J. Aquat. Plant Manage. 46: 100-106

Aquatic Plant Species Distributions and Associations in Arizona's Reservoirs

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ABSTRACT

We surveyed aquatic plants in 38 reservoirs throughout Arizona from 2004 through 2006 to develop an inventory of species and to determine species distribution and composition patterns. We identified 12 submersed, 3 floating, and 18 emergent aquatic plants to species level; some samples were only identified to genera, and none of the filamentous algae were identified to either genera or species. Two nonnative aquatic plant species were found during the surveys: Eurasian watermilfoil (*Myriophyllum spicatum* L.) was found in nine reservoirs and curly-leafed pondweed (*Potamogeton crispus* L.) was found at two reservoirs. Filamentous algae were found at most reservoirs, and muskgrass (*Chara* spp. L.) was found at 53% of the reservoirs surveyed. Among reservoirs the most prevalent vascular plant species were cattails (*Typha* spp. L.) and hard-stem bulrush (*Schoenoplectus acutus* [Muhl. ex Bigelow] A.&D. Löve) followed by coontail (*Ceratophyllum demersum* L.), sago pondweed (*Stuckenia pectinatus* [L.] Boerner), and northern watermilfoil (*Myriophyllum sibiricum* Komarov). Within reservoirs, coontail or sago pondweed dominated the plant community at five reservoirs, northern watermilfoil at eight reservoirs and Eurasian watermilfoil at four reservoirs. Elevation and depth were significant predictors of occurrence for several species, and the number of aquatic plant taxa was positively related to reservoir surface area. Seven taxa (filamentous algae, Eurasian watermilfoil, curly-leafed pondweed, coontail, sago pondweed, spiny naiad [*Najas marina* L.], and northern watermilfoil) are probably the best targets for management because they had high prevalence and percent composition in Arizona, and hence are most likely to be considered problematic.

Key words: aquatic plant assemblages, aquatic macrophyte, Eurasian watermilfoil, logistic regression, reservoir management, species occurrence.

INTRODUCTION

Aquatic freshwater plants tend to have large-scale distributions, spanning continents or even circumpolar (Santamaria 2002). At a local scale (e.g., within a reservoir), some species can be widespread, impairing or preventing recreational activities such as swimming, fishing, and boating. Further, excessive densities and biomass can result in stunted fish growth and overpopulation of small-bodied fishes (Lembi 2003). Some invasive aquatic plant species can form large continuous monocultures and out-compete native vegetation (Madsen et al. 1991). Understanding both large-scale (among reservoirs) and small-scale (within a reservoir) aquatic plant distribution patterns will help to effectively manage aquatic plants.

Several invasive aquatic plant species have been identified in Arizona, but no statewide survey documenting the distribution of aquatic plant species had been conducted. Arizona Game and Fish Department (AGFD) conducted this statewide aquatic plant survey to improve management of our lentic systems through knowledge of aquatic plant species distribution and abundance in Arizona sport-fishing waters. Our objectives were to develop an inventory of aquatic plant species found in sport-fishing reservoirs throughout Arizona to determine species distribution and composition patterns. These data will help focus management actions on problematic aquatic plant species.

MATERIALS AND METHODS

Our goal was to survey a minimum of one reservoir with sport fish from each of the U.S. Geological Survey watersheds in Arizona (8-digit Hydrologic Unit Code: HUC). Forty-eight of the 84 HUCs in Arizona have a reservoir or pond with sport fish. We excluded HUCs on tribal lands, except for the Navajo and Hopi Nations where we were permitted access, resulting in 45 potential HUCs to survey. Reservoirs were targeted for the presence of sport fish and a boat ramp, but if such water bodies were not found within a HUC, water bodies without boat ramps and sport fish were considered. Water bodies were randomly selected from each HUC for sampling. However, we wanted to survey all reservoirs where AGFD had harvested aquatic vegetation in the past, so in some instances, more than one water body per HUC was surveyed. Surveys were conducted from 2004 to 2006 in June through October during the period when aquatic macrophytes are flowering to allow for easier identification.

Aquatic macrophytes were surveyed using two point-transect methods similar to the line intercept method described in Titus (1993). In reservoirs ≤5 m in average depth, we determined the length of the long axis by measuring it on a topographic map (TOPO! 2002) or by using a range-finder in the field. We placed five transects perpendicular to the long axis of the reservoir at 1/6, 2/6, 3/6, 4/6, and 5/6 the length of the long axis (Figure 1). We surveyed 20 points along each transect, one point located 1 m from the interface of water and land on each side of the reservoir and the remaining 18 spaced evenly on the transect line.

