

**Patterns of removal and ecological response:  
A study of small dams in Wisconsin**

by

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## Chapter 1

### Introduction to dam removal

Dams are a prevalent feature on the landscape. According to Shuman (1995), there are 75,000 large and an undetermined, but certainly much greater, number of small dams distributed across the United States. In Wisconsin alone there are more than 3,800 dams in the state inventory (WDNR database). Many of these dams were built in the mid-1800's after the Wisconsin Mill Dam Act of 1840. The government promoted and supported dam construction during this period to support emerging logging, paper, and grain mill industries. These dams and resulting reservoirs played a vital role in the development of the early Wisconsin economy by aiding timber transport as well as power for mills (Doyle and others, 2000). With the development of hydroelectric power in the early 1900s, there was continued incentive to construct new dams and convert existing dams to generate electricity. Additionally, dams were constructed for flood control, recreation, residential development, and irrigation.

A growing body of evidence shows that small dams in Wisconsin and across the U.S. are failing structurally (Born and others 1998). The American Society of Civil Engineers estimates that  $\frac{1}{4}$  of all U.S. dams have reached their expected age of 50 years, and that 85% of dams will have reached that life span by the year 2020 (USACE, 2002). Inaction is often not an option for dam owners due to safety and liability issues of people and property downstream. Consequently, a relatively new kind of environmental controversy has arisen, as dam owners and surrounding communities have begun to face the dilemma of whether to repair, replace, or remove dilapidated structures. Ecologists and environmentalists have often advocated removal, while local residents, including but not limited to lakeshore property owners, generally favored repair or replacement.

Dam removal may be a powerful restoration tool if it is implemented in a deliberate and calculated way to join larger stretches of unregulated river or open up important habitat such as in the case of the Elwha dam in Washington State (Stoker and Williams, 1991). A good example of this type of focused effort is the 4 consecutive removals of aging dams on the Baraboo River in Central Wisconsin. The final removal in 2002 connected approximately 120 miles of mainstem river and the effort is expected to improve fish habitat and river recreation opportunities on the river (American Rivers, 1999).

Decisions about the future of the nation's small dams are proceeding on a piecemeal basis without a general set of guidelines to ensure that consequences of repair vs removal decisions are fully addressed. As new policies are being developed and implemented, there is opportunity and audience for new research in the ecological responses of rivers to dams and their removal. Although little research has been done on rivers' physical or ecological changes after dam removal (Shuman, 1995) there are multiple studies currently in progress (see special issue of *Bioscience* 52(8) 2002). This general lack of understanding of how rivers respond to dam removal events makes it difficult to describe realistic goals for river management that includes dam removal.

It has been hypothesized that dam removal changes the character of the habitat available in the area of the former impoundment, from shallow lake or wetland to riparian, seasonal wetland or floodplain characteristics (Bednarek, 2001). Very little research has documented if and when this change occurs. For several reasons, it is important to know what vegetation type will become established on former impoundment sediments. First, plants can help stabilize the sediments described above. Second, the

potential value of dried impoundment areas as wildlife habitat is often of major concern when the decision of whether or not to remove a dam is being made. Additionally, local area residents are often concerned about the appearance of the impoundment and vegetation is one measure of aesthetic value.

The following pair of studies is an addition to the growing body of information on dam removal and considers long-term patterns and responses to dam removal. Wisconsin is unique in that at least 75 dams have been removed since 1912, making it possible to study long-term effects of removals and to examine longer-term changes as removal sites age, by employing a space for time substitution. Chapter 2 is a study of the fate of impoundment areas after dam removal, how vegetation colonizes exposed sediment and the implications for future management of these sites. Chapter 3 is the result of collaboration between UW graduate students involved in the National Science Foundation Integrated Graduate Education and Research Traineeship program which at UW was titled Social and Aquatic Systems Interactions. It is a study of the patterns of dam removals across Wisconsin historically and today and of the reasons these patterns occur. A version of Chapter 3 was submitted as a manuscript to Environmental Management.

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## Chapter 2

### **Vegetation establishment and development on former impoundments after dam removal**

#### **Abstract**

Dam removal is becoming a more frequently chosen option for dealing with deteriorating small dams. Despite the prevailing impression that dam removal will have a positive affect on riverine ecosystems (American Rivers, 1999), there is fairly little known about ecological response to dam removal events (Bednarek, 2001). In this study I took advantage of a long history of dam removal in Wisconsin to determine rates and patterns of vegetation establishment on exposed sediment in areas that were formerly impoundments. I visited 30 dam removal sites between May and August, 2001 to assess their current condition. Vegetation surveys were conducted on 13 sites where dams had been removed 6 months to 46 years prior to the surveys. I found that fewer than half of the dam removal sites visited had been allowed to revegetate and the remaining sites were being used mainly for agriculture or as parks. On the sites that had unmanaged vegetation, there was no clear pattern of plant community change with time or in response to measured environmental gradient. The 3 oldest sites contained more trees than the 10 youngest sites, but species diversity, floristic quality, and dominance of other growth forms did not show patterns over time. This lack of environmentally driven pattern may mean that there is an opportunity for management activities to influence the outcome of plant community development on these sites.

## Introduction

Dam removal has become a serious issue for dam safety engineers, river managers and landowners alike. As aging dams and impending dam failures make it necessary to make decisions about the trade offs between repairing or removing structures, conflicts are arising due to lack of information about the consequences associated with the different options. While there is limited evidence that dam removal may be beneficial to some ecological aspects of rivers (Bednarek, 2000; Kanehl and others, 1997), very little is known about what becomes of individual dam removal sites in the context of long-term development and management. Recent short-term studies described immediate adjustments such as channel formation (Stanley and others, 2002) and fish movement (Kanehl and others, 1997) but long-term studies on the eventual result of dam removal and the fate of former impoundments do not exist. This makes planning for the management of newly drained reservoirs exceedingly difficult.

The main purpose of this study is to determine the fate of former reservoirs following dam removal and to address possible factors determining these outcomes. One of the possible fates for a dewatered impoundment is development for agriculture or recreation. Alternatively, a reservoir site may be allowed to revegetate without active management or it may be actively restored to some preexisting or otherwise desirable condition.

Understanding colonization of impoundment sediments by plants and determining patterns of species replacement is of particular interest to managers because vegetation establishment influences biotic, abiotic and even social processes shaping the eventual

organization of a site. The composition and persistence of plants on reservoir sediment will largely determine the quality of that site as riparian habitat. Vegetation can interact with geomorphic processes to determine physical structure of the river and the amount of sediment that gets transported downstream. Finally, the timing and quality of vegetation establishment may determine the likelihood of a site being converted to a new use and of future sites being considered for dam removal.

There is significant potential for former impoundments to act as riparian restoration sites. Restoration of these sites could help offset the loss of natural riparian habitat that reached 70% in 1990 and has continued since then (Willard and others, 1990). Riparian zones can be a significant source of regional biodiversity and play a critical role in the structure and function of stream ecosystems (Naiman and others, 1993). At the same time they are vulnerable to exotic species invasions (Hood and Naiman, 2000) and once invaded, riparian zones can act as havens for exotic species (Stohlgren, and others 1998). To understand the potential for impoundment sites to function as riparian zones or as exotic species strongholds requires an understanding of how they are colonized. Our goal was to determine what vegetation dominates revegetating reservoir sediments, how conservative or invasive that vegetation is and how it changes over time.

Sediment transport to downstream habitats is one of the major ecological concerns with dam removal (Bednarek, 2001). Vegetation growth on unconsolidated reservoir deposits may interact in a significant way with geomorphic processes to retain sediments and influence channel formation through several mechanisms. The development of roots can armor the channel and root mass in riparian areas has been used

to predict bank stability (Hupp, 1992). The presence of plants can alter channel geometry and flow dynamics (Gran and others, 2001). It has been hypothesized that vegetation establishment and the simultaneous process of channel formation act together to determine the ultimate form of an impoundment channel following the physical changes associated with dam removal (Shafroth, 2002).

We took advantage of the long legacy of dam removals in Wisconsin to study the pattern of vegetation establishment and species replacement on former impoundments over time. Multiple sites at different lengths of time post dam removal were surveyed as a substitute for following a single site through time. The main goal was to test hypotheses concerning vegetation development and identify potential determinants of differences between sites.

Several potential patterns of vegetation establishment post dam removal were considered in this study. The first scenario is that plant communities follow a predictable pattern of species replacement with time or in response to broad environmental gradients. Secondly, exotic or invasive species become established soon after dam removal and no subsequent species replacement occurs. This scenario is supported by Lenhart (2000), who found that plant communities on older impoundments were in a state of suppressed or arrested succession. Finally, species assemblages form in response to a complex and/or site-specific set of parameters. For each option there should be a clear pattern in sites across time:

1. Predictable progression – newer sites are dominated by early successional species, older sites show change in a consistent direction and community

composition is related to age of site. Specific species assemblages may be related to physical or chemical parameters of the sites.

2. Arrested succession – new sites are dominated with exotic or early successional species and no change in community composition is seen in older sites.
3. Complex pattern – species composition does not respond in a uniform way with time since removal or major environmental gradients.

To determine if patterns could be clarified by observing individual indicator species, we followed the dominance of particular species of interest across sites of differing ages. Four species of interest, an invasive grass, a native but aggressive forb and two native trees, were chosen for further analysis because they are indicators of particular types of habitat. Reed canary grass (*Phalaris arundinaceae*) has been noted as a particularly invasive species that remains dominant after establishment (Galatowitsch and others, 1999). It may be exceptionally successful in impoundments because the open canopy and rich soils create the high light (Lindig-Cisneros and Zedler, 1991) and high nitrogen (Maurer and Zedler, 2002) conditions that favor reed canary grass germination and persistence. Stinging nettle (*Urtica dioica*) was noted by Lenhart (2000) as being dominant on several of the sites he surveyed. Box elder (*Acer negundo*) is an early colonizing tree and might be an indication that a site is progressing towards tree domination. Silver maple (*Acer saccharinum*) is a tree common to Wisconsin floodplains and wetlands (Curtis, 1959).

## Methods

### Study site selection

Every site with a documented removal of a dam regulated by the WDNR in the Driftless Area or in South Central Wisconsin was included in this study (Figure 2.1).

Sites were selected for vegetation surveys if they met the following criteria.

- The site was accessible.
- Historic photographs showed a clearly defined impoundment before the dam was removed.
- At least half of the site was unmanaged or could be considered fallow.

