Using Remote Sensing and GIS to Quantify Fish and Wildlife Habitat in Orange Lake, Florida

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Abstract: In 2005, the Florida Fish and Wildlife Conservation Commission implemented a team approach to guide holistic management of Orange Lake, Florida (5100 ha). In 2007, 2010, and 2013, we evaluated the lakewide composition of aquatic plant communities and quantified their habitat benefits for focal fish and wildlife taxa. We found that habitat conditions in Orange Lake varied with changes in water level and all three years exhibited an excess of shrub swamp habitat (400–481 ha) and a shortage of shallow marsh habitat (65–160 ha). Overall habitat value for the group of focal taxa was greatest in 2010, coinciding with the highest coverage of deep marsh and submersed aquatic vegetation (SAV). More than half of the lake was ranked as having low overall habitat value in 2013, coinciding with the highest coverage of floating marsh and lowest coverage of SAV and open water. We identified 2364 ha of potential management area, where there is opportunity to improve habitat conditions for the greatest number of focal taxa. We demonstrated how habitat evaluations may be used to develop management objectives and to predict the effects of proposed management on habitat conditions for focal taxa.

Key words: habitat suitability, habitat management, aquatic plant communities

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The quality and quantity of aquatic habitats are declining worldwide. Approximately 37% of the ichthyofauna in the United States is at risk of or vulnerable to extinction (Stein et al. 2000) due primarily to alteration of physical habitat (Miller et al. 1989). Wildlife associated with aquatic systems, such as reptiles and amphibians, wading birds, and waterfowl, is similarly at risk (Dudgeon et al. 2006). Florida's aquatic resources include more than 200 freshwater fish species and more than 1000 marine fish species that are dependent on various aquatic habitats throughout their life histories. It is predicted that Florida's population will exceed 21 million residents by 2017 (Florida Department of Environmental Protection 2007), and the demand for freshwater and the environmental impact associated with urban growth will likely cause considerable stress to and degradation of aquatic ecosystems.

Habitat degradation in Florida aquatic systems due to landscape alterations has been well documented (Williams et al. 1985, Moyer et al. 1995, Toth et al. 1998, Allen and Tugend 2002). In particular, channelization, flood control, and suppression of natural fire cycles have changed the aquatic plant communities in lakes, which serve as habitat for fish and wildlife. In the absence of a natural water-flow regime, resource managers have relied on habitat management practices such as lake and reservoir drawdowns, mechanical harvesting, mechanical shredding, and organic sediment removal to mimic natural processes with the goal of restoring and maintaining historical plant communities and composition (Wegener and Williams 1974, Moyer et al. 1995, Alam et al. 1996, Allen and Tugend 2002, Mallison et al. 2010, Nagid et al. 2015). These management practices, however, often focused on achieving habitat benefits for sport fishery species such as largemouth bass (*Micropterus salmoides*). Comprehensive management plans that consider multiple fish and wildlife species and ecosystem function are increasingly important in light of future population growth, multiple resource values, and decreasing budgets.

In his review of ecosystem management and framework for implementation, Grumbine (1994) identified goals that were commonly endorsed to sustain ecological integrity. Achieving these goals and applying landscape management concepts requires an inventory of fish and wildlife species and their habitats, along with understanding of ecosystem functions. In addition, the identification and reversal of habitat degradation requires spatial assessment of habitat conditions and the range of landscape activities affecting it along with a multi-stakeholder process of identifying and deciding among alternative management scenarios (Esselman et al. 2011). Advancements in spatial technologies such as global positioning systems (GPS), geographic information systems (GIS), remote sensing, and aerial imagery have made acquiring and analyzing landscape information more readily available to resource biologists (Creque et al. 2005, Kaeser and Litts 2010). In particular, GIS revolutionized the ability to spatially represent resources relevant to the decision context by integrating hardware, software, and data for capturing, managing, analyzing, and displaying geographically referenced information (Everitt et al. 2003, Tugend et al. 2004). Moreover, the integration of GIS with habitat suitability criteria of fish and wildlife has enabled resource managers to explore the relationships between varying habitat conditions and species occurrence, species density, and specific life-history traits such as spawning locations (Guisan and Zimmermann 2000, Creque et al. 2005, Gillenwater et al. 2006, Wirth et al. 2012). But obtaining empirical habitat suitability criteria for multiple fish and wildlife species is often not feasible due to the temporal and economic constraints associated with collecting such information. In addition, the transferability of published habitat suitability criteria from one location to another has been disputed because published criteria may not represent the habitat characteristics of the location under investigation (Freeman et al. 1997). Consequently, expert knowledge has been successfully used to develop habitat suitability criteria for fish and wildlife when collecting empirically derived information was impractical (Bovee 1986, Store and Kangas 2001, Store and Jokimäki 2003).

