J. Aquat. Plant Manage. 41: 31-38

Changes in Behavior, Movement, and Home Ranges of Largemouth Bass Following Large- scale Hydrilla Removal in Lake Seminole, Georgia

STEVE M. SAMMONS[1], MICHAEL J. MACEINA[1], AND DAVID G. PARTRIDGE[2]

ABSTRACT

About 1,200 ha of hydrilla (*Hydrilla verticillata* L.f. Royle) was eliminated in the Spring Creek embayment of Lake Seminole, Georgia, using a drip-delivery application of fluridone (1- methyl-3-phenyl-5-[3-(trifluorometh1) phenyl]-4(1H)-pyridinone) in 2000 and 2001. Two groups of 15 and 20 largemouth bass (*Micropterus salmoides* Lacepede) were implanted with 400-day radio tags in February 2000 and 2001 to determine changes in movement and behavior before and after hydrilla reduction. Fish were located approximately every 10 days beginning two weeks after tag insertion; beginning in May 2000 diel movement was assessed once a month, and on each sampling date the fish were located every 4 hours for 24 hours (six locations per sampling date). Only fish that were at large in the lake for at least 200 days and with at least 35 locations were used for analysis; 19 fish met these criteria. Locations were grouped into two treatment levels based on the amount of hydrilla present in the system, a pre-treatment period (May to August 2000) when hydrilla coverage in Spring Creek was 72%, and a post treatment period (June to Octo-

[1]Department of Fisheries and Aquaculture, 203 Swingle Hall, Auburn University, Alabama, 36849, ssammons@acesag.auburn.edu.

[2]Georgia Department of Natural Resources, 109 Hatchery Access Road, Dawson, Georgia 31742.

Received for publication August 28, 2002 and in revised form October 27, 2002.

ber 2001) when coverage was 22%. Most largemouth bass remained in the treatment area and maintained similar home range sizes during both treatment periods. However, fish exhibited greater movement, inhabited greater depths, and switched from using hydrilla to large woody debris after hydrilla was reduced. Fish may have responded to better foraging conditions by changing feeding strategies from ambushing to searching, which should increase foraging success. Decreased water clarity and increased threadfin shad abundance may have precipitated the increased daytime movement we observed in this study. Our data demonstrated that while largemouth bass do not leave an area when hydrilla is reduced with fluridone, their behavior does change. Lake managers involved in aquatic plant removal programs can exchange this information with anglers concerning the effects of hydrilla treatment and potential impacts to the fishery.

Key words: reservoir, herbicide, aquatic plants, management, radio tracking.

INTRODUCTION

The presence and abundance of aquatic plants have been associated with fish community structure and population characteristics in a wide variety of systems (reviewed by Dibble et al. 1996). Although much of the early work on fish-aquatic plant interactions was conducted in north-temperate natural lakes (Weaver et al. 1996), with the invasion and spread of more robust and competitive exotic plants such as hydrilla, aquatic weed management has increased in public reservoirs and has fueled many of the major controversies that have arisen on these systems in recent years (e.g., Wilde et al. 1992, Wrenn et al. 1996).

Largemouth bass typically dominate reservoir sport fish communities and are the most important fish sought by anglers in southeastern impoundments (Durocher et al. 1984). High levels of aquatic plants often affect largemouth bass populations by enhancing recruitment, but can delay the onset of piscivory in age-0 fish and reduce growth rates of all ages of fish (Durocher et al. 1984, Moxley and Langford 1985, Bettoli et al. 1992, Maceina et al. 1995, Hoyer and Canfield 1996, Wrenn et al. 1996, Brown and Maceina 2002). Abundance and angler catch rates of largemouth bass often increase with aquatic plant coverage (Durocher et al. 1984, Maceina and Reeves 1996, Wrenn et al. 1996); however, mean size of fish tends to decrease as vegetation levels increase (Smith and Orth 1990, Dibble et al. 1996, Maceina 1996, Slipke et al. 1998).

Most researchers have found that moderate (15 to 30%) submersed vegetation coverages maximize age-0 largemouth bass production while still allowing adequate adult growth (Wiley et al. 1984, Moxley and Langford 1985, Maceina 1996). Economic analysis of the fishery at Lake Guntersville, Alabama, projected that the greatest positive impact on the local economy from recreation would be achieved at 20% plant coverage (Henderson 1996). This amount of coverage allowed the highest levels of angling and nonangling recreation without being hindered by excessive plant growth, and resulted in a projected value of $122 million annually to the surrounding areas (Henderson 1996). However, the estimated value of the fishery would decline by 82% and 57% at plant coverages of 50% and 0%, respectively. Clearly, weed management in reservoirs involves balancing the needs of many user groups and can have serious economic consequences (Colle et al. 1987, Henderson 1996, Wrenn et al. 1996, Slipke et al. 1998).

Lake Seminole was once a widely renowned largemouth bass fishery; however, catch rates of largemouth bass ≥305 mm TL in Lake Seminole declined by almost 50% between 1985 and 1996, while hydrilla coverage increased from 40% to 50% (Slipke et al. 1998). Annual visitation at Lake Seminole declined steadily from a high of 4.2 million visitor days in 1984 to a low of 0.9 million visitor days in 1997, consonant with the increase in hydrilla (USACE 1998). Spring Creek (Figure 1) is a 2,189-ha tributary of Lake Seminole that has been the epicenter of aquatic vegetation problems in the lake (USACE 1998). An areal survey in 1997 indicated that coverage of submersed aquatic plants, primarily hydrilla, was 76% in Spring Creek, compared to 26% in the Chattahoochee River and 32% in the Flint River arms (USACE 1998). Growth rate, relative weight, and fecundity of largemouth bass in Lake Seminole were considerably lower in Spring Creek than in the other two embayments of the lake (Brown and Maceina 2002).