The nature of human use was determined on all sites by visual inspection and interviews with landowners where possible. Primary and secondary land use was determined as the largest area of the site in each of 6 use categories; fallow, agricultural, park and other, at the time of the site visit. Vegetation and soil surveys were conducted on 13 and 15 sites respectively (Table 2.1). Because time since removal was considered a likely factor in determining site conditions, effort was made to choose sites removed over the widest range of time possible. However, dam removals were not conducted at even intervals. The distribution of available sites was skewed toward more recent removals (10 sites were less than 12 years post removal and 3 were more than 28 years post removal),

and there were no sites in the 12-28 year age range. The 13 sites selected represent the entire population of suitable sites in these regions.

### Vegetation Sampling

Frequency of occurrence of plant species was measured in former reservoir areas between 23 May-19 August, 2001. Frequency was chosen as a population estimate because it is a more stable estimate of abundance through a growing season than cover estimates, further it does not require choosing a counting unit and is therefore applicable across all growth forms (Elzinga and others, 1998). This method permits relatively rapid assessment and requires minimal expertise, and therefore allowed the completion of surveys on many sites in one season. If sites are resurveyed in the future, care should be taken in comparing these data to future estimates as frequency measures are affected by density and spatial distribution of a population (Elzinga and others, 1998).

Transect placement was determined before each site visit using historic aerial photographs from before and after the dam was removed. The extent of water coverage in the earlier photograph was used to define the extent of the former impoundment (Figure 2.2). For each impoundment, one side of the river channel was chosen based on accessibility and ten transects spaced evenly between the former dam site and the upstream end of the impoundment were established perpendicular to the channel. Five transects were then selected for sampling using a random number generator.

We used a 0.5m x 0.5m quadrat as the primary sampling unit, and frequency was measured as percentage of possible plots within the site occupied by each species. Ten plots were arranged systematically along each of the 5 random transects per site. Distance between plots was equal to 1/10<sup>th</sup> of the transect length. At each sampling point, the quadrat frame was placed directly down on the vegetation adjacent to the transect line and the boundary rule was used that if any portion of the plant was inside the plot it was counted as present. The frequency values are comparable between sites because the plots used were identical. Verification samples were collected for all uncommon species or species that were not identified in the field. These were pressed and identified with help from the UW herbarium staff.

#### Sediment sampling

Soil nutrient data were collected to include as parameters in statistical models of site diversity. Sediment samples were taken at 13 of the sites surveyed for vegetation sites (Table 2.1) using a 1-1/8" unslotted soil recovery probe to a depth of 9 cm. One core sample was collected at each quadrat position and individual samples were composited in a single transect sample. Composite cores were mixed in sealed polyethylene bags and stored in a cooler until return to the laboratory at which point they were frozen. All samples were analyzed at the UW Soil and Plant Analysis Lab for extractable phosphorus, and percent total nitrogen.

## Data analysis

### Multivariate statistical analyses:

Multivariate statistical analyses were used in the statistical software package PC-ORD (McCune and Mefford, 1999) to determine if physical features of the sites could explain patterns in plant assemblages across sites. An unconstrained ordination technique, Correspondence Analysis (CA), was paired with a constrained technique Canonical Correspondence Analysis (CCA), to determine if parameters included in the model were indeed the parameters driving variability in the sites.

CA is an ordination technique whereby sites and species are ordinated simultaneously on separate axis. A reciprocal averaging algorithm is used to maximize correlation between species scores and site scores and to sort sites on axes based on the most important gradients. The eigenvalue of an axis is equal to the correlation coefficient between species scores and site scores. These gradients are hopefully, but not necessarily related to the environmental variables in the explanatory matrix (McCune and Mefford, 1999).

CCA extracts the major explanatory axes that are also linear combinations of the explanatory variables. If the implicated variables are actually the variables controlling the gradients among the sites, then they should be similar to the variables implicated in the CA. For additional information on ordination see Palmer, (1993) and McGarigal and others (2000). It is useful to pair constrained and unconstrained ordinations to determine if the parameters chosen to be included as explanatory variables in the environmental

matrix are actually the best correlates to patterns in site variability. If the driving variables are in the environmental matrix then the pattern of site arrangement along the primary axes will be similar in the two methods. If parameters not included as explanatory variables are actually more important in explaining site to site differences, then the sites will sort along an unexplained axis in the CA and along a different, explained axis in CCA.

To avoid difficulties with these techniques associated with datasets that include many zero values, ordination was done on species data aggregated in to guilds. Species were sorted first as native or introduced and then into 7 categories (Table 2.2) based on growth form using information from the *Checklist of the Vascular Plants of Wisconsin* (Wetter and others 1999). Physical parameters used in the models were taken from the Wisconsin Department of Natural Resources (WDNR) dams database (<http://www.dnr.state.wi.us/org/water/wm/dsfm/dams/datacentral.html>) (Table 2.3) and from soil data. They were chosen for the likelihood of influence on species composition and for the completeness of the dataset. Because ordination techniques cannot handle empty fields in the environmental matrix, in two cases the database needed to be supplemented. The structural height of the Cross Plains dam was estimated from photographs and soil data averaged across all sites was used as Nitrogen and Phosphorus values for Hebron and Waterloo.

A second unconstrained ordination method, nonmetric multidimensional scaling (NMS) was used to verify the results found in the CA analysis. This was done because site data did not meet the CA assumption of multivariate normality. Even after data were aggregated into guilds there were many zero values in the main matrix. Common

transformations do not solve this problem and thus were not used. While CA is somewhat robust to non-normality, especially when used in description alone and not prediction, NMS uses rank order only in the dissimilarity matrix to separate sites and is more robust to non-normality (McGarigal and others, 2000).

#### Logistic regression statistical analysis:

Logistic regression was used to determine if the physical variables used in the multivariate analyses could predict presence or absence of species of interest (reed canary grass, box elder, silver maple and nettle) on a new site. Logistic regression uses either continuous (e.g. time) or categorical (e.g. WDNR management district) data to build a statistical model that best fits a binary response (either a species is present or absent). These models are fitted using the maximum likelihood method (Chatterjee and others 2000, Manel and others, 2001). All regression analyses were performed using the logistic regression function in MINITAB (MINITAB version 13.30, MINITAB Inc.).

#### Floristic quality assessment:

To determine the relative habitat value of each study site data on species present were used in a floristic quality assessment (FQA) using coefficients of conservatism developed by the Wisconsin Department of Natural Resources (Thomas W. Bernthal, Wisconsin Department of Natural Resources, written communication). FQA is a standardized method of assessment used to compare habitat quality between sampling sites or between different sampling periods on the same site. It uses a predetermined

coefficient of conservatism (C) that is a number from 0-10 assigned by regional experts to each native species in a region according to that species' tolerance for disturbance and association with a pre-European settlement plant community. Non-native species cannot be assigned C values. A single Floristic Quality Index (FQI) value calculated from the aggregate C values as the site mean C times the square root of the total number of native species found on the site was assigned to each study site. Higher FQI values indicate higher floristic quality and higher biological integrity as well as lower levels of disturbance than sites with lower FQI values (Swink and Wilhelm, 1994).

## **Results**

### Site use

Out of the approximately 30 sites visited, 15 sites were employed in a variety of human uses (Table 2.4) that fell into 4 categories (Figure 2.3). Fallow sites were sites that were either not managed in any way since the dam was removed or were planted with native species as the result of a restoration effort. Many sites were turned into a variety of types of parks including baseball diamonds, bike trails, picnic areas and playgrounds. Several sites were in some type of agricultural use. Hay fields, row crops and grazing were all consolidated into this category. Finally, a subset of sites were in other uses that included canoe rental businesses, a large driveway and garden and several residential backyards. There was a trend over time for sites dewatered longer ago to be in more permanent land uses; more elaborate agriculture, larger parks, and more prevalent

structures (Figure 2.4). The two sites of recent dam removal categorized as agriculture were both being used as pasture land by farmers who had owned the land since before the dams were built and were used to grazing riparian areas that were seasonally inundated. Two sites were being restored to native vegetation and 13 sites had been left fallow.

### Vegetation establishment and diversity

Vegetation returns quickly and is persistent on exposed reservoir sediments. There was almost complete vegetation cover on all sites including those in their first growing season following dam removal. Only 5 quadrats out of 650 surveyed across all sites were bare, and these were due to walking trails bisecting transects.

Overall sites were variable in their appearance. They ranged from fields of nettle and reed canary grass to dense and diverse, closed-canopy forest. They also varied in the evenness of plant distribution. One side of Parfrey Glen contained a small patch of box elder not found on the rest of the site and sedges dominated an upland area of Reedsburg while the remaining area was forested. Several sites such as Fulton and Hebron had an even distribution of a few species across the entire impoundment. Trees dominated the upland areas surrounding most sites, however edge species (Table 2.5) were not well represented in the impoundments indicating that these species, while available for colonization, were not dispersing into the impoundments.

Species diversity was highly variable in the first 10 years following dam removal (Figure 2.5), with most sites being dominated by a few aggressive species plus a variable

number of additional species. Hebron (removed 1996) was the least diverse, (7 species) while Mound Pond, removed only one year later contained 29 species. The three oldest sites Reedsburg (removed 1973, 37 species) McClure (removed 1968, 31 species) and Cross Plains (removed 1955, 34 species) were the most diverse, however several younger sites contained only slightly fewer species and diversity in the three oldest was not significantly higher than in the other 12. The most common species with high frequencies were reed canary grass (Cross Plains, Hebron, Parfrey Glen, Reedsburg, Slabtown, Waterloo, Willow Falls), nettle (Fulton, Hebron, Mound Pond), and rice cut grass (*Leersia oryzoides*) (La Valle, Token Creek, Waterloo) (see appendix 1 for species lists). Diversity was less variable in the three older sites than in younger ones.

Plant composition changed with time after removal (Figures 2.6- 2.9). Immediately after removal, sites were dominated by a combination of grasses and small or weedy forbs. Typical sites were Fulton, in its 8<sup>th</sup> growing season, which was dominated by stinging nettle (94%) and Hebron, 5 years post removal which had highest frequencies equally split between nettle (62%) and reed canary grass (56%). Sites older than 30 years post-removal showed a higher cover of tree species than younger sites (Figure 2.9) ( $t=6.02$ ,  $p = 0.001$ ). These three older sites had closed canopy trees with an understory of upland forbs on the main body of the site. For example, McClure, 33 years post removal was dominated by mature elms (62%) and box elder (38%), with 14 native forbs in the under story. Reedsburg was divided between a box elder (24%) and silver maple (24%) dominated riparian area closest to the river and a wetter, sedge dominated area away from the river. While older sites were significantly different from younger

ones, predictable patterns of replacement of one growth form by another, such as grasses to shrubs, was not apparent in plots of growth form with time.

