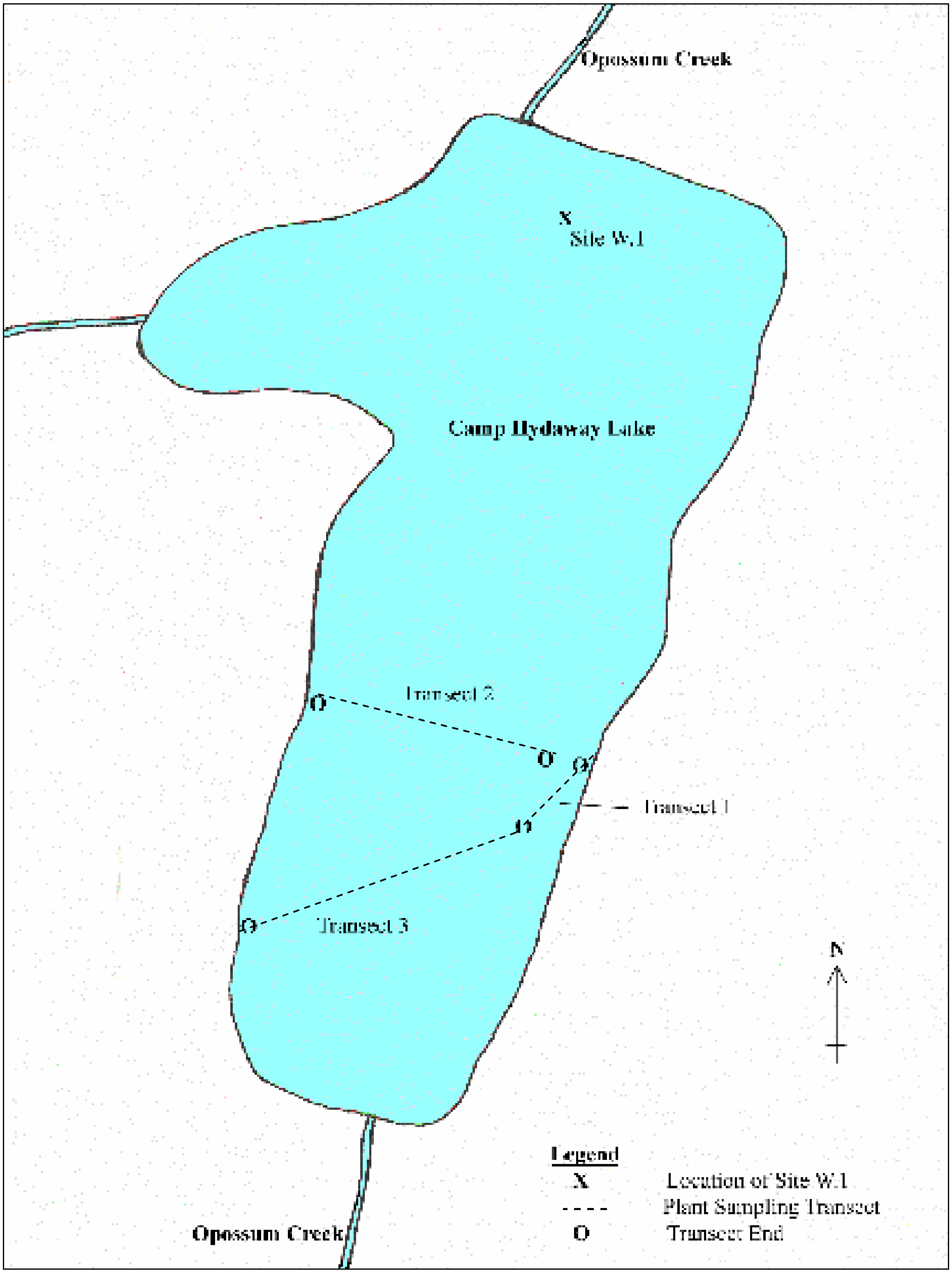
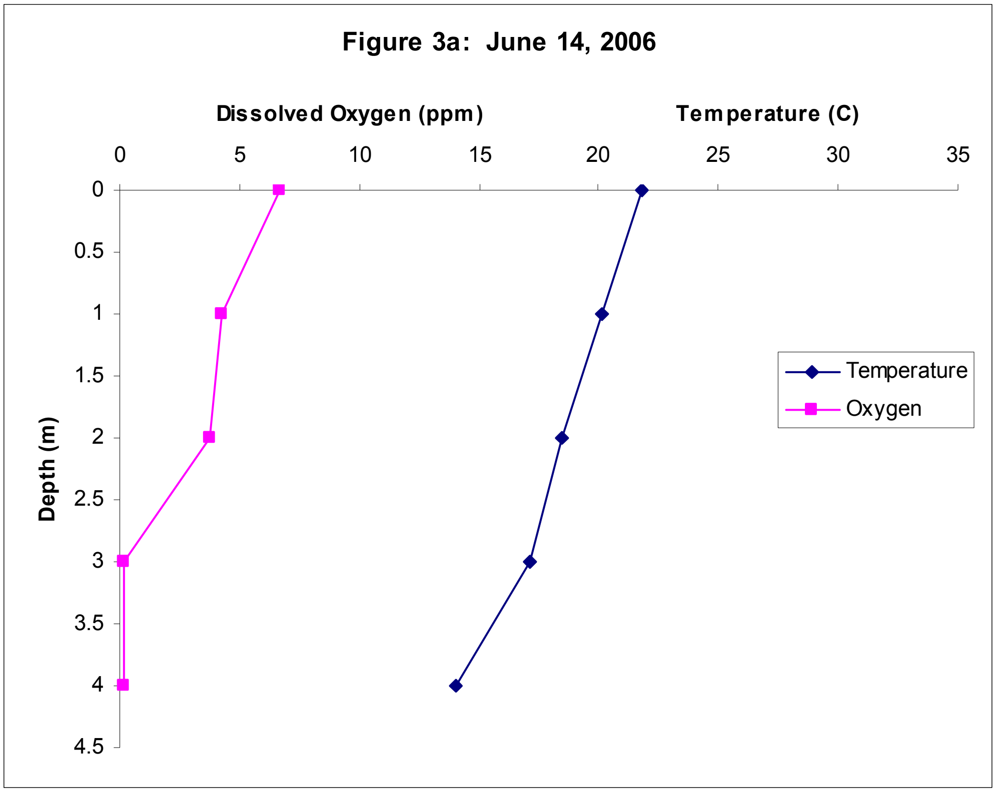


Figure 2: Map of Camp Hydaway Lake showing the location of Plant Sampling Transects 1, 2, and 3, and the location of Site W.1 where various measurements of water quality were obtained. The Stream flows into the southern side of the lake and flows out through a dam on the northern side.