As part of an overall hydrilla management plan for Lake Seminole, the U.S. Army Corps of Engineers (USACE) constructed a drip delivery fluridone system in Spring Creek

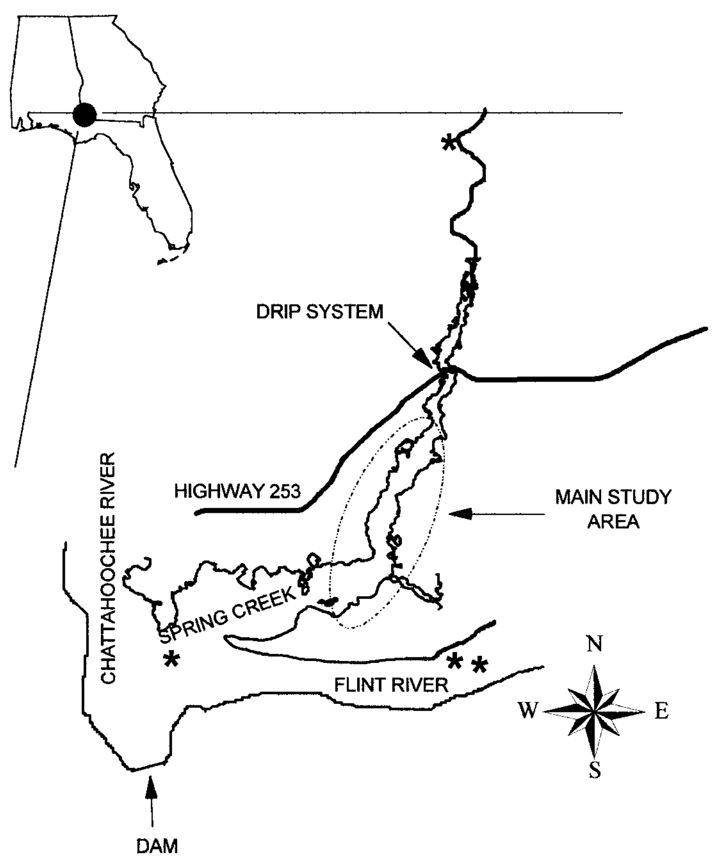

Figure 1. Map of Spring Creek, Lake Seminole, Georgia, showing location of drip system and main study area for this project. Asterisks denote approximate location of four tagged largemouth bass located outside the study area in 2001.

(Haller et al. 1990, Fox et al. 1994). Fluridone is a chemical that inhibits carotenoid synthesis in plants (MacDonald et al. 1993, Netherland et al. 1993). Applied at levels of 10 to 20 ppb, fluridone reduces turion and tuber production and growth and reduces biomass of aquatic plants such as hydrilla (MacDonald et al. 1993, Netherland et al. 1993). Since largemouth bass anglers preferred to fish in Spring Creek and exhibited more resistance to aquatic plant control than other angler groups (Slipke et al. 1998), angler concerns about the effect of this treatment on largemouth bass in Spring Creek were expected. To date, little information is available on largemouth bass behavioral response to herbicide applications (Bain and Boltz 1992, Bettoli and Clark 1992, Boyer 1994), and none of these studies examined the impacts of fluridone. In addition, the indirect effects of changes in aquatic plant abundance and species composition on largemouth bass movement and home range has not been examined. Thus the objectives of this study were to quantify the movement, behavior, home range, and habitat associations of adult largemouth bass before and after hydrilla reduction in Spring Creek.

MATERIALS AND METHODS

Study Area

Lake Seminole is a 13,919-ha impoundment on the Chattahoochee and Flint Rivers located on the Florida-Georgia border. Impounded in 1957, the reservoir has a mean depth of 3.0 m, a maximum depth of 10.7 m, and 155 km of shoreline (USACE 1998). The reservoir is operated primarily for navigation, although hydropower and water supply are also major uses (USACE 1998). Stable water levels (<1 m annual fluctuation) and the shallow depths of this reservoir have resulted in colonization by a wide variety of aquatic plants. Some common native plants found in the lake include variable-leafed milfoil (*Myriophyllum heterophyllum* Michaux), Illinois pondweed (*Potamogeton illinoensis* Morong), muskgrass (*Chara* sp. L.), stonewort (*Nitella* sp. L.), tape-grass (*Vallisneria americana* Michaux), and coontail (*Ceratophyllum demersum* L.). Exotic plants include Eurasian milfoil (*Myriophyllum spicatum* L.) and hydrilla. Hydrilla was discovered in Lake Seminole in 1967 and spread rapidly throughout the late 1970s, outcompeting most other submersed plants (USACE 1998). Vegetation dominated by hydrilla peaked in the early 1990s at about 65% areal coverage and receded to about 40% by 1997 due to flooding events in 1994 (USACE 1998).

Hydrilla Removal

The drip-delivery system was constructed at the Highway 253 bridge on the upper end of Spring Creek (Figure 1). The system was initiated in late May 2000 and was planned to be in operation for 60 days while maintaining a dose of 15 ppb of fluridone. However, the hydrilla canopy had not collapsed by the end of the 60-day period, and the USACE maintained the drip system until mid to late August 2000, when most of the hydrilla canopy collapsed in about a week (D. Morgan, USACE, pers. comm.). Hydrilla regrowth caused the USACE to restart the system in October 2000 and maintain it until early December 2000. The drip system was initiated again in May 2001 and remained on until September 2001, thereafter it was operated on biweekly intervals through the end of the year. Hydrilla coverage in the Spring Creek embayment declined from 72% to 22% when the hydrilla canopy collapsed in late August 2000; total control of hydrilla in Spring Creek was approximately 1,200 ha. Hydrilla coverage in the main study area (Figure 1) declined to nearly 0% in late August 2000, and thereafter never rose above 40% (J. Staigl, USACE, pers. comm.). In addition, some tape-grass and Illinois pondweed became established in the treatment area, but these plants covered less than 100 ha (D. Morgan, USACE, pers. comm.).

