ASSESSING FUNCTIONAL INTEGRITY OF MOIST-SOIL MANAGED WETLANDS BY COMPARISON WITH NEARBY NON-MANAGED SYSTEMS

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ABSTRACT

Our objective was to evaluate impacts of moist-soil habitat management on water quality and biological communities in wetland areas at the Strawberry Plains Audubon center in Holly Springs, MS. The study area is a 1000-ha farm presently undergoing conversion from agricultural land to wildlife habitat under the supervision of Audubon personnel, who assumed management of the property in 1998. In assessing the ecological status of the study wetlands, we evaluated a suite of physical water quality parameters (dissolved oxygen, turbidity, conductivity, pH, alkalinity, and temperature); concentration of nutrients, sediment, and chlorophyll *a* within surface waters; and plant cover, biomass, and species richness.

Certain attributes of these systems (dissolved oxygen, turbidity, and conductivity) did indicate differences among the wetlands under investigation. Among these, turbidity seemed most closely correlated with initial management activities. However, perturbations, as indicated by increased turbidity during installation of water control structures, were short-lived, presumably because of post-agriculture recovery already underway in the watersheds surrounding the study sites.

Based on data collected during the year prior to active wetlands management by Audubon, six impoundments were selected for continued monitoring following installation of standpipe control structures and initial management activities. These sites include four farm ponds (two unmanaged and two that will be managed to enhance moist-soil habitat), one natural beaver impoundment, and one created riparian wetland (Study Sites, at right). Recovery of the managed wetlands will be assessed in comparison with non-managed sites at Strawberry Plains, including the on-site beaver impoundment.

INTRODUCTION

This project was conducted in cooperation with the National Audubon Society to evaluate effects of moist-soil habitat management practices on water quality and other wetland functions. The study site is a 1000-ha farm near Holly Springs, MS, presently undergoing conversion from agricultural land to wildlife habitat under the supervision of Audubon personnel. Part of the Audubon management plan at Strawberry Plains is the enhancement of ecotonal areas (margins of forests, ponds, and streams) for bird and other wildlife use. In addition to a number of streams that make up a substantial portion of the Coldwater River headwaters, aquatic resources on the reserve include numerous farm ponds installed to aid in erosion control. Center managers plan to install or enhance water control structures along one major stream and around two farm ponds in order to increase moist-soil resources for waterfowl and other aquatic animal species, such as amphibians, fish, and mammals.

The aim of moist-soil management is to recreate more-or-less natural hydrologic cycles in managed wetlands to increase the diversity and production of plant and animal species for wildlife food and habitat (Fredrickson, 1996). Under moist-soil manipulation, water levels are lowered during the growing season to stimulate seed germination of wetland-adapted plants and to increase the oxygenation of soils to stimulate plant productivity. In autumn, water levels are raised to discourage establishment of non-wetland plant species and increase habitat diversity for invertebrate animals that serve as food for waterfowl and other aquatic wildlife, in addition to seeds that are produced by the moist-soil plant community. Water level manipulations often are accompanied by soil manipulations, such as tilling or disking, that maintain high plant species diversity and high seed production for wildlife (Fredrickson, 1996; Gray et al., 1999). Moist-soil management practices at Strawberry Plains will include mowing, tilling, and planting in shallow areas of each of three man-made impoundments to enhance early-successional herbaceous plant species for increased seed and invertebrate production.

Despite the substantial amount of land being converted to and managed as moist-soil waterfowl habitat (more than 80,000 ha throughout Arkansas, Louisiana, Mississippi, and Tennessee), there are no published comprehensive estimates on the effects of this manipulation on water quality and wetland plant communities. Data presented in this paper will serve as indicators of baseline conditions during our multi-year examination of the ecological impact of Audubon moist-soil habitat management.

