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The Use of Herbicides to Control Hydrilla and the Effects on Young Largemouth Bass Population Characteristics and Aquatic Vegetation in Lake Seminole, Georgia

MICHAEL J. MACEINA[1,2] AND JEFFERY W. SLIPKE[1]

ABSTRACT

From 1997 to 2003, we examined the impacts of two aquatic herbicides, fluridone (Sonar; 1-methyl-3-phenyl-5-[3-(triflurometh) phenyl]-4(1H)-pyridinone), and dipotassium salt of endothall (Aquathol K; 7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid), used to control dense hydrilla (*Hydrilla verticillata* L. f. Royle), on population characteristics of juvenile largemouth bass (*Micropterus salmoides* Lacepede) in small coves (<10 ha) in Lake Seminole, Georgia. In addition, we estimated areal coverage and species composition of submersed aquatic vegetation (SAV) communities in each cove. Fish and plants were sampled in both control (hydrilla infested) and herbicide treated coves in November and March-April each year. Electrofishing catch-per-effort for both number and weight of age-0 and age-1 fish for the 1997 to 2002 year classes was either the same or higher ($p < 0.05$) in herbicide treated than in control coves. Age-0 fish were larger ($p < 0.05$) in treated, than in control coves in November, but at age-1 in the following spring, fish were slightly longer ($p < 0.05$) in the control coves. Higher age-0 catches were associated with greater percent reductions in numeric catch between age-0 and age-1 and reduced lengths of fish in November indicating density-dependent effects. Age-0 fish lengths were also negatively correlated to percent cover of both total and native SAV. Total or native SAV coverages were not associated with catch-per-unit effort for number and weight, but nearly all control and herbicide treated coves had total SAV coverage greater than 40%. Applications of both Sonar and Aquathol K reduced total SAV coverage and hydrilla, permitted the establishment of native SAVs, and had either neutral or positive impacts on young largemouth bass in small coves in Lake Seminole.

Key words: submersed aquatic vegetation, largemouth bass, catch-per-effort, Sonar, Aquathol K, native submersed vegetation.

INTRODUCTION

Typically, young largemouth bass inhabit submersed aquatic vegetation (SAV) when present in water bodies (Dibble et al. 1996). Aquatic plants provide both protective cover for young fish from predators and food resources that can enhance largemouth bass recruitment to catchable size sought by anglers, although specific responses have been variable (Durocher et al. 1984, Moxely and Lankford 1985, Bettoli et al. 1992, Wrenn et al. 1996, Maceina 1996). Exotic plants including hydrilla and Eurasian watermilfoil (*Myriophyllum spicatum* L.) provide habitat utilized by young largemouth bass, but excessive levels can hinder recreational, aesthetic, and industrial uses of water bodies. Most biologists agree that some intermediate level of SAV is desirable for warm water fisheries, particularly for largemouth bass (Engel 1995, Henderson 1996, Hoyer and Canfield 2001).

Previous investigators have examined the relation between abundance of age-0 or age-1 largemouth bass and SAV for either whole water-body responses (Bettoli et al. 1992, Hoyer and Canfield 1996, Tate et al. 2003) or in site-specific habitats within a water body (Wrenn et al. 1996, Miranda and Pugh 1997). Valley and Bremigan (2002) examined the effects of variable Eurasian watermilfoil abundance manipulated with aquatic herbicides on feeding behavior and growth of largemouth bass. However, to our knowledge, the response of young largemouth bass population metrics to applications of aquatic herbicides in smaller coves and embayments of larger water bodies has not been examined.

Since the 1990s, lake managers have attempted to replace exotic submersed macrophytes such as hydrilla and Eurasian watermilfoil with native aquatic plants primarily by reducing the abundance of exotic plants with aquatic herbicides. Native plants are then planted or become reestablished via seed banks from previous colonizations (Smart et al. 1996). The objectives of this project were to document changes in SAV communities following applications of fluridone (Sonar; 1-methyl-3-phenyl-5-[3-(triflurometh) phenyl]-4(1H)-pyridinone) and dipotassium salt of endothall (Aquathol K; 7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid) to control hydrilla. We also compared the relative abundances and length-frequency distributions of young largemouth bass between hydrilla infested coves and coves treated with both herbicides.

[1]Department of Fisheries, 203 Swingle Hall, Auburn University, AL 36849
[2]Corresponding author. Received for publication September 15, 2003 and in revised form December 22, 2003.

