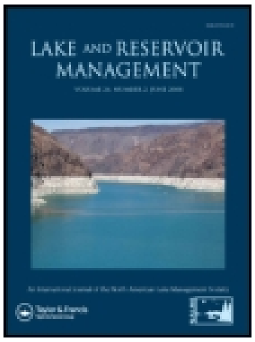

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The effects of residential docks on light availability and distribution of submerged aquatic vegetation in two Florida lakes

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Abstract

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This study was conducted to determine the effects of residential docks on the density and diversity of submerged aquatic vegetation (SAV) within two freshwater lakes in Orange County, Florida: Lake Butler and Lake Jessamine. From a lake manager's perspective, an improved understanding of the effects of docks should result in better planning and management to help ensure that additional docks do not harm the aquatic environment, while still providing reasonable access to the water. Major issues considered in this study included whether the amount of light penetrating beneath a dock affected the density and diversity of SAV growing beneath it, and whether other variables affected the density and diversity of SAV beneath docks, including lake trophic status. Ten docks and 10 reference sites were surveyed in each lake in June and July 2007. During each survey, we collected numbers and species of SAV, field water quality, surface and underwater light, dock measurements, and surrounding condition information. We documented a reduction in available light under docks with a corresponding decrease in plant density. Density of SAV was higher under docks oriented north/south compared to those oriented east/west. Overall, turbidity had the most influence on SAV diversity, while Secchi depth had the most influence on SAV diversity under docks. For this investigation overall, including beneath docks, SAV density was most affected by the percent of surface light above the SAV/bottom, while SAV diversity was most affected by the clarity of the water.

Key words: dock effects, dock impacts, SAV density, SAV diversity, submerged aquatic vegetation

Requests for permits to construct docks along the coasts and shores in marine, estuarine, and freshwater ecosystems have increased in recent years (Sanger and Holland 2002; Kelty and Bliven 2003; Alexander and Robinson 2004; 2006; Sanger *et al*. 2004a; Garrison *et al*. 2005). Population growth, a strong economy, increased discretionary spending, increased boat sales, and limited mooring and public docking facilities have all contributed to this trend; however, concerns about the cumulative impacts of dock proliferation along the coasts and shorelines have increased with each new request for a dock permit (NOAA 2001; Sanger and Holland 2002; Kelty and Bliven 2003; Alexander and Robinson 2004; 2006). As a result, regulatory agencies responsible for managing docks are increasingly being required to defend their dock permitting guidelines and policies. An improved understanding of the individual and cumulative effects of residential docks should result in better planning and management to help ensure that additional docks do not harm the aquatic environment, while still providing waterfront property owners reasonable access to the water (Kelty and Bliven 2003).

Docks intercept sunlight, alter patterns of water flow, introduce chemicals into the environment, and impact public access and navigation (Kelty and Bliven 2003). The vessels using docks also affect resources to varying degrees; however, scientific investigations and resulting literature quantifying the biological effects associated with the individual and cumulative impacts of docks in freshwater systems are

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limited (Kelty and Bliven 2003). The majority of studies that assess the impacts of docks on submerged or emergent vegetation have been conducted in estuarine ecosystems (Kearney *et al*. 1983; Molnar *et al*. 1989; Fresh *et al*. 1995; 2001; Loflin 1995; Burdick and Short 1999; Shafer 1999; Beal and Schmit 2000; MacFarlane *et al*. 2000; Sanger and Holland 2002; Steinmetz *et al*. 2004; Alexander and Robinson 2004; 2006; Sanger *et al*. 2004a; 2004b). Only one available study has evaluated the effects of docks on littoral zone habitat and communities in freshwater lakes (Garrison *et al*. 2005); the general lack of data in this area led us to initiate this study.

The effects of docks on submerged aquatic vegetation (SAV) must be better understood to enable lake managers, planners, and permitters to better protect this aspect of the lake community in the future. The SAV is an integral part of a healthy ecosystem. It provides shore protection from breaking waves; stabilizes soft sediments and reduces turbidity; provides refuge from fish predation; serves as critical shelter, spawning, and nursery habitat; provides food and substrate for algae, bacteria, invertebrates, fish, amphibians, reptiles, and birds; and produces dissolved oxygen required by aerobic organisms (Engel and Pederson 1998; Kelty and Bliven 2003; Garrison *et al*. 2005).

This study was conducted to determine the effects of residential docks on the density and diversity of SAV within two freshwater lakes in Orange County, Florida: Lake Butler and Lake Jessamine (Fig. 1 and Table 1). The major issues considered included whether the amount of light penetrating beneath a dock affected the density and diversity of SAV growing beneath it, and whether other variables, aside from light penetration, affected the density and diversity of SAV beneath docks, including lake trophic status.

Lake Butler, part of the Butler Chain of Lakes classified as Outstanding Florida Waters by the Florida Department of Environmental Protection (FDEP), is an oligotrophic/mesotrophic lake, while Lake Jessamine is a mesotrophic/eutrophic lake (Table 1). Oligotrophic lakes have low nutrient availability and, therefore, exhibit low productivity; these lakes support low densities of plants and wildlife. Mesotrophic lakes have moderate nutrient availability and, therefore, exhibit moderate levels of productivity, with corresponding moderate densities of plants and wildlife. Because of their high nutrient availability, eutrophic lakes exhibit high productivity and support an abundance of plants and wildlife. Trophic State Index values for Lake Butler have always been in the Good range (0–59, fully supports designated use), while values for Lake Jessamine have ranged from Good to Fair (60–69, partially supports designated use; Table 1).

Materials and methods

Ten docks and 10 reference sites were surveyed by boat in each lake from 25 June through 6 July 2007. Docks were selected based on the following criteria: (1) at least five years old, (2) permitted by the Orange County Environmental Protection Commission or were of a permitable size and configuration, and (3) distributed around the entire lake. Reference sites were typically selected near surveyed docks and were distributed around the entire lake. If there was no undisturbed shoreline near a surveyed dock, a reference site was selected in a location of undisturbed shoreline.

Field water quality measurements were collected at the lakeward end of the terminal dock platform at a water depth of 0.5 m. Water temperature, pH, dissolved oxygen concentration, and specific conductivity were determined using a YSI 6920 multi-parameter water quality sonde. The YSI 6920 was maintained and calibrated according to FDEP and YSI protocols and specifications. Turbidity was measured *in situ* with a Hach Turbidimeter Model 2100P using appropriate protocols. Similar field water quality information was collected at the lakeward end of each reference site. A Secchi disk reading was measured at the lakeward end of each dock or reference site. Sub-meter global positioning system (GPS) data (latitude/longitude) were collected at the lakeward edge of each dock and reference site using a Trimble Pro XR TDC1.

Table 1.-Characteristics of Lakes Butler and Jessamine, Orange County, Florida. Source: www.orange.wateratlas.usf.edu.