### Multivariate Analyses

The unconstrained ordination, CA (Figure 2.10) successfully sorted sites along gradients and large outliers did not drive the site pattern. Time since removal and soil N were the most significant gradients from the environmental matrix ( $R^2=0.20$ ), although both vectors are fairly short suggesting they are weak predictors of guilds. Sites did not fall into distinct groups along either axis. The second (constrained) analysis, CCA (Figure 2.11), showed the same pattern, although the position of sites was rotated with respect to the two explanatory axes. Time since removal and nitrogen remained as the major explanatory variables ( $R^2=0.30$ ) and the pattern of sites is similar to the CA, suggesting that the major drivers of site variability are indeed included in the environmental matrix. NMS results (Figure 2.12) showed a similar ordination suggesting that the non-linearity in the main matrix did not affect the CA and CCA results. Axis 1 and 2 in the NMS ordination explained 7.4% of the variability between sites.

### Floristic quality analysis

As with species diversity, site habitat quality was variable across study sites (Figure 2.13 ). Older sites showed similar range of variability as newer sites, indicating

that plant communities do not become more conservative habitats with time. FQI values also do not track species diversity. Having a greater number of species does not necessarily mean that a site will be of higher quality.

### Indicator species results

Plots of individual indicator species were not helpful in determining a pattern of site progression. Box elder presence (Figure 2.14) is variable in the first 5 years with frequencies ranging from 0 to 25%. Two of the 3 oldest sites show higher frequencies of approximately 40%, however the third site has little box elder. Silver maple (Figure 2.15), nettle (Figure 2.16) and reed canary grass (Figure 2.17) show no pattern with time.

### Regression

No reasonable and significant logistic regression model could be developed to predict the presence or absence of box elder, nettle, or silver maple across the sites. All models that contained a justifiable number of predictor variables were not statistically significant at  $p < 0.10$ . Only when the number of predictor variables approached the number of sites did the models become significant.

Logistic regression was not used for reed canary grass because it was found on 14 of the 15 sites. Linear regression shows that nitrogen is a moderate predictor of reed canary grass frequency ( $R^2 = 0.24$ ,  $p < 0.06$ ) and adding time since removal does not

improve the model. However, a plot of reed canary grass with N (Figure 2.18) shows no strong pattern.

## **Discussion**

### Human use

Many sites of past dam removal in Wisconsin are currently being used to support a variety of human activities (Figure 2.3). The number of sites employed in uses other than natural areas shows that former reservoirs may be seen as available land and land use may also change with time. At Hebron there was evidence that people were progressively moving their gardens and driveways onto the former reservoir as a way to expand their backyards. Land use may also be determined by negotiations that take place during the dam removal decision-making process. Several municipalities built parks along the river to compensate the community for their loss of impoundment-related recreation activities and as a way to maintain favorable aesthetic qualities. The Reedsburg and Cross Plains impoundments were both parks and natural areas, with parts of the land mowed and other sections left to re-grow as riparian habitat. The variety and frequency of alternate uses emphasize that there are social and economic factors that influence the use of impoundments post dam removal.

### Vegetation establishment

All sites included in this study had high cover and no exposed sediment. These results clearly demonstrate that vegetation is quickly established and persists following dam removal. Repeated observations of two recently dewatered impoundments from the time of dam removal to the end of the first growing season show that it can take as little as a month for a site to re-vegetate initially and there is strong evidence that sites retain high cover indefinitely.

Overall, sites showed a wide diversity of species assemblages and range of growth forms. Older sites had more tree cover than younger sites and the species found on the three oldest sites resemble mature riparian forest with an under story of upland forbs. The fact that older sites are diverse and dominated by trees suggests that sites have the potential for continued species replacement and this discounts the second hypothesized pattern of revegetation that suggests sites become arrested in an early successional stage. However there is not a clear directional pattern of succession. A longer amount of time for a plant community to develop post dam removal does not necessarily lead to a better quality, more conservative habitat. The FQI shows that there is not a progression from low quality, newly drained sites to high quality older sites, but rather a range of FQI values that sites of all ages fall into equally.

Sites within the first 10 years post removal show an enormous amount of variability in their diversity, species assemblages and dominance of exotic species. This variability is somewhat explained by the amount of time since the site was underwater and the soil N as is shown by the ordination results. This result is supported by studies that show soil N can enhance the reed canary grass dominance (Green and Galatowitsch 2002, Maurer and Zedler, 2002). Because reed canary grass was found on all sites and

was one of most frequent species on many of them, it is likely driving some of the pattern seen in the ordinations. While soil N and time are the best parameters to explain variability in ordinations, regression models that include these parameters fail to predict the presence or absence of individual, representative species on a site and particular guilds are not clearly associated with time since removal. None of the environmental parameters included in these models are good predictors of species composition or site similarity and they cannot be used alone to predict the eventual outcome of future dam removals.

Species composition changes with time but there is no clear pattern of species replacement or growth form change over time or along measured environmental gradients. Site-to-site variability is high and models including many possible predictors fail to describe the pattern seen in the sites. Additional, unmeasured, parameters may affect observed patterns. Groundwater input is likely to influence vegetation type, although Lenhart (2000) found water table height was not significantly related to vegetation on his sites. Other researchers have found water regime to control plant establishment (Budelsky and Galatowitsch 2000). Flood regime could also control the introduction of seeds from upstream and change nutrient dynamics in impoundment soils. The yet unexplained high variability between sites and lack of directional change in community composition with time leaves the third hypothesized pattern of revegetation as the best supported; that is that site development is complex and control of this development cannot be established with the number and distribution of sites included in this study.

It is additionally possible that the initial colonization of sites by aggressive species is affecting younger sites differently than older sites. Exotic species, such as reed canary grass, which were less prevalent 30-50 years ago when the first dams were removed, could prevent species replacement preferentially on younger sites where exotics have the opportunity to become monocultures early on. If this is the case and species composition of early colonization determines long-term outcomes of site development, this would mean that sites included in this study are not truly a time series because initial conditions at the time of removal were important and different. If site development is path dependent, initial conditions could put a site on a trajectory that may not be overcome by later changes. It is difficult to determine from a space for time substitution what mechanism is behind the patterns observed in these sites. Repeat surveys are needed to determine if early exotic species establishment destines a site to perpetual support of a high frequency of aggressive species or if other, more diverse assemblages will eventually establish.

Additional surveys would also benefit conclusions about general site development. The dataset used in this study did not include any sites 12-28 years post removal because there were no sites of this age that met the criteria. It would be interesting to survey sites that bridged the gap between the new, mostly treeless and the old, closed canopy sites to determine what intermediate stages might occur. This could be done by expanding the study to other regions of the state or country. However, adding more habitat types may increase the difficulty of interpreting the results. It would certainly be useful to resurvey these sites at an interval of 5 to 10 years. At that point the

existing sites will have reached the missing age range and comparisons could be made between their current state and the future state to gain more insight into mechanism.

## **Conclusions**

The development of former reservoirs is fundamentally determined by human influence. Sites are used for a variety of human activities and many are also being allowed to revegetate. Developing sites may act both as contributors to regional biodiversity and as havens for exotic species. All sites surveyed contained some level of exotic species cover. But high inter-site variability makes it unclear how the balance of exotics to native species changes with time. Sites of all ages fall into the same range of conservatism suggesting that newly drained sites are equally likely to contribute to local biodiversity as older sites. Species composition on a particular site cannot be predicted by environmental variables associated with that site and it is also unclear how an individual site is likely to change over time.

Space for time substitution is useful for examining processes through time when long-term data sets are not available. However, It is limited by the type and quality of sites available and considerations arise in data analysis because sites are not replicates of each other with time as the only independent variable. Ordination methods that employ many parameters to describe site similarity can be used to get around some of this difficulty. However, care should be taken in inferring process from the observable patterns. If species replacement mechanisms are path dependant, then conclusions about

overarching mechanism are not likely to be accurate predictors across a range of different sites.

Dams are ubiquitous across the state. The inevitable degradation of these structures under the heavy hand of time will certainly lead to more dam removals than we have seen thus far. It will also lead to both an opportunity to further study the ecological impacts of dam removal and a responsibility to apply the information gained to the design and implementation of future removals. Dam removal may present an opportunity to restore native, riparian vegetation to the landscape. However, the data presented here show no reason to believe that rivers will "restore themselves" or return unaided to some sort of pre-dam condition once a dam has been removed. It is likely that riparian vegetation on these sites will reflect some combination of the present environmental conditions and the effort put forth by managers to direct the sites to a desirable state. Because there is no strong environmental pressure for these sites to develop in a particular manner, there is an opportunity for restoration activities to influence the eventual outcome. The overall impact of management decisions made at individual dam removal sites will become more obvious as these sites multiply across the landscape.

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<http://www.dnr.state.wi.us/org/water/wm/dsfm/dams/datacentral.html>

## Tables for Chapter 2

Table 2.1: Sites visited and survey done at each. Most sites visited, but not surveyed were being used for parks or some type of agriculture.

<u>Site Name</u>	<u>Vegetation survey</u>	<u>Soil survey</u>	<u>Date of Removal</u>
Afton			breached ~1996
Island Woolen Mill		x	~1997
Black Earth			1955 and 1961
Bowen Mills			1996
Cross Plains	x	x	1955
Etrick		x	1976
Fulton	x	x	1993
Hebron	x		1996
Huntington			1965
La Valle	x	x	2001
Lemonweir			1993
Low Creek 1			~1994
McClure	x	x	1968
Mound Pond	x	x	1997
Mount Vernon			1950
Oak Street			2000
Ontario		x	1992
Parfrey Glen	x	x	1996
Readstown			1985
Reedsburg	x	x	1973
Rockdale			2001
Shopiere		x	2000
Slabtown	x	x	1992
Somerset			1965
Token Creek	x	x	breached ~1996
Waterloo	x		1995
Waterworks			1997
Whitehall			1988
Willow Falls	x	x	1991
Wonewoc	x	x	1996

Table 2.2. Guilds used in Multivariate Analyses

<u>Native Species</u>	<u>Introduced Species</u>
NT - trees	IT - trees
NS - sedges	IS - sedges
NV - vines	IV - vines
NG - grasses	IG - grasses
NSH - shrubs	ISH - shrubs

Table 2.3 Environmental Parameters for Multivariate Analyses

Age of dam at time of removal
Years since removal
Dam size – categorical small/large based on WDNR designation
WDNR district name
Drainage basin area
Impoundment area
Structural height of the dam
Latitude of impoundment
Longitude of impoundment
Average soil nitrogen for the site
Average soil phosphorus for the site.