For deeper (>5 m average depth) reservoirs, we also used the point-transect method. Our sampling was restricted to low-gradient, near-shore slopes because these were most like-

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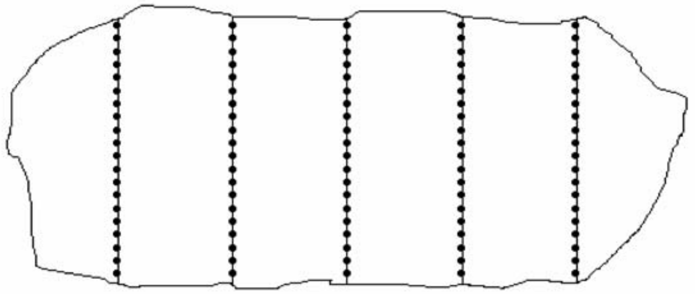

Figure 1. Diagram of transect layout for an aquatic plant survey of a shallow reservoir (mean depth <5 m).

ly to have established vegetation. We determined locations of low gradient near-shore slopes from a topographic map (TOPO! 2002) or our own visual examination at the reservoir. We selected 10 low-gradient slope locations around the reservoir, all at stream mouths as well as low-gradient areas near boat ramps, because these were likely invasion areas for invasive aquatic plants. We spread the remaining sampling locations relatively evenly around the reservoir shore to get a representative sample of the reservoir. At each location, we established a perpendicular-to-shore transect originating in the approximate center of the shoreline of the low-gradient slope and extending out to the edge of the aquatic weed bed, or out to the maximum depth we could reach the bottom with the fully extended 3.3-m sampling rake if the water was turbid and we could not see the edge of the aquatic weed bed. We sampled aquatic plants at 10 points along each transect beginning 1 m from the water-land interface, and the remaining nine located equidistant from each other.

A total of 100 points were sampled at each reservoir except at the following reservoirs: 20 points at Big Springs Pond because of its small size (0.4 ha), and at Marshall Lake one point was accidentally missed so only 99 points were sampled. Because of the large size (over 1,200 ha) of Topock Marsh, we added additional transects to acquire a better sample of the aquatic plants in this water body. At each sample point on each transect, we used a rake (Wolf Garten DO-M 35) with a 3-m long extendable pole (Wolf Garten, Vario ZM-V3) to collect aquatic plants, which restricted our maximum sampling depth to approximately 3.3 m. Aquatic plants were found on occasion to be at depths >3.3 m, depending on water turbidity. The rake head was lowered to the bottom and rotated 360° and then pulled to the surface (Gibbons et al. 1999). We recorded all taxa of aquatic macrophytes collected on the rake head. After all points on all transects were sampled, we did a roving survey around the reservoir to identify and record any species not found on transects. We collected a sample of each species for identification by a university botanist and took digital photographs for voucher of each aquatic plant species at each reservoir.

We identified aquatic vascular plants to species whenever possible. We did not identify all algae to species, so they were categorized into general groups (e.g., filamentous, encrusting), except for muskgrass and stoneworts (*Nitella* spp. C. A. Agardh), which were identified to the genus level. Cattails (*Typha* spp. L.) were typically identified to genus level. Terrestrial plants found along transects are not reported in this paper. For each aquatic plant species, we calculated prevalence (number of reservoirs with a species divided by the total number of reservoirs surveyed, multiplied by 100), percent frequency of occurrence (number of points with a species divided by the total number of points sampled, multiplied by 100), and percent composition (number of points with a taxa divided by the total number of points with plants, multiplied by 100). We only report percent frequency of occurrence for shallow lakes because these estimates derived from our point-transect methodology provide an estimate of percent cover for each species (Madsen 1999, Elzinga et al. 2001).

We used forward step-wise logistic regression (SPSS 2003) to assess if elevation, average depth, and average area were significant predictors of species occurrence. Variables were added or removed from the models by using likelihood ratio tests with a significance level of 0.05. We assessed goodness of fit of the models by examining -2 times the log of the likelihood (-2 LL), where the best model among those considered was the model with the smallest-2 LL value (Manly et al. 2002). Elevation, average surface area, and average depth of reservoirs were obtained from an AGFD database. All reservoirs surveyed were included in the logistic regression analyses except Lake Pleasant, which experiences large seasonal fluctuations in water elevations (18 to 24 m; Bryan 2005) because it is a water storage and delivery reservoir, which likely resulted in an absence of any aquatic vegetation at this reservoir.

To determine if our data supported biogeographic theory that the number of species increases with area, we assessed relationships between number of aquatic plant species (in categories submersed, emergent, or total) found in shallow reservoirs and average surface area (ha) with linear regression. Relationships between surface area and floating vegetation were not assessed because too few lakes had floating vegetation. Surface area was log transformed prior to analysis and was regressed against number of species, and in separate analyses, log-transformed number of species. Normality of data was assessed with probability plots of standardized residuals. Because most rooted species are limited to shallow waters, we only examined shallow reservoirs.

We used hierarchical cluster analysis to help describe typical aquatic plant assemblages in Arizona's reservoirs. Data used were binary: presence-absence of taxa at each lake. We formed two to seven clusters using the average linkage between groups (McGarigal et al. 2000) and used the phi 4-point correlation coefficient to assess between-group similarity and produce a dendrogram. To evaluate co-occurrence of taxa, we examined associations between pairs of species with two-way contingency table analysis and the phi coefficient (Zar 1984). Negative associations suggest potential competition, although species environmental requirements, dispersal characteristics, or stochastic events could also result in negative associations. We restricted the cluster and species association analyses to species that were found at five or more reservoirs.

