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Aquatic Plant Succession Following Tussock Control on Orange Lake, Florida

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INTRODUCTION

Tussocks (floating islands of vegetation) are composed of native and/or exotic plants growing on a buoyant mat of plant roots and organic matter. This definition includes small (<0.01 ha) free-floating mats and extensive, stationary mats that may cover hundreds of hectares (Mallison et al. 2001). Tussocks can form due to dense growth of floating plants or the surfacing of organic sediments, which often occurs following drought conditions when water levels increase rapidly (Clark and Reddy 1998). Tussocks can impede water flow and navigation, shade desirable rooted aquatic vegetation, contribute to poor water quality (low dissolved oxygen levels and high accumulation of organic matter below tussocks), and interfere with recreational activities (Hujik 1994, Alam et al. 1996, Clark and Reddy 1998).

The Florida Fish and Wildlife Conservation Commission (FWC) ranked habitat suitability of aquatic habitat types, including tussocks, for fish and wildlife groups (FWC Orange Creek Basin Working Group, unpublished data). Tussocks have no habitat value to waterfowl, and habitat use by fish and wading birds is generally limited to edges adjacent to open water. However, dense floating marshes are used extensively for nesting by alligators (*Alligator mississippiensis*). Tussocks provide important habitat for the round-tailed muskrat (*Neofiber alleni*), a species of conservation emphasis, and a wide variety of semi-aquatic and aquatic reptiles and amphibians. Tussocks comprise a habitat type that provides benefits for some, but not all, fish and wildlife groups. 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 groups. Excessive formation and expansion of tussocks, such as commonly occurs after low-water periods, can displace other habitat types including areas with rooted vegetation. Consequently, the FWC frequently implements management activities to eliminate some tussocks and promote establishment of other aquatic plant communities.

Tussocks have been present in Orange Lake, Florida (5080 ha), for more than 100 years (Clark and Reddy 1998), and they covered an estimated 800 ha in 1997 (Mallison et al. 2001). Tussock-control efforts conducted by the FWC on Orange Lake have included chemical and mechanical methods. In 1997 and 1998, 26 ha of tussocks were removed with a trackhoe on a floating barge (Mallison and Hujik 1999). During a drought in 2002, heavy machinery was used to re-

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move tussocks and underlying muck from 65 ha of shoreline (Ager et al. 2002). Aerial herbicide treatments (glyphosate [N-phosphonomethyl-glycine] and 2,4-D [2,4-dichlorophenoxy acetic acid]) targeted willows (*Salix caroliniana*) on 162 ha of tussocks in June 2003 (Mallison et al. 2003). All methods were successful in reducing tussocks in the short term (<1 yr), but long-term effects on aquatic plant communities were not documented. Although Mallison and Hujik (2001) monitored initial plant succession following tussock removal with the trackhoe on a floating barge, this evaluation ended prematurely when the study areas completely dried out in 2000. Plant succession needs to be documented so that effects of tussock control on aquatic habitats can be accurately predicted and appropriately evaluated when considering costs and benefits of management alternatives.

Mallison et al. (2001) described two types of tussocks on Orange Lake: (1) floating-plant tussocks consisting primarily of low-growing plants on a buoyant mat <30 cm thick and composed of 75% or more live plant roots, and (2) mud tussocks consisting of larger plant species growing on a buoyant mat >30 cm thick and composed of 50% or more organic material in addition to live plant roots. During 2004 and 2005, management activities conducted on Orange Lake by the FWC and the Florida Department of Environmental Protection included herbicide treatments using diquat [6,7-dihydrodipyrido(1,2-a:2',1'-c)pyrazinediium ion] to control floating-plant tussocks, and mechanical shredding using a "cookie cutter" to control mud tussocks. Management goals were to improve habitat quality for fish and waterfowl by restoring deep-marsh habitat (i.e., at least 25% coverage of vegetation dominated by floating-leaved and/or submersed aquatic vegetation in water depths of 1 to 3 m) and to provide access for recreational activities (fishing, boating, and hunting). Management activities were completed along the northwest shoreline (Pasture site, 12 ha) during December 2004 to November 2005, the northeast shoreline (Plum Creek site, 16 ha) during November 2004 to May 2005, and the E shoreline (Rawling's Park site, 24 ha) during December 2004 to January 2005. The objectives of this study were to quantify the rate and extent of aquatic plant succession and to document plant species composition after tussock-control methods had been used.