MATERIALS AND METHODS

Study Sites and Herbicide Applications

Lake Seminole (Georgia-Florida), is a 13,158 ha impoundment of the Chattahoochee and Flint Rivers managed by the U.S. Army Corps of Engineers (USACE). Annual water level fluctuations in this shallow reservoir (mean depth 3.0 m) are typically less than 0.7 m, and provide favorable environmental conditions for submersed aquatic macrophyte colonization. During the past 12 years, areal coverage of submersed macrophytes (primarily hydrilla) has varied from 40-70% (Brown and Maceina 2002) and aquatic vegetation control methods included the application of EPA approved aquatic herbicides.

Ten to 12 coves were sampled for young largemouth bass and SAV between fall 1997 and spring 1999 and 4 of these same coves were also sampled from fall 1999 to spring 2003 (Table 1, Figure 1). All coves were less than 10 ha and sampling coincided with assessment of six year-classes of largemouth bass produced from 1997 to 2002. Herbicide applications at these coves were part of the USACE hydrilla control program on Lake Seminole. For age-0 and age-1 fish sampled in November 1997 and March 1998, five coves had been treated with Sonar in 1996 or 1997 and five coves served as hydrilla infested control coves (Table 1). In November 1998 and March 1999, six areas served as herbicide treated coves, some of which were not retreated with Sonar in 1998 as hydrilla reduction persisted, and six areas were hydrilla control coves.

From November 1999 to April 2003, four coves (Figure 1) that were sampled from November 1997 to March 1999 were repeatedly sampled for young largemouth bass, SAV cover, and frequency of occurrence of SAV species to test the efficiency of Aquathol K to reduce hydrilla, promote the establishment of native SAVs, and attempt to maintain 20-40% coverage of SAV. For the 1999 to 2002 year classes of largemouth bass, Ranger Cove served as a herbicide treated cove for all four years. In Fairchild Cove, the 2000 to 2002 largemouth bass year classes were classified as treatment cohorts and in Kelly and Buenva Vista Coves, treatment periods encompassed the 2001 and 2002 year classes of age-0 and age-1 largemouth bass (Figure 1).

Aquatic Plants

For the 10-12 coves sampled from November 1997 to March 1999, SAV coverage was estimated each November and March using a recording fathometer (Maceina and Shireman 1980) and a global position system (GPS). At each waypoint taken with the GPS unit, a simultaneous fix mark was placed on the recording fathometer tracing to determine whether SAV was present or absent at each way point. Way points and their associated vegetation attributes were imported into ArcView (ESRI, Inc., Redlands, CA) to create vegetation cover polygons and estimate percent areal coverage. Predominance of different species of SAVs were estimated by visual inspection in these shallow coves.

After March 1999, submersed aquatic plants were sampled in the four coves twice a year from 1999 to 2003, each November and April using the same procedures employed in 1997-1999. Frequency of occurrence of plants was determined from 75 to 125 systematic locations with a plant rake and recorded with GPS. All plant species observed for each sample were recorded. Frequency of occurrence of native SAV which included Illinois pondweed (*Potamogeton illinoensis* Morong), muskgrass (*Chara* sp. L.), stonewort (*Nitella* sp. L.), coontail (*Ceratophyllum demersum* L.), and fanwort (*Cabomba caroliniana* Gray) were pooled when multiple species were present and multiplied by total SAV cover to estimate percent areal coverage of native SAV. In addition, Eurasian milfoil was visually observed in two control coves sampled in 1997-1999.

TABLE 1. SAMPLE COVES, TREATMENTS, SUBMERSED AQUATIC VEGETATION (SAV) COVER, AND PREDOMINANT SAV SPECIES IN ORDER OF DOMINANCE OBSERVED FROM 1997 TO 1999. FLURIDONE WAS APPLIED TO COVES TREATED WITH HERBICIDES AND MONTH AND YEAR OF APPLICATION WAS INDICATED (E.G., 10/1996 = OCTOBER 1996). NONE INDICATED THAT FLURIDONE OR OTHER AQUATIC HERBICIDES WERE NOT APPLIED THAT YEAR. PONDWEED IS ILLINOIS PONDWEED AND MILFOIL IS EURASIAN MILFOIL.