RESULTS AND DISCUSSION

We sampled 38 reservoirs within 29 HUCs in Arizona from 2004 to 2006 (Figure 2). We did not reach our target of sampling a reservoir in the 45 available HUCs due to the drying of reservoirs in four HUCs, lack of access on tribal lands in three

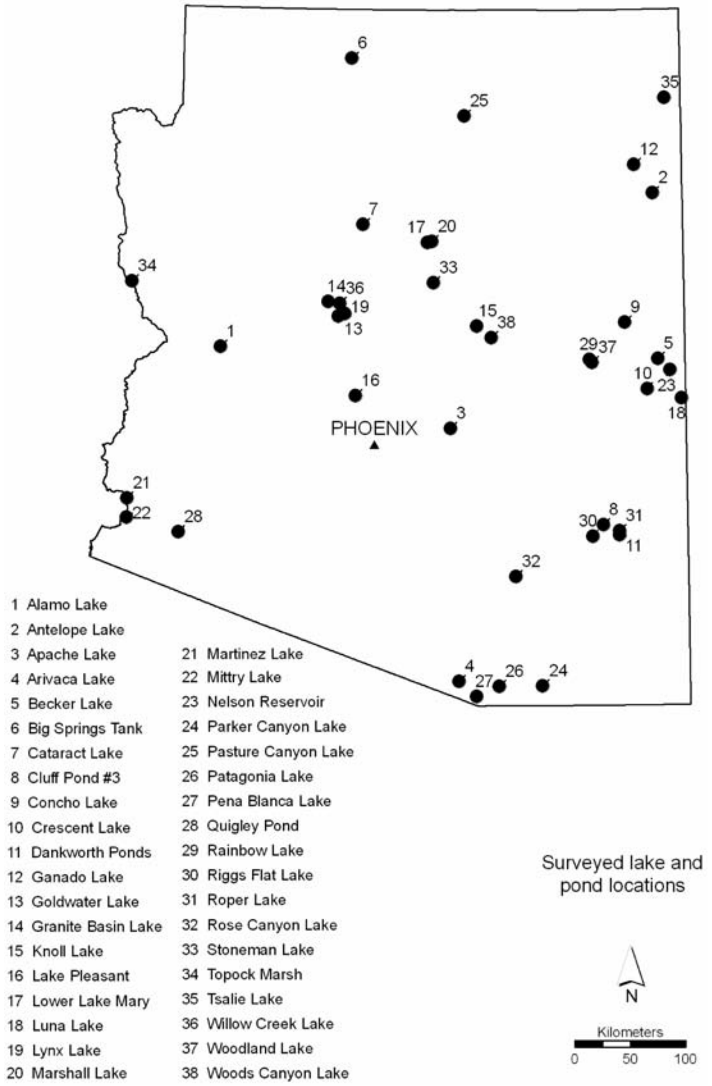

Figure 2. Map of Arizona showing reservoirs surveyed for aquatic vegetation from 2004 through 2006.

HUCs, rough road conditions in one HUC, and international border issues in one HUC. We did not sample reservoirs in seven other HUCs because of time and budgetary constraints.

During this study, the most prevalent taxa were filamentous algae, present at 76% of the sampled reservoirs (Table 1), and another alga taxon, muskgrass (*Chara* spp. L.), found at 53% of the sites surveyed. Our data supports Santamaria (2002) conclusion that aquatic vascular plants generally have broad geographic ranges. The most prevalent native aquatic plants in our survey had broad statewide distributions and were found at a wide range of elevations. The most prevalent vascular plant species were coontail (*Ceratophyllum demersum* L.), sago pondweed (*Stuckenia pectinatus* [L.] Boerner), cattails, and hard-stem bulrush (*Schoenoplectus acutus* [Muhl. ex Bigelow] A.&D. Löve), which were found in 42 to 47% of the reservoirs surveyed. Other species commonly found (prevalence 26 to 37%) in our surveys were northern watermilfoil (*Myriophyllum sibiricum* Komarov), water knotweed (*Polygonum amphibium* L.), two-leaf elodea (*Elodea bifoliata* St. John), and small pondweed (*Potamogeton pusillus* L.). Two nonnative aquatic macrophyte species were found on transects during our surveys: Eurasian watermilfoil (*Myriophyllum spicatum* L.) and curly-leafed pondweed (*Potamogeton crispus* L.). Eurasian watermilfoil was found at nine (24%) of the reservoirs we surveyed and curly-leafed pondweed was found at two (5%); however, at one of these reservoirs curly-leafed pondweed was not found on a transect but was seen floating at the boat ramp. Some of the plants in this study were not identified to species because of lack of identifying structures such as seeds or flowers.