MATERIALS AND METHODS

A total of nine sites were initially included in pre-management monitoring (Fig. 1, plus an additional riverine beaver impoundment on a large tributary to the Coldwater River). Depending on site hydrology, one to three inflow and outflow collection points were established in March of 2002 for measurement of: nitrogen (ammonia, nitrate, nitrite) and phosphorus (phosphate) concentration; sediment load within surface waters; dissolved oxygen, turbidity, conductivity, pH, and temperature; and wetland plant assemblage (Table 1). Inflow samples were collected in areas with obvious surface hydrologic inputs, and outflow samples were collected at the mouth of the water control structure on the wetland side of the levee or at obvious outflow points along the levee or beaver dam. The multiple measurements were used to calculate average values for water quality parameters measured at each site.

Field measurements

Approximately monthly field measurements were conducted to evaluate patterns in dissolved oxygen, conductivity, pH, temperature, and turbidity of water in each wetland. Each of these parameters provides important information regarding ecological health of the wetland in performing its natural water filtration functions (Table 1). Dissolved oxygen, conductivity, pH, temperature, and turbidity were measured with a Yellow Springs Instruments (YSI) handheld multi-probe environmental monitoring system.

Organic and inorganic sediment accretion was measured by anchoring sediment traps atop the existing soil/sediment along two random transects through each wetland area (methodology similar to Brueske and Barrett, 1994 and Fennessy et al., 1994). Transects were established at depths of 30cm and 60cm, and each consisted of 4 sediment collection traps (a total of 8 traps per wetland). Each trap was built from a pre-weighed, wide-mouth plastic bottle, anchored to the sediments with a plastic stake. At the time of placement, traps were filled with frozen tap water to prevent deposition of the disturbed sediments within traps. Traps were collected once water levels subsided such that some trap mouths became exposed to air. After settling of contents, water was siphoned from each trap, and the bottle and contents dried (105°C for 24h) to determine dry mass of sediment deposition.

Laboratory analyses

Ammonia, nitrite, nitrate, and phosphate concentrations were measured by standard colorimetric methods (APHA et al., 1998), through the use of pre-mixed, self-filling reagent vials (CHEMetrics VACUvials®) and spectrophotometric determination of nutrient concentrations, based on analyses of a known standard curve.

Alkalinity was measured by direct titration of water samples with standard acid to the phenolphthalein and total alkalinity endpoint (LaMotte alkalinity kit).

Concentration of suspended solids in the water column was measured by filtering water samples through pre-combusted (500°C), pre-weighed 0.7 mm glass fiber filters. Filters were dried at 105°C and re-weighed after drying to yield mg dry matter per mL water (APHA et al., 1998).

Water column algal biomass was represented by chlorophyll *a* concentration. Chlorophyll *a* content (mg chl *a* per mL) was determined by the phytoplankton method of Wetzel and Likens (2000), as follows. Water was collected at each sampling point and filtered through 0.7 μm glass fiber filters. These filters were then placed into glass centrifuge tubes and ground in 3 mL alkaline 90% acetone to extract pigments. Pigment concentration was then assayed by measuring absorbance of the centrifuged extract (before and after acidification) at 665 nm (chl a) and 750 nm (turbidity correction); these values were used in the equations provided by Wetzel and Likens (2000) to determine mg chlorophyll *a* per mL water.

Plant Community

Permanent line transects and quadrats were established in the wetland zone of each impoundment to monitor development of the plant community. Two transects were placed in each wetland: one longitudinal transect extending from the inflow sample collection site(s) toward the outflow and one transect along the land-water interface at time of transect set-up. The length of each transect intercepting plant canopies was recorded by plant species. These data were used to calculate species richness and percent cover by species for each wetland.

In addition to evaluation of wetland vegetative cover along these transects, two square 1m^2 quadrats were established at randomly selected locations near the inflow data collection points. These quadrats were used to collect percent coverage and biomass data. Biomass harvest was made in late August to determine mean above-ground biomass of the plant communities. All above-ground plant material located within these quadrats was harvested, separated into species, dried (105°C, 24h), and weighed.

Statistical analyses

Water quality field parameter data were analyzed by repeated-measures multivariate analysis of variance (RM MANOVA). Other data were examined by principle components analysis and cluster analysis to determine which parameters, of the many evaluated, contributed most to differences among sites and to determine which sites were most similar to one another, based on the most informative parameters.