The Florida Fish and Wildlife Conservation Commission (FWC) began stressing the importance of a holistic approach in 2004 using interdisciplinary teams to address complex resource-management issues. The FWC Orange Creek Basin Working Group (OCBWG), composed of resource biologists who have specific knowledge of and expertise in fish and wildlife species and their habitats in the Orange Creek Basin (OCB), was formed in 2005 to implement and coordinate management strategies that promote an equitable habitat distribution approach to optimizing the sustainability and diversity of fish and wildlife populations and benefits for people. Orange Lake is the largest lake in the OCB (surface area = 5100 ha, mean depth = 1.7 m) and is characterized as a eutrophic system (Gottgens and Montague 1987, Lasi and Shuman 1996). Due to high productivity, Orange Lake has historically supported abundant and diverse fish and wildlife populations that significantly contribute to the local economy (Milon et al. 1986, Colle et al. 1987). Since the mid-1970s, Orange Lake has experienced drastic changes in aquatic macrophyte abundance and species composition, eutrophication, and record high and low water levels. Natural processes that formerly occurred during extreme flood and drought events have been severely altered as a result of changes in the OCB. Sediment and vegetative transport during floods have been hindered by modifications to the lake outlet (Warr et al. 1999). Burning of excessive plant material and organic substrate during droughts has been eliminated due to safety concerns associated with nearby interstates and highways. And most recently, a severe drought in 2011 and subsequent active sinkholes drained the lake to record low water levels by 2013, and excessive vegetation growth expanded beyond the former littoral zone into areas that had been open water or deep marsh habitat. As a result, management strategies were needed to reclaim aquatic habitats in Orange Lake from deleterious habitat succession. Thus, the objectives of this study were to 1) evaluate the lakewide composition of aquatic plant communities in Orange Lake on a three-year interval, 2) quantify the habitat benefits of those plant communities for focal fish and wildlife taxa, and 3) develop a holistic lake-management approach designed to provide the habitat requirements for focal taxa.

Methods

We used the habitat classification described by Bryan and Warr (1998) as the basis for quantitatively describing plant communities in the OCB and establishing habitat suitability targets for focal taxa there. For habitat types with multiple distinct plant communities, we further defined subcategories based on dominant vegetation (Table 1). We mapped the littoral vegetation in Orange Lake to document aquatic plant communities on a three-year interval. Color-infrared digital aerial imagery at a pixel resolution of 0.3 m was acquired in April–June of 2007, 2010, and 2013. Photointerpretation with ground truthing was used to identify and delineate areas (polygons) on the imagery that displayed distinct plant-community signatures (OCBWG 2013). Within six weeks of the acquisition of each set of imagery we surveyed the lake by airboat to document the location of known plant communities at up to 30 sampling points per class per year. For each mapping event, six points per class were randomly selected and retained as assessment points. The remaining points were used during map production to identify classes that corresponded to signatures in the photography. Delineated polygons were classified by dominant vegetation according to an amended version of the Florida Land Use, Cover and Forms Classification System (Florida Department of Transportation 1999). Accuracy of maps was evaluated by scoring classification of polygons that contained assessment points. Maps were revised as necessary to attain a minimum 90% thematic accuracy of classification (i.e., at least 90% of the polygons containing assessment points were correctly coded in the map). Additionally, plant coverage within each polygon was ranked as sparse (1%–33% areal coverage of vegetation), medium (34%–66%), or dense (67%–100%) based on the photography (OCBWG 2013).