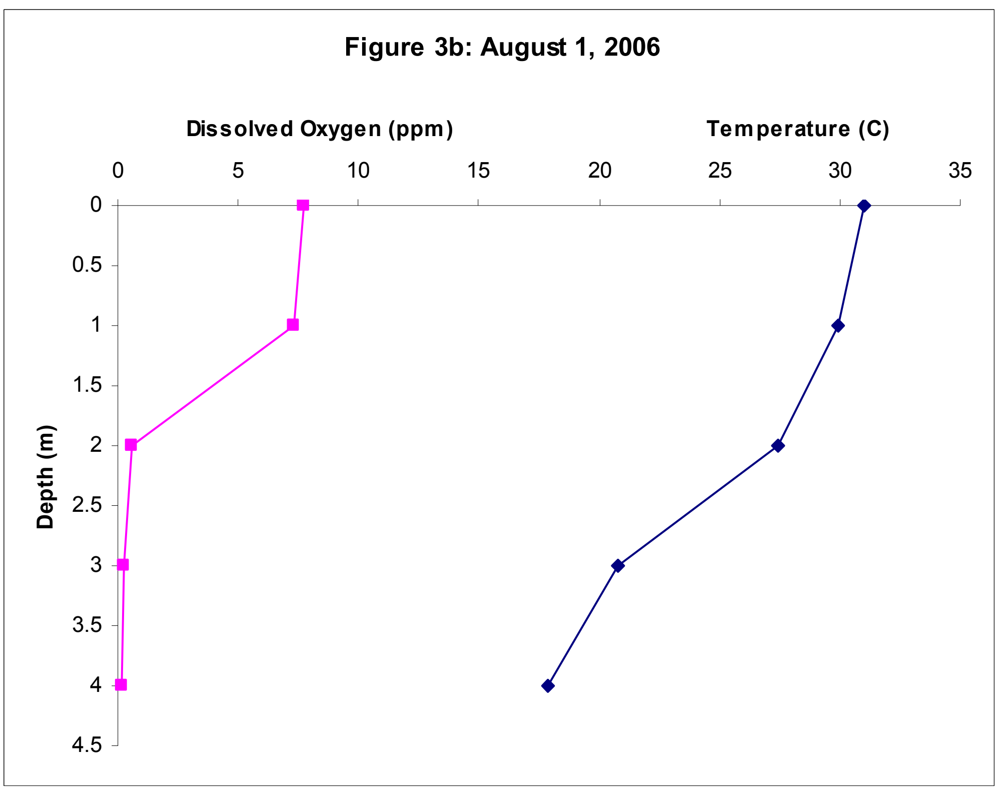
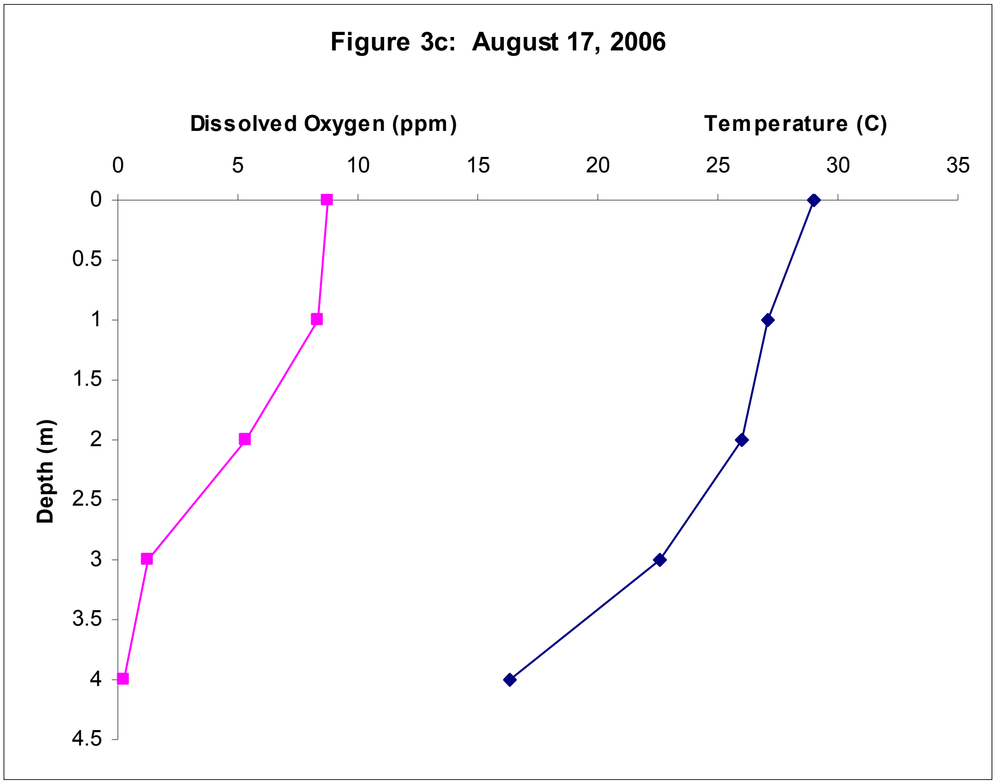


Figure 3a-b: Dissolved oxygen and temperature profile for data obtained from Site W.1 of Camp Hydaway Lake on June 14 and August 1, 2006.