	Lake Butler	**Lake Jessamine**
Surface Area (Acres)	1,700	292
Latest Value (Historic Range) Trophic State Index	28:Good (8:Good-54:Good)	48:Good (27:Good-68:Fair)
Latest Value (Historic Range) Total Nitrogen (μg/l)	530 (103–5,440)	850 (187–1,810)
Latest Value (Historic Range) Total Phosphorus (μg/l)	12 (0–450)	18 (2–100)
Latest Value (Historic Range) Chlorophyll (μg/l)	1.8 (0–35.8)	12.3 (1.4–74)
Latest Value (Historic Range) Secchi Depth (m)	2.9 (0.2–7)	1.4 (0.3–4.3)
Latest Value (Historic Range) Turbidity (NTU)	1.4 (0.2–3.2)	4.4 (0.8–14)
Latest Value (Historic Range) Dissolved Oxygen (mg/l)	8.3 (4.7–10.9)	6.7 (6.1–9.5)

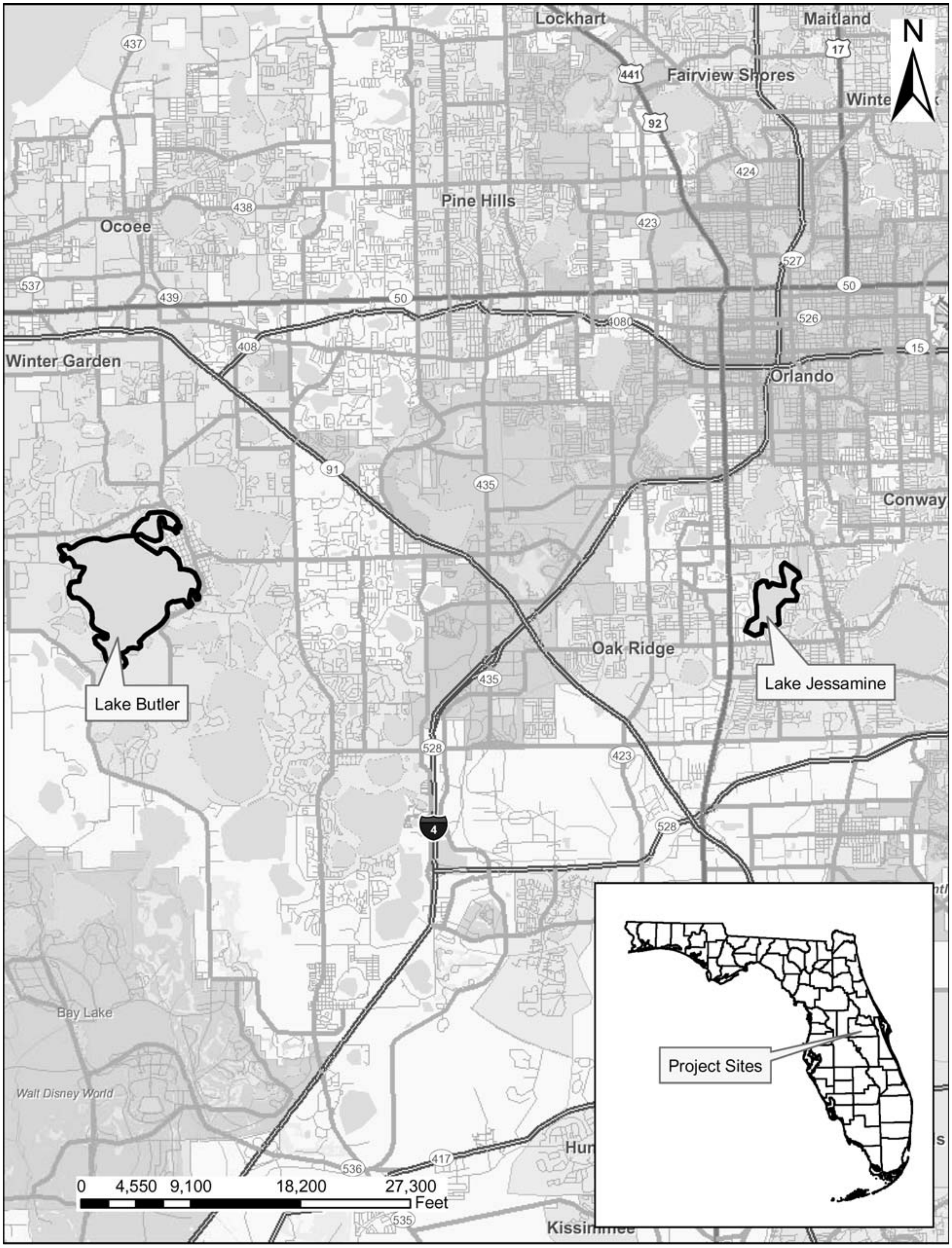

Figure 1.-Locations of Lakes Butler and Jessamine, Orange County, Florida.

Levels of photosynthetically active radiation (PAR; μmol/m^2/sec) were collected using an LI-192SA underwater quantum sensor attached to a lowering frame connected to an LI-1400 data logger (LI-Cor, Inc., Lincoln, Nebraska). The data logger was set to record the mean PAR level collected over a 30-sec period, and measurements were done sequentially under similar weather/cloud cover conditions. Levels of PAR were measured in three locations at each dock: (1) on the terminal platform dock surface, (2) just above the water surface under the center of the terminal platform, and (3) underwater under the center of the terminal platform just above the lake bottom or at the top of the SAV. At the center or lakeward end of each reference site, PAR levels were measured just above the water surface and underwater just above the lake bottom or at the top of the SAV. The lowering frame with the attached quantum sensor was held from the boat to determine PAR levels on each terminal dock platform surface. All PAR measurements were collected by a snorkeler just above the water surface and underwater. The boat and snorkeler were positioned such that they did not affect the PAR readings. In addition to the PAR values obtained, light data under the docks and underwater are presented as a percentage of surface light using a comparison to the almost simultaneous light measurements obtained at the dock or water surface.

Two line transects were set up by snorkelers under the terminal platform of each dock to survey the SAV. The transects ran from the landward to the lakeward end of the terminal platform and were equidistant from the dock edge and each other; their length depended on the length of the terminal platform. Each end of the measuring tapes was secured with wire staff flags. Information on the numbers and species of SAV present was collected using a 0.5 m × 1.0 m (0.5 m^2) PVC rectangular quadrat, with the 1.0 m side placed parallel to the transect and the transect measuring tape in the center of the quadrat. Enough quadrat samples were collected along each transect so that at least 50% of each transect was sampled. The number, percent coverage, and species of SAV found in each quadrat were recorded by snorkelers in Dive Rite underwater notebooks. The same procedure was used to survey the SAV at each reference site. The transect lengths and distances between transects for each reference site were similar to those used to survey the SAV under the terminal platforms of docks and represented the range of different transect lengths and distances.

For each dock, we measured height of terminal dock platform above water, length and width of terminal platform, and dock plank spacing and materials. Additional comments recorded for each dock included information regarding boathouses and scoured areas, the presence of jet skis and boats, cleared access corridors, the associated shoreline and other lakeshore activities, the types of emergent and floating vegetation present around the dock and the associated shoreline, and other pertinent information. For each reference site, the genus and species of emergent and floating vegetation present were recorded. Some of these additional data, as well as other information collected (e.g., addresses of properties where docks were located, GPS coordinates of docks and reference sites) are not presented in this manuscript but can be found in Campbell and Durbin (2007).