Habitat objectives for Orange Lake were derived by evaluating the habitat needs of focal fish and wildlife taxa (Ryti 1992, Pearman et al. 2006). Focal taxa were selected based on one or more of the following unranked criteria: high economic importance, high recreational importance, sensitivity to habitat manipulation, keystone species (a species that has a disproportionate effect on its environment relative to its abundance), and rare or listed and in need of specific habitat protection. Focal taxa included American alligator (*Alligator mississippiensis*), other herpetofauna (the American alligator was singled out due to its importance), wad-

Table 1. Habitat types and descriptions based on plant communities common in Orange Lake during 2007–2013.

Habitat type	Dominant vegetation and defining characteristics
Hardwood swamp	Mature (>7 m) trees such as red maple (*Acer rubrum*) and bald cypress (*Taxodium distichum*), adjacent to the lake shoreline
Tree island	Mature (>7 m) trees such as red maple and bald cypress, not adjacent to the lake shoreline; generally <5 ha in size
Shrub swamp	Small (<7 m) trees and shrubs, often intermixed with herbaceous wetland vegetation
Mixed shrub swamp	Buttonbush (*Cephalanthus occidentalis*), elderberry (*Sambucus canadensis*), wax myrtle (*Morella cerifera*), and willow (*Salix* spp.)
Willow shrub swamp	Willow
Shallow marsh	Rooted herbaceous vegetation, often intermixed with submersed plants; generally occurring in water depths <1 m
Flag shallow marsh	Pickerelweed (*Pontederia cordata*), arrowheads (*Sagittaria* spp.) and arrow arum (*Peltandra virginica*)
Maidencane shallow marsh	Maidencane (*Panicum hemitomon*)
Mixed shallow marsh	Mixture of rooted herbaceous vegetation
Tall linear-leaved shallow marsh	Cattail (*Typha* spp.), giant bulrush (*Schoenoplectus* spp.) and sawgrass (*Cladium jamaicense*)
Floating marsh	Herbaceous vegetation growing on a buoyant mat consisting of plant roots and organic matter, often intermixed with floating vegetation; attached to shoreline vegetation (not free-floating)
Low floating marsh	Knotweed (*Polygonum densiflorum*), burhead sedge (*Oxycaryum cubense*), water pennywort (*Hydrocotyle* spp.) and frog's-bit (*Limnobium spongia*)
Complex floating marsh	Mixture of herbaceous vegetation, usually including pickerelweed, cattail, water primrose (*Ludwigia* spp.), and bur marigold (*Bidens* spp.)
Deep marsh	Rooted emergent or floating-leaved vegetation, often intermixed with submersed plants; generally occurring in water depths >1 m
Floating-leaved deep marsh	Spatterdock (*Nuphar luteum*), water lilies (*Nymphaea* spp.), and lotus (*Nelumbo lutea*)
Grass deep marsh	Egyptian paspalidium (*Paspalidium geminatum*) and maidencane
Floating island	Same as floating marsh except this habitat type was free-floating
Open water	No vegetation
Submersed aquatic vegetation	Hydrilla (*Hydrilla verticillata*) and coontail (*Ceratophyllum demersum*)

ing birds, round-tailed muskrat (*Neofiber alleni*), wood duck (*Aix sponsa*), ring-necked duck (*Aythya collaris*), black crappie (*Pomoxis nigromaculatus*), largemouth bass, and other centrarchids (black crappie and largemouth bass were singled out due to their importance). For American alligator and wading birds, requirements for both foraging habitat and nesting or roosting habitat were defined to account for the diverse habitat needs of these focal taxa (OCBWG 2013). Habitat requirements for focal taxa were developed according to the habitat classification described above and were based on lakewide coverage of habitat types, plant coverage and density, plant species composition, location, and block size. Individual habitat requirements for focal taxa were pooled to establish target ranges (percentage of lakewide area) for each habitat type, such that attaining the targets would provide habitat requirements for all focal taxa (OCBWG 2013). Habitat types were considered exclusive (i.e., only one habitat type was present at any defined location) with the exception of SAV, which often grew intermixed with emergent vegetation. Thus the SAV target represented total coverage, including coverage by understory plants within other habitat types. Mapped coverage of habitat types was compared to target ranges to evaluate the status of lakewide habitat conditions in 2007, 2010, and 2013. When observed coverage fell short of a target range for a habitat type, it was considered deficient (i.e., insufficient area of that habitat type was available to support the focal taxa). When observed coverage exceeded a target range for a habitat type, it was considered excessive (i.e., although sufficient area of that habitat type was available to support the focal taxa, insufficient area remained to attain target ranges for all the other habitat types).