	1997-1998			1998-1999		
Cove	Treatment type	Total SAV (%)	Predominant SAV species	Treatment type	Total SAV (%)	Predominant SAV species
Buena Vista				Herbicide (6/1998)	28-36	hydrilla
Desser	Control	100	hydrilla	Control	95-100	hydrilla
Fairchild				Herbicide (6/1997)	72-80	hydrilla, pondweed, stonewort
Kelly	Herbicide (10/1996)	1-3	pondweed, hydrilla	Control	90-96	hydrilla, pondweed
Knight	Control	88-93	hydrilla, pondweed, milfoil	Control	84-85	hydrilla, pondweed, milfoil
Pear Orchid	Herbicide (10/1996)	0-32	muskgrass, pondweed	Herbicide (6/1997)	0	
Ranger	Herbicide (10/1996)	88-92	pondweed, hydrilla	Herbicide (none)	71-91	pondweed, hydrilla
Reynold	Herbicide (10/1996)	57-88	pondweed, hydrilla, stonewort	Herbicide (none)	64-67	pondweed, hydrilla, stonewort
Saunder	Control	32-100	hydrilla, pondweed	Control	85-86	hydrilla, pondweed
Three Fingers	Control	66-86	hydrilla, coontail, milfoil	Control	67-68	hydrilla, coontail, milfoil
Upper Lewis	Control	35-100	hydrilla, pondweed	Control	97-100	hydrilla, pondweed
Van Zant	Herbicide (6/1997)	73-85	stonewort, pondweed, hydrilla	Herbicide (none)	89-93	stonewort, pondweed, hydrilla

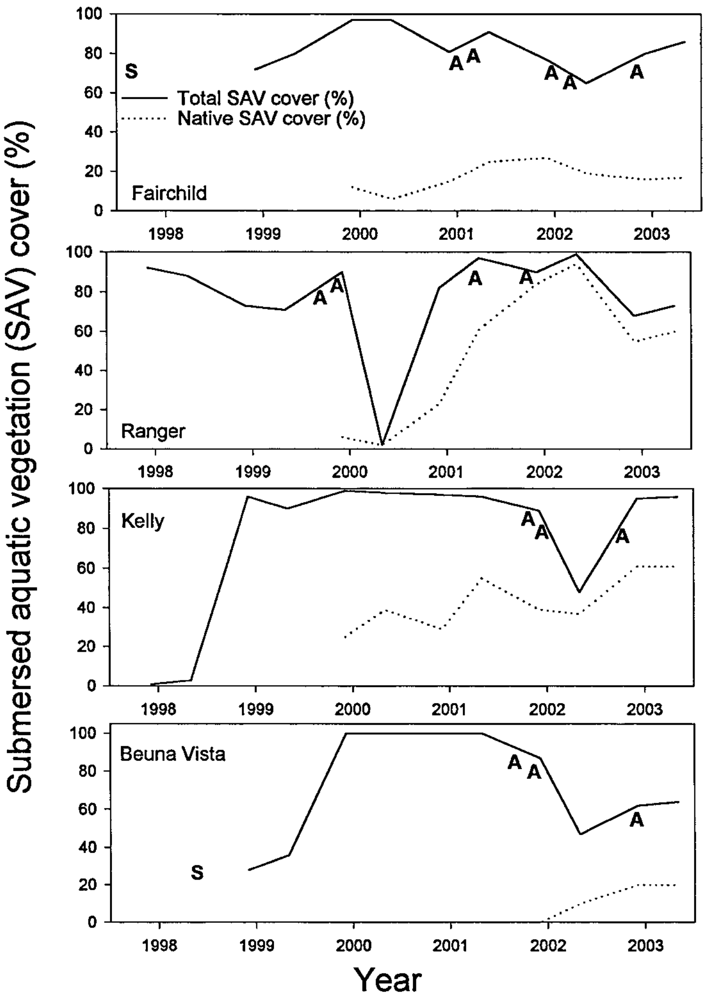

Figure 1. Submersed aquatic vegetation (SAV) cover for total and native SAV in four coves sampled from fall 1997-1998 to spring 2003. S and A indicates the time of Sonar and Aquathol K applications. Sonar was applied to Kelly and Ranger cove in October 1996.