Data were analyzed using JMP® software (SAS Institute 2002). To determine the effects of lake and site type on dock data, reference site data, field water quality data, PAR data, and SAV survey data, data were first cast into a two-way multiple analysis of variance (MANOVA) using lake, site type, and their interaction as factors ($p = 0.05$). Significant effects and interactions were further explored with one-way and two-way analysis of variance (ANOVA) and Tukey multiple comparison procedures ($p = 0.05$). Multiple regression procedures yielding multivariate and Pearson product-moment correlations were used to determine significant correlations ($p = 0.05$) between SAV density and diversity and various light, water quality, and dock parameters. Diversity indices (Simpson's and Shannon-Wiener) were calculated for SAV data obtained from each surveyed dock and reference site using EcoMeth Software (Exeter Software 2003), a companion to Krebs (1999). Diversity measurements and confidence limits (95%) were calculated by bootstrapping (5,000 iterations).

Results

With the exception of a cove in the northwest corner of Lake Butler that was avoided deliberately because of previous clearing, filling, and restoration activities, docks and reference sites were surveyed in all areas of the lake (Fig. 2). Docks and reference sites were surveyed in all areas of Lake Jessamine with the exception of areas that were sprayed for the control of hydrilla (*Hydrilla verticillata*) immediately before the surveys, which included the southern coves and portions of the northeastern areas of the lake (Fig. 3). The majority of the docks and reference sites surveyed in both lakes were oriented east/west (Figs. 2 and 3; Tables 2 and 3).

The MANOVA of dock data indicated that lake was an effect ($F = 4.986$, $p = 0.0002$). Surveyed docks were of a similar age in both lakes and ranged in age from 5 to 17 years (Tables 2 and 4). The terminal platforms of docks surveyed in Lake Butler were larger than those surveyed in Lake Jessamine; however, the terminal platforms lengths and widths were similar between lakes (Table 4). Four docks surveyed in Lake Butler had no spacing between planks, while only one dock surveyed in Lake Jessamine had no plank spacing (Table 2); plank spacing of docks surveyed in both lakes

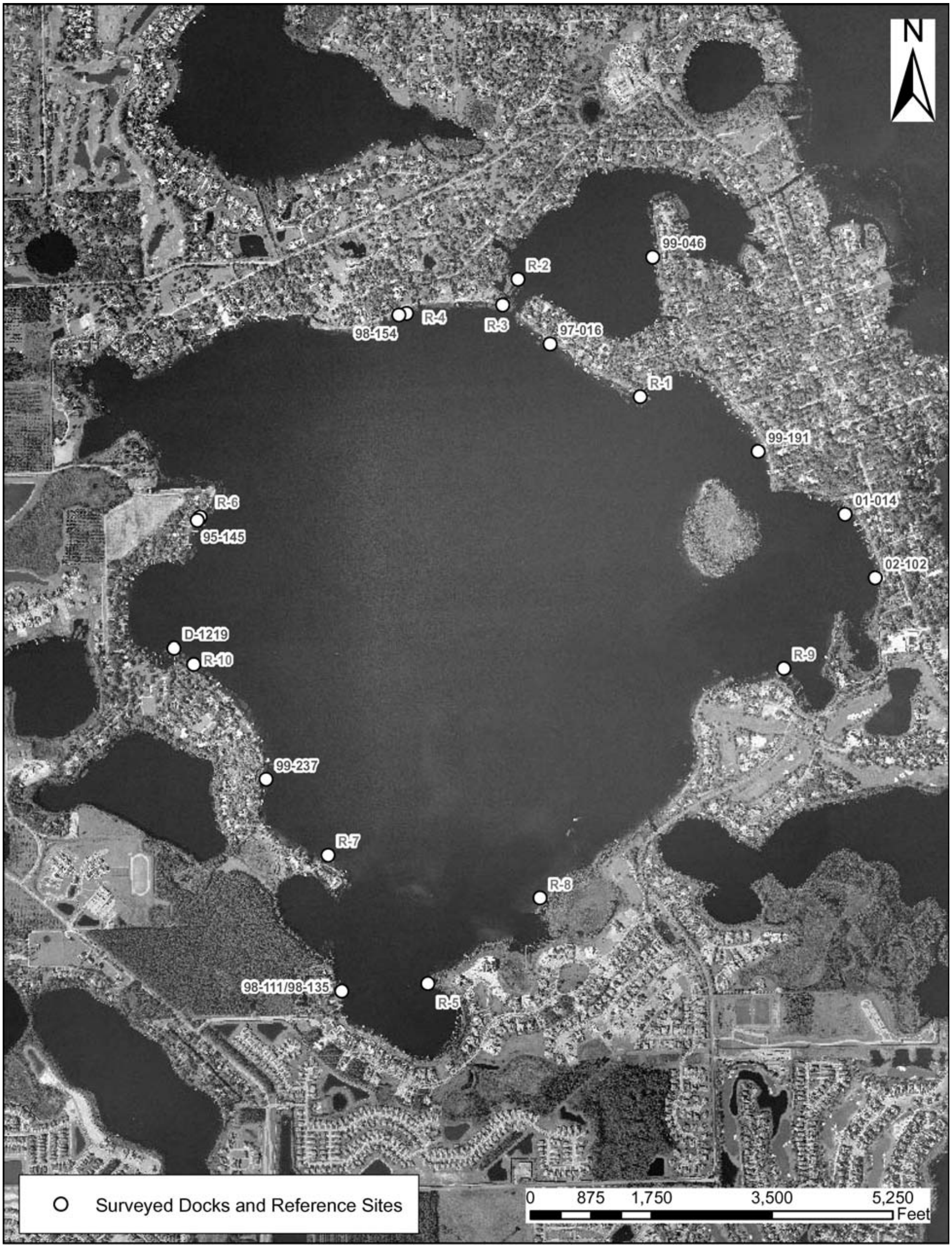

Figure 2.-Location of docks and reference sites surveyed in Lake Butler, Orange County, Florida, 25–27 June 2007.

Figure 3.-Location of docks and reference sites surveyed in Lake Jessamine, Orange County, Florida, 28 June–6 July 2007.

Table 2.-Information for each dock surveyed in Lakes Butler and Jessamine, Orange County, Florida, 25 June–6 July 2007.