METHODS

Frequency of occurrence of aquatic vegetation was estimated by using procedures modeled after those of the U.S. Department of the Interior (1996). In December 2005, three fixed-line transects per site were established within the Pasture site, the Plum Creek site, and the Rawling's Park site (nine transects total). Each transect was positioned perpendicular to the shoreline and extended the full width of the study site. Transect endpoints were demarcated with PVC poles, and corresponding GPS (Garmin 72) coordinates were recorded. Sampling points were selected along each transect at 15 m intervals. Two samples were collected at each point, approximately 3 m apart and perpendicular to the transect line. For each sample, a pole with four hooks attached at the end (with a collective diameter of 20 cm) was lowered to the substrate, rotated, and retrieved. Exact position of individual samples varied between dates. Presence (hit) was the occurrence of any part of a living plant within the sample area. For tussocks, presence (hit) was the occurrence of a buoyant mat within the sample area. Hits were recorded for all submersed, emergent, and floating plant taxa and tussocks occurring within each sample. Bare samples (i.e., no vegetation present) were also recorded to determine frequency of occurrence of total vegetation (total number of samples minus number of bare samples on each transect). Frequency was sampled each spring and fall from December 2005 to October 2008 and in summer 2006. No sampling was conducted prior to tussock control, but field observations and review of 2004 satellite imagery indicated that all sites initially consisted of nearly 100% coverage of tussocks.

For analyses, data were categorized into 11 plant classes: coontail (*Ceratophyllum demersum*), hydrilla (*Hydrilla verticillata*), other submersed plants, American lotus (*Nelumbo lutea*), maidencane (*Panicum hemitomon*), spatterdock (*Nuphar luteum*), other emergent plants, floating plants, tussocks, mixed shoreline plants, and total vegetation. In classes containing multiple plant taxa, a single hit was tallied if any or all of the specified taxa occurred in a sample (i.e., maximum one hit per class per sample). In samples with more than one class present, a hit was tallied for each class present regardless of dominance. Percent frequency of each class on each transect was calculated by dividing the total number of hits per class by the total number of samples per transect and multiplying by 100. Mean percent frequency of each class at each site was generated by averaging data (total number of hits /total number of samples x 100) for the three transects at each respective site. Succession of total vegetation was examined by comparing percent frequency of total vegetation on each transect to the number of months after tussock-control activities had been completed at that site. Regression analysis was used to describe the rate of succession at each site, and analysis of covariance (ANCOVA) was used to test for differences between sites (SAS v 9.2; SAS Institute, Inc., Cary, NC).

RESULTS AND DISCUSSION

During 2005 to 2008, 24 plant taxa were identified along the nine transects in Orange Lake. At all sites, coontail, hydrilla, and spatterdock were common (Table 1). Other noteworthy plants included southern naiad (*Najas guadalupensis*, Pasture), American lotus (Plum Creek and Rawling's Park), water pennywort (*Hydrocotyle* sp., Rawling's Park), yellow water-lily (*Nymphaea mexicana*, Rawling's Park), and frog's-bit (*Limnobium spongia*, Plum Creek). These results were similar to our observations of the aquatic plants that grew after mechanical tussock removal in 1997 and 1998 (Mallison and Hujik 2001).

The first samples were collected in December 2005, one month after completion of tussock control at the Pasture site. Mean frequency of occurrence of total vegetation (all taxa) was only 2% (Table 1). Total vegetation increased during every sampling event throughout the study. Mean frequency of occurrence of total vegetation exceeded 70% during the final 23 months (13 to 36 months after tussock control). During that time, coontail had the highest mean

TABLE 1. PERCENT FREQUENCY OF OCCURRENCE (WEIGHTED MEAN OF THREE LINE TRANSECTS) OF PLANT CLASSES SAMPLED AT PASTURE, PLUM CREEK, AND RAWLING'S PARK IN ORANGE LAKE 2005 TO 2008.