Young Largemouth Bass

In November 1997 and 1998 and March 1998 and 1999, age-0 and age-1 largemouth bass were collected along transects in each cove using a DC electrofishing unit mounted to an air boat. Because Copeland and Noble (1994) found that most age-1 and younger largemouth bass maintained site fidelity in reservoir embayments, we assumed immigration and emigration from coves was minimal. Sampling was conducted during the day with three replications taken in each cove during each sampling period. Collection time was measured with active pedal time and ranged from 10 to 30 minutes per replicate. For larger individuals collected, otoliths were removed on site to separate age-0 and age-1 fish. From November 1999 to 2002 and from April 2000 to 2003, age-0 and age-1 largemouth bass from the 1999 to 2002 year-classes were collected from four coves that were previously sampled using the same procedures with three replicates of 10 to 15 minutes of electrofishing effort conducted in each cove.

Data Analysis

To test for differences in catch-per-effort for number and weight between control and treatment coves, we conducted two-way log-linear analysis of variance (Kimura 1988) which partitions the variation due to year class and treatment type. This analysis was conducted for two sets of data; the 10-12 coves sampled from November 1997 to March 1999 and the four coves sampled from November 1999 to March 2003. Length distributions between treatment and control coves were compared using the Kolmogorov-Smirnov two-sample test and t-tests for the 1997-1999 and 1999-2003 time periods.

For the entire six year classes collected in November (fall) and March-April (spring), correlation coefficients were computed for best fits between untransformed, or single and double $\log_{10}$ transformed variables that compared among mean catch-per-effort for each cove, average length of fish collected, total and native SAV coverage, and treatment effects (0 = control, 1 = herbicide). For each season, multiple regression equations were computed to predict mean lengths of fish from each cove from a number of independent variables. For fish collected in fall, covariate analysis was conducted to test for treatment effects (control or herbicide) on mean fish lengths for a given level of numerical catch. Finally, the percent difference in numerical catch-per-effort between age-0 fish in the fall and age-1 fish in the spring was computed to determine if over-winter survival was associated with initial age-0 abundance, mean length, and herbicide treatment effects. This variable was derived by subtracting the age-0 numerical catch-per-effort from age-1 catch-per-effort; dividing this difference by age-0 catch-per-effort, then multiplying by 100 to create a percentage.

RESULTS AND DISCUSSION

Aquatic Plants

For two coves treated with Sonar in 1996, total SAV coverage was less than 40% in 1997-1998, and native SAVs were the predominant plant (Table 1). In the other treatment coves sampled in 1997-98, total SAV coverage ranged from 57 to 92%, native SAVs predominated, but hydrilla was not eliminated from these coves. A massive rain event and rise in water levels in the Fish Pond Drain region of Lake Seminole resulted in a large decline in total SAV in March 1998 in two control coves (Desser and Saunder). In 1998, Sonar application in Buena Vista Cove resulted in hydrilla reduction, but native SAV did not become established (Table 1). In the other five herbicide treatment coves sampled in 1998-99, Sonar applications were not conducted as native SAV species were the dominant plants in these previously hydrilla infested coves (Table 1). In coves sampled from 1999 to 2003, native SAV generally increased over time in all four coves after applications of Aquathol K (Figure 1). In Fairchild Cove, Illinois pondweed and stonewort abundance was maintained or increased slightly between 2000 and 2003 (Figure 1). In Ranger Cove, fanwort nearly completely replaced hydrilla after 2000 and was the predominant SAV species in the cove in 2002-03 (Figure 1). In Kelly Cove, Illinois pondweed, stonewort, and coontail replaced hydrilla after 2001, but these changes were evident prior to treatment with Aquathol K (Figure 1). In Buena Vista Cove, Aquathol K applications in 2002 and early 2003 were associated with an increase in coontail, and a reduction in total SAV coverage, but hydrilla was still the dominant plant in this cove in 2003 (Figure 1).

As expected, a weak ($p < 0.05$), but negative correlation was computed between total SAV coverage and treatment effects for all data pooled between 1997 and 2003 (Table 2). In fall, treated coves contained higher native SAV coverages than non-treated coves (Table 2). However areal coverage of all species of SAV generally exceeded 40%. Prior to hydrilla colonization, Lake Seminole contained a diverse native plant community (Gholson 1984), seed banks of these species still exist in sediments, and these seeds germinated and grew after hydrilla was reduced or eliminated with Sonar. After 1999, native SAV either increased or was maintained in coves treated with Aquathol K where hydrilla was the predominant plant. Although total SAV coverage was reduced with Aquathol K, our target goal of 20-40% areal coverage of all SAVs was not achieved as a decision was made not to reduce native SAV with herbicides. Lake Seminole is extremely shallow, the maximum depth in most of the sample coves was less than 3 m, and with sufficient light, native SAVs colonized most of the bottom after hydrilla reduction.