Dock Permit Number(or Number Assigned if Not Known)	Age of Dock	Dock Orientation	Dock Terminal Platform Length (m)	Dock Terminal Platform Width (m)	Dock Terminal Platform Size (m^2)	Dock Plank Spacing (mm)	Height of Dock Terminal Platform Above Water (m)	Water Depth at Lakeward End (m)	Substrate Type
				Lake Butler					
99-191	8	East/West	9.24	3.70	34.19	0	1.18	1.05	Sand
97-016	10	North/South	6.00	4.90	29.40	0	1.11	0.95	Sand
99-046	9	East/West	7.15	4.39	31.39	0	1.27	1.38	Sand
98-154	9	North/South	7.40	4.20	31.08	0	1.30	1.10	Sand
02-102	5	East/West	3.90	4.30	16.77	6	1.24	1.08	Sand
98-111/98-135	9	East/West	2.90	4.10	11.89	8	1.15	1.00	Sand
01-014	6	East/West	7.40	4.10	30.34	2	1.20	1.75	Sand
D-1219	17	North/South	6.00	4.20	25.20	10	1.27	1.65	Sand
99-237	8	East/West	7.30	4.12	30.08	6	1.25	1.48	Sand
95-145	12	East/West	3.34	4.24	14.16	6	1.26	0.81	Sand
				Lake Jessamine					
99-093/00-015	8	East/West	4.10	4.10	16.81	6	0.85	1.20	Muck
91-015	16	East/West	7.33	4.60	33.72	8	0.57	0.65	Muck
00-117	7	North/South	3.75	4.80	18.00	6	0.67	0.72	Muck
97-132	10	East/West	6.00	3.00	18.00	5	0.81	1.22	Sand
96-004	11	North/South	2.90	4.25	12.33	4	0.86	1.72	Muck
D-5143	9	East/West	2.89	4.38	12.66	6	0.83	0.92	Muck
05-075	12	East/West	2.54	3.70	9.40	0	0.94	1.00	Muck/Sand
00-207	7	North/South	2.90	4.12	11.95	10	0.86	0.65	Sand
01-007	6	North/South	7.47	2.60	19.42	10	0.90	1.30	Sand
02-123	5	East/West	2.20	3.85	8.47	14	0.86	0.45	Sand

was similar (Table 4). With the exception of one dock in each lake that was constructed of plastic composite planks, the surface of all docks was constructed of pressure treated wood. The height of the terminal platform above water for docks surveyed in Lake Butler was higher than that of docks surveyed in Lake Jessamine (Table 4).

The water depth at the lakeward end of the terminal platforms of the docks surveyed in Lakes Butler and Jessamine was similar ($F = 2.356$, $p = 0.1422$; Table 2). The water depth at the lakeward end of reference sites in Lakes Butler and Jessamine was also similar ($F = 2.217$, $p = 0.1538$; Table 3). The substrate under all docks surveyed in Lake Butler was sand, while half of the docks surveyed in Lake Jessamine had muck underneath (Table 2). For reference sites in Lake Butler, the substrate type was sand with the exception of one site, and half of the reference sites in Lake Jessamine had muck substrate (Table 3).

All docks surveyed in this study had associated boathouses. Of the 20 docks surveyed, only three had empty boathouses. Scouring was observed under the boathouses in 40% of the docks surveyed in Lake Butler, while 70% of the docks surveys in Lake Jessamine had scouring under the boathouses. Jet skis were present at half of the docks surveyed in Lake Butler and at 30% of the docks surveyed in Lake Jessamine. Eighty percent of the docks surveyed in Lake Butler and 30% of the docks in Lake Jessamine had associated access corridors. All of the docks surveyed in Lake Butler had beaches or sandy areas associated with them, while only half of the docks surveyed in Lake Jessamine had associated beaches.

The MANOVA of field water quality data indicated that lake was an effect ($F = 14.974$, $p = 0.0001$), site type (dock or reference site) was not an effect ($F = 0.098$, $p = 0.6718$), and the lake-site type interaction was not an effect ($F = 0.052$, $p = 0.8909$). Water temperatures obtained during surveys in Lakes Butler and Jessamine were similar (Table 5). The pH values recorded during surveys in Lake Jessamine were higher than those obtained for Lake Butler, while the dissolved oxygen concentrations measured during surveys in both lakes were similar (Table 5). Specific conductivity values obtained during surveys in Lake Butler were higher than levels measured in Lake Jessamine (Table 5). Turbidity levels and Secchi disk readings measured in both lakes were different, with higher turbidities and lower clarities in Lake Jessamine as compared to Lake Butler (Table 5).

Table 3.-Information for each reference site surveyed in Lakes Butler and Jessamine, Orange County, Florida, 25 June–6 July 2007.

Reference Site Number	Reference Site Orientation	Water Depth at Lakeward End (m)	SubstrateType	Shoreline Type
		Lake Butler		
R-1	East/West	0.85	Sand	Vegetated
R-2	East/West	0.85	Muck	Vegetated
R-3	North/South	0.92	Sand	Vegetated
R-4	North/South	1.20	Sand	Vegetated
R-5	East/West	1.10	Sand	Vegetated
R-6	East/West	0.60	Sand	Vegetated
R-7	East/West	1.27	Sand	Sand/Vegetated
R-8	East/West	1.06	Sand	Sand/Vegetated
R-9	North/South	1.72	Sand	Sand/Vegetated
R-10	North/South	1.27	Sand	Sand/Vegetated
		Lake Jessamine		
R-1	East/West	1.05	Muck	Sand/Vegetated
R-2	East/West	0.65	Muck/Sand	Muck/Vegetated
R-3	North/South	0.56	Sand	Vegetated
R-4	East/West	1.20	Muck	Vegetated
R-5	East/West	1.00	Sand	Beach
R-6	North/South	0.77	Muck	Vegetated
R-7	East/West	1.01	Sand	Vegetated
R-8	East/West	0.70	Sand	Vegetated
R-9	East/West	1.12	Sand/Riprap	Vegetated
R-10	North/South	1.00	Muck	Vegetated

The percent of surface PAR below surveyed docks in Lake Butler was higher than values calculated for docks surveyed in Lake Jessamine ($F = 5.555$, $p = 0.0300$; Table 6). The ANOVA of PAR data indicated that lake was an effect ($F = 5.961$, $p = 0.0197$), site type was an effect ($F = 131.727$, $p = 0.0001$), and the lake-site type interaction was not an effect ($F = 1.095$, $p = 0.3024$). Therefore, the percent of surface PAR calculated for just above the SAV/bottom obtained for docks and reference sites was higher in Lake Butler as compared to Lake Jessamine (Fig. 4). In addition, the percent of surface PAR calculated for just above the SAV/bottom was higher at reference sites as compared to docks in both lakes (Fig. 4).

Six species of SAV were found in both lakes: coontail (*Ceratophyllum demersum*), tape grass (*Vallisneria americana*), hydrilla, Illinois pondweed (*Potamogeton illinoensis*), leafy bladderwort (*Utricularia foliosa*), and stonewort (*Nitella* spp.). Lemon bacopa (*Bacopa caroliniana*), muskgrass (*Chara* spp.), and southern naiad (*Naja guadalupensis*) were found only in Lake Butler, while spikerush (*Eleocharis* spp.) was observed only in Lake Jessamine. The SAV in Lake Butler was thin and small compared to the SAV that occurred in Lake Jessamine, which was often very large, very dense, and reaching the surface of the lake.

The MANOVA of SAV data indicated that lake was an effect ($F = 1.897$, $p = 0.0001$), site type was an effect ($F = 0.663$, $p = 0.0045$), and the lake-site type interaction was an effect ($F = 0.728$, $p = 0.0026$). The total number of SAV species found during surveys was similar for docks and reference sites; however, the total number of SAV species observed in Lake Butler was higher than that found in Lake Jessamine (Table 7). There was a difference between the SAV density (i.e., total number of stems of SAV/m^2)observed at Lake Butler docks, Lake Butler reference sites, Lake Jessamine docks, and Lake Jessamine reference sites (Fig. 5). In addition, the SAV density calculated for docks and reference sites was higher in Lake Butler compared to Lake Jessamine, and the SAV density was higher at reference sites compared to docks in both lakes (Fig. 5).