Tracking

A total of 35 largemouth bass greater than 1.5 kg were surgically implanted with 30 g radio tags (Advanced Telemetry Systems), 15 in February 2000 and the remainder in February 2001. Tags were inserted following the procedures of Maceina et al. (1999). We followed the recommendation of Winter (1996) of not implanting a tag greater than 2% of body weight to ensure that behavior and movement will not be affected. Tags had a 400-day life expectancy and were fitted with a mortality sensor. If the tag was motionless for at least 24 hours due to death or expulsion, then the signal rate doubled. All fish were collected using electrofishing downstream and within 4 km of the drip system located at the State Highway 253 bridge, which crosses Spring Creek (Figure 1). Immediately upon capture fish had a radio tag implanted with a unique frequency number and were released at the site of capture.

Fish were tracked approximately every 10 days beginning approximately 2 weeks after tag insertion, to allow fish time to recover from surgery. Beginning in May 2000, fish were found every 4 hours for a 24-hour period every other tracking period (i.e., once a month) to assess diel movement patterns. The first group of fish were tracked until the fish died or the tag expired. The second group of fish were tracked from 2 weeks after tag insertion through December 2001. The precise location (within 5 m) of each fish was mapped using a GPS receiver. The primary habitat type and depth were recorded at each location, and water temperature and dissolved oxygen were recorded at surface and bottom (only surface measurements were taken if water depth <1 m). On two occasions (July 2001 and October 2001), missing fish were located using an airplane.

Data Analysis

Only diel locations were used for these analyses because single locations 10 days apart were not representative of largemouth bass behavior. However, determination of these single locations were used to describe fish movement out of the Spring Creek area. For diel locations, only fish that were at large in the lake for at least 200 days and with at least 35 locations were used for analysis (Table 1). Fish locations were divided into two time periods: a pre-treatment period (May to August 2000), when vegetation coverage in the Spring Creek embayment and the main study area was 72%, and a

Table 1. Total length, weight, date tagged, days at large, number of locations, and fate of 19 of 35 largemouth bass implanted with radio tags in Lake Seminole, Georgia. Only fish at large for more than 200 days and with at least 35 locations were used in this study.

Tag	Total Length (mm)	Weight (g)	Date Tagged	Last Date Found	Days at Large	Number Locations	Fate
013	471	1740	09 Feb 2000	22 May 2001	468	95	Tag Expired
023	511	2240	09 Feb 2000	05 Apr 2001	421	80	Tag Expired
044	444	1535	09 Feb 2000	08 Sep 2000	212	43	Fish Died
054	539	2205	09 Feb 2000	21 May 2001	467	92	Fish Died
083	525	2515	09 Feb 2000	05 Apr 2001	421	81	Tag Expired
095	546	2533	09 Feb 2000	26 Apr 2001	442	89	Tag Expired
114	609	4168	09 Feb 2000	22 Aug 2001	560	117	Tag Expired
124	525	2150	09 Feb 2000	25 Apr 2001	441	84	Fish Died
156	480	1688	09 Feb 2000	05 Apr 2001	421	82	Tag Expired
173	571	3115	09 Feb 2000	25 Apr 2001	441	86	Fish Died
303	541	2750	25 Feb 2001	13 Dec 2001	291	40	Study Ended
324	579	3150	25 Feb 2001	13 Dec 2001	291	42	Study Ended
383	522	2420	25 Feb 2001	13 Dec 2001	291	40	Study Ended
403	490	1847	25 Feb 2001	13 Dec 2001	291	46	Study Ended
464	481	1490	25 Feb 2001	13 Dec 2001	291	45	Study Ended
481	485	1770	25 Feb 2001	19 Oct 2001	236	49	Study Ended
503	434	1670	25 Feb 2001	13 Dec 2001	291	50	Study Ended
524	468	1555	25 Feb 2001	13 Dec 2001	291	36	Study Ended
544	598	2110	25 Feb 2001	13 Dec 2001	291	50	Study Ended

post-treatment period (June to October 2001), when vegetation coverage in the Spring Creek embayment was 22% and coverage in the main study area was less than 15%. In each period, mean movement, mean depth, and home ranges were calculated for each fish. Primary habitat for each location was grouped into one of seven categories: hydrilla, large woody debris, submersed (native) aquatic plants, floating-leaved plants, emergent vegetation, bare (no plant material on the bottom), and other. Percent occurrence of fish in each of these habitat categories was compared between the pre and post-treatment periods.

Movement (m/h) was estimated as the distance moved divided by the number of hours between locations in a 24-hour tracking period. Home ranges were calculated for each fish in each treatment using a kernel estimator (Seaman and Powell 1996). This method was shown to be the least-biased estimate of home range, and can be used to identify high use areas (Seaman and Powell 1996). For this study we used the 95% density estimate to represent overall home range of the fish, and the 50% density estimate to represent the high-use or core area of the fish (Hooge et al. 2001). Site fidelity of each fish in each treatment period was tested using the Monte Carlo random walk test developed by Spencer et al. (1990), modified by Hooge et al. (2001). Fish that did not exhibit site fidelity were excluded from home range analysis (Spencer et al. 1990, Hooge et al. 2001). Movement and depth were further subdivided in each treatment period into diel time periods: dawn, 2 hours before and after sunrise, dusk, 2 hours before and after sunset, day, and night (Snedden et al. 1999). Dawn and dusk were combined into one time period called the crepuscular period to increase statistical power. Movements were assigned to the time period in which the majority of the time between locations occurred.

Movement and depth distributions in each treatment period were compared using a Kolmogorov-Smirnov Test (SAS 1999). Mean movement, depth, 95% kernel home range, and core use area were compared in each area using a t-test (SAS 1999). Movement and depth data were non-normally distributed and were $\log_e$-transformed prior to analysis. Mean depth and movement were compared between the two treatments in each time period using a t-test (SAS 1999). All comparisons were considered significant at $P < 0.10$.