Young Largemouth Bass

For age-0 largemouth bass collected in November 1997 and 1998, numerical catch-per-effort was similar ($p = 0.12$) between control and treatment coves, but catch-per-effort for weight was higher ($p < 0.05$) in the mixed plant communities treated with herbicides than in the densely infested hydrilla coves (Figure 2). For age-1 fish collected the following March in 1998 and 1999, catch for both number and weight were higher ($p < 0.05$) in the herbicide treated than in the hydrilla infested coves.

For the four coves, sampled from 1999 to 2003, numerical catch-per-effort of age-1 fish was higher ($p < 0.05$) in April in the coves treated with herbicides (Figure 3). In November when fish were age 0, catch-per-effort for number and weight were similar ($p > 0.4$) between treatment and control coves, and no differences in age-1 catch-per-effort for weight was detected ($p = 0.11$) between control and treatment coves for data collected in April.

For data pooled between 1997 and 2003, catch-per-effort for both number and weight of age-1 fish was weakly ($p < 0.05$), but positively associated with herbicide treatment (Table 2). Similarly, higher catch for weight in fall was weakly correlated to coves treated with herbicides (Table 2). Age-0 and age-1 catches for number or weight were not related ($p > 0.10$) to total or native SAV coverage for both control and treatment coves pooled or analyzed separately. Although young largemouth bass abundance tended to be higher in herbicide treated coves, no relation ($p > 0.10$) was evident between total and native SAV cover and catch-per-effort for both number and weight. Maceina (1996) found an asymptotic relation between age-0 density of largemouth bass and SAV coverage that reached a maximum at SAV volume infestation of 35% in Florida lakes greater than 54 ha. However, in our sample coves, total SAV coverage was nearly always greater than 40%. Thus, at SAV coverages greater than 40%, we detected no impact of SAV coverage on fish catch-per-effort except that in some instances, relative abundances were greater in herbicide treated coves.

In November 1997-1998, age-0 fish averaged 112 mm TL in treatment coves and were slightly longer ($p < 0.01$) than fish inhabiting dense hydrilla (average 107 mm TL). In addition, length distributions varied ($p < 0.05$) between vegetation types as 64% of the fish inhabiting dense hydrilla were less than 110 mm TL compared to 53% in the mixed plant communities that had been treated with Sonar. In March 1998-1999, however, age-1 fish were slightly longer ($p < 0.05$) in dense hydrilla (average = 136 mm TL) and skewed ($p < 0.05$) towards longer fish (42% ≥ 140 mm TL) compared to fish collected from treated coves (average = 129 mm TL, 25% ≥ 140 mm TL).

Similarly in November 1999-2002, age-0 fish collected from the treatment coves averaged 116 mm TL and were longer ($p < 0.01$) than fish inhabiting the control coves (average = 101 mm TL). Length-frequency distributions also dif-

Table 2. Correlation matrices among mean catch-per-effort indices, mean length of fish collected, and plant coverages in each cove for data collected from 1997 to 2003. For fall samples, N = 38, except for native SAV (submersed aquatic vegetation), where N = 21. For the treatment variable, 0 = control; 1 = herbicide. For spring samples, N = 37, except for native SAV (submersed aquatic vegetation), where N = 19. Correlations were significant at P < 0.05 (**) or P < 0.10 (*).

Variable	CPE-number	CPE-weight	Mean length	Total SAV (%)	Native SAV (%)
			Fall		
CPE-weight	0.89**	—	—	—	—
Mean length	-0.43**	0.02	—	—	—
Total SAV (%)	-0.06	-0.19	-0.38**	—	—
Native SAV (%)	0.18	-0.01	-0.42**	0.37	—
Treatment (0,1)	0.15	0.32**	0.26	-0.47**	0.38*
			Spring		
CPE-weight	0.84**	—	—	—	—
Mean length	-0.47**	0.17	—	—	—
Total SAV (%)	0.09	-0.07	-0.15	—	—
Native SAV (%)	0.14	-0.17	-0.29	0.52**	—
Treatment (0,1)	0.41**	0.41**	-0.14	-0.36**	0.33