Simpson's and Shannon-Wiener Diversity Index values were higher in Lake Butler compared to values calculated for Lake Jessamine; however, there was no difference in Simpson's and Shannon-Wiener Diversity Index values calculated for docks and reference sites (Table 7). There was a difference in the Diversity Index values calculated for Lake Butler docks, Lake Butler reference sites, Lake Jessamine docks, and Lake Jessamine reference sites (Table 7).

Table 4.-Summary descriptive information regarding docks surveyed in Lakes Butler and Jessamine, Orange County, Florida, 25 June–6 July 2007. Values not having the same letter are significantly different ($p < 0.05$).

	Mean (Range) Dock Age (Years)	Sig.	Mean (Range) Dock Terminal Platform Length (m)	Sig.	Mean (Range) Dock Terminal Platform Width (m)	Sig.	Mean (Range) Dock Terminal Platform Size (m^2)	Sig.	Mean (Range) Plank Spacing (mm)	Sig.	Mean (Range) Height of Dock Terminal Platform Above Water (m)	Sig.
Lake Butler Docks (n = 10)	9.3 (5–17)	A	6.06 (2.90–9.24)	A	4.23 (3.70–4.90)	A	25.45 (11.89–34.19)	A	3.8 (0–10)	A	1.22 (1.11–1.30)	A
Lake Jessamine Docks (n = 10)	9.1 (5–16)	A	4.21 (2.20–7.47)	A	3.94 (2.60–4.80)	A	16.07 (8.47–33.72)	B	6.9 (0–14)	A	0.82 (0.57–0.94)	B

Table 5.-Summary field water quality data for surveyed docks and reference sites in Lakes Butler and Jessamine, Orange County, Florida, 25 June–6 July 2007. Values not having the same letter are significantly different ($p < 0.05$).

	Mean (Range) Water Temperature (C)	Sig.	Mean (Range) pH (SU)	Sig.	Mean (Range) Dissolved Oxygen Concentration (mg/l)	Sig.	Mean (Range) Specific Conductivity (mS/cm)	Sig.	Mean (Range) Turbidity (NTU)	Sig.	Mean (Range) Secchi Depth (m)	Sig.
Lake Butler Docks and Reference Sites (n = 20)	30.03 (29.15–31.07)	A	7.76 (7.49–8.13)	A	7.73 (7.21–8.57)	A	0.254 (0.252–0.256)	A	1.28 (0.87–2.42)	A	1.15 (0.60–1.75)	A
Lake Jessamine Docks and Reference Sites (n = 20)	29.65 (27.86–31.26)	A	8.52 (7.17–8.89)	B	7.33 (1.49–9.13)	A	0.234 (0.228–0.255)	B	4.85 (2.30–18.10)	B	0.75 (0.45–1.30)	B

Table 6.-Summary of photosynthetically active radiation (PAR) data for surveyed docks and reference sites in Lakes Butler and Jessamine, Orange County, Florida, 25 June–6 July 2007.

Dock/Reference Site Number	PAR at Dock/Reference Surface (μmol/m^2/sec)	PAR Below Dock Above Water Surface (μmol/m^2/sec)	Percent Surface PAR Below Dock	PAR Just Above Submerged Vegetation/Bottom (μmol/m^2/sec)	Percent Surface PAR Just Above Submerged Vegetation/Bottom
Lake Butler Docks					
99-191	1,380	32.4	2.35	40.35	2.92
97-016	498.1	16.8	3.37	16.7	3.35
99-046	1,084	18.82	1.74	5.2	0.48
98-154	2,105	40.4	1.92	51.6	2.45
02-102	521.2	41.73	8.01	49.5	9.50
98-111/98-135	514	41.7	8.11	46.1	8.97
01-014	1,894	21.4	1.13	12.7	0.67
D-1219	757.3	52.23	6.90	276.8	36.55
99-237	1,260	19.88	1.58	21.47	1.70
95-145	1,586	53.2	3.35	123.4	7.78
Lake Butler Reference Sites					
R-1	784.5	na	na	347.1	44.24
R-2	695.4	na	na	305.2	43.89
R-3	549.5	na	na	212.9	38.74
R-4	2,318	na	na	1,420	61.26
R-5	2,126	na	na	1,031	48.49
R-6	432.2	na	na	395.2	91.44
R-7	2,017	na	na	1,087	53.89
R-8	2,185	na	na	1,350	61.78
R-9	2,244	na	na	1,265	56.37
R-10	2,252	na	na	1,083	48.09
Lake Jessamine Docks					
99-093/00-015	835.6	15.2	1.82	29.8	3.57
91-015	1,499	2.3	0.15	1.5	0.10
00-117	1,999	12.3	0.62	22.1	1.11
97-132	1,741	8.9	0.51	10.03	0.58
96-004	1,173	13.3	1.13	19.03	1.62
D-5143	2,024	11.8	0.58	3.1	0.15
05-075	756.4	11.3	1.49	50.2	6.64
00-207	1,327	8.5	0.64	5.5	0.41
01-007	1,865	25.9	1.39	11.7	0.63
02-123	518	31.2	6.02	35.2	6.80
Lake Jessamine Reference Sites					
R-1	1,436	na	na	316	22.01
R-2	449	na	na	222.2	49.49
R-3	2,084	na	na	962.8	46.20
R-4	838	na	na	393	46.90
R-5	1,063	na	na	103.6	9.75
R-6	611.8	na	na	279.5	45.68
R-7	2,285	na	na	1261	55.19
R-8	839.9	na	na	334.4	39.81
R-9	1,230	na	na	511.6	41.59
R-10	1,531	na	na	913	59.63

Overall, for surveyed docks and reference sites in both lakes, the variable that was most correlated with SAV density was the percent surface light or PAR just above the SAV/bottom (Table 8). There were correlations between SAV density and pH and specific conductivity. The SAV diversity (Simpson's and Shannon-Wiener Diversity Indices) for surveyed docks and reference sites was most correlated with turbidity (Table 8). There was a correlation between both SAV

Table 7.-Summary data obtained during submerged aquatic vegetation (SAV) surveys for surveyed docks and reference sites in Lakes Butler and Jessamine, Orange County, Florida, 25 June–6 July 2007. Values not having the same letter are significantly different ($p < 0.05$).