RESULTS

Nineteen largemouth bass were tracked long enough and had enough locations to be used for these analyses. These fish were at large for 212 to 560 days and were located 36 to 117 times (Table 1). Of the other 16 fish, nine died, one tag malfunctioned, four fish left the study area, and two fish disappeared and were never located again. Of the four fish that left the study area in 2001, two were suspected to have been moved by anglers into the Flint River, as these fish were found twice near a popular fishing camp that hosts bass fishing tournaments. Another fish moved more than 10 km upstream into Spring Creek above the reservoir (Figure 1). Two fish, one in the pre-treatment period and one in the post-treatment period, did not exhibit site fidelity and were excluded from home range analysis.

Movement of largemouth bass ranged from 0 to 324 m/h before hydrilla reduction and 0 to 465 m/h afterwards, and mean movement of largemouth bass was greater after hydrilla reduction (Table 2). Movement was typically low (<50 m/h) in both treatment periods; however, frequency distributions were different between treatments (Figure 2). Depths of tagged largemouth bass ranged from 0.4 to 5.3 m before hydrilla reduction and 0.4 to 6.0 m afterwards. Mean depth of largemouth bass was greater after hydrilla reduction (Table 2), and depth distribution was deeper (Figure 3). Home range size ranged from 3.1 to 40.0 ha and core use area ranged from 0.3 to 8.4 ha during the pre-treatment period, whereas home range size ranged from 1.9 to 39.9 ha and

Table 2. Mean movement, depth, and home ranges of largemouth bass before and after hydrilla removal in Spring Creek, Lake Seminole, Georgia, in 2000 and 2001.

	Pre		Post			
	Mean (N)	Standard Error	Mean (N)	Standard Error	t- value	P-value
Diel Movement (m/h)	39.8 (10)	5.4	54.3 (9)	8.2	2.02	0.0441
Depth (m)	2.4 (10)	0.2	3.0 (9)	0.3	1.94	0.0676
95% Kernel Home Range (ha)	18.9 (9)	4.4	19.1 (8)	4.3	0.02	0.9831
Core Use Area (ha)	3.40 (9)	0.9	3.82 (8)	1.2	0.29	0.7795

core use area ranged from 0.3 to 9.6 ha after hydrilla removal. However, mean home range and core use areas of the fish did not change after hydrilla was reduced (Table 2). Largemouth bass movement did not change after hydrilla reduction in the crepuscular and night periods; however, movement during the day more than doubled (Figure 4). Mean depth of largemouth bass increased in the crepuscular and daytime periods, but was not different at night (Figure 4). Habitat use of largemouth bass was primarily hydrilla and large woody debris before hydrilla reduction; large woody debris were the primary habitat used afterwards (Figure 5).

DISCUSSION

Hydrilla reduction in Spring Creek was associated with changes in largemouth bass movements and depth distributions, but had little effect on home ranges. Similar to our study, home ranges reported for largemouth bass generally ranged from <0.1 to 50 ha (Lewis and Flickinger 1967, Warden and Lorio 1975, Fish and Savitz 1983, Mesing and Wicker 1986, Wanjala et al. 1986, Colle et al. 1989, Bain and Boltz 1992, Lyons 1993, Furse et al. 1996, Woodward and Noble 1997). Rapid hydrilla loss in late summer 2000 did not cause fish to leave the area in search of hydrilla. Unlike those tagged in 2001, the first group of tagged largemouth bass were subjected to widely disparate abundances of hydrilla. Only two fish from the group tagged in 2000 became missing, and one of those was almost certainly the result of tag failure, since contact was lost during a 24-hour tracking period. The fate of the other fish remained unknown; however, contact was lost 2 months before the hydrilla canopy collapsed in August 2000. All the other fish remained in the study area and in most cases home ranges before and after hydrilla removal were broadly overlapping.

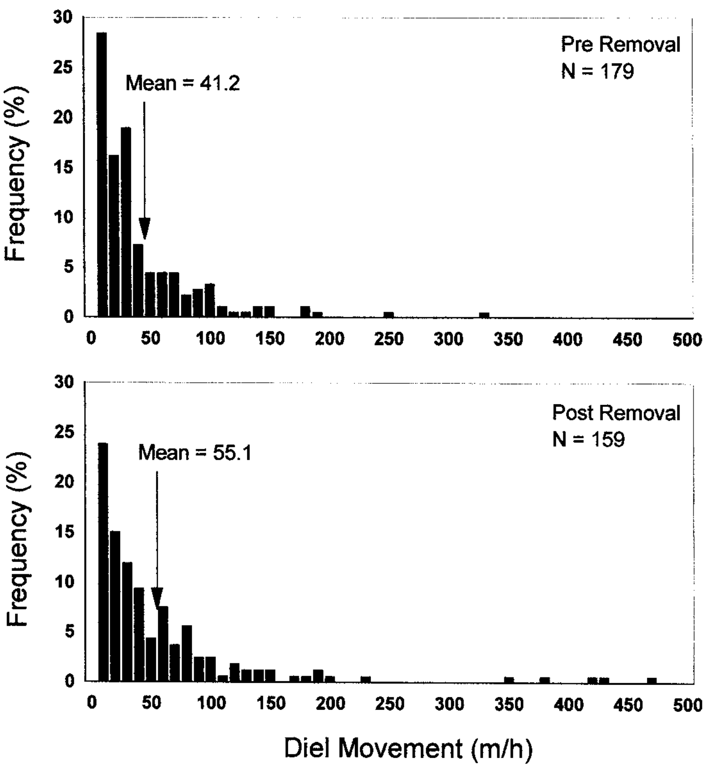

Figure 2. Frequency distributions (10-m/h increments) of diel movement observed for largemouth bass before and after hydrilla reduction in Spring Creek, Lake Seminole, Georgia, in 2000 and 2001. Distributions were different between treatments (Kolmogorov-Smirnov Test, KSa = 1.30, P = 0.07).