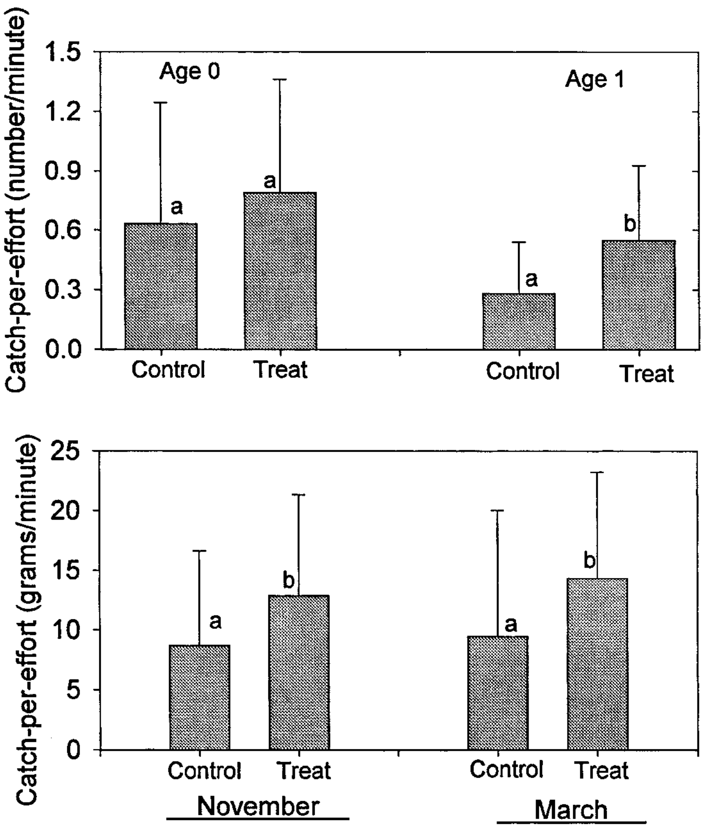

Figure 2. Mean age-0 and age-1 catch-per-effort for largemouth bass collected from 10 to 12 coves, November 1997 to March 1999. Error bars represent standard deviations of the mean and mean catch-per-effort values annotated by the same letter were not significantly ($p > 0.05$) different.

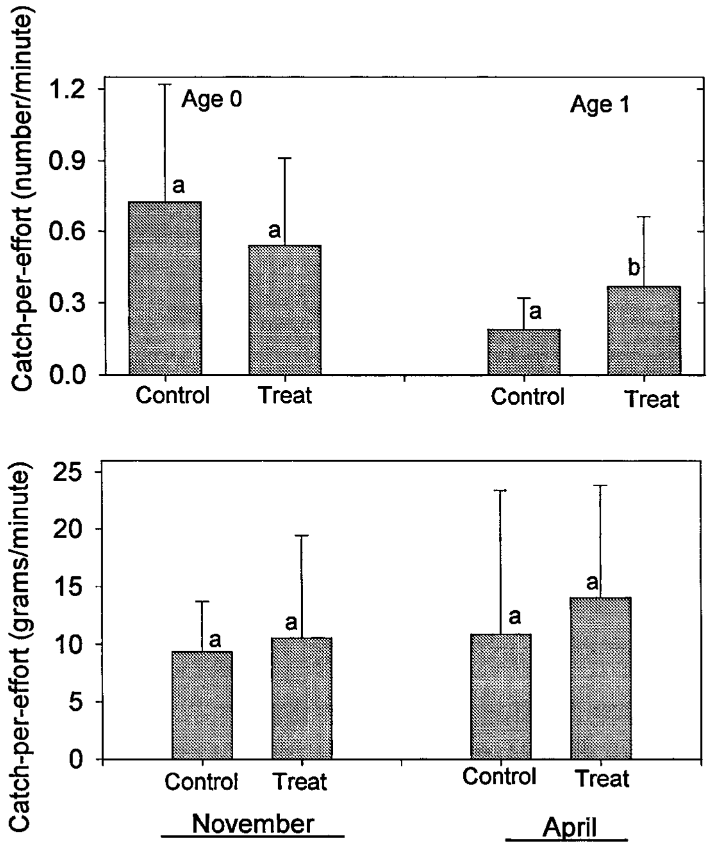

Figure 3. Mean age-0 and age-1 catch-per-effort for largemouth bass collected from 4 coves, November 1999 to April 2003. Error bars represent standard deviations of the mean and mean catch-per-effort values annotated by the same letter were not significantly ($p > 0.05$) different.