To quantify the amount of available habitat for the focal taxa, we developed GIS analyses in a model-builder framework using ArcGIS tools (ESRI 2013). Analyses incorporated taxon-specific habitat characteristics to identify areas in the littoral vegetation maps that contained aquatic plant communities and coverages known to provide usable habitat conditions, including high-quality habitat (provides excellent conditions) and acceptable habitat (provides suitable conditions) for each of the focal taxa (OCBWG 2013). Analyses for focal taxa were based on dominant aquatic plant communities, plant coverage, and proximity to important habitat types. Details for the fish group are presented in Table 2 but were not included for the other focal taxa due to space limitations (OCBWG 2013).

For each mapping year, results for all the focal taxa were combined to evaluate overall lakewide habitat value, based on the classification of high-quality or acceptable habitat for the group of focal taxa. We ranked overall habitat value as "high" for areas identified as high-quality habitat for four or more focal taxa, identified as high-quality or acceptable habitat for seven or more focal taxa, or identified as important rookeries. Areas identified as high-quality habitat for no more than two focal taxa and identified as high-quality or acceptable habitat for no more than four focal taxa were ranked as "low." Open water in the limnetic zone that qualified as low was ranked as "low (open water)" to distinguish these areas, which would not be appropriate for management activity. All other areas were ranked as "medium." All polygons classified as hardwood swamp or tree island were designated as "forested wetland" regardless of ranking, because these areas would not be

Table 2. Characteristics (habitat type, plant coverage, and proximity to other habitat types) used to define high-quality and acceptable habitat for black crappie, largemouth bass, and other centrarchids on Orange Lake. Plant coverage categories were sparse (S, 1%–33%), medium (M, 34%–66%), dense (D, 67%–100%), or unspecified when all coverage categories applied. W = habitat types with functional amounts of open water, including open water, submersed aquatic vegetation (SAV), deep marsh, and all other habitat types at coverage of S or M (OCBWG 2013).

Habitat value	Characteristics
Black crappie	
High-quality	Tall linear-leaved shallow marsh (S), deep marsh (S), and open water.
Acceptable	Within 30 m of W: hardwood swamp, tree island, shrub swamp, tall linear-leaved shallow marsh (M), other shallow marsh, floating marsh, deep marsh (M, D), floating island, and SAV.
Largemouth bass	
High-quality	Tall linear-leaved shallow marsh (M) and deep marsh (M).
	Within 30 m of tall linear-leaved shallow marsh (M), deep marsh (M), or SAV: tall linear-leaved shallow marsh (S), deep marsh (S, D), and open water.
	SAV within 30 m of other high-quality habitat.
Acceptable	Remaining area of tall linear-leaved shallow marsh (S), deep marsh (S, D), and SAV.
	Within 30 m of tall linear-leaved shallow marsh (S, M), deep marsh, SAV, or open water: tree island, shrub swamp, shallow marsh except tall linear-leaved (M), floating marsh, and floating island.
	Open water within 30 m of high-quality habitat or other acceptable habitat.
Other centrarchids	
High-quality	Tall linear-leaved shallow marsh (M), other shallow marsh (D) within 30 m of W, and deep marsh (M),
	SAV within 30 m of tall linear-leaved shallow marsh (S, M), other shallow marsh (M, D), deep marsh, or open water.
	Within 30 m of other high-quality habitat: tall linear-leaved shallow marsh (S), other shallow marsh (M), deep marsh (S, D), and open water.
Acceptable	Remaining area of tall linear-leaved shallow marsh (S), other shallow marsh (M, D), deep marsh (S, D), SAV, and open water.
	Within 30 m of high-quality habitat or other acceptable habitat: hardwood swamp, tree island, shrub swamp, floating marsh, and floating island.

considered for management. Within areas ranked as low, polygons dominated by a habitat type that exceeded its target range during the most recent mapping event were chosen as potential management areas. Proposed management objectives within these areas were designed to reduce the area of habitat types that exceeded their target range and to increase the area of habitat types that fell short of their target range.