Table 2.4: Dominant land uses by site.

<u>Site</u>	<u>Main use</u>	<u>Second use</u>
Afton	Fallow	
Island Woolen Mill	Park	
Black Earth	Row crop	
Bowen Mills	Hay field	Row crop
Cross Plains	Fallow	Park
Ettrick	Backyards	Row crop
Fulton	Fallow	
Hebron	Fallow	Garden
Huntington	Not located	
Ithica	Fallow	Row crop
La Valle	Fallow	Grazing
Lemonweir	No impoundment	
Lowe Creek 1	Fallow	
McClure	Fallow	
Mound Pond	Fallow	
Mount Vernon	Hayfield	
Oak Street	Restoration	
Ontario	Park	Fallow
Parfrey Glen	Fallow	
Readstown	Park	
Reedsburg	Restoration	Park
Shopiere	Park	
Slabtown	Fallow	
Somerset	Park	
Token Creek	Fallow	
Waterloo	Fallow	
Waterworks	Park	
Whitehall	Not located	
Willow Falls	Fallow	
Wonewoc	Fallow	

Table 2.5: List of dominant canopy trees surrounding selected sites.

---

Baraboo

Acer negundo  
Acer saccharinum  
Alnus ssp  
Catalpa speciosa  
Cornus stolonifera  
Juglans nigra  
Populus deltoides  
Quercus alba  
Rhamnus cathartica  
Salix ssp  
Ulmus americana

Hebron

Acer negundo  
Acer saccharinum  
Fraxinus pennsylvanica  
Salix ssp

Reedsburg

Acer negundo  
Acer saccharinum  
Fraxinus pennsylvanica  
Populus deltoides  
Salix ssp

Rockdale

Acer negundo  
Acer saccharinum  
Juglans cinerea  
Juglans nigra  
Morus alba  
Populus deltoides  
Prunus virginiana  
Quercus rubra  
Rhus glabra  
Salix ssp  
Tilia americana  
Ulmus americana

Table 2.5 cont.

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Token Creek

Acer negundo  
Acer saccharinum  
Juglans cineraea  
Populus deltoides  
Quercus albus  
Quercus rubra  
Salix ssp

Waterloo

Acer negundo  
Acer saccharinum  
Populus deltoides  
Quercus alba  
Salix ssp  
Tilia americana  
Ulmus americana

Wonewoc

Acer negundo  
Fraxinus pennsylvanica  
Pinus strobus  
Salix ssp  
Sambucus canadensis

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## Figures for Chapter 2

Figure 2.1: Location of sites included in this study.

Counties

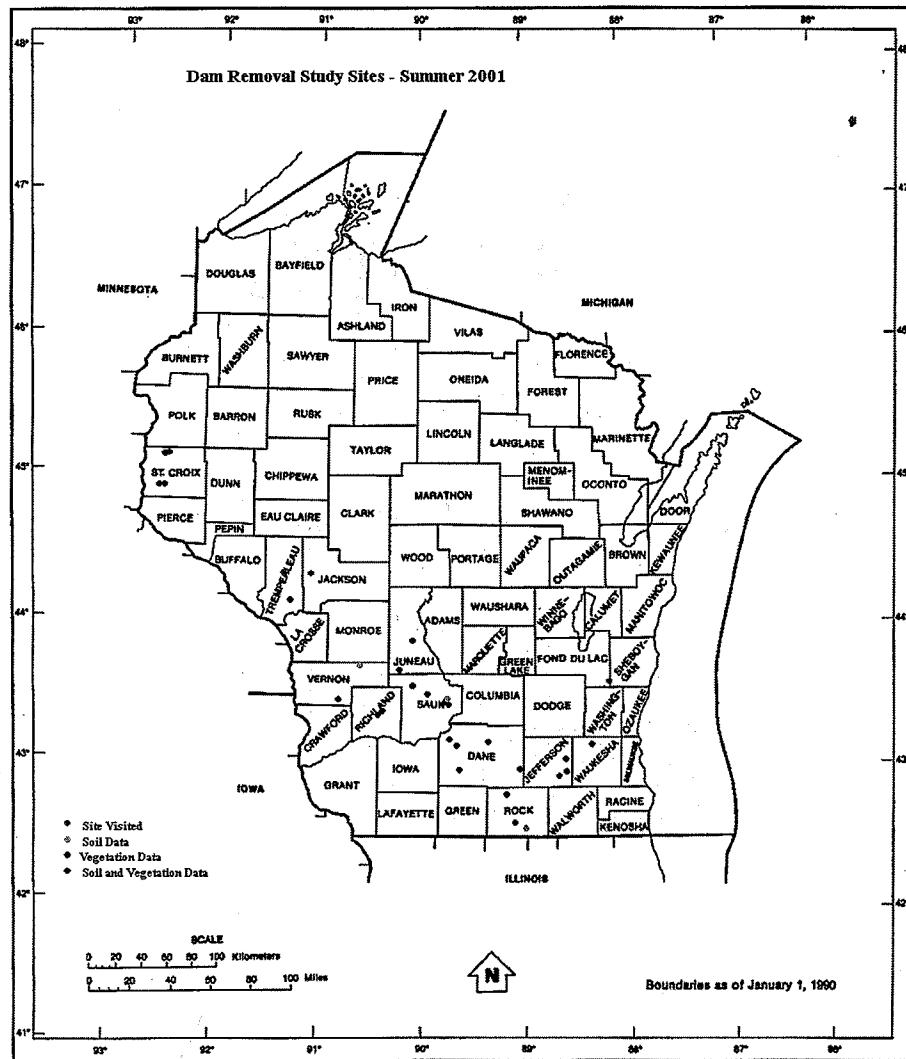
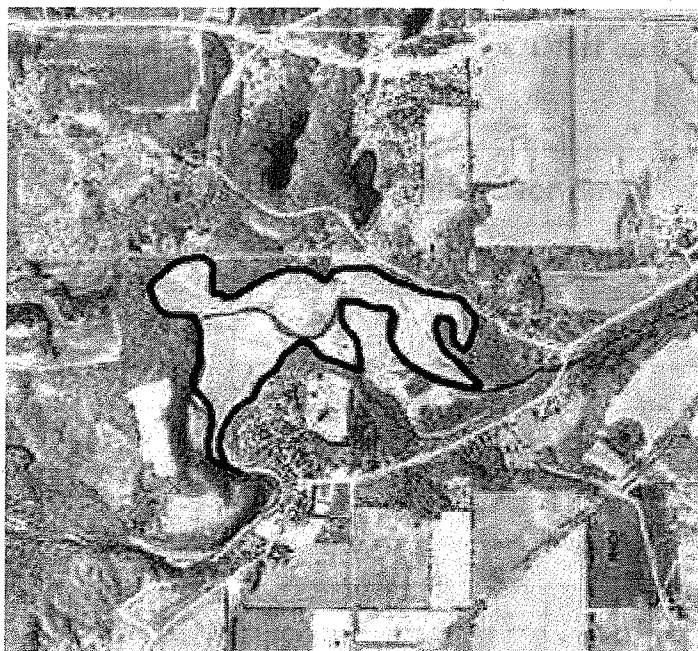
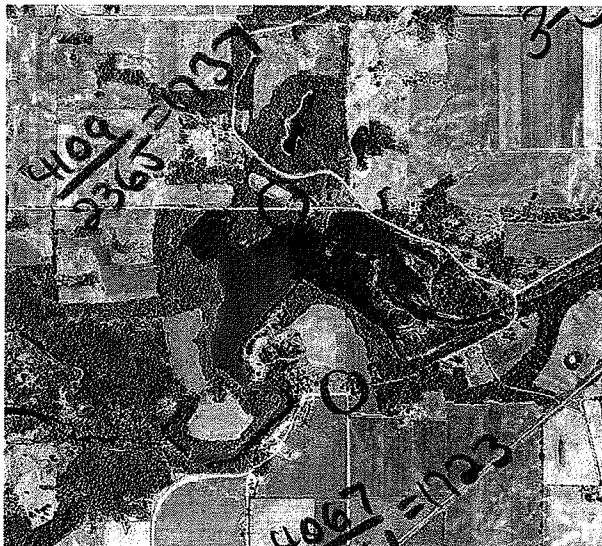


Figure 2.2:

Willow Falls aerial photos from pre-removal (1958) and post-removal (1993) and delineated impoundment area. Water boundaries are clearly visible both before and after the dam was removed. The dark line in the third photograph is the extent of the impoundment used for sampling.



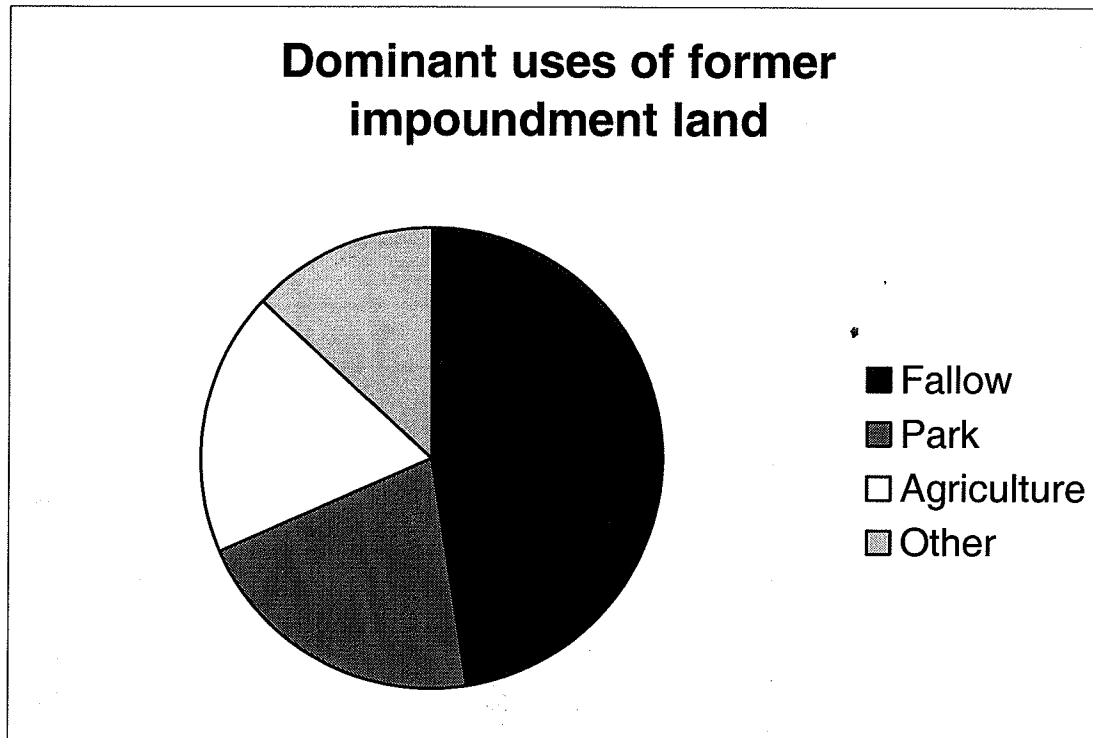


Figure 2.3: Breakdown of year 2001 uses for former impoundments. Fallow indicates no active manipulation of the site. Park includes mowed areas as well as developed areas. Agriculture includes grazing, hay fields and row crops. Other uses were varied and included parking lots and canoe launches.