Principle components factor analysis was used to evaluate which parameters were most informative of differences among sites. These PC analyses were conducted with correlation matrices, using a minimum eigenvalue of 1.0 as a cut-off for selecting important PCA axes. Euclidean distances were used to determine separation of sites among clusters determined by Ward's linkage estimation (McCune et al., 2002).

RESULTS

Field-measured water quality (WQ) data provided insight into two aspects of the study: comparisons among sites (and guidance for grouping sites for our continued investigations) and responses of these ponds and associated wetlands to initial disturbance involved with initiating moist-soil management (Figs. 2-4).

Repeated-measures MANOVA of WQ data indicated significant differences among sites for pH, temperature, and conductivity during the June through February period (for the eight complete sets of data available for all sites) (Fig. 2A, C, E). Dissolved oxygen saturation also might have been considered marginally different among sites during this period ($P = 0.07$; Fig. 2B). However, in Jan & Feb 2003, after preparative drawdown, only conductivity and DO % saturation were significantly different among sites (Fig. 2B, E).

Despite differences based on WQ parameters, cluster analyses (guided by PC analysis of the full set of WQ parameters listed above) indicated that the sites for which data are presented were most similar among the nine surveyed for pre-manipulation baseline data (Fig. 3). Those nine sites included sites A, B, and 1-6 from Fig. 1 and an additional beaver pond along a 3rd-4th order tributary to the Coldwater River. The cluster tree represented was derived from data collected in March and May through September 2002. Results indicated that the sites most closely resembling the upland impoundments designated for management were upland sites 3 and 4.

Biotic data illustrated additional similarities among the six sites selected for continued investigation. Avifauna use information was unavailable for all nine sites; data were collected for only three of the sites examined in 2002-2003 (Table 2). These data showed that the two upland sites designated for manipulation are very similar in wildlife function to the natural beaver impoundment, with most species observed in the two upland sites also represented at the beaver impoundment. Presently, none of the bird species found to use the wetland areas of Strawberry Plains are sufficiently rare to be listed as threatened or endangered in the US, but some are of special conservation concern because of their exclusive use of wetland habitats (e.g., prothonotary warbler). Vegetation analyses also indicated similarities among the four upland sites (Table 3).

DISCUSSION

These data provided information on two important points regarding our study design and the management activities being employed by Audubon. First, we have grouped sites based on indications among the baseline data, whose patterns consistently demonstrated that the four farm ponds discussed here are most similar from among the six included in our baseline study. The most likely cause of the differences that were observed are the larger surface area of those ponds that were warmer and had higher dissolved oxygen concentrations and pH. The larger surface area permits greater insolation and higher total photosynthesis, which increases both DO and pH. Still, because of similarities in overall water quality among these sites, our continued monitoring should provide information on the potential impact of the management being implemented.

Secondly, the lower number of differences found among sites following the preparative drawdown indicates that the disturbed systems are recovering rapidly. Further, there is marked similarity in pH and dissolved oxygen between all four farm ponds and the beaver pond, also suggesting some degree of ecological integrity of those man-made ponds and their wetland fringes. These factors likely are the result of the protection provided to these ponds and wetlands by Audubon's removal of agriculture and grazing from the supplying watersheds in 1998. Vegetation succession in those uplands probably has resulted in substantial buffering against external perturbations.

It has been demonstrated repeatedly that biotic components of disturbed or created wetlands are highly variable in their capacity for recovery after perturbations. In a study of 10 natural and 10 restored wetlands, restored wetlands were found to be very similar in plant species composition three years after restoration was completed (Galatowitsch and van der Valk, 1996). Wetlands designed for treatment of mine drainage possessed reptile and amphibian communities very similar to those of nearby natural wetlands within 5 years after construction (Lacki et al. 1992); however, restored wetlands in New York did not perform similar habitat functions as local reference wetlands 2 years after restoration because bird communities, although similar in numbers of species and individuals, supported very different species compositions (Brown and Smith 1998).