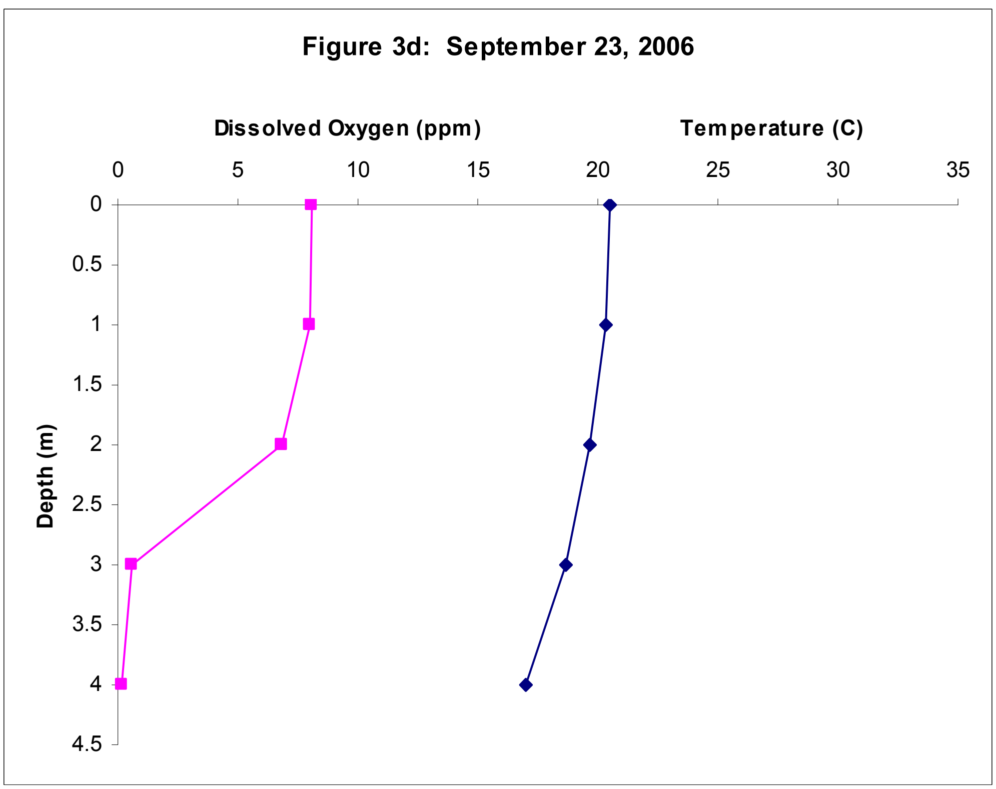


Figure 3c-d: Dissolved oxygen and temperature profile for data obtained from Site W.1 of Camp Hydaway Lake on August 17 and September 23, 2006.

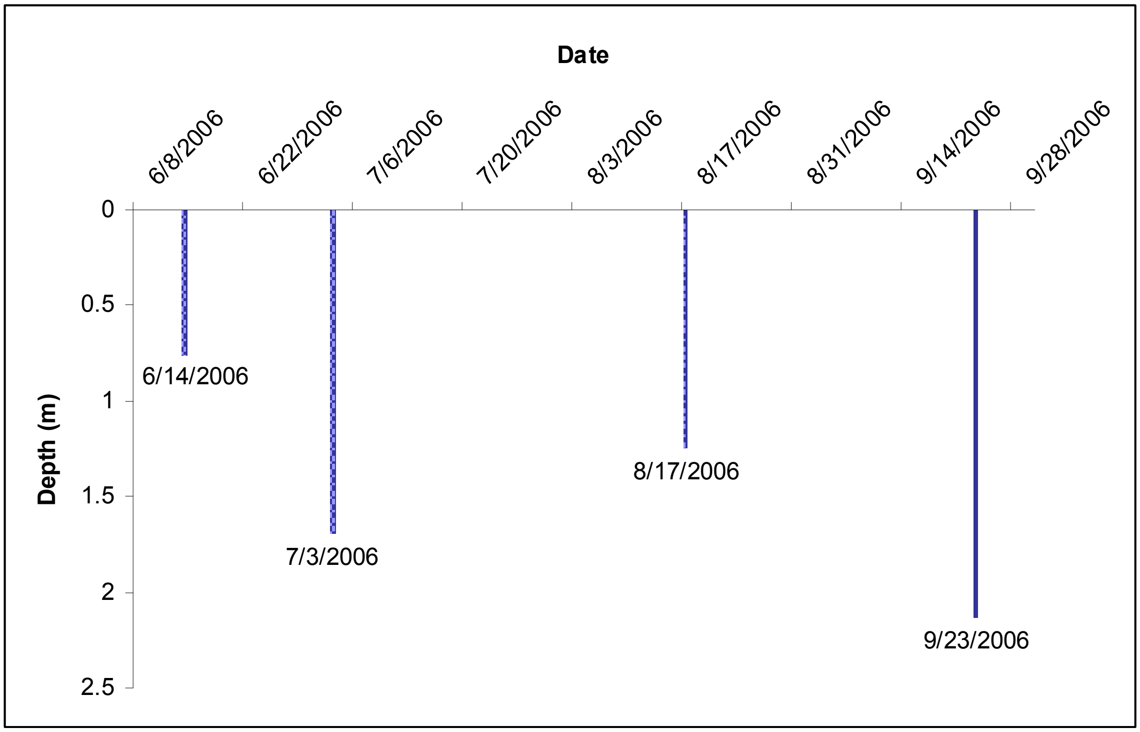


Figure 4: Sechi disk depths obtained at Site W.1 of Camp Hydaway Lake on the dates shown for each data point.