Results

Littoral vegetation maps of Orange Lake revealed changes in habitat types over the study period. From 2007 to 2010, lakewide coverage decreased for open water and increased for deep marsh and SAV (Table 3). Extremely high coverage of floating marsh in 2013 (and consequentially low coverage of deep marsh, floating island, open water, and SAV) was due to severe drought in preceding years. Based on target ranges, in all three years there was an excess of shrub swamp and a shortage of shallow marsh (Table 3). Tree island was the only habitat type within target range in every year. All other habitat types were variable among their target range, each meeting the target in at least one year.

Between 2007 and 2010, the amount of high-quality habitat increased for all focal taxa except round-tailed muskrat and black crappie (Table 4). For those two focal taxa, the amount of acceptable habitat increased. By 2013, changes in aquatic vegetation caused by the drought led to the lowest amount of high-quality and acceptable habitat during the study period for American alligator foraging, wading bird foraging, wood duck, ring-necked duck, black crappie, largemouth bass, and other centrarchids. Results were plotted to determine locations of high-quality and acceptable habitat for all focal taxa; as an example, results for 2013 are presented in Figure 1. In all years, the amount of total habitat (high-quality plus acceptable) was greatest of all focal taxa for other herpetofauna (79%–99% of the lake) and other centrarchids (54%–90%). Focal taxa with the least amount of total habitat included American alligator nesting (22%–25%) and wading bird

Table 3. Area (ha) and coverage (percentage of the lake) for each habitat type (excluding hardwood swamp) mapped in Orange Lake in 2007, 2010, and 2013; and target ranges for optimal fish and wildlife habitat (OCBWG 2013).

	2007		2010		2013		Target range
Habitat type	ha	%	ha	%	ha	%	%
Tree island	81	1.6	113	2.2	118	2.3	0.5–7.5
Shrub swamp	789	15.2	828	16.2	865	16.9	2.5–7.5
Shallow marsh	974	18.8	865	16.9	874	17.1	20.0–30.0
Floating marsh	290	5.6	401	7.8	2515	49.1	5.0–22.5
Deep marsh	214	4.1	703	13.7	266	5.2	7.5–20.0
Floating island	35	0.7	45	0.9	21	0.4	0.8–5.0
Open water	1641	31.6	635	12.4	460	9.0	30.0–50.0
SAV	1169	22.5	1533	29.9	8	0.2	20.0–57.5

Table 4. Total area (ha) of high-quality habitat (H) and acceptable habitat (A) for focal taxa on Orange Lake in 2007, 2010, and 2013, based on GIS analysis of littoral vegetation maps.

	2007		2010		2013	
Focal taxa	H	A	H	A	H	A
American alligator foraging	1670	1445	1969	1013	642	642
American alligator nesting	792	377	879	475	1909	541
Other herpetofauna	3103	1176	3262	2070	5018	174
Wading bird foraging	53	2052	240	2165	21	916
Wading bird roosting	116	1128	149	1306	245	2352
Round-tailed muskrat	572	797	395	1238	564	2324
Wood duck	887	493	1270	383	219	172
Ring-necked duck	1567	620	2517	417	61	239
Black crappie	1655	1756	709	2583	462	1366
Largemouth bass	903	1154	1309	1769	33	880
Other centrarchids	1059	3810	1409	3414	41	2859

