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Effects of Landscape-Scale Factors on Wetland Biomanipulations[1]

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Abstract – Landscape factors, particularly the presence of grasslands within a watershed, play a role in successful biomanipulations. Five of 12 experimental wetland basins in west-central Minnesota were considered successful biomanipulations. Success, as defined by Herwig et al. (2004) was a basin that showed increased water clarity and macrophyte abundance. The amount of grassland within a watershed was correlated with the success of biomanipulations and secchi disk depth. The randomization of treatment ponds likely played a large role in determining the success or failure of the biomanipulations. Stocking walleye fry into systems with watersheds consisting mainly of grasslands has the greatest chance of a successful biomanipulation.

Current ecological theory regarding why Minnesota wetlands and other shallow lakes exhibit poor water quality takes into consideration a holistic ecosystem approach developed by Scheffer (1998). The theory is based upon a complex set of negative feedback loops between nutrients, water quality, invertebrates, and fish. The combination of relationships results in one of two stable states for water quality. The more desirable of the two is a clear, macrophyte-dominated state with low levels of available nutrients, and high densities of filtering zooplankton. The less desirable state features high turbidity with a phytoplankton dominated plant community, high amounts of sediment re-suspension, higher levels of available nutrients, fewer filtering zooplankton, and lower macrophyte production. Many Minnesota wetlands and shallow lakes fall into the latter of the two stable states.

Wetland drainage, consolidation and inter-connectivity, combined with persistent populations of undesirable fish species, are thought to be the major factors affecting water quality in these wetlands. Agriculture dominates the landscape of Minnesota's prairie pothole region. To facilitate large-scale agricultural processes, most seasonally flooded wetlands in Minnesota have been drained or consolidated into permanently flooded Type V wetlands (Steward and Kantrud 1971). The

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draining of the seasonally flooded wetlands and the increased use of sub-surface tile lines has greatly increased the amount of water entering these remaining wetlands (Euliss et al. 1999). These increases in water volume also bring increased levels of nutrients and chemicals in the form of pesticides and herbicides (Grue et al. 1989). The connectivity among wetlands created by drainage and tiling moves water directly into consolidated basins with few nutrients being filtered as it moves through the manipulated watersheds. Intensive land use surrounding these remaining wetlands further reduces their quality.

In Minnesota, phosphorus is the nutrient of greatest concern because the amount of this nutrient determines the magnitude of algal production in lakes (Schupp and Wilson 1993). Generally, lakes within highly cultivated watersheds have high epilimnetic phosphorus concentrations (Fandrei et al. 1988). Furthermore, Heiskary and Wilson (1990) demonstrated that land developed via urbanization also contributed significantly to rates of phosphorus loading that met or exceeded cultivated lands.

Fish also play a vital role in structuring food webs, often affecting algal production through direct and indirect effects, and thus water quality of prairie pothole wetlands (Zimmer et al. 2001; Zimmer et al. 2006). Fathead minnow *Pimephales promelas*, the most common fish species in Minnesota wetlands, have been shown to negatively affect water quality and wetland food webs (Hanson and Riggs 1995; Duffy 1998; Zimmer et al. 2000; Zimmer et al. 2001). Normally, fathead minnow populations are regulated by wet-dry cycles, and a general lack of connectedness among wetlands (Hanson et al. 2005). However the previously noted landscape-level changes (consolidation, tiling, etc.) have enabled fathead minnow populations to persist.

Given the strong structuring influences of fathead minnows, researchers have experimented with biomanipulation as a tool to improve wetland conditions (Herwig et al. 2004). The intention was to reduce or eliminate fathead minnows by stocking a predator, walleye *Sander vitreus*, in 12 wetlands in Minnesota's prairie pothole region. Theoretically, the predation on fathead minnows would reduce their effects on the food web, increasing the amount of invertebrates, particularly filtering zooplankton, and eventually improving water clarity which promotes macrophyte growth. While this approach was deemed successful in several cases, in some situations other factors likely influenced the food web dynamics greater than the biomanipulations themselves.