Whereas biological communities may take 3 to 5 or more years to fully establish in created wetlands, water quality improvement may begin much more quickly. Henry et al. (1995) reported approximately 50% reduction in phosphorus concentration and a 50 to 70% reduction in ammonium concentrations within 2 years after stream channel restoration in a Rhône River restoration project. In two created wetlands in Ohio, phosphorus removal ranged from 45% to 89% during the first three years after construction, nitrogen removal from 25% to 49%, and turbidity reduction (light absorption by suspended and dissolved materials) ranged from 38% to 68% during this early period (Mitsch et al., 1998). Experimental created wetlands in Illinois showed removal rates of up to 99% of nitrogen, phosphorus, and suspended solids within 5 years after construction (Dey et al., 1994).

Thus, most studies indicate that while water quality improvements may be observed relatively quickly, especially where water quality is represented by such parameters as turbidity and dissolved nitrogen or phosphorus, changes in biotic assemblages require substantially more time. These are precisely the patterns we have observed in our first year of monitoring habitat recovery at Strawberry Plains. Although there was a great deal of variation in some biotic parameters among sites, there also was a significant amount of overlap between the managed and unmanaged sites in vegetation characteristics. Furthermore, water quality perturbations resulting from Audubon's early habitat manipulations have abated relatively quickly, presumably because of the four years of recovery experienced in the immediately surrounding watersheds of the study sites.

Typically, studies of wetland areas managed as wildlife habitat focus on factors of those ecosystems of direct influence on the species towards which management is targeted. Studies of fire as a management tool in coastal marshes of Louisiana demonstrated benefits to both plant and bird communities but failed to consider the effects of burning on water quality or other hydrologic factors (Gabrey et al., 2001). Similarly, most studies of moist-soil management for waterfowl evaluate management effects only on waterfowl food species such as moist-soil plants or aquatic invertebrates (Gray et al., 1999; Anderson and Smith, 2000), and even those studies are a recent addition to investigations of manipulation effects on wetland ecosystems (Anderson and Smith, 2000).

Data collected to date will serve as indicators of baseline conditions during our multi-year examination of the ecological impact of Audubon habitat management. Year two will coincide with initial implementation of moist-soil management practices, after the April 2003 installation of water control structures in the three impoundments designated for manipulation. Investigations during subsequent years will provide some of the first available information on the degree to which habitat manipulation affects ecological structure and function of the wetland areas. Similar investigations on the Missouri River floodplain are in progress, in which such comparisons are being conducted among different wetland basins, that are managed or unmanaged, but those studies are not yet complete (Leigh H. Fredrickson, Director, Missouri Agricultural Experiment Station Gaylord Wetland and Waterfowl Ecology and Management Laboratory, personal communication).

One study, however, has reported a benefit to no-till management of moist-soil overwintering habitat for waterfowl. Kaminski et al. (1999) reported that tillage in rice fields after harvest resulted in 1000 pounds per acre erosion, whereas untilled field lost only 31 pounds per acre over the winter. This single study indicates the potential for substantial impacts on water quality as a result of soil manipulation practices in moist-soil managed waterfowl habitat, especially in light of intensive management efforts to increase the acreage of these wetlands along migratory paths. For example, in recent years, Ducks Unlimited has installed or assisted in installation of around 85,400 hectares of winter habitat, including flooded cropland throughout Arkansas, Louisiana, Mississippi, and Tennessee (Tim Willis, MS DU Project Biologist, personal communication). Our continued monitoring of management and reclamation efforts by Audubon should provide much-needed information regarding the broader ecological impact of management activities on such lands.