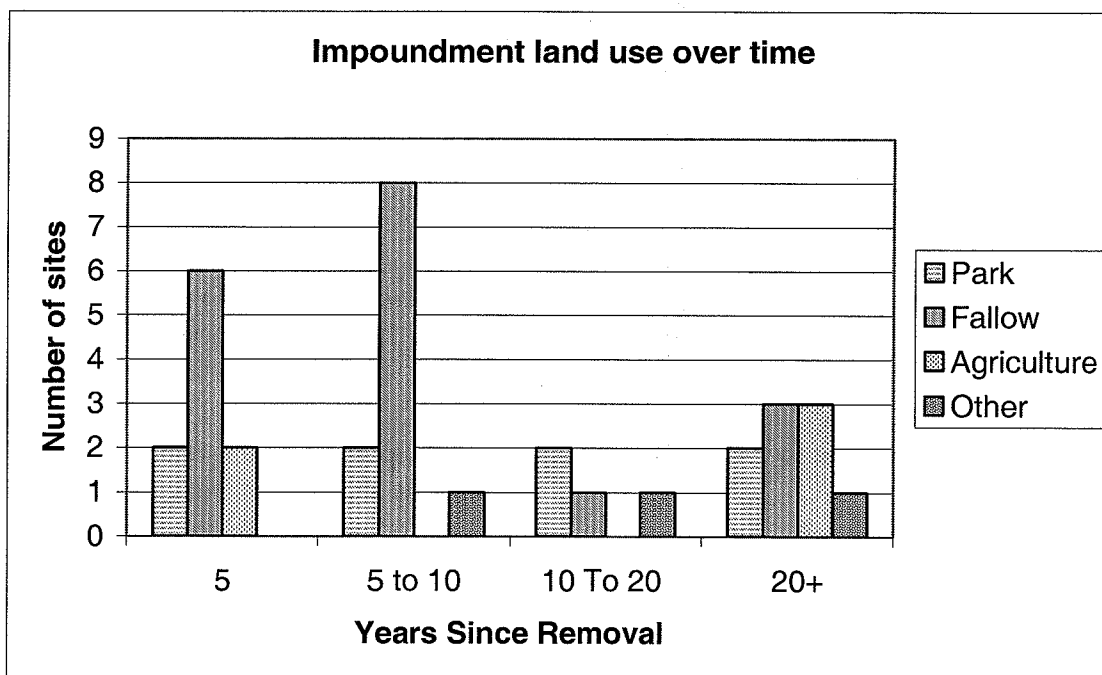


Figure 2.4: Land use by years past since dam was removed. Agricultural uses were grazing on newer sites and row crops on older sites.

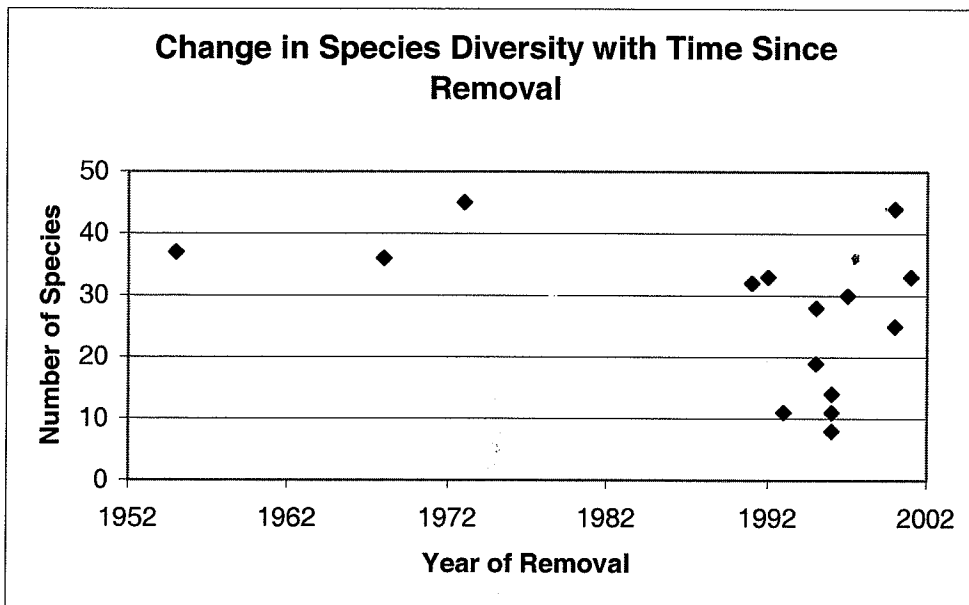


Figure 2.5. Diversity in early years post-removal is variable and variability is higher in sites removed prior to 1975. Diversity is not significantly higher in older sites.

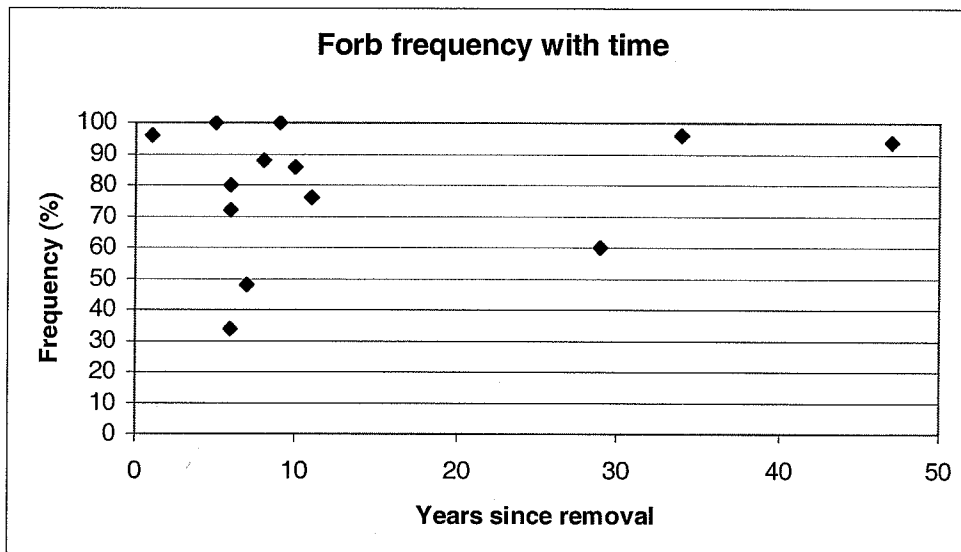


Figure 2.6. Change in forb frequency per site with time after dam removal. Frequency and variability are high across all sites.

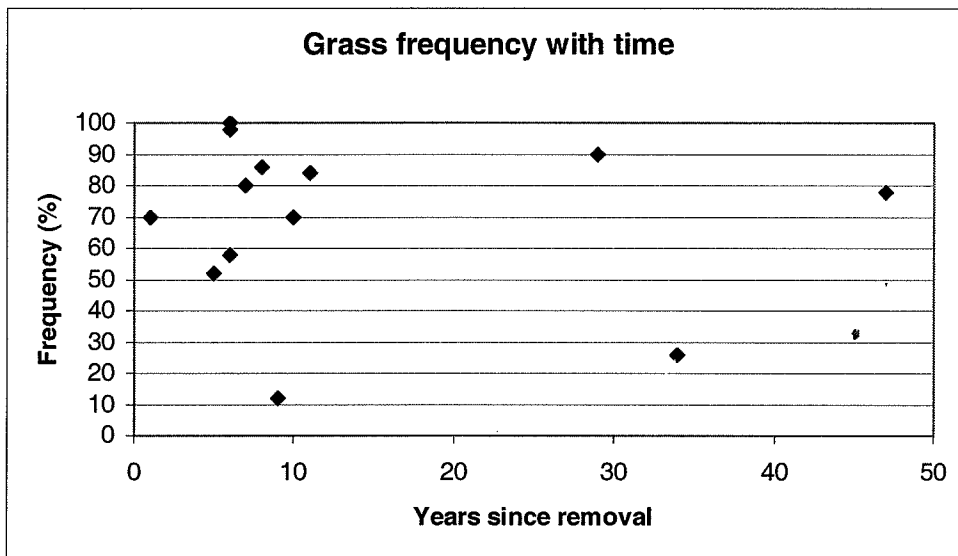


Figure 2.7. Change in grass frequency with time. Grasses may be slightly less dominant on older sites than newer ones.

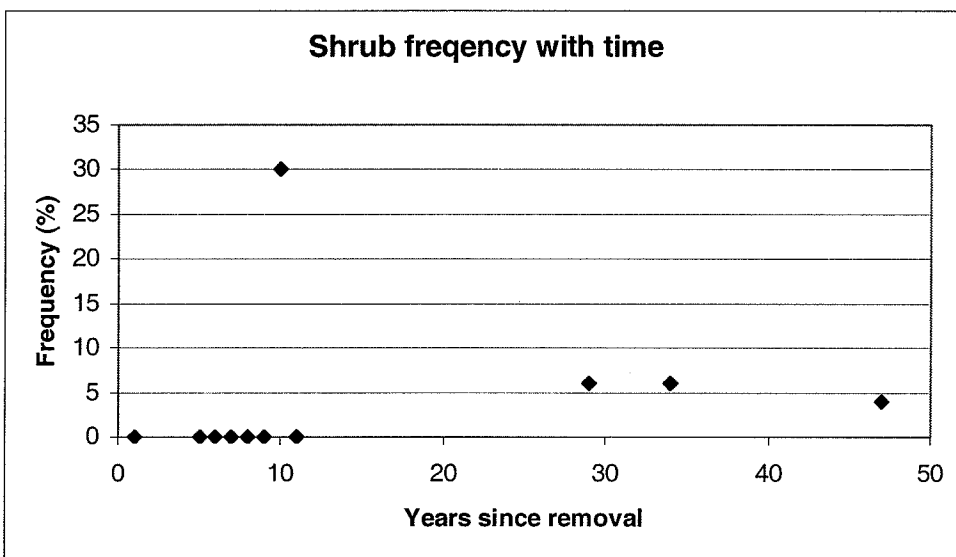


Figure 2.8. Change in shrub frequency with time. There were few shrubs on any site, although shrub abundance may be slightly higher overall on the older sites.