Despite the knowledge that land use and food webs can affect water quality of shallow lakes, only recently have researchers begun to look at them together. Furthermore, most of these efforts have focused on one trophic level. For example, zooplankton populations in Wisconsin ponds surrounded by agricultural uses had significantly lower taxon richness than did ponds outside agriculturally dominated watersheds (Dodson and Lillie 2001). They also found other invertebrates to be rare or non-existent near agriculturally impacted sites. Similarly, 19 North Dakota wetlands surrounded by intensive agriculture had significantly fewer taxa of cladocerans, ephippia, planorid and physid snails, and ostracods than did a similar number of wetlands that were surrounded by grasslands (Euliss and Mushet 1999).

The geomorphic-trophic model developed by Hershey et al. (1999) demonstrates the relationships that exist between several trophic levels and the surrounding landscape. They concluded that because landscape criteria control the distribution of fishes, and fish control the lake trophic structure, the landscape indirectly controls the lake trophic structure. Similarly, Magnuson et al. (1998) highlighted the role of geomorphology in structuring the spatial variability of fish populations. Cross and McInerny (1995) found lakes situated in Minnesota's agricultural landscapes to be dominated by populations of black bullhead *Ameiurus melas* and common carp *Cyprinus carpio*. Although the latter two studies focused on the effects of landscape on fish populations and communities, they did not make a connection linking landscape, fish, and other trophic levels.

The objective of this study was to attempt to link landscape features surrounding the 12 treatment wetlands used in the Herwig et al. (2004) study to the success or failure of the biomanipulations. I hypothesized that landscape factors played a role in the success or failure of the biomanipulations. By identifying these factors, it is hoped that biomanipulation efforts can be focused on wetlands and basins with a higher probability of success.

Methods

Twelve Type V wetlands used by Herwig et al. (2004) were used in this research. All of the wetlands are located in western Minnesota, and spanned a geographic range from Ortonville in the south to Lake Park in the north. Wetlands varied in size from 6 to 28 ha (Table 1). All of the wetlands were located on publicly owned land, either Waterfowl Production Areas under the jurisdiction of the United States Fish and Wildlife Service, or Wildlife Management Areas under the jurisdiction of the Minnesota Department of Natural Resources.

All 12 of the study wetlands were randomly assigned a biomanipulation treatment. Six of the wetlands were stocked with larval walleye while the remaining six were stocked with juvenile and adult walleye (Table 1). Details of stocking procedures as well as monitoring of the ecological effects of the treatments can be found in Herwig et al. (2004). Water clarity, measured by secchi disk readings collected by Herwig et al. (2004), was used as a measure of improvement for each treatment (Table 2). These data were used to determine if water clarity was correlated with land use within the watershed of each wetland. Finally, improvements in, or maintenance of water clarity was the determining factor as to whether or not the biomanipulations were deemed successful or not.

Immediate watersheds of each of the wetland basins was determined using ArcView. Within each of the watersheds, land use was determined and categorized as either row crop, grassland, forested, wetland, or developed. Developed land included roads. Field observations in the summer 2004 were used to verify the amount of row crops and grasslands within each watershed. Field observations were also used to identify connections with other nearby wetlands as well as agricultural drainage lines, both surface lines and underground tile lines.

A 100m buffer around each wetland was also identified using ArcView software. Within each buffer, land use was also determined and categorized as either row crop, grassland, forested, wetland, or developed. Again, field observations were used to verify land use.

Differences in watershed composition by treatment and success of treatment were examined with student t-tests at the 0.05 level. Correlation was used to identify relationships between secchi disk, turbidity, chlorophyll *a* readings, and watershed characteristics. It should be noted that, despite knowing that fry treatments were more successful than were adult treatments (Herwig et al. 2004), for this portion of the analysis both treatments were combined to increase sample size. A Bonferroni correction was applied to correlations, and tests were conducted at the 0.007 level of significance.