A few of the aquatic macrophyte species dominated (percent compositions >50%) the species assemblage at study reservoirs where they were found (Table 1). Curly-leafed pondweed, an invasive nonnative, dominated (87% composition) the assemblage at the one reservoir where it was found on transects. Eurasian watermilfoil, also an invasive nonnative, was the most dominant aquatic macrophyte at four of the eight reservoirs where it was found on transects and had a mean composition of 61% at these eight reservoirs. For native species, the most dominant species was spiny naiad (*Najas marina* L.), which was found on transects at eight reservoirs (mean composition of 57%) and was the dominant aquatic macrophyte at five of those reservoirs (>75% composition). Spiny naiad was dense in backwater reservoirs along the Colorado River such as Martinez Lake near Yuma, Arizona, and Topock Marsh near Kingman, Arizona. Northern watermilfoil was the next most dominant native species, being the most common plant at 8 of the 13 reservoirs where it was found, with a mean composition of 54%. Several other native species that tended to dominate the aquatic plant communities included coontail, which dominated at 5 of 16 reservoirs where it was present and had a mean percent composition of 48%; two-leaf elodea, which dominated at 3 of 11 reservoirs where it was present and had a mean percent composition of 44%; and sago pondweed, which dominated at 5 of 16 reservoirs where it was present and had a mean percent composition of 42%. Coontail, spiny naiad, sago pondweed, northern watermilfoil, Eurasian watermilfoil, and filamentous algae were especially abundant, with percent compositions in excess of 90% at nine reservoirs.

We detected 19 significant ($p < 0.05$) positive associations (co-occurrence) between pairs of aquatic plant taxa (Table 2). For taxa groupings with more than two species, the most common aquatic plant assemblage in Arizona reservoirs was comprised of two-leaf elodea, water knotweed, and coontail (Figure 3); this assemblage was found at 10 lakes. An assemblage comprised of these three species plus sago pondweed was found at six lakes. Other groupings of more than two taxa were less common.

Negative species associations (Table 2) might result from competition or other factors such as environmental requirements, dispersal vectors, or stochastic processes; experimental studies would be needed to confirm competition. Cattail and creeping spikerush (*Eleocharis palustris* [L.] Roemer & J.A. Schultes) were negatively associated with one another, and given that both are emergent species, they might compete for resources. Eurasian watermilfoil was negatively associated with muskgrass, suggesting the two species might compete, or environmental requirements might be different, or other environmental conditions such as water quality and

Table 1. Aquatic plant taxa found in 38 Arizona reservoirs during 2004 through 2006 surveys, giving plant type (T: E = emergent, F = floating, S = submersed), prevalence (N_P = number of lakes with taxa present, and % P = percent of lakes with taxa present), mean percent composition (N_C = number of lakes with taxa found on transect points, and % C = number of points with taxa divided by total number of points with plants), and mean percent frequency of occurrence (only for shallow lakes; N_F = number of shallow lakes with taxa present, and % F = number of points with taxa divided by total number of points sampled). Also given are the minimum and maximum reservoir elevation (m), minimum and maximum average reservoir depth (m), and minimum and maximum average reservoir surface area (ha). N_P is greater than N_C when taxa were not found on transects but were found during the roving survey after transect sampling was complete.