fered ($p < 0.01$), with 53% of the fish greater than 110 mm TL in the treatment coves compared to 25% in the control coves. Similar to data collected in 1998-1999, fish were longer ($p < 0.01$) in the control coves in April at age-1 and averaged 159 mm TL compared to 142 mm TL in the treatment coves. In the control and treatment coves, 57 and 45% of the fish were longer than 140 mm TL, respectively.

Assuming spawning times were similar between treatment and control coves, fish growth rates were slightly faster by November in herbicide treated coves. However, by the following spring, age-1 fish were slightly longer in the control than the treatment coves. Possibly, lower largemouth bass density in conjunction with the natural reduction in hydrilla abundance during winter in control coves allowed young largemouth bass to feed more effectively, grow faster, and attain slightly larger sizes than in treated coves.

For data pooled between 1997 and 2003, mean length was weakly but inversely related ($p < 0.05$) to numerical catch-per-effort in fall and spring when fish were age 0 and age 1, respectively (Table 2). This suggested modest density-dependent growth depression occurred. In fall for age-0 largemouth, both numerical catch-per-effort (NUM-CPE) and total SAV coverage (SAV-COVER) were negative regressors of mean fish length and the equation was computed:

$$\log_{10}(\mathrm{MTL}) = 2.095 - 0.0645(\log_{10}\mathrm{NUM\text{-}CPE}) - 0.000788(\mathrm{SAV\text{-}COVER})$$

Both independent variables were highly significant ($p < 0.01$) terms and the equation explained 35% of the variation in mean lengths. Thus, lower lengths of age-0 fish were associated with higher catch rates and SAV coverages. Based on semi-partial squared correlation coefficients (pr^2), catch-per-effort ($pr^2 = 0.23$) was a slightly more influential variable in the model than total SAV coverage ($pr^2 = 0.20$). In addition, covariate analysis indicated that for a given numerical catch rate, mean lengths were higher ($p < 0.05$) for age-0 fish collected in herbicide treated than control coves (Figure 4). Thus, these analyses indicated that age-0 fish collected in the fall were larger in herbicide treated coves where native SAVs were more abundant and total SAV coverage was lower. Contrary to our observations, age-0 length, growth, seine catches, and plant abundances in Michigan lakes were not interrelated or were not associated in untreated or herbicide treated lakes to reduce Eurasian watermilfoil (Valley and Bremigan 2002).

Similar statistical procedures were applied to data collected in spring for age-1 fish, and only numerical catch-per-effort was negatively related to mean lengths. The response of mean lengths to numerical catch was similar between treatment and control coves and total and native SAV coverage did not influence lengths at age 1.

As numeric age-0 catch-per-effort increased, the percent difference in numeric abundance between age-0 and age-1 decreased ($r = -0.61$, $p < 0.01$) in both control and herbicide

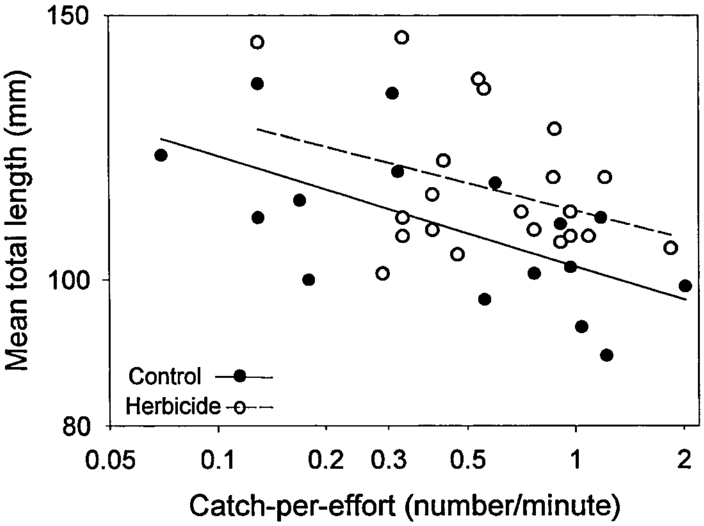

Figure 4. For all age-0 fish collected from 1997 to 2002 in November, the relation between catch-per-effort and mean total length in herbicide treated and control coves. In control coves, the regression equation was mean total length = 102.6 -18.6*$\log_{10}$(catch-per-effort) and in treated coves, the regression equation was mean total length = 111.4 -17.2*$\log_{10}$(catch-per-effort).