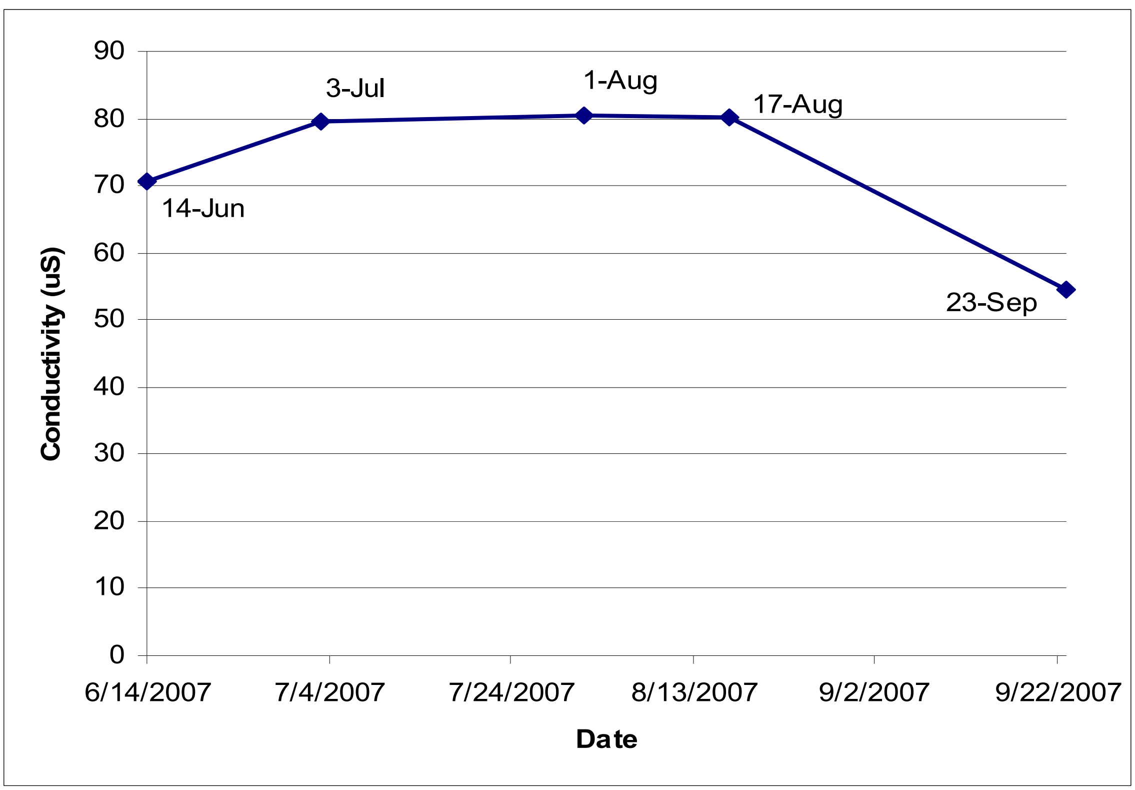


Figure 5: Conductivity measurements obtained at Site W.1 of Camp Hydaway Lake on June 14, July 3, August 1, August 17, and September 23, 2006.

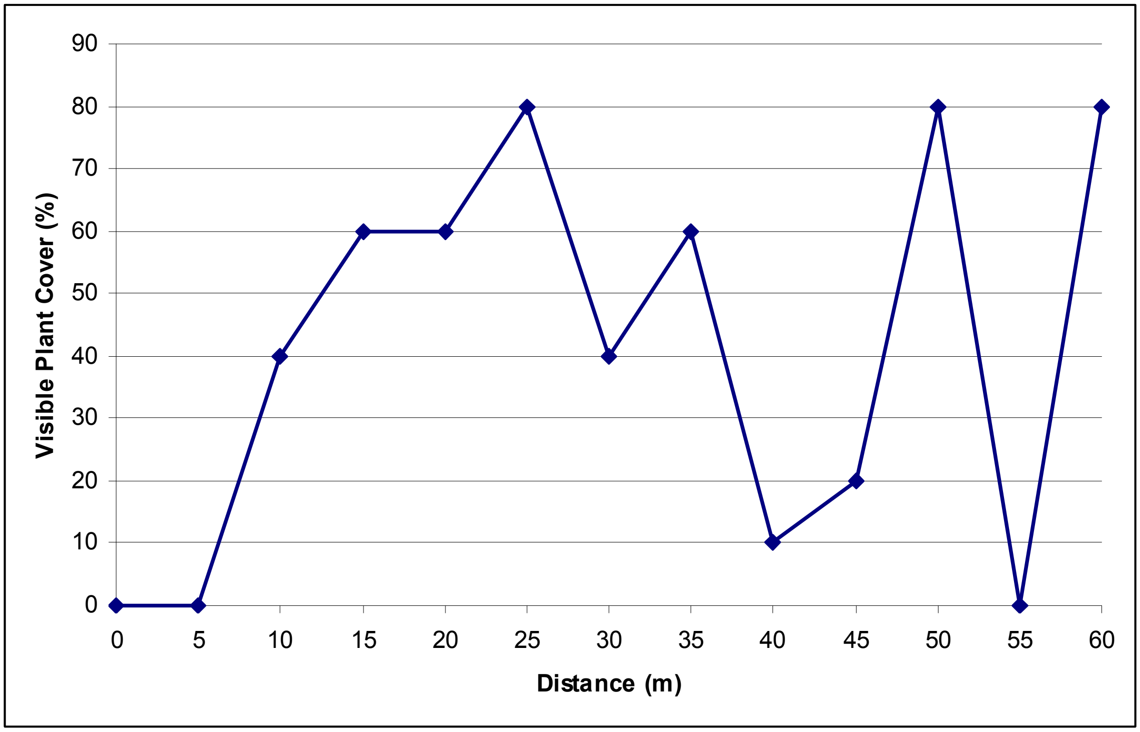
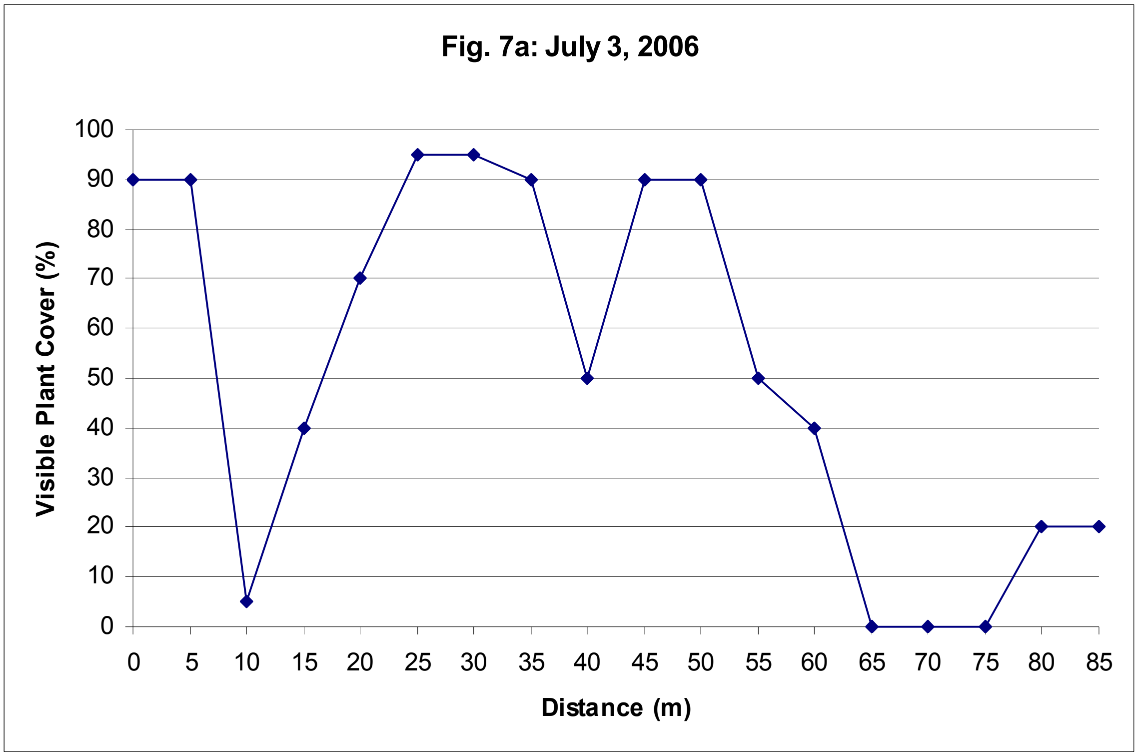