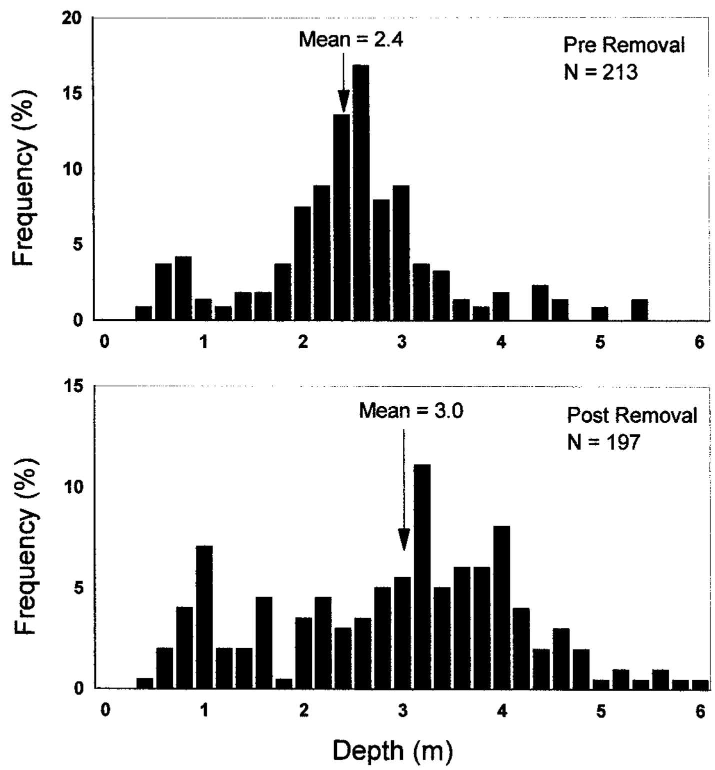

Figure 3. Frequency distributions (0.2-m increments) of depth observed for largemouth bass before and after hydrilla reduction in Spring Creek, Lake Seminole, Georgia, in 2000 and 2001. Distributions were different between treatments (Kolmogorov-Smirnov Test, KSa = 3.48, P = 0.0001).

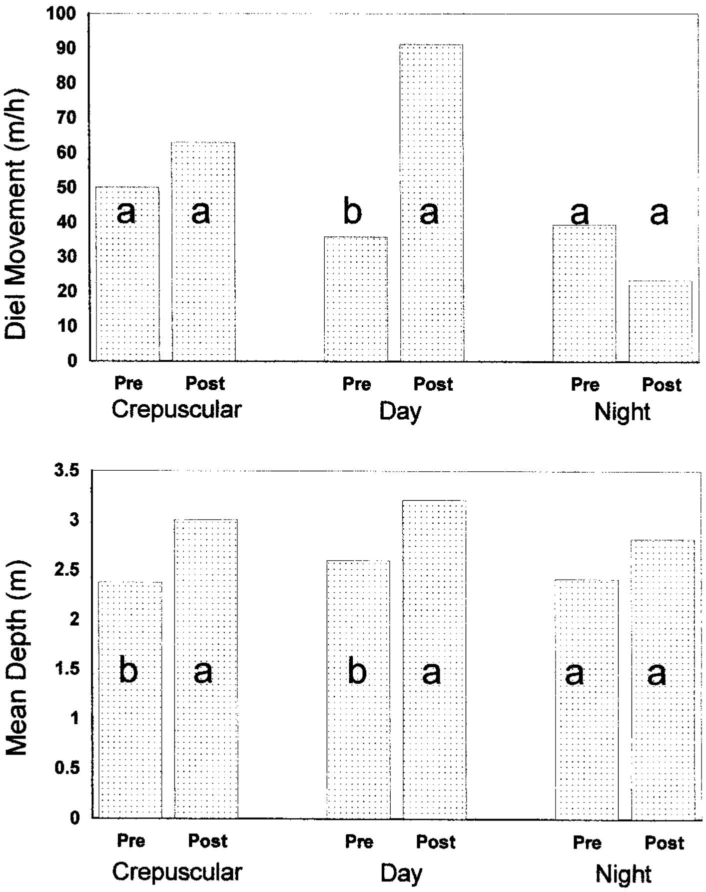

Figure 4. Mean diel movement and depth of largemouth bass at three diel periods before and after hydrilla reduction in Spring Creek, Lake Seminole, Georgia, in 2000 and 2001. Means with the same letter within each diel period were not different (t-test, P > 0.10).

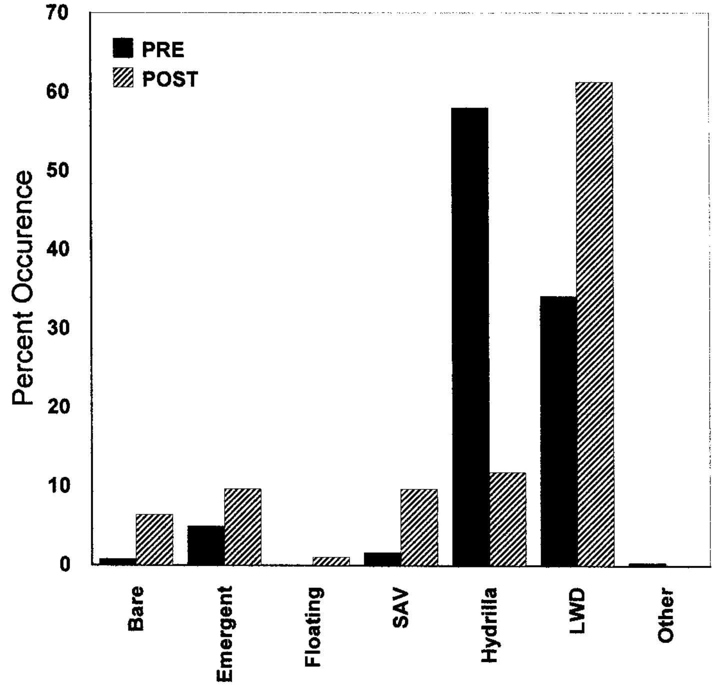

Figure 5. Habitat use of tagged largemouth bass before and after hydrilla reduction in Spring Creek, Lake Seminole, Georgia, in 2000 and 2001. Habitat categories are: bare (no plants or other cover), emergent vegetation, floating-leaved plants, SAV (submersed native aquatic plants), hydrilla, LWD (large woody debris), and other (e.g., docks).