treated coves (Figure 5). Thus, density-dependent mechanisms, in part, likely influenced the percent decline or survival of young largemouth bass between fall and spring. At age-0, catch-per-effort greater than 1 fish/minute was associated with the greatest percentage decline in year-class abundance over time. The elevation of the regression line between percent difference in age-0 and age-1 catch and age-0 catch appeared higher in the herbicide compared to the control coves and suggested potentially greater recruitment in treated coves for a given age-0 catch (Figure 5). However, the difference in elevation was statistically similar (p = 0.13) for these two regression equations. At times, age-1 catch rates were higher than age-0, an anomaly to our sampling, but these observation occurred at lower age-0 catches. Mean total length at age 0 was weakly, but positively correlated (r = 0.29, p = 0.07) to lower percentage declines between age-0 and age-1 catch and suggested slightly greater survival and recruitment to age 1 in coves with faster growing and longer age-0 fish. Miranda and Pugh (1997) found electrofishing catch for age-1 largemouth bass in March was highest at about 20% coverage of SAV and greatest survival between age 0 and age 1 occurred at 10-20% SAV cover.

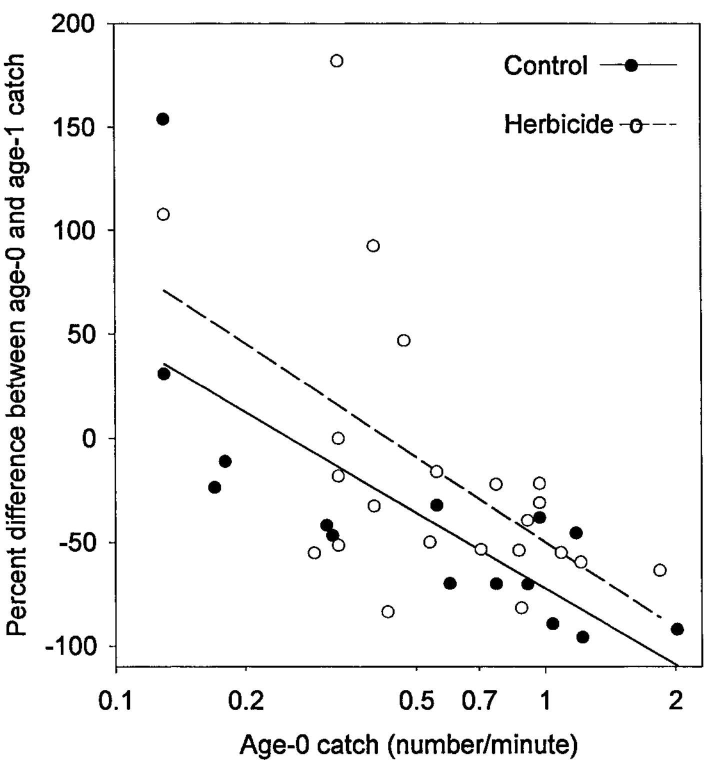

Figure 5. The percent difference between age-0 and age-1 catch-per-effort within a year class and age-0 catch-per-effort in control and herbicide treated coves. In the control coves, the regression equation was percent difference = -72.3 - 121.8*$\log_{10}$(catch-per-effort) and in treated coves, the regression equation was percent different = -50.1- 136.8*$\log_{10}$(catch-per-effort).

In conclusion, applications of both Sonar and Aquathol K to reduce hydrilla in small coves promoted the establishment of native SAV, and were associated with either neutral or positive impacts on young largemouth bass. However, in some instances, applications of these herbicides may completely eliminate hydrilla and reduce total SAV coverage to nil, but our study could not address the impact of complete removal of SAV on young largemouth bass populations characteristics in these small coves. Miranda and Pugh (1997) found in mixed exotic and native SAV communities that aerial coverage of 10-25% provided optimal conditions for abundance, over winter survival, and growth of young largemouth bass.

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