	Dec 05	Apr 06	July 06	Nov 06	Apr 07	Oct 07	Apr 08	Oct 08
Pasture								
Months after tussock control	1	6	8	13	18	23	30	36
Number of samples	124	110	128	132	128	134	128	142
Coontail	2%	9%	25%	61%	84%	72%	71%	77%
Hydrilla	1%			13%	24%	65%	56%	82%
Other submersed plants			1%	1%	12%	6%	14%	9%
American lotus						1%		
Maidencane						1%		
Spatterdock				7%	8%	11%	16%	27%
Other emergent plants		2%	6%	5%	9%	1%	1%	3%
Floating plants		1%	5%	2%		7%		11%
Tussocks			2%			2%	6%	6%
Mixed shoreline plants		5%	3%	7%	5%	13%	16%	14%
Total vegetation	2%	13%	29%	71%	91%	94%	96%	99%
Plum Creek								
Months after tussock control	6	11	13	18	23	28	35	41
Number of samples	108	96	106	112	112	108	114	120
Coontail	25%	29%	59%	80%	89%	63%	52%	58%
Hydrilla	27%	15%	35%	77%	66%	40%	18%	30%
Other submersed plants	2%	2%	3%	5%	5%		1%	3%
American lotus	1%	1%	8%	14%	16%	27%	23%	25%
Maidencane	5%	2%	7%	2%	1%	2%	1%	
Spatterdock	7%	13%	18%	16%	15%	21%	31%	42%
Other emergent plants	1%	1%	4%	2%				2%
Floating plants	1%		2%	7%	2%	20%		21%
Tussocks						2%		
Mixed shoreline plants		5%	2%	5%	5%	26%	24%	22%
Total vegetation	45%	47%	78%	93%	99%	96%	84%	93%
Rawling's Park								
Months after tussock control	10	15	17	22	27	32	39	45
Number of samples	168	156	166	188	178	188	198	186
Coontail	23%	29%	58%	69%	84%	49%	50%	53%
Hydrilla	31%	22%	47%	77%	86%	69%	35%	68%
Other submersed plants	6%	6%	7%	2%	2%	3%	3%	4%
American lotus			1%	2%		12%	13%	17%
Maidencane	5%	1%	1%				2%	2%
Spatterdock	4%	1%	2%	3%	4%	5%	8%	7%
Other emergent plants	1%	3%	3%	2%		10%	12%	16%
Floating plants	2%	1%	13%	5%		2%	4%	9%
Tussocks	4%	6%	5%	11%	3%	8%	12%	7%
Mixed shoreline plants		1%		8%	9%	20%	22%	22%
Total vegetation	45%	39%	69%	98%	100%	97%	90%	99%

frequency of occurrence (61-84%) of any class. Receding water levels stimulated expansion of mixed shoreline vegetation to a mean frequency of 14% when final samples were collected in October 2008.

The first samples (December 2005) were collected 6 months after completion of tussock control at the Plum Creek site and 10 months after completion of tussock control at the Rawling's Park site (Table 1). Colonization of aquatic plants had already begun, and mean frequency of occurrence of total vegetation during the first sample period was 45% at both sites. Total vegetation reached 99 to 100% frequency in April 2007 and declined slightly thereafter. At both sites, coontail and hydrilla were dominant, and mean frequency of occurrence of mixed shoreline vegetation increased to 22% by study's end.

Regression analysis of the percent frequency of total vegetation over time revealed that trend lines differed significantly between the three sites (ANCOVA, $F_{2, 65} = 6.1$, $P < 0.01$; Figure 1). However, a comparable rate of succession was documented at all sites. Total vegetation increased to moderate levels (25-50% frequency) within 6 to 12 months and to dense levels (>70% frequency) 18 months after tussock control. After 3.5 years, study sites contained abundant submersed aquatic vegetation and patches of floating-leaved plants.

Throughout this study, aquatic plant communities at all sites provided habitat value for fish and waterfowl and recre-

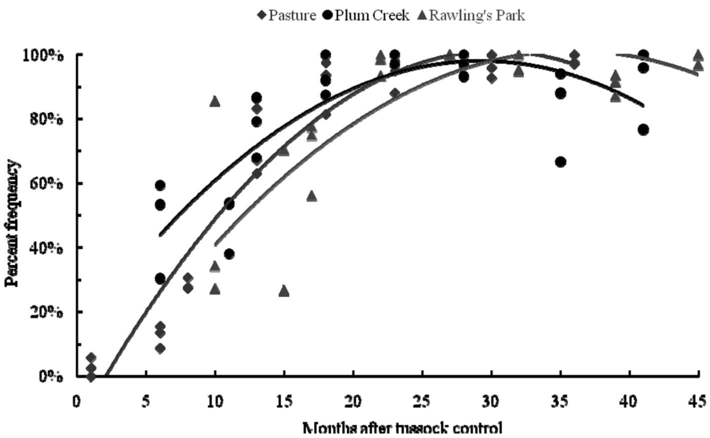

Figure 1. Percent frequency of occurrence of total vegetation (all taxa) collected along line transects in Orange Lake 2005 to 2008 following tussock removal. Lines represent second order polynomial regression lines for each site (R^2 = 0.94 for Pasture, 0.68 for Plum Creek, and 0.61 for Rawling's Park; all $P < 0.01$).

ational accessibility. Prior to tussock control, these sites were characterized by rank tussock communities, which provide minimal habitat value for sport fish (Moyer et al. 1995) and waterfowl and virtually no recreational access. Mean percent frequency of occurrence of tussocks remained below 7% at Pasture, 3% at Plum Creek, and 13% at Rawling's Park (Table 1). Management efforts were effective in controlling tussocks and promoting the establishment of deep-marsh habitats. However, mixed shoreline vegetation increased over time because of low water levels. These areas have the potential to form mud tussocks when water levels return to normal stage because organic sediments may break loose from the lake bottom and form buoyant mats (Clark and Reddy 1998). Additional management efforts will likely be required to maintain habitat improvements over the long term. Water levels in Orange Lake will greatly influence the frequency (duration) and extent (amount of area enhanced) of these management needs.

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