Largemouth bass movement increased following hydrilla reduction. Movement of largemouth bass has been found to be influenced by light levels (Messing and Wicker 1986, Colle et al. 1989), and large reductions of aquatic plants can result in decreased water clarity (Canfield et al. 1983, Leslie et al. 1983, Maceina et al. 1992). Similarly, Secchi disk depths decreased in Spring Creek, following hydrilla reduction. Before the decline in hydrilla, Secchi depths were unable to be taken because of the dense vegetation. However, in a few bare places the bottom could be clearly seen in water depths up to 5 m. In contrast, mean Secchi transparency in summer 2001 was 2.7 m. Thus the reduction in water clarity may have accounted for the large increase in daytime movement observed after hydrilla removal.

The change in habitat complexity may also have contributed to the increase in largemouth bass movement. Largemouth bass in experimental systems have been found to change predation tactics in response to decreases in aquatic plant densities, switching from active searching to ambushing prey (Savino and Stein 1982). Dense vegetation provides abundant cover for prey fishes, which decreases feeding efficiency by predators such as largemouth bass (Savino and Stein 1982, Dibble et al. 1996), leading to reduced growth and poor body condition (Colle and Shireman 1980, Maceina and Shireman 1985, Maceina et al. 1991, Bettoli et al. 1992), which Brown and Maceina (2002) observed in Spring Creek prior to hydrilla reduction. Also, dense vegetation can also depress dissolved oxygen levels, leading to more concentrated prey fish in oxygenated refugia (Miranda et al. 2000); whereas, dissolved oxygen and prey distributions can be more uniform in absence of aquatic plants (Miranda and Hodges 2000). Thus largemouth bass in Spring Creek may have began actively searching for prey after hydrilla reduction, leading to higher movement rates.

Vegetation losses can also affect species abundance and composition (Bettoli et al. 1991, 1993). Top predators such as largemouth bass may be confronted by an entirely new fish fauna community with drastic changes in plant abundance, causing them to change prey selection and feeding strategies, causing differences in behavior. Pelagic fish species, such as gizzard shad (*Dorosoma cepedianum* Lesueur), and threadfin shad (*D. petenense* Günther), generally increase in abundance following plant reduction (Maceina and Shireman 1985, Bettoli et al. 1993), and threadfin shad appeared to be increasing in Spring Creek as hydrilla decreased. Switching from a more littoral prey species such as bluegill (*Lepomis macrochirus* Rafinesque) to shad should change behavior, and may contribute to the increase in daytime movement we observed, since shad tend to congregate near the surface during the day and may be more vulnerable to predation (Vondracek and Degan 1995; Sammons and Bettoli 2002).

As hydrilla was reduced in Spring Creek, largemouth bass switched from using primarily hydrilla to large woody debris (mostly stumps). Largemouth bass are a structurally-oriented fish (Schlagenhaft and Murphy 1985, Colle et al. 1989, Lyons 1993, Annett et al. 1996), and when aquatic vegetation is present, these fish will usually use this habitat more often than other available habitats (Betsill et al. 1986, Mesing and Wicker 1986, Smith and Orth 1990, Lyons 1993). In a lake where all the vegetation had been removed, Colle et al. (1989) found that largemouth bass in inshore areas preferred emergent weedy areas, avoiding bare areas, while fish that stayed offshore were closely associated with piers. Largemouth bass in Spring Creek would occasionally be found in shallow silty flats or in bare areas that formerly harbored hydrilla, but usually they would be associated with some form of cover. The general increase in depth distribution by largemouth bass after hydrilla removal may have been a response to the loss of shallow cover by shifting to using large woody debris such as stumps, which were generally found in deeper water.

MANAGEMENT IMPLICATIONS

Largemouth bass anglers prefer fishing submersed vegetation such as hydrilla, and are generally not supportive of vegetation removal or reduction programs, believing that any such programs will reduce largemouth bass abundance and negatively affect the fishery (Klussman et al. 1988, Wilde et al. 1992, Slipke et al. 1998). Our results indicated that largemouth bass did not abandon areas where vegetation was reduced, but they did respond differently to habitat changes. Our data showed largemouth bass tended to inhabit deeper water, exhibit greater movement within their home ranges, and used woody structure and not other vegetation such as emergent or floating-leaved that was present following hydrilla reduction.

Fisheries such as Lake Seminole are extremely valuable to surrounding communities, and changes in the plant community of a system, along with the corresponding changes in fish communities, whether real or perceived, can have economic impacts. Angling effort on Lake Guntersville, Alabama declined 63% over a 3-year period when vegetation levels decreased, causing a drop of $1.4 million in angling expenditures over that time (Wrenn et al. 1996). Anglers at Lake Conroe, Texas, remain convinced that the fishery was negatively impacted by total removal of hydrilla from the system in the early 1980s, despite data to the contrary (Wilde et al. 1992). Clearly balancing the needs of and perceptions of various user groups is vital for success of any vegetation management project. Our study showed some impacts to largemouth bass behavior by vegetation reduction did occur, but most fish did not migrate away from the fluridone application and the decline in hydrilla. When large-scale vegetation reduction occurs similar to those we observed in Spring Creek, anglers will have to alter their fishing behavior to remain successful.

ACKNOWLEDGMENTS

Funding for this project was provided by the Georgia Department of Natural Resources through Federal Aid to Sportfish Restoration Project F-64. Support was also provided to S. M. Sammons with student scholarships provided by the Midsouth Aquatic Plant Management Society and the Reservoir Committee of the Southern Division of the American Fisheries Society, and with a fellowship provided by Auburn University. Mike Mitchell, Alabama Cooperative Fishery and Wildlife Research Unit at Auburn University provided technical advice on kernel home range estimations.