Taxa	T	Min elev.	Max elev.	Min depth	Max depth	Min area	Max area	N_P	% P	N_C	% C	N_F	% F
Azolla filiculoides Lam.	F	1,567	1,567	15.2	15.2	8.1	8.1	1	2.6	1	7.1	1	6.0
Bacopa monnieri (L.) Pennell	E	23	23	2.4	2.4	131.5	131.5	1	2.6		—		—
Carex spp. L.	E	2,403	2,403	2.4	2.4	30.4	30.4	1	2.6	1	1.3	1	1.0
Carex stipata Muhl. Ex Willd.	E	2,664	2,664	13.7	13.7	4.5	4.5	1	2.6		—		—
Ceratophyllum demersum L.	S	23	2,403	0.9	27.4	4.0	283.3	16	42.1	16	48.0 (32.8)	13	37.0 (24.8)
Chara spp. L.	S	23	2,664	0.9	27.4	0.4	1295.0	20	52.6	20	21.8 (26.0)	19	17.8 (23.1)
Crypsis schoenoides (L.) Lam.	E	1,567	1,567	15.2	15.2	8.1	8.1	1	2.6	1	2.4	1	2.0
Cyperus esculentus L.	E	1,685	1,685	12.2	12.2	22.3	22.3	1	2.6	1	2.2	0	—
Cyperus odoratus L.	E	1,642	1,642	25.0	25.0	50.6	50.6	1	2.6	1	2.1	0	—
Cyperus spp. L.	E	55	2,168	0.9	73.2	14.2	1092.7	4	10.5	3	18.3 (2/8.3)	1	1.0
Echinochloa crus-galli (L.) Beauv.	E	1,685	2,143	1.8	12.2	22.3	1295.0	3	7.9	1	6.7	0	—
Eleocharis palustris (L.) Roemer &J.A. Schultes	E	1,488	2,403	0.9	15.2	0.4	1295.0	8	21.1	8	3.1 (2.1)	8	2.6 (1.8)
Eleocharis parishii Britt.	E	1,567	2,044	1.8	15.2	8.1	32.4	2	5.3	2	1.1 (0.1)	2	1.0 (0.0)
Eleocharis spp. R. Br.	E	2,664	2,664	13.7	13.7	4.5	4.5	1	2.6	1	1.6	1	1.0
Elodea bifoliata St. John	S	1,567	2,757	0.9	15.2	4.0	1295.0	11	28.9	11	43.5 (28.3)	11	38.3 (25.2)
Filamentous algae		23	2,757	0.9	25.0	0.4	1295.0	29	76.3	28	30.3 (29.6)	24	24.9 (26.2)
Glyceria grandis S. Wats.	E	2,044	2,403	1.8	2.4	30.4	32.4	2	5.3	1	2.5	1	2.0
Juncus effuses L.	E	2,113	2,113	13.4	13.4	2.8	2.8	1	2.6	0	—	0	—
Lemna minor L.	F	335	1,700	1.8	24.4	2.0	1092.7	3	7.9	3	2.9 (2.2)	2	2.5 (2.1)
Myriophyllum sibiricum Komagorov	S	1,008	2,757	0.9	15.2	1.2	1295.0	14	36.8	13	53.9 (33.5)	12	37.3 (27.4)
Myriophyllum spicatum L.	S	335	2,664	1.8	25.0	4.5	1092.7	9	23.7	8	61.4 (32.2)	5	39.6 (26.5)
Najas guadalupensis (Spreng.) magnus	S	1,567	1,567	15.2	15.2	8.1	8.1	1	2.6	1	3.6	1	3.0
Najas marina L.	S	23	1,567	1.8	27.4	4.0	1214.1	8	21.1	8	56.6 (42.5)	6	46.9 (26.1)
Nitella spp. L.	S	977	1,642	4.6	25.0	4.0	50.6	2	5.3	2	11.8 (13.7)	1	17.0
Phragmites australis (Cav.) Trin. Ex Steud.	E	23	583	2.4	73.2	131.5	1039.3	3	7.9	3	16.4 (17.2)	2	3.5 (0.7)
Polygonum amphibium L.	E	1,488	2,403	0.9	15.2	4.0	1295.0	13	34.2	10	11.6 (10.0)	10	8.9 (7.0)
Polygonum argyrocoleon Steud. Ex Kunze	E	1,685	1,685	12.2	12.2	22.3	22.3	1	2.6	1	2.2	0	—
Polygonum lapathifolium L.	E	1,168	2,143	12.2	25.0	18.2	105.2	4	10.5	0	—	0	—
Polygonum spp. L.	E	55	583	3.0	73.2	259.0	1039.3	2	5.3	1	2.8	0	—
Pontederia spp. L.	E	2,044	2,044	1.8	1.8	32.4	32.4	1	2.6	1	7.1	1	7.0
Potamogeton crispus L.	S	23	1,700	1.8	2.4	2.0	131.5	2	5.3	1	86.5	1	64.0
Potamogeton foliosus Raf.	S	1,567	1,567	15.2	15.2	8.1	8.1	1	2.6	1	1.2	1	1.0
Potamogeton pusillus L.	S	23	2,664	1.8	19.8	1.2	1295.0	10	26.3	9	19.7 (26.1)	8	16.9 (21.4)
Rannunculus longirostris Godr	S	2,168	2,664	0.9	13.7	1.2	30.4	5	13.2	5	5.4 (3.3)	5	4.4 (2.6)
Rorippa nasturtium-aquaticum (L.) Hayek	E	2,117	2,117	0.9	0.9	0.4	0.4	1	2.6	1	11.1	1	10.0
Schoenoplectus acutus Muhl. ex Bigelow A.&D. Love	E	23	2,664	0.9	25.0	2.0	1214.1	17	44.7	13	9.8 (10.4)	12	7.1 (8.9)
Scirpus microcarpus J. & K. Presl	E	2,664	2,664	13.7	13.7	4.5	4.5	1	2.6	0	—	0	—
Sparganium spp. L.	E	2,047	2,047	3.0	3.0	68.8	68.8	1	2.6	1	1.0	1	1.0
Spirodela polyrhiza (L.) Schleiden	F	1,168	1,168	19.8	19.8	18.2	18.2	1	2.6	1	4.0	0	—
Stuckenia filiformis (Pers.) Boerner	S	951	951	6.1	6.1	13.0	13.0	1	2.6	1	2.0	1	1.0
Stuckenia pectinatus (L.) Boerner	S	23	2,757	0.9	15.2	4.0	1295.0	16	42.1	16	42.2 (29.1)	16	36.4 (28.6)
Typha spp. L.	E	23	2,259	1.2	73.2	2.0	1214.1	18	47.4	15	22.1 (27.2)	11	5.1 (4.1)
Veronica anagallis-aquatica L.	E	1,567	1,567	15.2	15.2	8.1	8.1	1	2.6	1	1.2	1	1.0

Table 2. Co-occurrence (phi coefficient; Zar 1984) of aquatic plant taxa found in Arizona reservoirs during surveys 2004 through 2006. Significant ($P < 0.05$) phi coefficients are indicated with an asterisk; N = 38 reservoirs. Coefficients with water buttercup and hard-stem bulrush were not significant and so are not shown.