Figure 6: Percent plant cover at five-meter intervals along Transect 2 in Camp Hydaway Lake obtained on the first sampling date, June 30, 2006. The average percent cover for this sample was 40.8%. All samples taken along this transect at later dates after the herbicide was added showed 0% plant cover at all points



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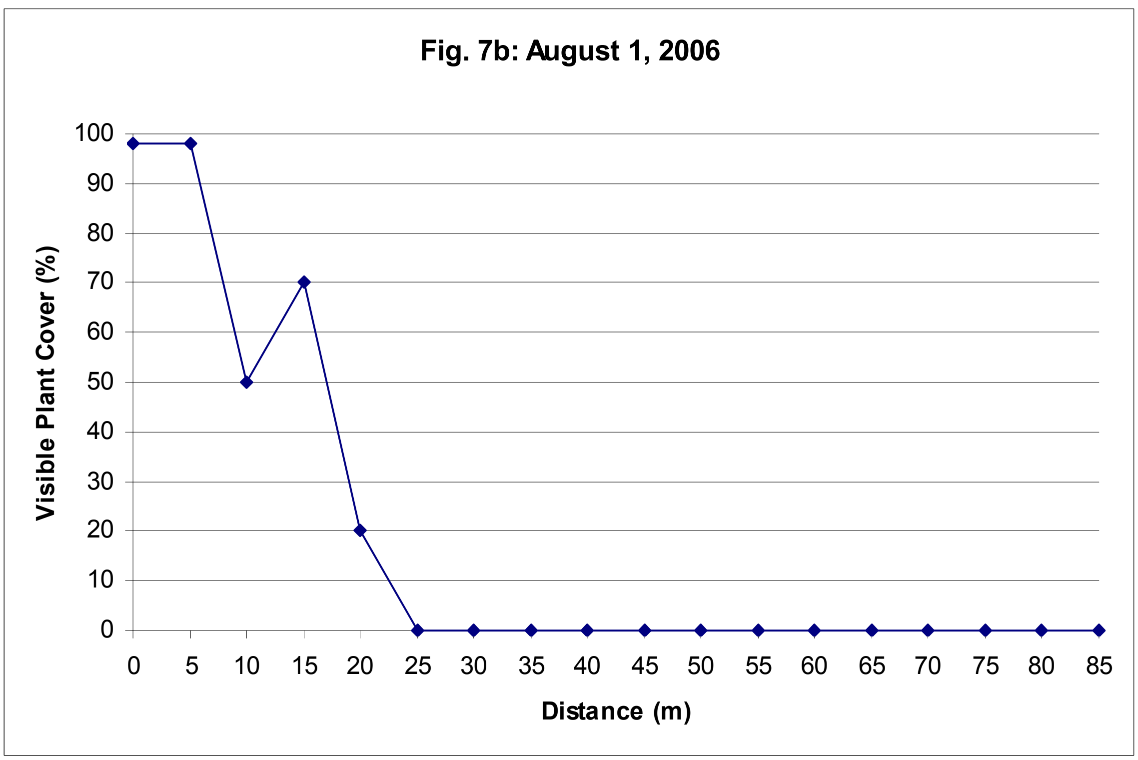
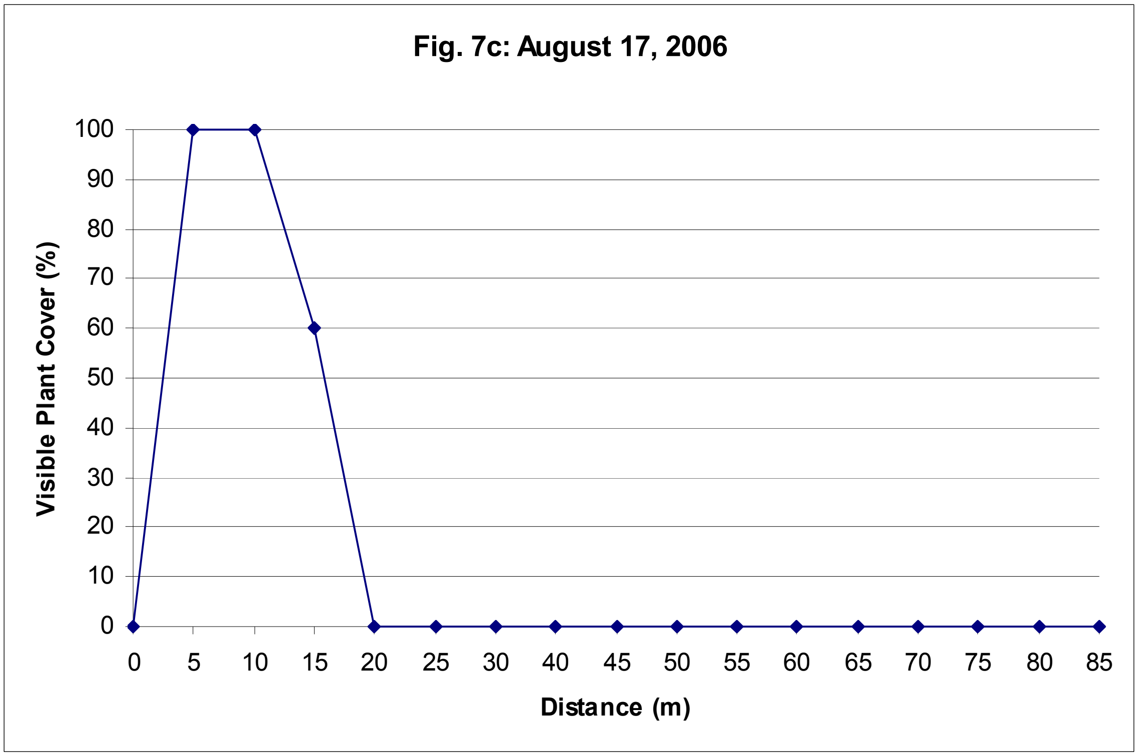


Figure 7a-b: Percent plant cover along Transect 3 in Camp Hydaway Lake, with distances measured from the western shore at 5-meter intervals. The data were obtained on the dates listed with each graph.