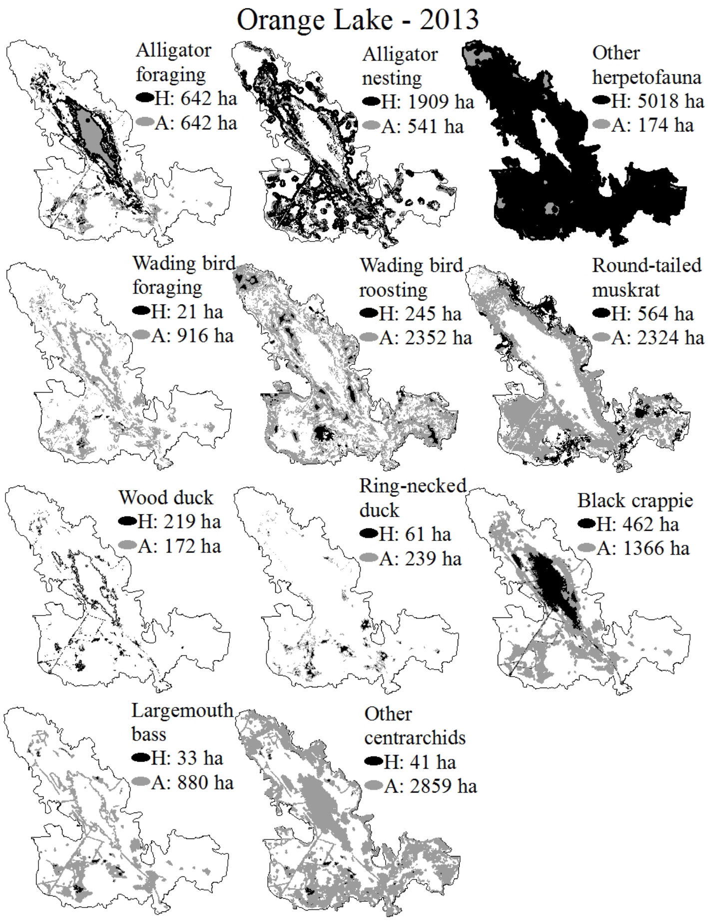

Figure 1. Location and total area (ha) of high-quality (H) and acceptable (A) habitat for focal taxa on Orange Lake in 2013 based on littoral vegetation mapping and GIS analysis.

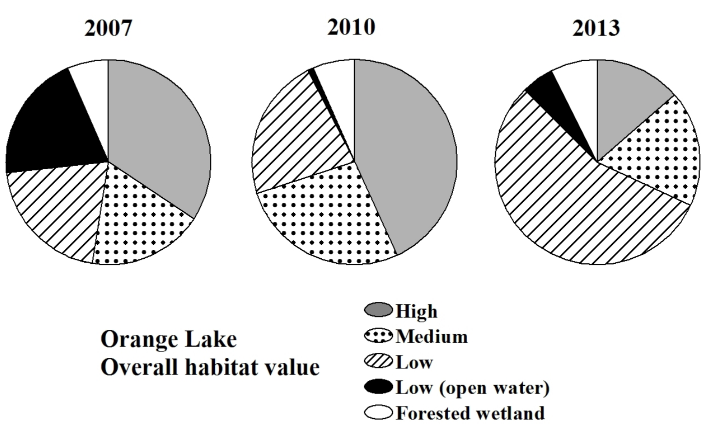

Figure 2. Overall habitat value on Orange Lake in 2007, 2010, and 2013, based on littoral vegetation mapping and GIS analysis. High = areas identified as high-quality habitat for ≥4 focal taxa, identified as high-quality or acceptable habitat for ≥7 focal taxa, or identified as important rookeries; Low = areas identified as high-quality habitat for ≤2 focal taxa and identified as high-quality or acceptable habitat for ≤4 focal taxa (with low open water areas in the limnetic zone further specified); Forested wetland = all polygons classified as tree island or hardwood swamp; and Medium = all other areas.

roosting (23%–27%) in 2007 and 2010 and ring-necked duck (6%) and wood duck (7%) in 2013.