		Coontail	Muskgrass	Two-leaf elodea	Creeping spikerush	Filamentous algae	Northern watermilfoil	Eurasian watermilfoil	Spiny naiad	Water knotweed	Small pondweed	Sago pondweed
Muskgrass	Φ_2	0.275										
	P	0.094										
Two-leaf elodea	Φ_2	0.513	0.141									
	P	0.001*	0.400									
Creeping spikerush	Φ_2	0.213	0.102	0.382								
	P	0.198	0.542	0.018*								
Filamentous algae	Φ_2	0.350	0.339	0.356	0.288							
	P	0.031*	0.037*	0.028*	0.080							
Northern watermilfoil	Φ_2	0.233	0.178	0.355	0.141	0.297						
	P	0.160	0.284	0.029*	0.399	0.070						
Eurasian watermilfoil	Φ_2	0.152	-0.339	0.054	0.016	0.019	-0.297					
	P	0.363	0.037*	0.748	0.924	0.909	0.070					
Spiny naiad	Φ_2	-0.048	0.361	-0.187	-0.108	-0.168	-0.261	-0.136				
	P	0.774	0.026*	0.260	0.517	0.314	0.114	0.416				
Water knotweed	Φ_2	0.621	0.240	0.763	0.444	0.271	0.484	0.120	-0.236			
	P	0.000*	0.147	0.000*	0.005*	0.100	0.002*	0.472	0.153			
Small pondweed	Φ_2	0.096	0.208	0.014	0.131	0.333	0.163	0.089	-0.015	-0.053		
	P	0.568	0.210	0.934	0.433	0.041*	0.328	0.596	0.927	0.752		
Sago pondweed	Φ_2	0.352	0.382	0.513	0.344	0.350	0.343	-0.224	0.344	0.509	-0.147	
	P	0.030*	0.018*	0.001*	0.034*	0.031	0.035*	0.176	0.034*	0.001*	0.380	
Cattail	Φ_2	-0.169	-0.050	-0.257	-0.361	-0.215	-0.178	-0.157	0.286	-0.240	0.031	-0.062
	P	0.312	0.766	0.119	0.026*	0.194	0.284	0.348	0.082	0.147	0.851	0.712

nutrient composition in specific reservoirs might be causing this negative association.

Although results of other studies (Madsen et al. 1991, Boylen et al. 1999) have indicated that a decline in native vegetation can occur under dense Eurasian watermilfoil canopies, our data for the most part do not support this contention. Eurasian watermilfoil had greater percent composition than the cumulative percent composition of native plants at only three of the nine reservoirs where it occurred, and at only two reservoirs, Parker Canyon Lake and Goldwater Lake, was Eurasian watermilfoil by far the most dominant aquatic plant. Madsen (1998) found that reservoirs with more than 50% Eurasian watermilfoil dominance had less than 60% cumulative native plant coverage. Our data do not support this contention; at five of the nine lakes with Eurasian watermilfoil in our study, Eurasian watermilfoil had compositions greater than 50%, but of these five, four were shallow lakes for which we estimated percent coverage and only one had less than 60% cumulative native plant coverage. At the five reservoirs where native aquatic plants had higher percentage composition than Eurasian watermilfoil, possibly more time is needed for this macrophyte to increase coverage, or native species in Arizona may out-compete this nonnative macrophyte, or environmental requirements and dispersal vectors may be limiting this species success in Arizona.

Other studies have concluded that Eurasian watermilfoil could out-compete northern watermilfoil (Nichols 1994, but see Valley and Newman 1998 for an opposite conclusion) and spiny naiad (Agami and Waisel 1985). We did not detect a significant negative association in occurrence between the Eurasian watermilfoil and northern watermilfoil (Table 2), but at the one reservoir where the two species co-occurred (Goldwater Lake), Eurasian watermilfoil had a greater percent composition (87%) than northern watermilfoil (69.6%), lending some indirect support to the hypothesis that Eurasian watermilfoil is the superior competitor. Similarly, we did not detect a significant negative association between Eurasian watermilfoil and spiny naiad, but at Alamo Lake, the only reservoir where both species were present, spiny naiad comprised 12% of the species composition and Eurasian watermilfoil was 41%, lending indirect support to the findings of Agami and Waisel (1985).

Results of our logistic regressions indicate that average depth and elevation were significant predictors of species occurrence (Table 3). Average depth was a significant predictor of occurrence for muskgrass, water knotweed, and sago pondweed, three species that may be light-limited and so were more likely to be found in shallow than deep reservoirs; average depth was not a significant predictor of occurrence for other species examined. Elevation was a significant predictor of species occurrence for six species. Cattails and spiny naiad were more likely to occur at low elevation reservoirs than at high elevation reservoirs, whereas, two-leaf elodea, northern watermilfoil, water knotweed, and water buttercup (*Rannunculus longirostris* Godr.) were more likely to occur at high elevation reservoirs than at low elevation reservoirs. Elevation was not a significant predictor of occurrence of Eurasian watermilfoil, coontail, small pondweed, creeping spikerush, and hard-stem bulrush. Eurasian watermilfoil presence at reservoirs below 1000 m of elevation displays its ability to be an invasive at lower elevations where northern watermilfoil was not found. Monitoring of reservoirs where Eurasian watermilfoil is present will help us better understand its invasive ability