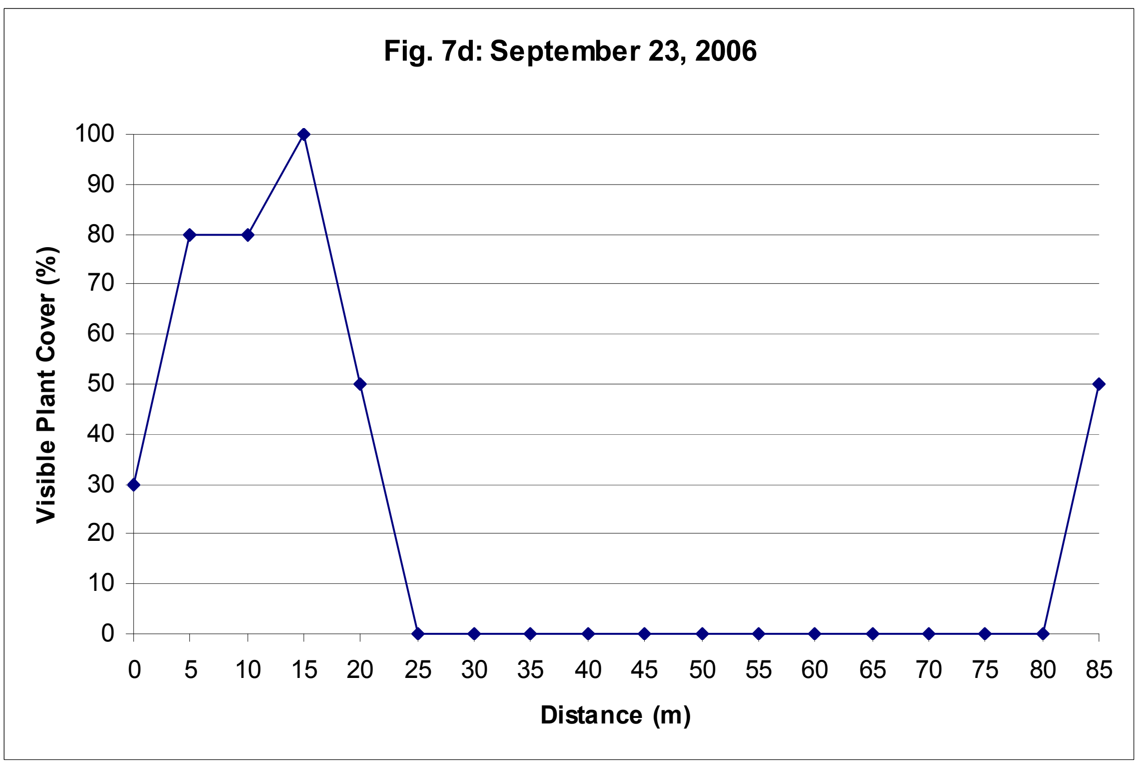


Figure 7c-d: Percent plant cover along Transect 3 in Camp Hydaway Lake, with distances measured from the western shore at 5-meter intervals. The data were obtained on the dates listed with each graph.