The percentage of the lake classified as having high overall habitat value, in addition to the percentage of the lake that would not be considered for management action (forested wetlands and low [open water]), decreased from 60% in 2007 to 51% in 2010 and to 25% in 2013 (Figure 2). The overall habitat value was ranked low for 22% of the lake in 2007 and 2010 and increased to 56% in 2013. The amount of area ranked as high overall habitat value was greatest in 2010 (Figure 2), coinciding with the highest coverage of deep marsh and SAV (Table 3). More than half of the lake was ranked as low overall habitat value in 2013, coinciding with the highest coverage of floating marsh and lowest coverage of SAV and open water. Within areas ranked as low overall habitat value in 2013, habitat types that exceeded their target range included shrub swamp (763 ha) and floating marsh (1601 ha). These 2364 ha were chosen as potential management areas, where there is opportunity to improve habitat conditions for the greatest number of focal taxa.

Discussion

A balanced aquatic ecosystem requires a diversity of habitat types and a sufficient area of each habitat type to satisfy the habitat requirements of all fish and wildlife (Mallison et al. 2010). Management frequently aims to maintain this balance by controlling nuisance vegetation that has expanded to problem levels (Tugend and Allen 2004, Mallison et al. 2008) or by promoting expansion of native plants into areas lacking vegetation (Mallison and Thompson 2010a, 2010b). Management may also be used to convert an area from one habitat type to another. For example, aquatic herbicides and mechanical shredders were used to remove 52 ha of excess floating marsh on Orange Lake in 2005. Within 6–12 mo, treatment areas were dominated by SAV and deep marsh habitats (Mallison et al. 2010). Additionally, Hutchinson and Langeland (2010) demonstrated that herbicide applications can convert shrub swamp to herbaceous marsh for at least two years, and they suggested that subsequent prescribed burns may improve long-term management.

Conversion of habitat types (by either management or natural fluctuations) is necessary to attain the lakewide habitat targets on Orange Lake. We identified 763 ha of shrub swamp within potential management areas during the final sampling year. Converting at least 481 ha (and as much as 737 ha) to a different habitat type would bring the lakewide coverage of shrub swamp to within the target range. Potential management areas also included 1601 ha of floating marsh, which exceeded its target range in 2013. Converting at least 1362 ha (and as much as 1601 ha) to a different habitat type would bring the lakewide coverage of floating marsh to within the target range. In 2013, we found a shortage of shallow marsh (151 ha), deep marsh (118 ha), floating island (17 ha), open water (1078 ha), and SAV (1017 ha). Strategies for converting shrub swamp and floating marsh to these habitat types would be helpful in achieving lakewide habitat targets. An appropriate primary management objective may be to create shallow marsh from 500 ha of excess shrub swamp within potential management areas, using herbicides to control woody vegetation and a prescribed-burn regime to prevent succession (Hutchinson and Langeland 2010). In addition, 1000 ha of excess floating marsh within potential management areas may be converted to open water, SAV, and deep marsh using aquatic herbicide treatments combined with mechanical shredders or harvesters (Mallison et al. 2010). Although this would not reduce floating marsh to a level within its target range, observations indicate that some conversion will occur naturally after refilling of the lake basin, as occurred in 2013.

Results of GIS analyses can be used to predict the effects of proposed management on habitat conditions for fish and wildlife. For example, let P_i = the proportion of habitat type i that qualifies as habitat for a focal taxon, A_i = the change in area for habitat type i, and N = the number of habitat types. Then

$$C=\sum_{i}^{N} P_i \times A_i$$

where C = the change in area of qualifying habitat for a focal taxon. For P_i, we used the mean percentage (2007, 2010, and 2013) of lakewide area per habitat type that qualified as high-quality or acceptable habitat for each of the focal taxa (Table 5). For A_i, we used the proposed management objectives of reducing by shrub swamp by 500 ha and converting to an equal area of shallow marsh, as well as converting 1000 ha of floating marsh to equal amounts (333.3 ha) of deep marsh, open water, and SAV. Achieving management objectives would be expected to increase total habitat by at least 400 ha for American alligator foraging, wading bird foraging, wood duck, ring-necked duck, black crappie, largemouth bass, and other centrarchids, decrease total habitat by at least 800 ha for American alligator nesting and wading bird roosting, and have minimal effect (<150 ha change) on total habitat for other herpetofauna and round-tailed muskrat (Table 5).