Results

Watersheds were delineated for each basin, and land use within each watershed was determined (Table 1). Watersheds ranged in size from 31 to 149 ha. Grassland area varied from < 1 ha (0.02 % of the watershed) to 113 ha (80% of the watershed). Cultivated land ranged from 0 to 57 ha (70% of the watershed). While most of the remaining land use categories were found in each of the watersheds, none were overly abundant in any of the watersheds.

Buffers (100 m) around each of the wetlands consisted mainly of grassland, and ranged from 30% to 100% (Table 3). Cultivated land was much less common along the buffer than it was within the entire watershed. However, there were two cases, Reisdorph 1 and Rolland, where 35 and 30%, respectively, of the buffer consisted of cultivated land. Forested land was more prevalent in the buffer than it was represented in the watershed as a whole.

Table 1. Watershed size, percent of land use type within each watershed, and treatment information of study sites. All area measurements are in hectares.

Study Site	Watershed Area	Surface Area	Developed %	Grassland %	Forested %	Wetland %	Agricultural %	Treatment	Success
Bellvue	57	13	3	16	2	3	29	Adult	No
Cuba	149	28	2	46	<1	2	30	Fry	Yes
Froland	31	6	1	66	3	9	0	Fry	No
Hagstrom	67	15	<1	75	3	2	2	Fry	Yes
Lunde	40	13	2	2	1	5	57	Adult	No
Mavis, East	140	21	1	80	1	1	0	Fry	Yes
Morrison	53	15	22	33	2	3	33	Fry	Yes
Reisdorph 1	32	13	0	20	0	0	41	Adult	No
Reisdorph 2	64	15	<1	58	1	3	13	Fry	Yes
Rolland	83	15	6	4	1	0	70	Adult	No
State Hospital	48	15	2	22	1	2	5	Adult	No
Weigers	31	6	0	73	0	8	0	Adult	No

Table 2. Measurements of total phosphorus (ppm), turbidity (NTU), cholorophyll *a* (ppm), and secchi depth (cm) of wetlands in August 2002.

Study Site	Total P	Turbidity	Chl *a*	Secchi Depth
Bellvue	3.1	28.6	49	39
Cuba	3.3	13.5	26	87
Froland	5.1	55.6	186	20
Hagstrom	1.5	5.0	2.6	185
Lunde	3.6	27.3	36	20
Mavis East	1.3	9.1	9.9	250
Morrison	3.5	11.9	6.8	201
Reisdorph 1	4.4	5.3	20	28
Reisdorph 2	3.4	52.9	50	151
Rolland	3.7	27.7	71	41
State Hospital	3.6	22.5	120	48
Weigers	2.3	14.7	50	47

Table 3. Land use composition of 100 m buffer surrounding study ponds.

Study Site	Percent Agriculture	Percent Grassland	Percent Developed	Percent Forested
Bellvue	0	30	35	35
Cuba	0	90	10	0
Froland	0	53	2	45
Hagstrom	0	90	10	0
Lunde	0	80	15	5
Mavis East	0	91	1	8
Morrison	0	65	5	30
Reisdorph 1	35	60	0	5
Reisdorph 2	0	98	1	1
Rolland	30	30	30	10
State Hospital	0	63	33	4
Weigers	0	100	0	0

When differences between wetlands that were subjected to the two treatments were examined, only the area of the watershed that were composed of grasslands differed significantly between the two treatments (Table 4). Wetlands that received fry treatments had an average of 51 ha of grassland, whereas wetlands that were stocked with larger walleye had an average of 9 ha of grasslands within their watersheds ($t = 2.23$; $P = 0.0001$).

Watershed area, surface area, and the area of watershed consisting of grasslands were all significantly larger in wetlands where the treatments were considered successful than those where the treatments failed (Table 5). Watershed size of wetlands with successful treatments was more than twice the size of unsuccessful treatments. The amount of grasslands within watersheds of successful treatments was nearly five times greater.