Site Type	Mean (Range) Total No. of SAV Species	Sig.	Mean (Range) SAV Density (Total No. of Stems SAV/m^2)	Sig.	Mean (Range) SAV Diversity (Simpson's Diversity Index)	Sig.	Mean (Range) SAV Diversity (Shannon-Wiener Diversity Index)	Sig.
Lake Butler Docks (n = 10)	2.8 (1–5)	A	115.74 (4.5–457)	A	0.3208 (0–0.582)	A	0.7709 (0–1.446)	A
Lake Butler Reference Sites (n = 10)	3.6 (2–6)	A	400.67 (118–667.25)	B	0.5104 (0.088–0.681)	B	1.2554 (0.309–1.831)	B
Lake Jessamine Docks (n = 10)	2.3 (0–3)	A	34.98 (0–108.5)	C	0.3894 (0–0.627)	C	0.8575 (0–1.479)	C
Lake Jessamine Reference Sites (n = 10)	1.9 (1–3)	A	87.63 (17.5–347)	D	0.0916 (0–0.290)	D	0.2448 (0–0.664)	D
Lake Butler (n = 20)	3.2 (1–6)	A	258.21 (4.5–667.25)	A	0.4156 (0–0.681)	A	1.0132 (0–1.831)	A
Lake Jessamine (n = 20)	2.1 (0–3)	B	61.30 (0–347)	B	0.2405 (0–0.627)	B	0.5512 (0–1.479)	B
Docks (n = 20)	2.6 (0–5)	A	75.36 (0–457)	A	0.3551 (0–0.627)	A	0.8142 (0–1.479)	A
Reference Sites (n = 20)	2.8 (1–6)	A	244.15 (17.5–667.25)	B	0.3010 (0–0.681)	A	0.7501 (0–1.831)	A

diversity indices and Secchi depth, while Shannon-Wiener Diversity Index values were also correlated with specific conductivity.

For surveyed docks in both lakes, SAV density was correlated with the percent surface light or PAR just above the SAV/bottom (Table 9). The SAV density under docks in both lakes that were oriented north/south (mean = 156.97 stems SAV/m^2, range = 0–457 stems SAV/m^2) was higher than the density under docks that were oriented east/west (mean = 41.37 stems SAV/m^2, range = 4.5–213 stems SAV/m^2) ($F = 5.261$, $p = 0.0348$). There was a correlation between SAV diversity under docks (calculated by the Shannon-Wiener Diversity Index) and Secchi depth (Table 9).

Discussion

Similar to previous studies conducted in estuarine ecosystems in Alabama, Georgia, South Carolina, Virginia, Connecticut, and Massachusetts (Kearney *et al*. 1983; Burdick and Short 1999; Shafer 1999; Sanger and Holland 2002;

Table 8.-Correlations (Pearson Product-Moment Correlation Coefficients) between submerged aquatic vegetation (SAV) density and diversity calculated for surveyed docks and reference sites in Lakes Butler and Jessamine and various light and water quality parameters.

	SAV Density (No. Stems SAV/m^2)	p	SAV Diversity (Simpson's Diversity Index)	p	SAV Diversity (Shannon-Wiener Diversity Index)	P
Percent of Surface Light Above SAV/Bottom	0.6522	0.0000	0.1982	0.2202	0.1689	0.2976
pH (SU)	−0.5271	0.0005	−0.2570	0.1094	−0.2899	0.0696
Specific Conductivity (mS/cm)	0.4615	0.0027	0.3046	0.0560	0.3421	0.0307
Turbidity (NTU)	−0.1147	0.4810	−0.3814	0.0152	−0.3955	0.0115
Secchi Depth (m)	0.3072	0.0539	0.3205	0.0437	0.3931	0.0121

Table 9.-Correlations (Pearson Product-Moment Correlation Coefficients) between submerged aquatic vegetation (SAV) density and diversity calculated for surveyed docks in Lakes Butler and Jessamine and various dock, light, and water quality parameters.

	SAV Density (No. Stems SAV/m^2)	p	SAV Diversity (Simpson's Diversity Index)	p	SAV Diversity (Shannon-Wiener Diversity Index)	P
Orientation of Dock (N/S or E/W)	0.4277	0.0600	−0.3866	0.0923	−0.3868	0.0920
Height of Dock Above Water (m)	0.3328	0.1516	0.2774	0.2363	0.3504	0.1298
Percent of Surface Light Above SAV/Bottom	0.8214	0.0000	−0.1634	0.4913	−0.1375	0.5633
pH (SU)	−0.3015	0.1965	−0.3899	0.0893	−0.4407	0.0518
Specific Conductivity (mS/cm)	0.3404	0.1419	0.3448	0.1365	0.3970	0.0831
Turbidity (NTU)	−0.3051	0.1909	−0.3736	0.1047	−0.3995	0.0810
Secchi Depth (m)	0.2727	0.2448	0.4322	0.0570	0.4980	0.0255

Alexander and Robinson 2004; 2006; Sanger *et al*. 2004a; 2004b) and the one available lake study conducted in Wisconsin (Garrison *et al*. 2005), the results of this study documented a reduction in available light under docks with a corresponding decrease in SAV density. For this investigation overall, including beneath docks, SAV density was most affected by the percent of surface light above the SAV/bottom. However, the correlation between SAV density and the percent of surface light measured just above the SAV/bottom was much stronger for the data collected under docks as compared to all of the surveyed sites.

We found that shading increased the closer the dock terminal platform was to the water surface; therefore, the height of the dock terminal platform above water was a major factor influencing the percent of surface light reaching the SAV/bottom. Because of the higher dock terminal platforms in Lake Butler as compared to Lake Jessamine, the percent

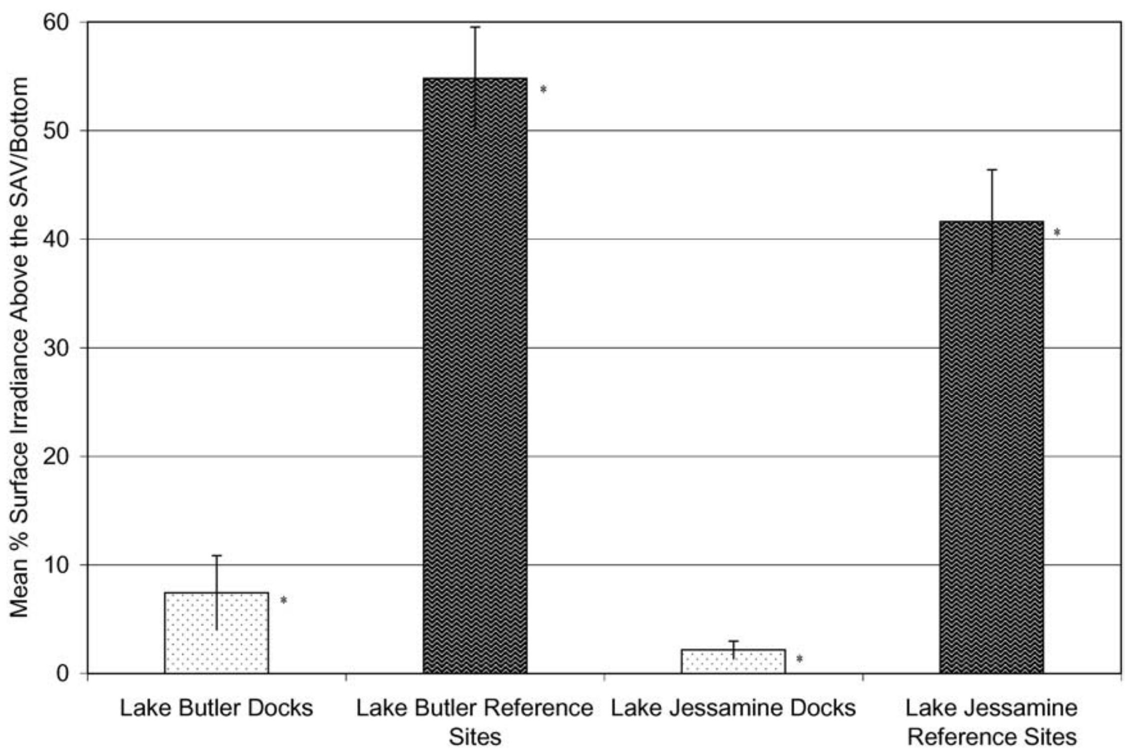

Figure 4.-Mean percent of surface light measured just above the submerged aquatic vegetation (SAV)/bottom for surveyed docks and reference sites in Lakes Butler and Jessamine, Orange County, Florida. Error bars represent the standard error, and an asterisk indicates significant differences ($p < 0.05$).