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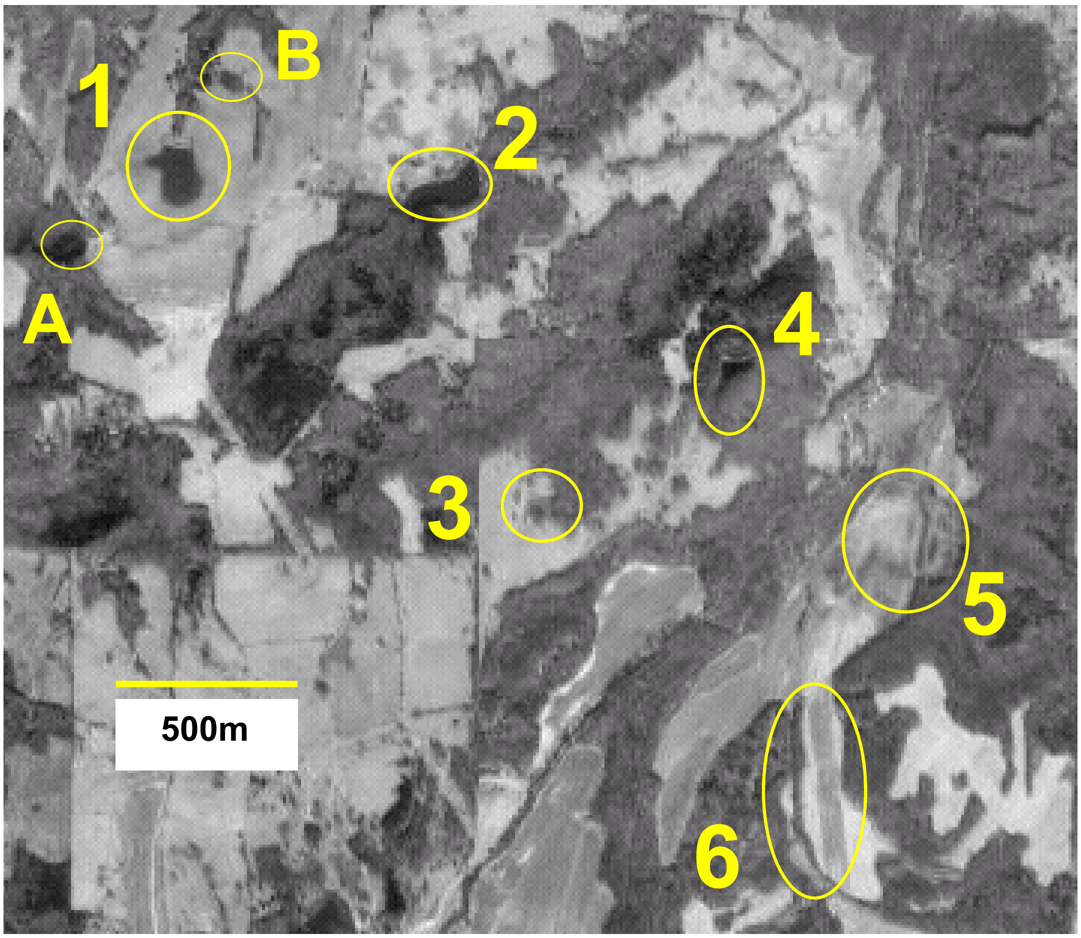

Figure 1. Location of the individual study sites at the Strawberry Plains Audubon Center, Holly Springs, MS. Sites are (A) Farm Pond 1; (B) Farm Pond 2; (1) Manipulated Pond 1; (2) Manipulated Pond 2; (3) Farm Pond 3; (4) Farm Pond 4; (5) Beaver Pond; (6) Created Riparian Impoundment.