LITERATURE CITED

Annett, C., J. Hunt and E. J. Dibble. 1996. The compleat bass: Habitat use patterns of all stages of the life cycle of largemouth bass. Multidimensional approaches to reservoir fisheries management. Am. Fish. Soc. Symp. 16:306-314.

Bain, M. B. and S. E. Boltz. 1992. Effect of aquatic plant control on the microdistribution and population characteristics of largemouth bass. Trans. Am. Fish. Soc. 121:94-103.

Betsill, R. K., R. L. Noble and W. H. Neill. 1986. Distribution and habitat selection of telemetered northern and Florida largemouth bass in two small Texas impoundments. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 40:275-286.

Bettoli, P. W. and P. W. Clark. 1992. Behavior of sunfish exposed to herbicides: a field study. Environ. Toxicol. Chem. 11:1461-1467.

Bettoli, P. W., M. J. Maceina, R. L. Noble and R. K. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. N. Am. J. Fish. Manage. 12:509-516.

Bettoli, P. W., M. J. Maceina, R. L. Noble and R. K. Betsill. 1993. Response of a reservoir fish community to aquatic vegetation removal. N. Am. J. Fish. Manage. 13:110-124.

Bettoli, P. W., J. E. Morris and R. L. Noble. 1991. Changes in the abundance of two atherinid species after aquatic vegetation removal. Trans. Am. Fish. Soc. 120:90-97.

Boyer, M. G. 1994. Effect of 2,4-D amine on the movement and feeding behavior of largemouth bass. Master of Science Thesis, University of Florida, Gainesville.

Brown, S. J. and M. J. Maceina. 2002. The influence of disparate levels of submersed aquatic vegetation on largemouth bass population characteristics in a Georgia reservoir. J. Aquat. Plant Manage. 40:28-35.

Canfield, D. E., K. A. Langeland, M. J. Maceina, W. T. Haller and J. V. Shireman. 1983. Trophic state classification of lakes with aquatic macrophytes. Can. J. Fish. Aquat. Sci. 40:1713-1718.

Colle, D. E., R. L. Cailteux and J. V. Shireman. 1989. Distribution of Florida largemouth bass in a lake after elimination of all submersed aquatic vegetation. N. Am. J. Fish. Manage. 9:213-218.

Colle, D. E. and J. V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. Trans. Am. Fish. Soc. 109:521-531.

Colle, D. E., J. V. Shireman, W. T. Haller, J. C. Joyce and D. E. Canfield, Jr. 1987. Influence of hydrilla on harvestable sport-fish populations, angler use, and angler expeditures at Orange lake, Florida. N. Am. J. Fish. Manage. 7:410-417.

Dibble, E. D., K. J. Killgore and S. H. Harrel. 1996. Assessment of fish-plant interactions. Multidimensional approaches to reservoir fisheries management. Am. Fish. Soc. Symp. 16:357-372.

Durocher, P. P., W. C. Provine and J. E. Kraai. 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. N. Am. J. Fish. Manage. 4:84-88.

Fish, P. A. and J. Savitz. 1983. Variations in home ranges of largemouth bass, yellow perch, bluegills, and pumpkinseeds in an Illinois lake. Trans. Am. Fish. Soc. 112:147-153.

Fox, A. M., W. T. Haller, and G. D. Shiling. 1994. Use of fluridone for hydrilla management in the Withlacoochee River, Florida. J. Aquat. Plant Manage. 32:47-55.

Furse, J. B., L. J. Davis, and L. A. Bull. 1996. Habitat use and movements of largemouth bass associated with changes in dissolved oxygen and hydrology in Kissimmee River, Florida. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 50:12-25.

Haller, W. T., A. M. Fox and D. G. Shiling. 1990. Hydrilla control program in the upper St. Johns River, Florida, USA. Proc. European Weed Soc. Symp. on Aquatic Weeds 8:111- 116.

Henderson, J. E. 1996. Management of nonnative aquatic vegetation in large impoundments: Balancing preferences and economic values of angling and nonangling groups. Multidimensional approaches to reservoir fisheries management. Am. Fish. Soc. Symp. 16:373-381.

Hooge, P. N., W. M. Eichenlaub and E. K. Solomon. 2001. Using GIS to Analyze Animal Movements in the Marine Environment, p. 37-51. *In:* G. H. Kruse, N. Bez, A. Booth, M. W. Dorn, S. Hills, R. N. Lipcius, D. Pelletier, C. Roy, S. J. Smith, and D. Witherell (eds.). 2001 Spatial Processes and Management of Marine Populations. Alaska Sea Grant College Program, Anchorage, Alaska.

Hoyer, M. V. and D. E. Canfield, Jr. 1996. Largemouth bass abundance and aquatic vegetation in Florida lakes: An empirical analysis. J. Aquat. Plant Manage. 34:23-32.

Leslie, A. J., Jr., L. E. Nall and J. M. Van Dyke. 1983. Effects of vegetation control by grass carp on selected water-quality variables in four Florida lakes. Trans. Am. Fish. Soc. 112:777-787.

Lewis, W. M. and S. Flickinger. 1967. Home range tendency of the largemouth bass (*Micropterus salmoides*). Ecology 48:1020-1023.

Lyons, B. W. 1993. Distribution and habitat selection of Florida and northern largemouth bass in Lake Tawakoni, Texas. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 47:633-641.

MacDonald, G. E., D. G. Shilling, R. L. Doong and W. T. Haller. 1993. Effects of fluridone on hydrilla growth and reproduction. J. Aquat. Plant Manage. 31:195-198.

Maceina, M. J. 1996. Largemouth bass abundance and aquatic vegetation in Florida lakes: An alternative interpretation. J. Aquat. Plant Manage. 34:43-47.

Maceina, M. J., P. W. Bettoli, W. G. Klussman, R. K. Betsill and R. L. Noble. 1991. Effect of aquatic macrophyte removal on growth of black crappies and white crappies in Lake Conroe, Texas. N. Am. J. Fish. Manage. 11:556-563.