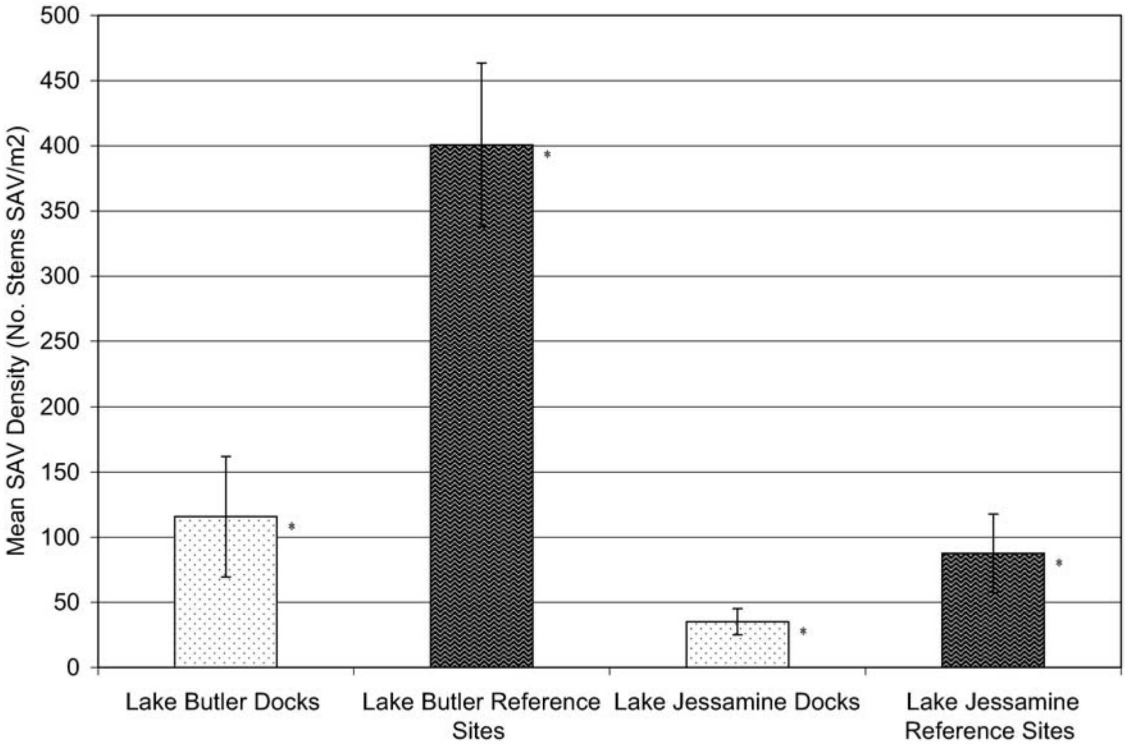

Figure 5.-Mean submerged aquatic vegetation (SAV) density for surveyed docks and reference sites in Lakes Butler and Jessamine, Orange County, Florida. Error bars represent the standard error, and an asterisk indicates significant differences ($p < 0.05$).

of surface PAR below surveyed docks, as well as the corresponding SAV density, was higher in Lake Butler compared to Lake Jessamine. Garrison *et al*. (2005) found shading under piers with a corresponding reduction in aquatic plant abundance in a study conducted in two lakes in southeastern Wisconsin. In a study conducted in Connecticut, Kearney *et al*. (1983) found that dock height was the major physical parameter influencing saltmarsh cordgrass (*Spartina alterniflora*) beneath docks. Burdick and Short (1999) found that eelgrass (*Zostera marina*) populations in two estuaries in Massachusetts were impacted under and directly adjacent to docks, as shown by depressed shoot density and canopy structure; they identified dock height as the most important factor affecting light intensities and plant densities.

Similar to results from Burdick and Short (1999), we found that SAV density was higher under docks oriented north/south compared to those oriented east/west in Lakes Butler and Jessamine. In a study conducted in Perdido Bay, Alabama, Shafer (1999) attributed the continued survival of seagrasses under docks to their north/south orientation.

Density of SAV was most affected by the clarity of the water, which is related to lake trophic status. Overall, turbidity had the most influence on SAV diversity, while Secchi depth had the most influence on SAV diversity under docks. Turbidity and Secchi depth are both related to the clarity of the water and are affected by lake water quality; these parameters served as indicators of water quality associated with a surveyed dock or reference site since water quality samples were not collected as part of this investigation. Higher SAV diversity was observed in oligotrophic/mesotrophic Lake Butler because of its superior water quality, lower productivity, and corresponding lower nutrient levels as compared to mesotrophic/eutrophic Lake Jessamine (Table 1). Compared to Lake Butler, the water in Lake Jessamine is less clear because of the phytoplankton and other suspended particles present in the water column resulting from the lake's higher biological productivity. Because of the high clarity of the water in Lake Butler, the percent of surface light measured just above the SAV/bottom was also higher compared to values obtained for Lake Jessamine.

Because of the moderate to high nutrient availability in Lake Jessamine, large and robust SAV was observed in the lake as compared to Lake Butler, which has low to moderate nutrient availability. In addition, many areas of Lake Jessamine contained undesirable levels of SAV because of the mesotrophic/eutrophic conditions of this lake.

While a comparison of SAV species growing under docks and in the open water was beyond the scope of this study, tape grass was more commonly observed growing under docks in Lake Jessamine, as compared to Illinois pondweed, the most dominant native SAV species observed in the lake. In two lakes in Southeast Wisconsin, Garrison *et al*. (2005) found that tape grass was more common under docks as compared to control areas. Tape grass is particularly well adapted to growing in low light conditions (Titus and Stephens 1979).

The higher pH measured in Lake Jessamine compared to Lake Butler could have been due to higher photosynthesis associated with the more productive plant community. Specific conductivity values for Lake Butler were higher than those measured in Lake Jessamine, most likely because the Butler Chain of Lakes is a spring-fed system and receives more groundwater input than Lake Jessamine. The correlations between SAV density and pH and specific conductivity, as well as between Shannon-Wiener Diversity and specific conductivity, were most likely due to the differences in pH and specific conductivity between these two lakes.