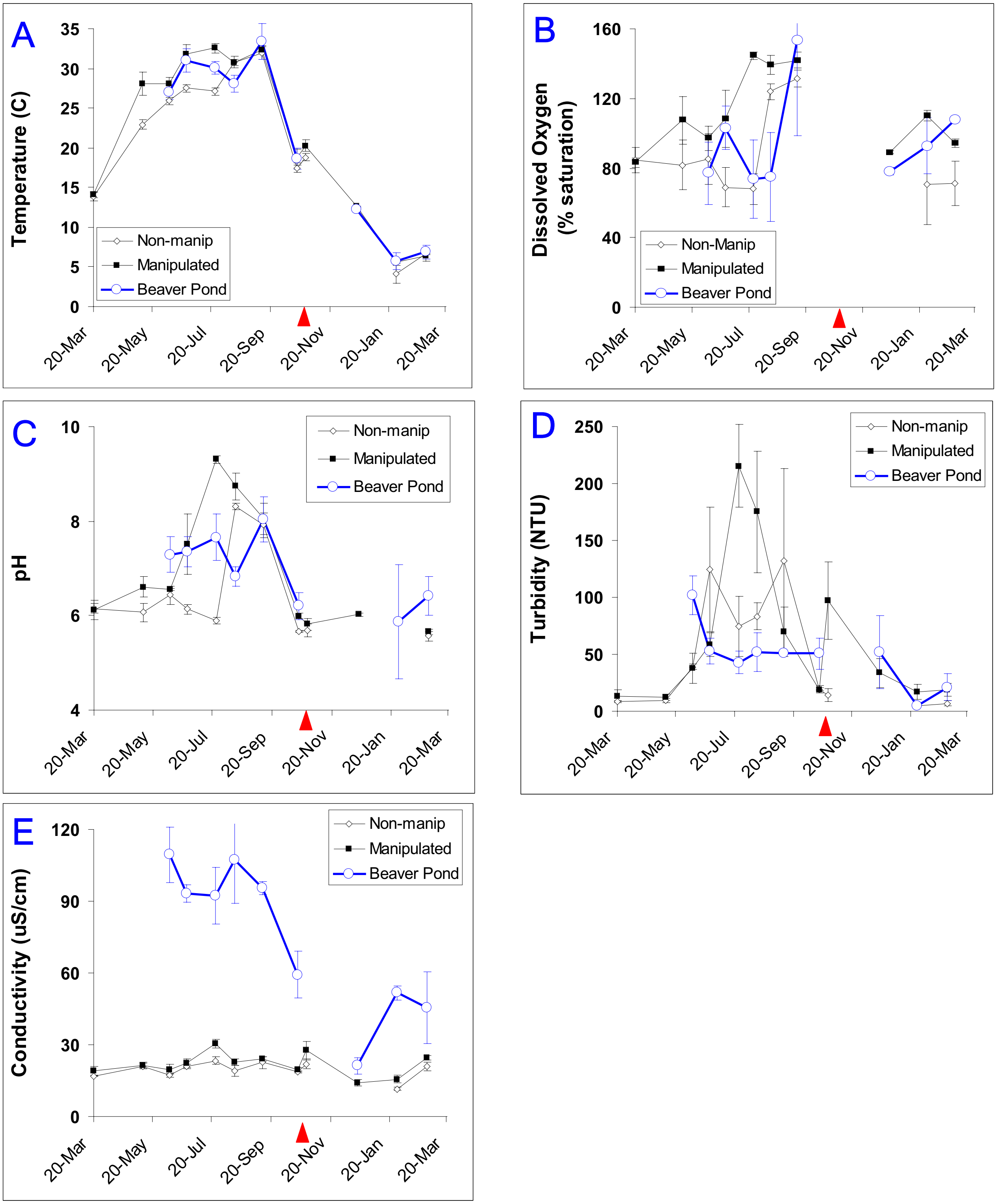

Figure 2. Basic water quality data (mean for all sampling pts per site ± 1SE) from the four upland sites, compared with on-site beaver pond. Non-manipulated sites are Farm Ponds 3 and 4, manipulated are nos. 1 and 2, and the beaver pond is site number 5 (Fig. 1). The red arrow indicates the date of drawdown for installation of riser-board standpipes. Data gaps resulted from difficulties with the field instrument.