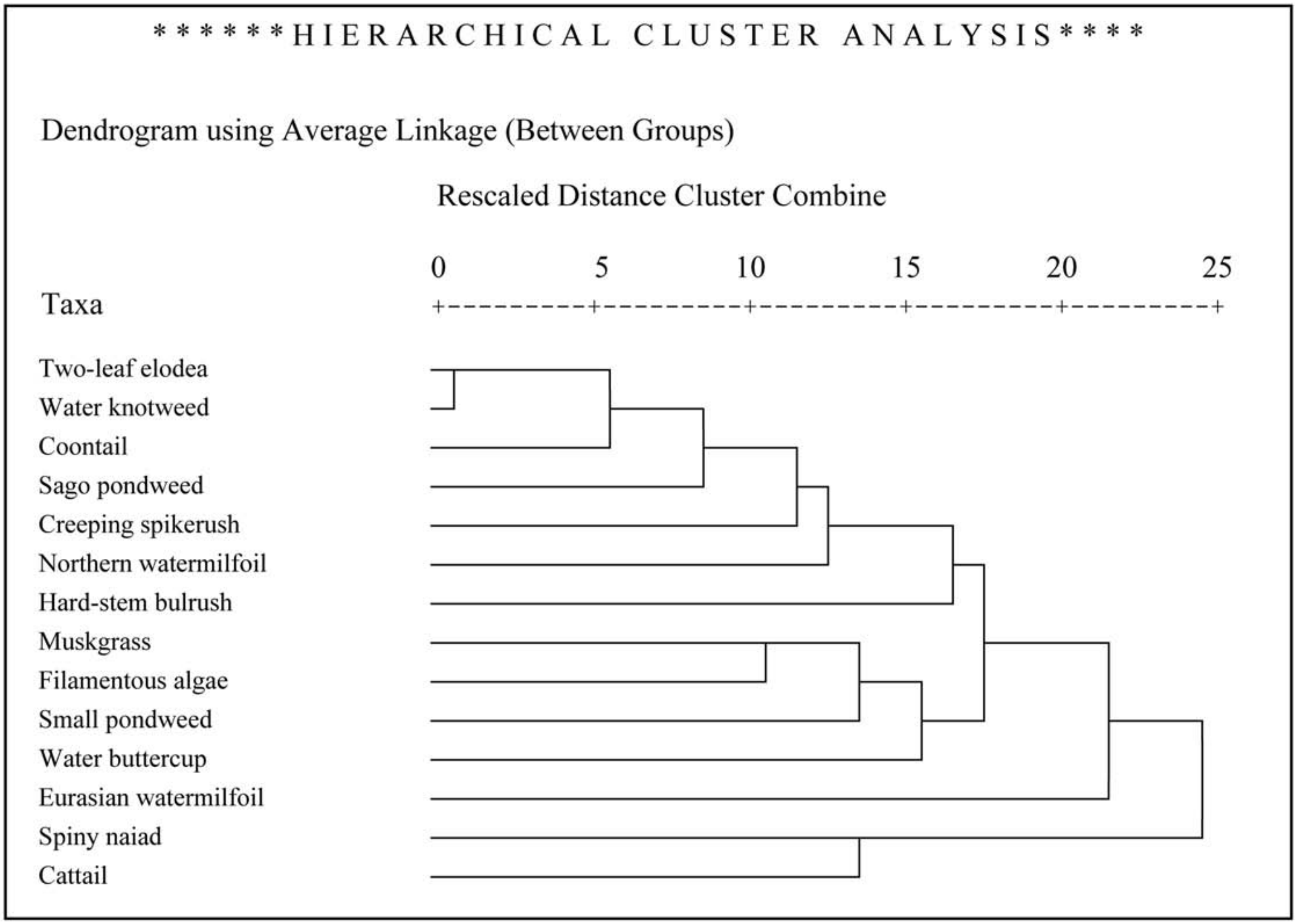

Figure 3. Dendrogram resulting from hierarchical cluster analysis of aquatic plant occurrence in Arizona reservoirs, where clusters were formed using average linkage between groups and were assessed with the phi 4-point coefficient (SPSS 2003).

and probability of spread in Arizona. Average surface area was not a significant predictor of occurrence for any of the species examined. Average surface area (log transformed) was however, significantly related to the log transformed number of submersed aquatic plant taxa found at reservoirs [log species = 0.386 + 0.117(log area), $r^2 = 0.151$, df = 1, 24, $p = 0.05$]; no relationships between surface area and number of emergent species or total species were statistically significant.