Many studies have shown that boat activity associated with docks adversely affects the plant community (Loflin 1995; Burdick and Short 1999; Sanger and Holland 2002). While quantitative data on boating activity were not collected as part of this investigation, the qualitative data, as well as observations during the surveys, indicated that SAV was not only affected by shading from docks, but also from boat traffic around the docks. Of the docks surveyed in this study, 85% had full boathouses, and fishing boats, ski boats, and jet skis were frequently observed in and around the boathouses in both lakes. The scouring observed under the boathouses, as well as the shading caused by the boathouse roofs, typically resulted in no SAV under the boathouses. More scouring was most likely observed in Lake Jessamine as compared to Lake Butler because of the softer, muckier sediments. More access corridors were observed around the docks in Lake Butler as compared to Lake Jessamine, and aquatic plants were usually not present in these access corridors. However, the areas around many of the docks in Lake Jessamine were so choked with submerged and floating-leaved vegetation that access into and out of the dock and maintaining an access corridor could be extremely difficult. Because of the more desirable conditions (e.g., clearer water, less vegetation) found in Lake Butler as compared to Lake Jessamine, all Lake Butler docks surveyed in this investigation had associated beaches or sandy areas used to access the lake for swimming.

In summary, overall, as well as beneath docks, SAV density was most affected by the percent of surface light above the SAV/bottom. The height of the dock terminal platform above water was a major factor influencing the percent of surface light reaching the SAV/bottom. In both lakes, SAV density was higher under docks oriented north/south compared to those oriented east/west. Diversity of SAV was most affected by the clarity of the water, which is related to lake trophic status. Secchi depth had the most influence on SAV diversity under docks, and turbidity had the most influence on SAV diversity overall. Oligotrophic/mesotrophic Lake Butler had higher clarity and lower turbidity than mesotrophic/eutrophic Lake Jessamine, which resulted in higher SAV diversity in Lake Butler as compared to Lake Jessamine.

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References

Alexander, C.R. and M.H. Robinson. 2004. GIS and field-based analysis of the impacts of recreational docks on the saltmarshes of Georgia. Applied Coastal Research Laboratory, Georgia Southern University, Savannah.

Alexander, C.R. and M.H. Robinson. 2006. Quantifying the ecological significance of marsh shading: the impact of private recreational docks in Coastal Georgia. Coastal Resources Division, Georgia Department of Natural Resources, Brunswick.

Beal, J.L. and B.S. Schmit. 2000. The effects of dock height on light irradiance (PAR) and seagrass (*Halodule wrightii* and *Syringodium filiforme*) cover. P. 49-53. *In* S.A. Bortone (ed.). Seagrasses, Monitoring, Ecology, Physiology, and Management. CRC Press, Boca Raton, FL.

Burdick, D.M. and F.T. Short. 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. Environ. Manage. 23:231–240.

Campbell, K.R. and D.J. Durbin. 2007. Effects of docks on submerged aquatic vegetation in Lakes Butler and Jessamine, Orange County, Florida. Prepared for the Orange County Environmental Protection Division by Biological Research Associates, Riverview, FL.

Engel, S. and J.L. Pederson, Jr. 1998. The construction, aesthetics, and effects of lakeshore development: a literature review. Wisconsin Department of Natural Resources, Report 177, Madison.

Exeter Software. 2003. EcoMeth, Version 6.1.1. Distributed by Exeter Software, East Setauket, NY.

Fresh, K.L., B. Williams and D. Penttila. 1995. Overwater structures and impacts on eelgrass (*Zostera marina*) in Puget

Sound, Washington. Puget Sound Research ’95, Puget Sound Water Quality Authority, Olympia, WA.

Fresh, K.L., B.W. Williams, S. Wyllie-Echeverria and T. Wyllie-Echeverria. 2001. Mitigating impacts of overwater floats on eelgrass *Zostera marina L.* in Puget Sound, Washington. Puget Sound Research 2001, Puget Sound Water Quality Authority, Olympia, WA.

Garrison, P.J., D.W. Marshall, L. Stremlick-Thompson, P.L. Cicero and P.D. Dearlove. 2005. Effects of pier shading on littoral zone habitat and communities in Lakes Ripley and Rock, Jefferson County, Wisconsin. Wisconsin Department of Natural Resources, Jefferson County Land and Water Conservation Department, and Lake Ripley Management District, PUB-SS-1006 2005.

Kearney, V.F., Y. Segal and M.W. Lefor. 1983. The effects of docks on salt marsh vegetation. Connecticut State Department of Environmental Protection, Water Resources Unit, Hartford.

Kelty, R. and S. Bliven. 2003. Environmental and aesthetic impacts of small docks and piers. Workshop report: developing a science-based decision support tool for small dock management, Phase 1: Status of the science. NOAA Coastal Ocean Program Decision Analysis Series Number 22. National Centers for Coastal Ocean Science, Silver Spring, MD.

Krebs, C.J. 1999. Ecological methodology, second edition. Addison-Wesley Educational Publishers, Inc., New York, NY.

Loflin, R.K. 1995. The effects of docks on seagrass beds in the Charlotte Harbor Estuary. Fla. Scientist 58:198-205.

MacFarlane, S.L., J. Early, T. Henson, T. Balog and A. McClennen. 2000. A resource-based methodology to assess dock and pier impacts on Pleasant Bay, Massachusetts. J. Shellfish Res. 19:455-464.

Molnar, G., S. Markley and K. Mayo. 1989. Avoiding and minimizing damage to Biscayne Bay seagrass communities from the construction of single family residential docks. Dade County Department of Environmental Resources Management, Biological Resources Section, Freshwater Wetlands Program, Miami, FL.

NOAA. 2001. Private docks: fighting for the public’s rights in New York. National Oceanic and Atmospheric Administration. Coastal Services Linking People, Information, and Technology 4(6):4-6.

Sanger, D.M. and A.F. Holland. 2002. Evaluation of the impacts of dock structures on South Carolina estuarine environments. Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston.

Sanger, D.M., A.F. Holland and C. Gainey. 2004a. Cumulative impacts of dock shading on *Spartina alterniflora* in South Carolina estuaries. Environ. Manage. 33:741-748.

Sanger, D.M., A.F. Holland and D.L. Hernandez. 2004b. Evaluation of the impacts of dock structures and land use on tidal creek ecosystems in South Carolina estuarine environments. Environ. Manage. 33:385-400.

SAS Institute. 2002. JMP®, Version 5.0, Statistical Discovery Software, Cary, NC.

Shafer, D.J. 1999. The effects of dock shading on the seagrass *Halodule wrightii* in Perdido Bay, Alabama. Estuaries 22:936-943.

Steinmetz, A.M., M.M. Jeansonne, E.S. Gordon and J.W. Burns, Jr. 2004. An evaluation of glass prisms in boat docks to reduce shading of submerged aquatic vegetation in the Lower St. Johns River, Florida. Estuaries 27:938-944.

Titus, J.E. and M.D. Stephens. 1979. Coexistence and the comparative light relations of the submersed macrophytes *Myriophyllum spicatum* L. and *Vallisneria americana*. Oecologia (Berl.) 40:273-286.