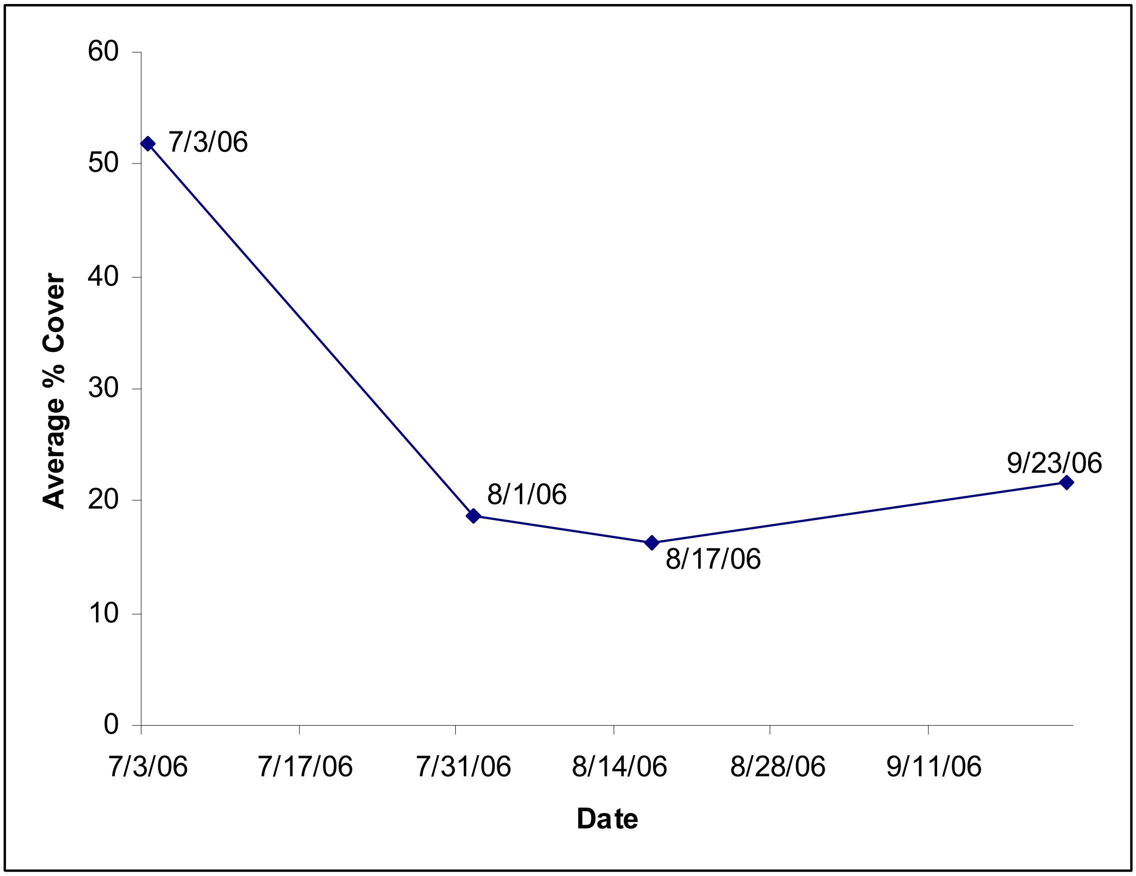


Figure 8: Average percent plant cover found along Transect 3 in Camp Hydaway on July 3, August 1, August 17, and September 23, 2006. The herbicide was added on July 3-4.

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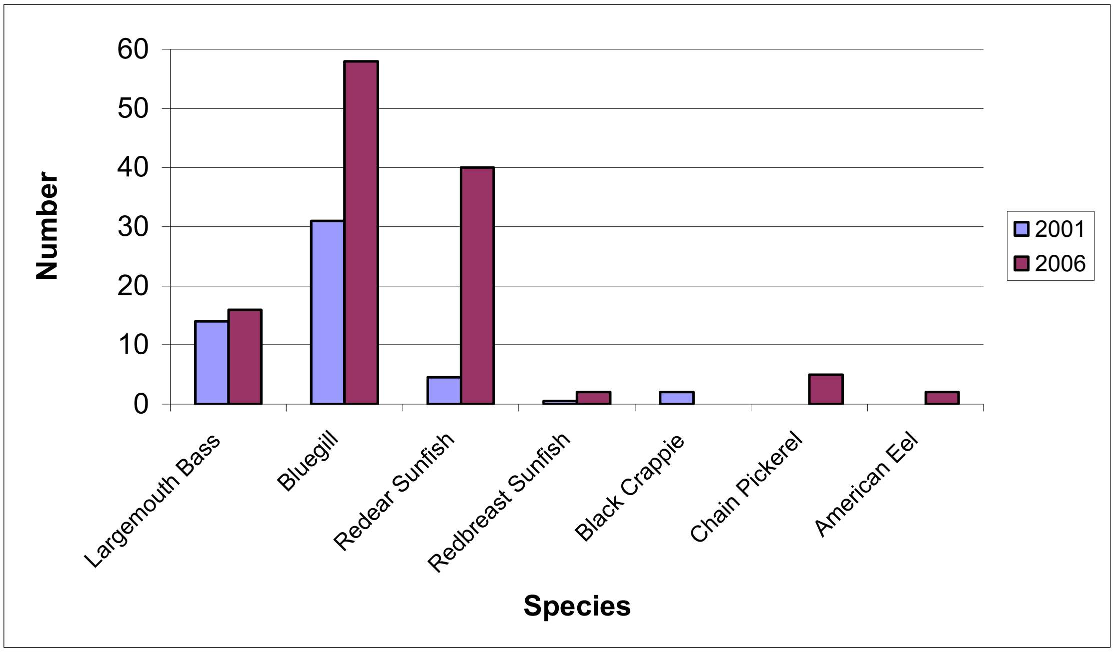

Figure 9: Number of each species of fish sampled by boat electrofishing in Camp Hydaway Lake on July 2, 2001 and June 14, 2006.

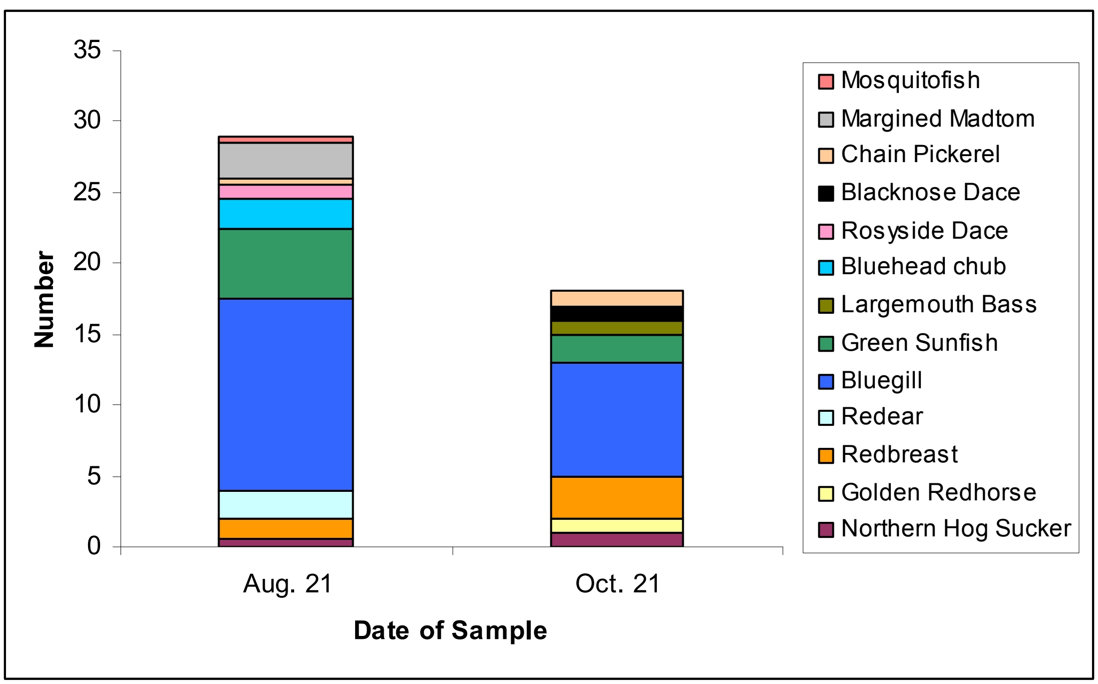

Figure 10: Number of each species of fish sampled by backpack electrofishing at Site F.2 of Opossum on August 21 and October 21, 2006.