Table 5. Mean percentage (2007, 2010, and 2013) of lakewide area per habitat type that qualified as high-quality or acceptable habitat for each of the focal taxa on Orange Lake, and predicted change in the amount of habitat following proposed management (i.e., conversion of 500 ha of shrub swamp to shallow marsh, and conversion of 1000 ha of floating marsh to 333.3 ha each of deep marsh, open water, and SAV).

Focal taxa	Shrub swamp	Shallow marsh	Floating marsh	Deep marsh	Open water	SAV	Change (ha)
American alligator foraging	1%	1%	19%	100%	100%	100%	810
American alligator nesting	45%	45%	80%	0%	0%	0%	–800
Other herpetofauna	100%	100%	100%	98%	59%	100%	–143
Wading bird foraging	27%	26%	5%	100%	42%	71%	655
Wading bird roosting	100%	3%	60%	0%	0%	0%	–1085
Round-tailed muskrat	0%	100%	85%	65%	0%	0%	–133
Wood duck	12%	11%	3%	72%	33%	62%	522
Ring-necked duck	0%	5%	0%	100%	50%	100%	858
Black crappie	7%	7%	50%	100%	100%	100%	500
Largemouth bass	6%	0%	39%	100%	46%	100%	400
Other centrarchids	64%	97%	61%	100%	100%	100%	555

An effective long-term approach must integrate management with assessment to appropriately adapt objectives and plans, based on actual conditions observed within dynamic systems such as Orange Lake (Holling 1978, Walters 1986, Van Winkle et al. 1997). We created a framework developed by a team of interdisciplinary biologists by which lakewide habitat targets were established based on habitat requirements of important fish and wildlife focal taxa. By using a combination of habitat suitability modeling, trends from three years of lake mapping data, and GIS analytical techniques, we identified excesses and shortages of specific habitat types, which can be used to develop lake-management objectives in a changing environment. This framework and the techniques used to achieve landscape goals are well supported by the literature and contemporary habitat initiatives (National Fish Habitat Board 2012). Store and Kangas (2001) and Store and Jokimäki (2003) presented case studies in which integrated habitat suitability indices developed by expert opinion combined with GIS provided a functional way to output and manage landscape suitability information as well as evaluate the models. Our framework also enabled us to evaluate the consequences associated with the changes in quality and quantity of different habitat types to focal fish and wildlife taxa. This has important implications for resource managers because it can be used to identify management needs by revealing excesses or shortages of either habitat types or available habitat for fish and wildlife and to predict the effect of proposed management alternatives on lakewide habitat conditions.

Habitat targets were based on focal taxa selected to represent all fish and wildlife taxa that utilize the aquatic resources within the OCB, and the collective results and resulting habitat management objectives mimic the principles and concepts inherent in sustaining ecological integrity and ecosystem management (Grumbine 1994). Our framework conceptually maintains viable populations of all native species, is representative of all native habitat types across their natural range of variation, can maintain evolutionary and ecological processes if management practices that mimic natural disturbance patterns are used, and is intended to be a long-term guiding tool for the management of lakewide habitat over periods of time long enough to maintain the evolutionary potential of species and ecosystems. These principles, however, were not evaluated in our study and represent a potential direction for future research. In particular, the predictability and uncertainty in our habitat suitability criteria must be examined to ensure that management alternatives accurately reflect species needs (Burgman et al. 2001, Van der Lee et al. 2006). Additionally, long-term monitoring of the focal fish and wildlife taxa must be implemented to provide model feedback and to make certain that management actions are achieving the desired outcomes (Walters 1986, Lyons et al. 2008).

Due to the dynamic nature of vegetation communities in Orange Lake (Warr et al. 1999), we recommend that these results be used to guide management toward providing lakewide habitat requirements (to identify general trends or substantial deficiencies) rather than attempting to identify absolute areas needing management. Efforts should strive to move toward the targets while monitoring natural variations in lakewide coverage of various habitat types. Additionally, values outside of the target ranges should be considered suboptimal but not necessarily undesirable (OCBWG 2013). Furthermore, habitat conditions in any area developed as they did because environmental conditions favored those habitat types. Comprehensive restoration efforts need to address not only the habitat but also the driving factors that originally shaped the ecosystem.

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