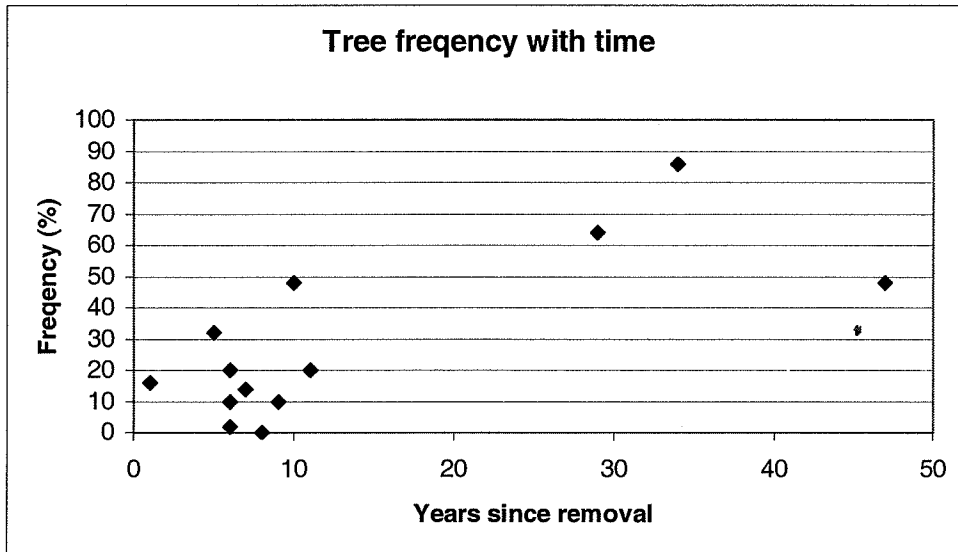


Figure 2.9. Change in tree frequency with time. Although there is not a significant relationship between tree frequency and time, the oldest three sites as a group have significantly higher frequency of trees than the other sites combined.

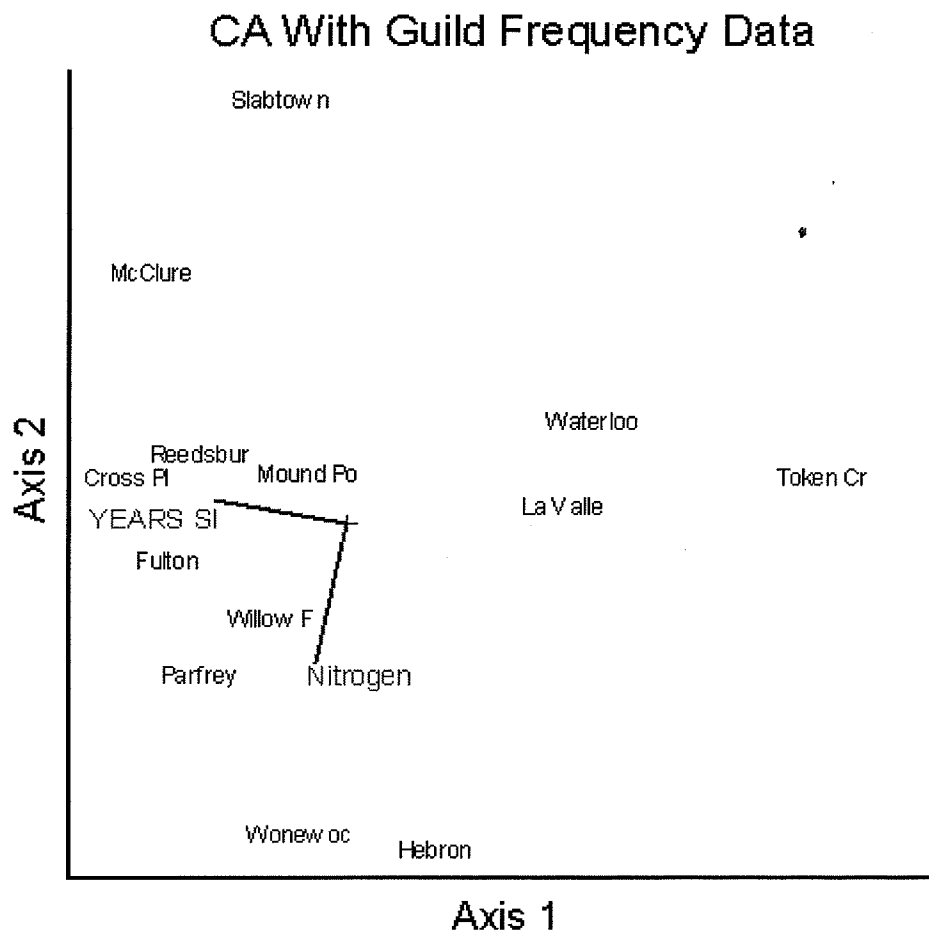


Figure 2.10: Result of CA ordination using frequency data on plant guilds. At  $R^2 = 0.2$  Years since removal and soil nitrogen concentrations are the strongest gradients describing sites.

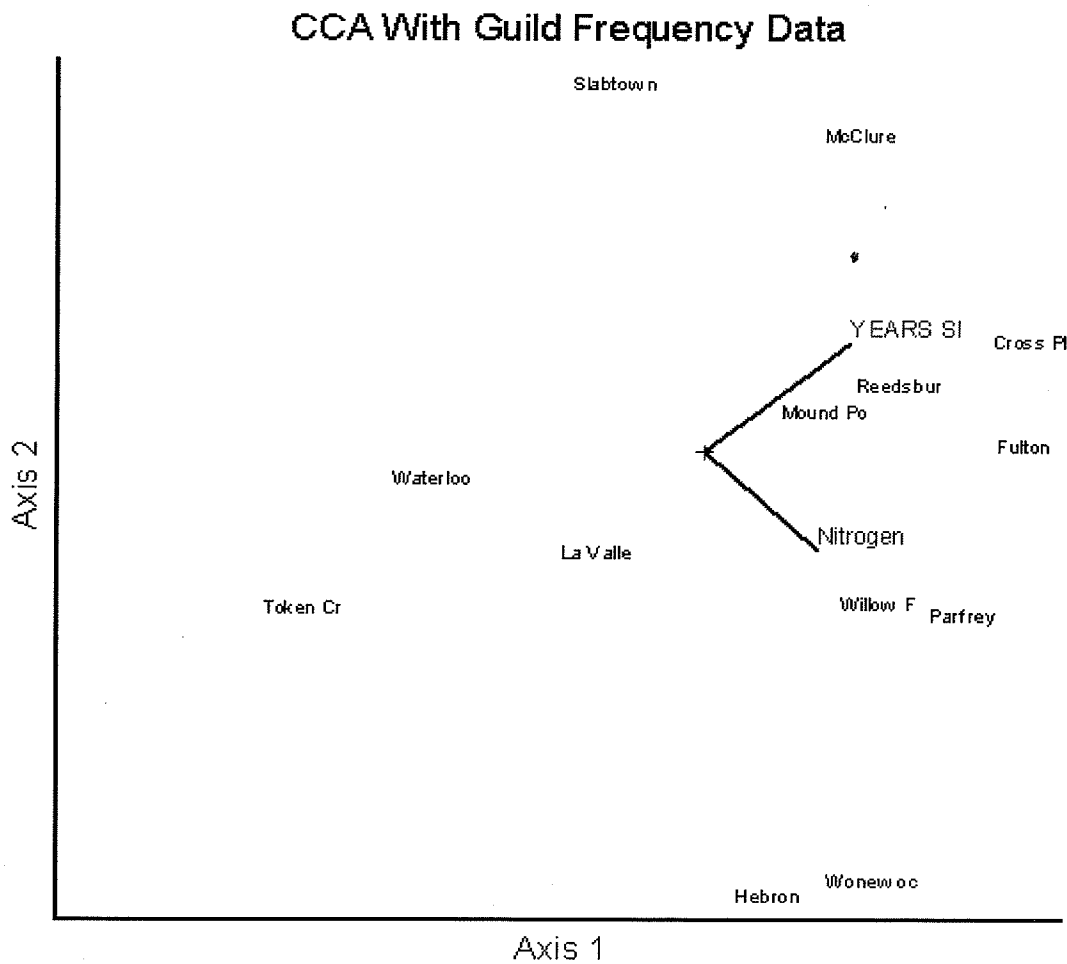


Figure 2.11. CCA ordination results for frequency data on plant guilds. With  $R^2 = 0.3$  The same gradients appear as most important in explaining site variance as in the CA ordination. Sites also sort into a similar pattern as in the CA ordination. Axis 1 and 2 explain 42% of the variability in sites.