Maceina, M. J., M. F. Cichra, R. K. Betsill and P. W. Bettoli. 1992. Limnological changes in a large reservoir following vegetation removal by grass carp. J. Freshw. Ecol. 7:81-95.

Maceina, M. J. and W. C. Reeves. 1996. Relations between submersed macrophyte abundance and largemouth bass tournament success on two Tennessee river impoundments. J. Aquat. Plant Manage. 34:33-38.

Maceina, M. J., S. J. Rider and S. T. Szedlmayer. 1995. Density, temporal spawning patterns, and growth of age-0 and age-1 largemouth bass (*Micropterus salmoides*) in vegetated and unvegetated areas of Lake Guntersville, Alabama, p. 497-511. *In:* D. C. Secor, J. M. Dean, and S. E. Campana (eds.). Recent Developments in Fish Otolith Research. University of South Carolina Press, Columbia.

Maceina, M. J. and J. V. Shireman. 1985. Influence of dense hydrilla infestation on black crappie growth. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 36:394-402.

Maceina, M. J., J. W. Slipke and J. M. Grizzle. 1999. Effectiveness of three barrier types for confining grass carp in embayments of Lake Seminole, Georgia. N. Am. J. Fish. Manage. 19:968-976.

Messing, C. L. and A. M. Wicker. 1986. Home range, spawning migrations, and homing of radio-tagged Florida largemouth bass in two central Florida lakes. Trans. Am. Fish. Soc. 115:286-295.

Miranda, L. E. and K. B. Hodges. 2000. Role of aquatic vegetation coverage on hypoxia and sunfish abundance in bays of a eutrophic reservoir. Hydrobiologia 427:51-57.

Miranda, L. E., M. P. Driscoll and M. S. Allen. 2000. Transient physicochemical microhabitats facilitate fish survival in inhospitable aquatic plant stands. Freshw. Biol. 44(4):617-628.

Moxley, D. J. and F. H. Langford. 1985. Beneficial effects of hydrilla on two eutrophic lakes in central Florida. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 36:280-286.

Netherland, M. D., K. D. Getsinger and E. G. Turner. 1993. Fluridone concentration and exposure time requirements for control of Eurasian watermilfoil and hydrilla. J. Aquat. Plant Manage. 31:189-194.

Sammons, S. M. and P. W. Bettoli. 2002. Spatial and diel variation in distribution of limnetic larvae of fishes in a Tennessee Reservoir. J. Freshw. Ecol. 17:45-53.

SAS Institute Inc. 1999. SAS system for linear models. Release 6.10. Cary, North Carolina.

Savino, J. F. and R. A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Trans. Am. Fish. Soc. 121:255-266.

Schlagenhaft, T. W. and B. R. Murphy. 1985. Habitat use and overlap between adult largemouth bass and walleye in a west Texas reservoir. N. Am. J. Fish. Manage. 5:465- 470.

Seaman, D. E. and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075-2085.

Slipke, J. W., M. J. Maceina and J. M. Grizzle. 1998. Analysis of the recreational fishery and angler attitude toward aquatic hydrilla in lake Seminole, a southeastern reservoir. J. Aquat. Plant Manage. 36:101-107.

Smith, S. M. and D. J. Orth. 1990. Distributions of largemouth bass in relation to submerged aquatic vegetation in Flat Top Lake, West Virginia. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 44:36-44.

Snedden, G. A., W. E. Kelso and D. A. Rutherford. 1999. Diel and seasonal patterns of spotted gar movement and habitat use in the lower Atchafalaya River basin, Louisiana. Trans. Am. Fish. Soc. 128:144-154.

Spencer, S. R., G. N. Cameron and R. K. Swihart. 1990. Operationally defining home range: Temporal dependence exhibited by hispid cotton rats. Ecology 71:1917-1822.

USACE (U. S. Army Corps of Engineers, Mobile District). 1998. Lake Seminole, FL-GA-AL hydrilla action plan. Final Supplement to the Master Plan and Final Supplement to the Environmental Impact Statement. 208 pp.

Vondracek, B. and D. J. Degan. 1995. Among- and within-transect variability in estimates of shad abundance made with hydroacoustics. N. Am. J. Fish. Manage. 15:933-939.

Wanjala, B. S., J. C. Tash, W. J. Matter and C. D. Ziebell. 1986. Food and habitat use by different sizes of largemouth bass (*Micropterus salmoides*) in Alamo Lake, Arizona. J. Freshw. Ecol. 3:359-369.

Warden, R. L. and W. J. Lorio. 1975. Movements of largemouth bass (*Micropterus salmoides*) in impounded waters as determined by underwater telemetry. Trans. Am. Fish. Soc. 104:696-702.

Weaver, M. J., J. J. Manguson and M. K. Clayton. 1996. Habitat heterogeneity and fish community structure: Inferences from north temperate lakes. Multidimensional approaches to reservoir fisheries management. Am. Fish. Soc. Symp. 16:335-346.

Wilde, G. E., R. K. Riechers and J. Johnson. 1992. Angler attitudes toward control of freshwater vegetation. J. Aquat. Plant Manage. 30:77-79.

Wiley, M. J., R. W. Gordon, S. W. Waite and T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: A simple model. N. Am. J. Fish. Manage. 4:111-119.

Winter, J. D. 1996. Advances in underwater biotelemetry, p. 555-590. *In:* B. R. Murphy and D. W. Willis (eds.). Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Woodward, K. O. and R. L. Noble. 1997. Over-winter movements of adult largemouth bass in a North Carolina reservoir. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 51:113-122.

Wrenn, W. B., D. R. Lowery, M. J. Maceina and W. C. Reeves. 1996. Largemouth bass and aquatic plant abundance in Guntersville Reservoir, Alabama. Multidimensional approaches to reservoir fisheries management. Am. Fish. Soc. Symp. 16:382-392.