There was a correlation between higher secchi disk depth measurements at the end of the biomanipulation treatments (a measure of success), and the amount of grassland within the watershed ($R^2 = .53$, $P = 0.0069$) (Table 6). No significant correlations were identified with any of the buffer types and secchi disk measurements.

Table 4. Differences in average watershed area by type and buffer composition between treatment types (fry and adult walleye).

Watershed (ha)	Fry	Adult	t	P
Surface area	16	13	-1.14	0.28
Watershed area	84	49	-1.66	0.12
Developed area	2	1	0.22	0.83
Grassland area*	51	9	-2.76	0.02
Forested area	1	<1	-1.69	0.12
Agricultural area	12	22	1.16	0.27
Wetland area	2	1	-1.63	0.13
Buffer (%)				
Agricultural buffer	0	11	1.57	0.15
Developed buffer	4	19	2.19	0.05
Grassland buffer	80	63	-1.42	0.18
Forested buffer	15	9	-0.73	0.48
Secchi Disk*	149	39	-3.23	0.00

*denotes significant differences between means

Table 5. Differences in average watershed area by type and buffer composition between successful and unsuccessful treatments.

Watershed (ha)	Successful	Unsuccessful	t	P
Surface area*	18	12	-2.29	0.04
Watershed area*	95	46	-2.55	0.03
Developed area	1	1	-0.11	0.92
Grassland area*	52	10	-3.28	0.01
Forested area	1	<1	-1.79	0.10
Agricultural area	19	15	0.57	0.58
Wetland area	2	1	-0.80	0.44
Buffer (%)				
Agricultural buffer	0	9	1.29	0.23
Developed buffer	4	16	1.62	0.14
Grassland buffer	86	60	-2.06	0.07
Forested buffer	14	10	0.46	0.65
Secchi Disk*	175	36	-6.05	0.00

*denotes significant differences between means

All but one of the wetlands examined in the study were connected, albeit by varying degree, to other wetlands or other permanent water bodies. Agricultural tile lines were identified leading directly into 7 of the 12 basins.

Discussion

Grasslands likely played a role in the success or failure of the biomanipulation treatments. Differences in the size of experimental units, the size of the watershed surrounding the experimental wetlands, and the differences in land use surrounding the wetlands also contributed to the success of the biomanipulation treatments. However, the need to combine treatment types makes it impossible to determine just how important any of these factors may be. The correlation identified in this study between abundant grasslands and successful biomanipulation reflected that fry treatments were usually successful, and those treatments had a significantly greater amount of grasslands within their watersheds. Because the treatments were assigned randomly, it is not known how successful these treatments would have been

Table 6. Results of correlation analysis of secchi disk, turbidity, and chlorophyll *a* by with watershed characteristics and 100 meter buffer composition.

	Secchi Depth (cm)		Turbidity (NTU)		Chl *a* (ppb)	
	r^2	P	r^2	P	r^2	P
Watershed						
Surface area	0.16	0.1887	0.006	0.8031	0.177	0.1719
Watershed area	0.26	0.0879	0.07	0.3783	0.143	0.2262
Developed area	0.00	0.9199	0.16	0.1872	0.001	0.8909
Grassland area*	0.54	0.0069*	0.021	0.6490	0.137	0.2541
Forested area	0.47	0.0130	0.18	0.1627	0.058	0.4400
Wetland area	0.00	0.9251	0.03	0.5823	0.028	0.6009
Agricultural area	0.09	0.3189	0.06	0.4386	0.001	0.9201
Buffers (%)						
Grass	0.22	0.1180	0.05	0.4615	0.154	0.2058
Forested	0.01	0.6819	0.01	0.6812	0.224	0.1171
Agricultural	0.22	0.1180	0.09	0.3246	0.005	0.8124
Developed	0.13	0.2310	0.31	0.0513	0.051	0.4769

*denotes significant correlation at the 0.007 level

had the amount of grasslands been less, or at least not so drastically different. Conversely, how would biomanipulations conducted by stocking fingerling and larger walleyes affected by having greater amounts of grasslands within their watersheds? The same is true for watershed area and basin size. On average, larger basins and basins with large watersheds received fry treatments.