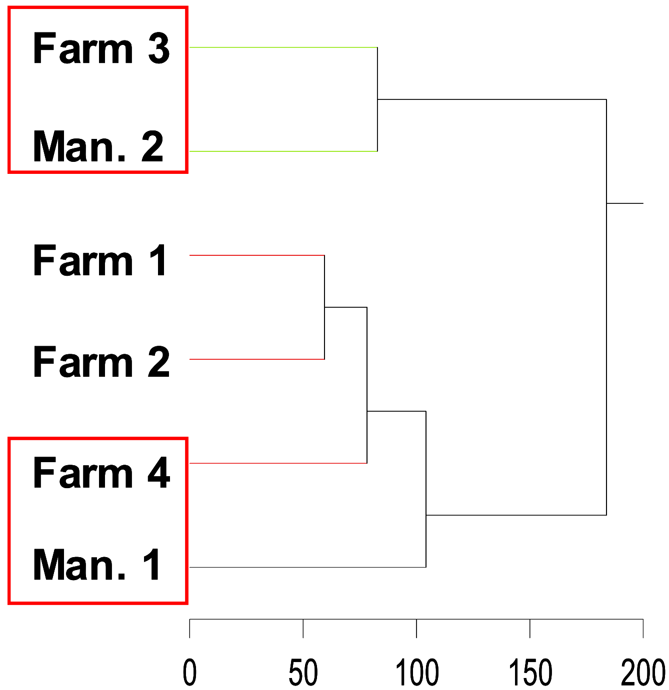

Figure 3. Cluster analysis of the six upland impoundments, based on water quality parameters indicated as most important through factor analysis of monthly measurements. Parameters included ammonium-N concentration, conductivity, dissolved oxygen, pH, phosphate-P concentration, sedimentation rates, and turbidity. Scale represents Euclidean distance along branches determined via Ward's linkage estimation (McCune et al., 2002).