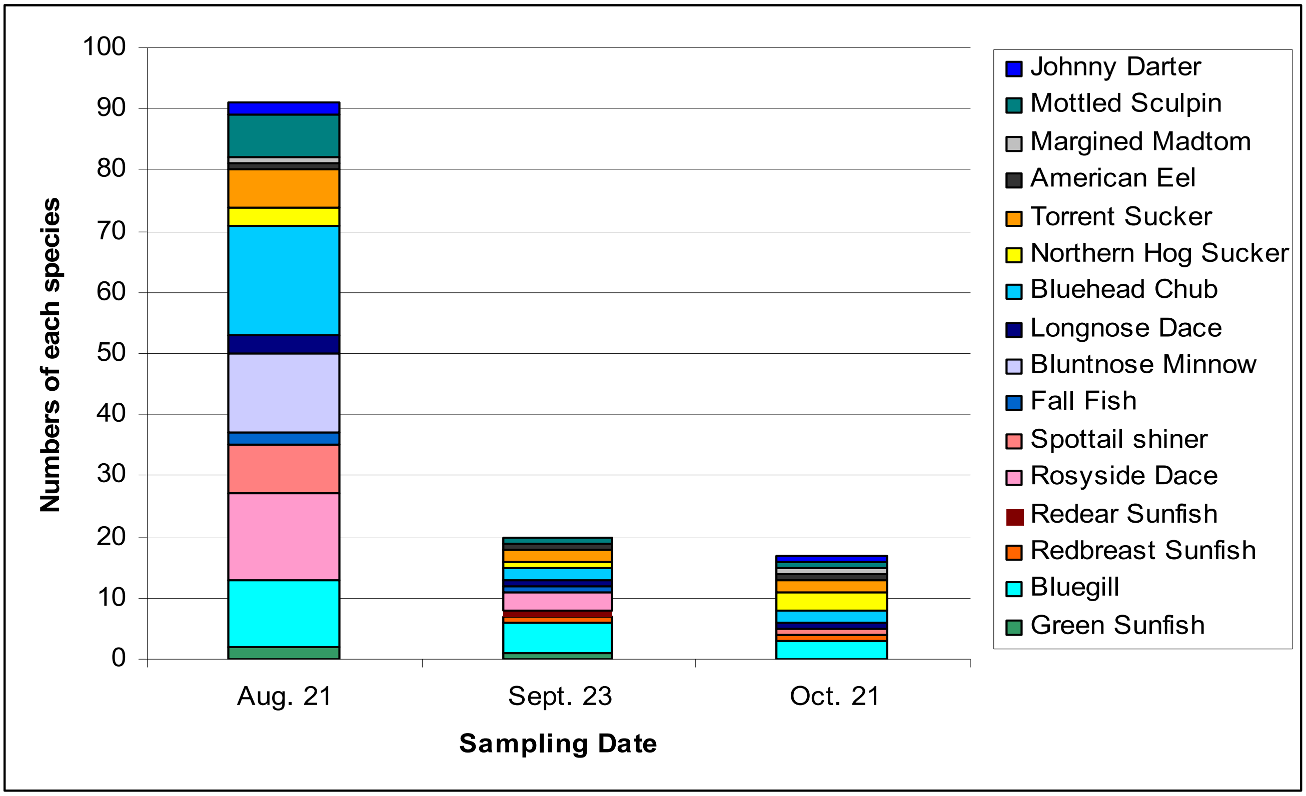

Figure 11: Number of each species of fish sampled by backpack electrofishing at Site F.3 of Opossum Creek on August 21, September 23, and October 21, 2006.

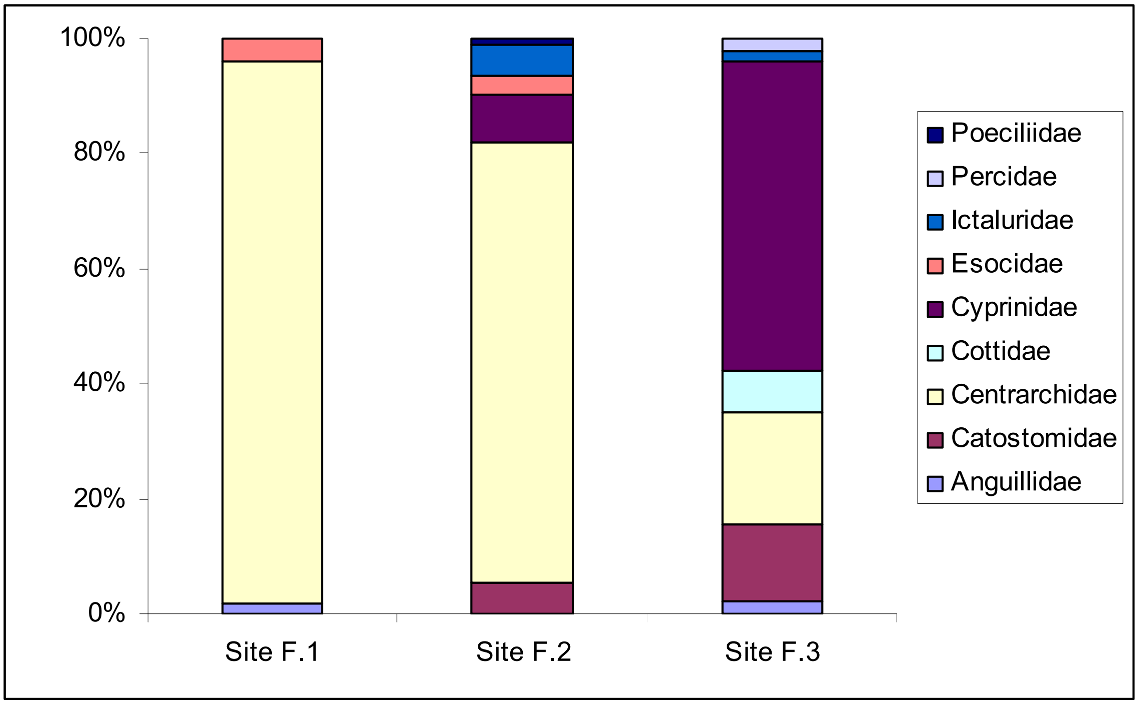

Figure 12: Percent composition of each family of fishes of Camp Hydaway Lake (Site F.1) and Sites F.2 and F.3 of Opossum Creek. The data shown from the lake are from the 2006 sample and the data for the creek sites are combined for all 2006 samples obtained at each site.