## NMS With Guild Frequency Data

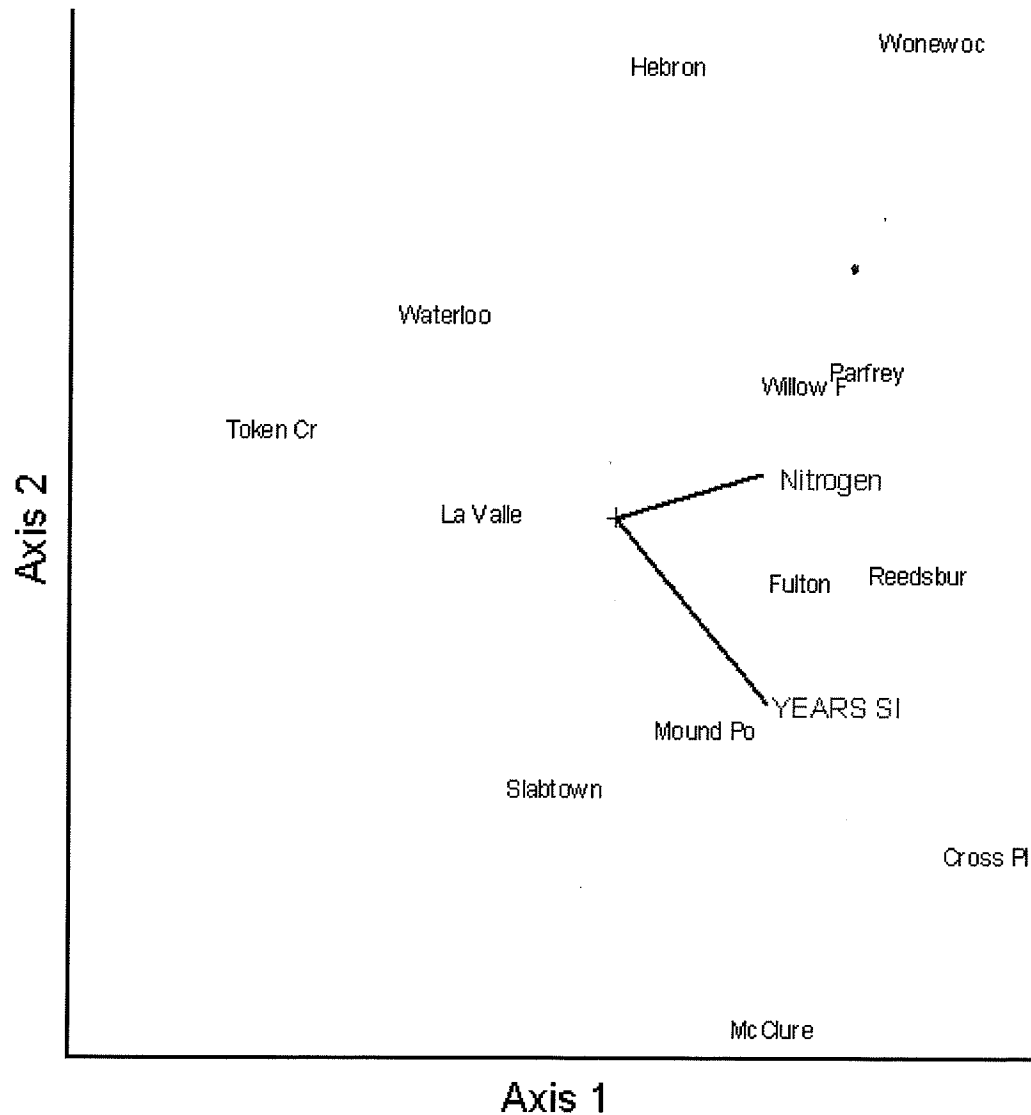


Figure 2.12. Results for NMS ordination of frequency data for plant guilds. At  $R^2 = .3$  this ordination technique produces similar gradients and site pattern. Stress = 14 for the two dimensional solution. Axis 1 and 2 explain 74% of the variability in sites.

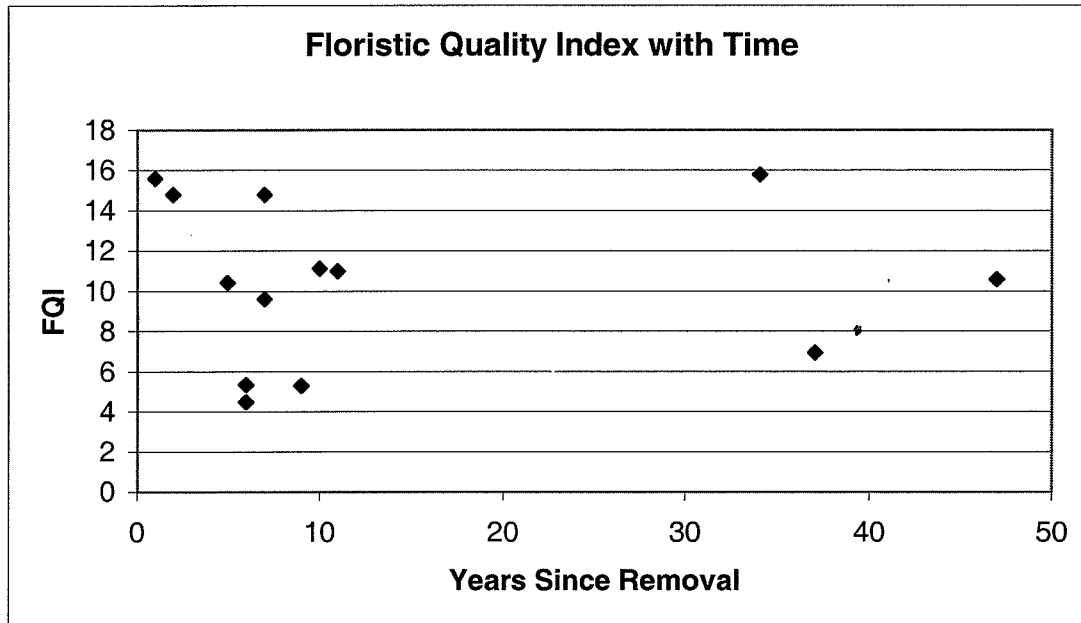


Figure 2.13. Change in floristic quality of sites with time since removal shows that older sites are of similar floristic quality to newer sites.

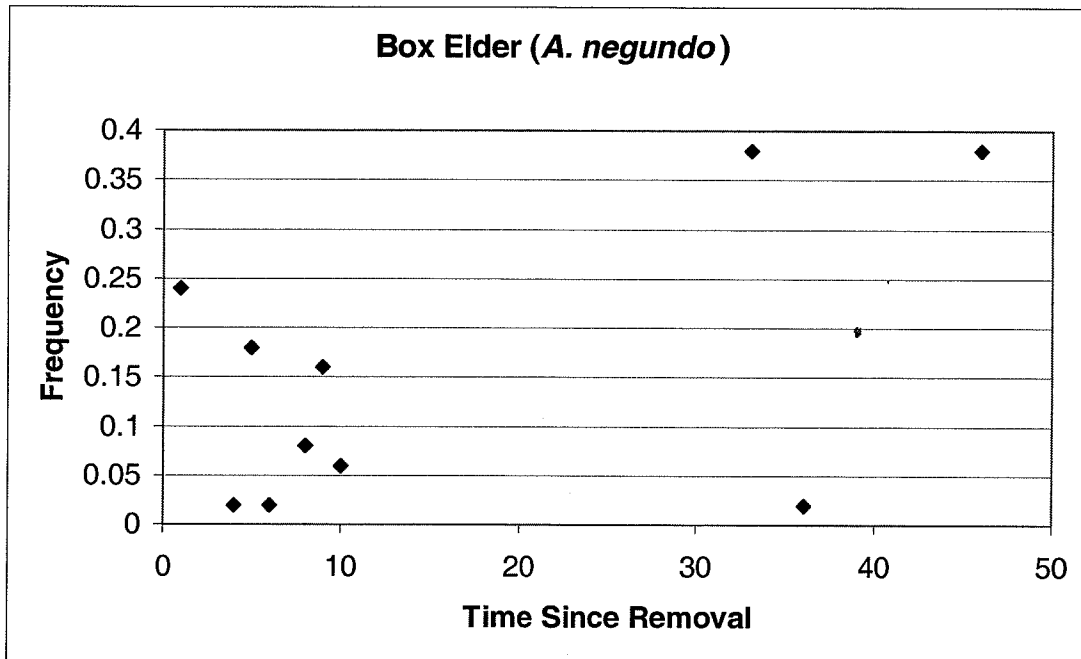


Figure 2.14. Change in frequency of *A. negundo* with time after removal. While there is no pattern across younger sites, two of the three oldest sites have high frequency of box elder.

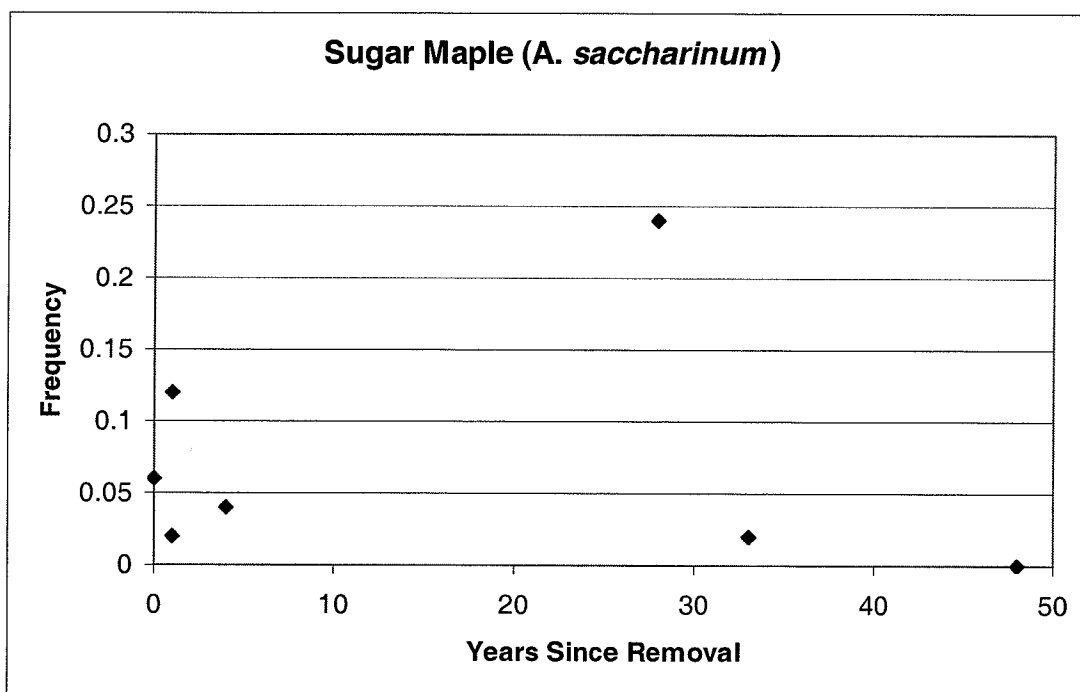


Figure 2.15. Change in frequency of *A. saccharinum* with time. There is no pattern in maple frequency with time. At younger sites, the species was represented by small seedlings, while mature trees were present on the older sites with maples.