By focusing biomanipulation efforts on impaired wetlands that have substantial amounts of grasslands within their watersheds, wetland managers may increase the probability of a successful biomanipulation. Angeler et al. (2003) noted that the complex nature of abiotic and biotic parameters complicates the predictability of ecosystem responses to fish manipulations. This study supports this statement. The usefulness of biomanipulation in eutrophication abatement is complicated by this uncertainty. However, it is apparent that biomanipulation was a useful tool for improving wetland quality in certain circumstances, particularly when walleye fry are used (Herwig et al. 2004).

In general, this scenario is supported by observations of wetlands used by the Section of Fish Management for walleye fingerling propagation. Many of these wetlands have been stocked with walleye fry for a number of years. However, despite the potential benefits of what is essentially a biomanipulation, many of these wetlands remain in a turbid and/or algal dominated state (Minnesota Department of Natural Resources unpublished data). Apparently, these wetlands reflect the intensive land use practices within their watersheds, and even repeated stockings of walleye are unable to abate the highly eutrophic conditions commonly observed.

Herwig et al. (2004) suggested that biomanipulation efforts should be concentrated on sites that are isolated from other surface waters. This would theoretically eliminate contamination of fish from other nearby water bodies and reduce the amount of water input into a wetland. I was unable to examine this theory as all but one of the experimental units was connected in some way to another water body. On the present day landscape, isolated basins are rare. Limiting biomanipulations to isolated basins would considerably limit its use.

There was no correlation between the composition of the 100 m buffer and the success of the biomanipulation treatments. This is likely due to the fact that even in the most disturbed watersheds, buffers were composed mainly of grasslands. It is also possible that 100 m is not enough of a buffer to provide any noticeable benefits. The hyper-eutrophic nature of many of these wetlands makes it likely that internal nutrient processes play a significant role in determining the trophic interactions within the systems.

No relationship was identified between turbidity and the various land use parameters. Row crops were prevalent in all of the watersheds, some even within the 100 m boundary. The turbidity of a system may play a large role in the success of biomanipulations, particularly when fry are involved. Walleye fry are dependent on an abundant supply of zooplankton early in their lives (Mathias and Li 1982; Hoxmeier et al. 2004). Turbid waters can reduce their foraging efficiency, thereby limiting their survival.

Unlike many of the study areas, a great deal of Minnesota's prairie habitat consists of a homogenous agricultural landscape. As the landscape loses it heterogeneity, nutrient movements, particularly nitrogen, are affected (Baudry and Burel 2004). A lack of heterogeneity, as found on much of the current landscape, facilitates nutrient runoff or leaching when large fields are left fallow after harvest. The watersheds of the study areas probably reflect a "best case scenario" as all of the basins were on publicly held land. Because of this, most of the surrounding uplands are managed as grasslands to boost waterfowl production. The watersheds in this study were likely more heterogeneous than what is typical of other watersheds in Minnesota's prairie pothole region. This would likely affect the success of biomanipulation as well.

Biomanipulation is a promising tool for wetland managers. However, a few guidelines can increase the odds of the biomanipulations being successful. Wetland managers wishing to optimize the benefits of biomanipulation should identify basins having watersheds composed largely of grasslands. Managers should not be apprehensive to try biomanipulation in basins that are large or have a large watershed. Fry treatments were highly successful under each of these scenarios. Future research regarding biomanipulation should focus on the use of larval walleye (as per Herwig et al. 2004) in systems surrounded by heterogeneous land use.

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