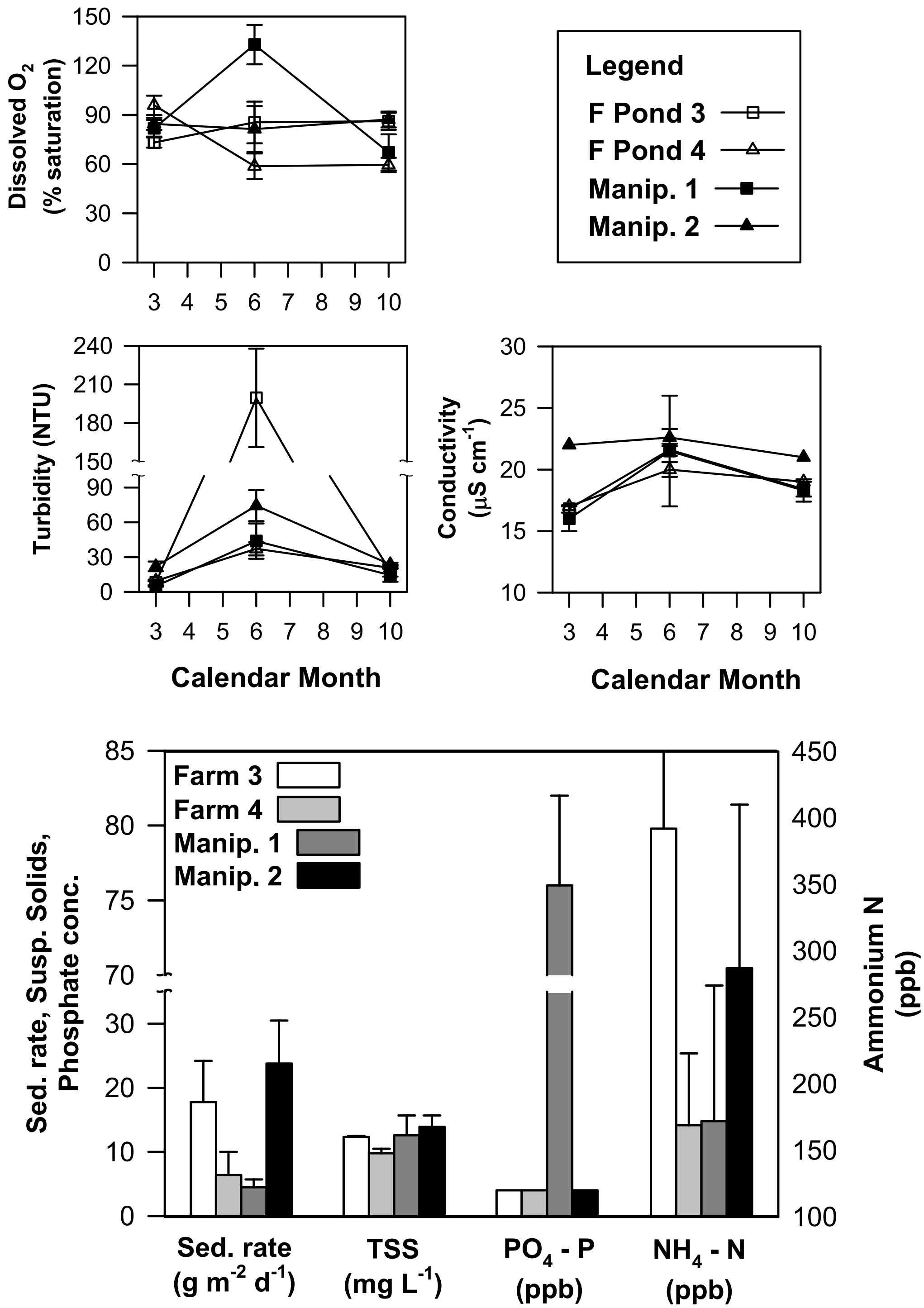

Figure 4. Values for water quality parameters used to determine sites to include in the second and third years of this study. These data were selected based on factor analyses from a suite of variables measured during March through October 2002 in each of six man-made impoundments. The four sites represented are described in Table 2. In three of the four sites, phosphate concentrations were at or below detection limit of 4 ppm. Sed. rate = sedimentation rate; TSS = total suspended solids.

Table 1. Water quality and biotic community parameters evaluated during year one of this study (March 2002 – March 2003).

Category	Parameter	Significance to Wetland Function
Water Quality	Dissolved oxygen	Oxygen concentration is important for metabolism of macro- and microorganisms that inhabit wetland
	Conductivity	An indirect measure of nutrient and other solute concentrations
	Temperature	Water temperature affects chemical and biological processes within the water
	pH, alkalinity	Measures of buffering capacity of the waters against detrimental effects of chemical contaminants
	Nitrogen and Phosphorus concentration	Indicates potential for pollutant transport or retention
	Suspended solids	Indicates potential for sediment transport or retention
	Sediment accrual	Increasingly developed sediments provide diverse microhabitats for microbial processing of transported materials
Biotic Communities	Plant community	A diverse assemblage of wetland-adapted plant species increases diversity of wetland function
	Algal biomass (chl *a*)	Water column productivity in wetlands enhances microbial degradation of pollutants
	Bird community *	Birds are important biotic indicators and a primary Audubon management objective

* Limited data on avian habitat utilization were collected by Audubon Society interns.

Table 2. Bird species encountered in surveys of three of the six sites to be monitored during years two and three. **Bold type** indicates species encountered in all three sites, *italics* indicate those present in only two sites. The beaver pond is one of the least disturbed areas on the Strawberry Plains property.

Manipulated Site 1	Manipulated Site 2	Beaver Pond
Semi-palmated sandpiper	Prothonotary warbler	Blue winged teal
		Least bittern
Belted kingfisher	**Belted kingfisher**	**Belted kingfisher**
Great blue heron	**Great blue heron**	**Great blue heron**
Green heron	**Green heron**	**Green heron**
Killdeer	**Killdeer**	**Killdeer**
Solitary sandpiper	**Solitary sandpiper**	**Solitary sandpiper**
Spotted sandpiper	**Spotted sandpiper**	**Spotted sandpiper**
Wood duck	**Wood duck**	**Wood duck**
Eastern bluebird		*Eastern bluebird*
Eastern kingbird		*Eastern kingbird*
Gadwall		*Gadwall*
Great egret		*Great egret*
Least sandpiper		*Least sandpiper*
Lesser yellowlegs		*Lesser yellowlegs*
Little blue heron		*Little blue heron*
Mallard		*Mallard*
Pectoral sandpiper		*Pectoral sandpiper*
Snowy egret		*Snowy egret*

Table 3. Summary data for plant communities at the four upland sites. Data are means ± standard error for all plots measured at each site.

Site	Tree BA ($m^2\ ha^{-1}$)	Herbaceous % Cover	Herbaceous Biomass ($g\ m^{-2}$)	Species Richness ($spp.\ m^{-2}$)
Farm Pond 3	11.2 ± 11.2	70.3 ± 9.8	711.1 ± 320.8	8.5 ± 0.5
Farm Pond 4	54.2 ± 18.6	12.5 ± 9.5	16.6 ± 4.0	5.5 ± 0.5
Man. site 1	no trees	52.5 ± 22.4	436.1 ± 135.0	6.5 ± 0.5
Man. site 2	21.5 ± 11.8	34.8 ± 19.7	43.5 ± 0.1	6.5 ± 2.5