In four surveyed reservoirs, we detected no aquatic macrophytes in the water: Cataract Lake, Knoll Lake, Lake Pleasant, and Woods Canyon Lake (Woods Canyon Lake and Cataract Lake had emergent taxa along the bank). Unlike other reservoirs we examined, Lake Pleasant experiences large seasonal fluctuations in water level, which likely resulted in the absence of aquatic vegetation at this reservoir; U.S. Bureau of Reclamation pumps water into and stores water in the reservoir during winter and pumps water out into the Central Arizona Project canal during summer. Knoll Lake and Woods Canyon Lake were deep and had steep rocky sides and rocky substrates, so areas suitable for rooted aquatic vegetation were restricted to the few shallow stream inflow areas with fine substrates, which for some unknown reason were still absent of aquatic vegetation. Cataract Lake was not as deep as the other three reservoirs, but it still had mostly steep rocky sides and its bottom substrate was the same as the deeper lakes.

Filamentous algae and the native aquatic plants coontail, northern watermilfoil, sago pondweed, and spiny naiad, and the nonnative Eurasian watermilfoil had relatively high prevalence statewide (>21%), and each had percent frequency of occurrence (an estimate of percent cover in our shallow lakes) in excess of 24%. These six taxa are therefore good targets for integrated management approaches. Muskgrass had a high prevalence but low percent frequency of occurrence within reservoirs; therefore, it is probably less of a management concern. Another species, curly-leafed pondweed, was listed as a problem by eight states because of its invasive and competitive abilities with other native aquatic plants (Bartodziej and Ludlow 1997). This species may become problematic in Arizona but at present is not of widespread concern. Curly-leafed pondweed was only found at two reservoirs; it was rare at Mittry Lake, but at Granite Basin Lake it covered 64% of the reservoir with a composition of 87%.

TABLE 3. RESULTS OF FORWARD-STEPWISE LOGISTIC REGRESSIONS, SHOWING COEFFICIENTS WITH STANDARD ERRORS, WALD STATISTICS, PROBABILITIES, AND -2 TIMES LOG-LIKELIHOOD (-2 LL) OF THE INCLUDED VARIABLES IN THE FINAL MODELS. ELEVATION (M), AVERAGE DEPTH (M), AND AVERAGE AREA (HA) WERE INPUT INTO EACH MODEL. MODELS FOR COONTAIL, CREEPING SPIKERUSH, EURASIAN WATERMILFOIL, SMALL PONDWEED, AND HARD-STEM BULRUSH WERE NOT SIGNIFICANT, AND ARE NOT SHOWN.

Taxa	Variable	B	SE	Wald	P	-2 LL
Muskgrass	Constant	0.876	0.495	3.131	0.077	
	Depth (m)	-0.085	0.047	3.271	0.071	45.955
Two-leaf elodea	Constant	-5.265	2.164	5.919	0.015	
	Elevation (m)	0.002	0.001	5.079	0.024	34.859
Northern watermilfoil	Constant	-2.273	1.204	5.111	0.024	
	Elevation (m)	0.001	0.001	4.272	0.039	43.251
Spiny naiad	Constant	2.007	1.084	3.431	0.064	
	Elevation (m)	-0.003	0.001	9.278	0.002	22.253
Water knotweed	Constant	-1.849	1.375	1.809	0.179	
	Elevation (m)	0.001	0.001	4.403	0.036	32.603
	Depth (m)	-0.224	0.104	4.670	0.031	
Water buttercup	Constant	-12.679	5.630	5.072	0.024	
	Elevation (m)	0.005	0.003	4.235	0.040	18.551
Sago pondweed	Constant	0.958	0.548	3.060	0.080	
	Depth (m)	-0.188	0.082	5.261	0.022	39.794
Cattail	Constant	2.627	1.150	6.672	0.022	
	Elevation (m)	-0.002	0.001	5.218	0.010	41.592

We recommend that management of aquatic plants in Arizona's reservoirs should focus on filamentous algae, the nonnative species Eurasian watermilfoil and curly-leafed pondweed, and the native species coontail, sago pondweed, spiny naiad, and northern watermilfoil. These species can cover extensive areas of reservoirs and form dense stands that hinder various recreational activities such as boating access, fishing, and water quality for fish stocking. Management of these species will inadvertently affect other plant species in the assemblage, particularly those that we found to co-occur with these species. The occurrence of the nonnative invasive species Eurasian watermilfoil, curly-leafed pondweed, and others that have been recorded in the state in the past, such as giant salvinia (*Salvinia molesta* Dum.) and Hydrilla (*Hydrilla verticillata* [L. f.] Royle), need to be monitored so that action can be taken to prevent their spread.

ACKNOWLEDGMENTS

The Sport Fish Restoration State Trust Grant F-14R program funded this project. A special thanks to all who helped with the fieldwork: Bob Achee, Lorraine Avenetti, Dana Bayer, Kirby Bristow, John Broecher, Scott Bryan, Todd Buck, Chris Cantrell, Matt Chmiel, Michelle Crabb, Garret Fabian, Dannette Ihle, Jason Kline, Anne Kretschmann, Marianne Meding, Richard Myers, Richard Ockenfels, Matt Rinker, Diana Rogers, Tim Rogers, Shondra Seils, Scott Sprague, Bill Stewart, Shawn Wagner, and to Sue Boe for the map of Arizona showing reservoirs surveyed. We appreciate all the helpful comments on the manuscript provided by Chris Cantrell, Marianne Meding, Chantal O'Brien, Bill Persons, and David Ward.

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