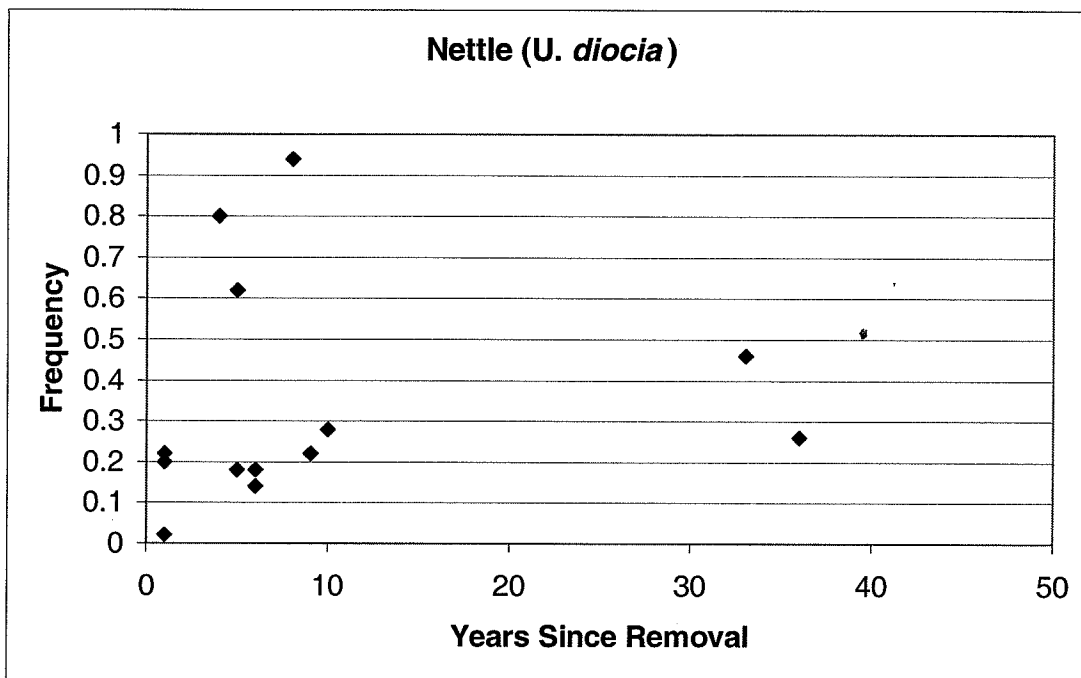


Figure 2.16. Change in frequency of *U. dioica* with time. Nettles were present on 13 of the 15 study sites with varying frequencies.

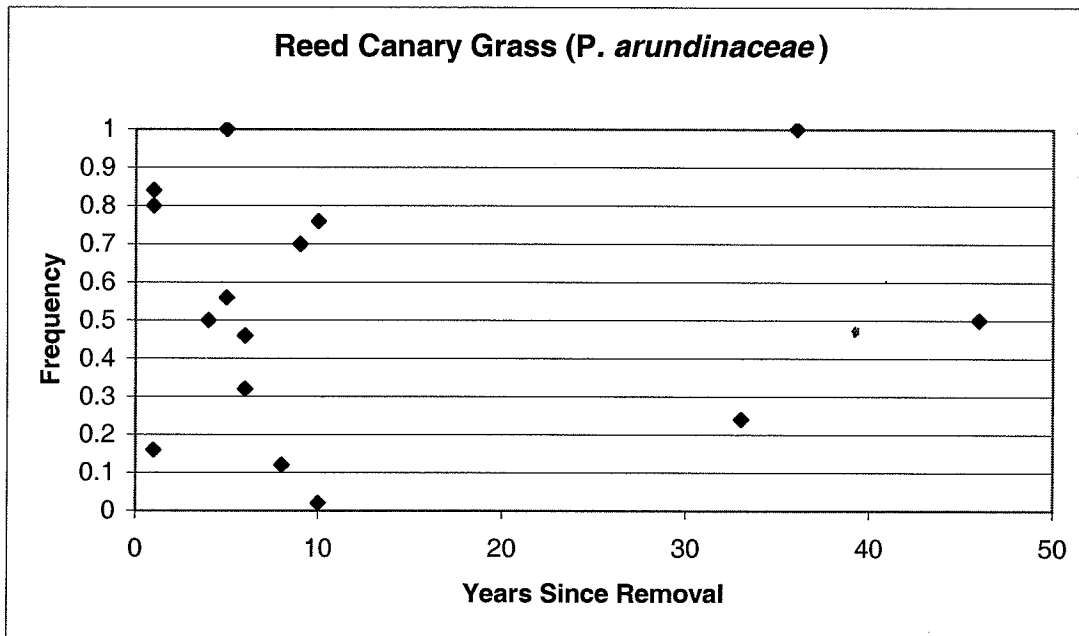


Figure 2.17. Change in frequency of *P. arundinaceae* with time. Reed canary grass was found at 14 of the 15. The single site where it was not present was dominated by grasses planted as a groundcover just after the removal.

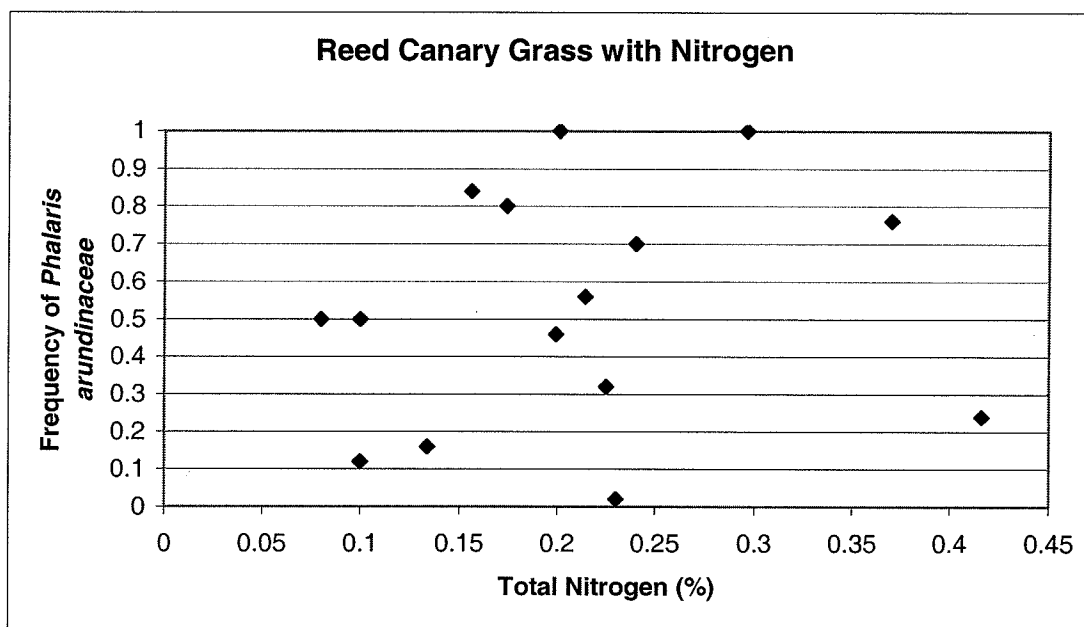


Figure 2.18. Change in frequency of *P. arundinaceae* with soil nitrogen. While soil nitrogen explains 24% of the variability in reed canary grass frequency, plotting frequency with nitrogen does not yield a discernable pattern.

## Chapter 3

### An analysis of social and physical variables leading to small dam removal in Wisconsin

This chapter was produced as the result of a collaboration between 6 students in the UW-Madison IGERT program "Integrating Social and Aquatic Systems" during the 2001-2002 school year. A version of this paper was submitted as a manuscript to Environmental Management with the following authorship:

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#### Abstract

The decision to remove or repair a dam depends on multiple variables, many of which encompass both physical and social factors. In Wisconsin, the Department of Natural Resources is mandated to inspect small dams every ten years. A safety inspection often acts as a trigger event to a dam removal or repair decision. Although managers are likely to view a dam removal decision as an ecological issue, the decision is strongly influenced by social factors. In this work, we analyze descriptive variables of Wisconsin dams that were inspected and consequently removed or maintained between 1985 and 1990. We hypothesize that geographic location, height of dam, size of impoundment, age of dam, and type of ownership determine the likelihood of a safety inspection, and the subsequent likelihood of removal. Using a logistic model, we find that publicly owned dams had the greatest probability of inspection after 1985. Of these dams, older dams and those with smaller impoundments were most likely to be removed. We were unable to

build a strong predictive model for dam removal with our suite of variables, suggesting that a community's decision to remove or maintain a dam is complex and heterogeneous.

## **Introduction**

Dam removal has gained national attention and is increasingly being discussed as a viable solution to aging dams that have become safety hazards. Dam removal is also being evaluated for its potential as a river restoration tool. There is substantial literature on the ecological impacts of dams (see review by Bednarek, 2001) and an emerging body of work on the ecological changes following dam removal (Bednarek 2001, Doyle and others 2000, see also special edition of *Bioscience* in press). There is growing evidence that, in some situations, dam removal may have real ecological benefits such as fish passage (American Rivers, 2000), and water quality improvements (Doyle and others 2000). An aging dam could be viewed as an environmental opportunity. However, even in conditions where dams no longer fulfill their original purpose and dam removal may have significant benefits to the river, most aging dams are repaired, even when repair or replacement is more expensive and the dam in question no longer provides its original purpose. We were interested in the social and physical factors that influence a removal or repair decision and in determining how removed dams differ from those that are maintained.

Many of small dams in Wisconsin outlasted their engineered life expectancy and have fallen into disrepair. Some dams were poorly maintained and are no longer

economically viable. Reservoirs behind aging dams accumulate silt through time, which decreases the storage capacity and blocks water flow for hydroelectric power generation. Furthermore, timber and grain mills no longer depend on small dams for powering their operations. Regulation of these structures falls to the Wisconsin Department of Natural Resources (WDNR website) except for the 5% of dams that are both large and produce hydroelectric power, which are under the jurisdiction of the Federal Energy Regulatory Commission. The state of these decaying historic remnants has caused some of these structures to fall within Wisconsin State Statute 31.19, which charges the WDNR with the removal of "unsafe structures" (WDNR website). Many of these dams are proximal to residential areas, which create a physical hazard for those individuals who may utilize the dam for recreation. Potential dam failure, another danger of aging dams, can cause or exacerbate property-damaging floods and release large quantities of accumulated sediments downstream.

Dam owners are responsible for repair versus removal decisions. Approximately 50% of the dams in Wisconsin are owned by private individuals, 19% by the State of Wisconsin, 16% by municipalities such as townships or county governments, and 15% by other ownership types (WDNR website). Property owners who wish to keep the dam may opt to repair it at their own expense. In some cases, owners may transfer ownership to a municipality that will repair and maintain the dam. However, local governments are often wary of accepting responsibility for a potential safety hazard. Previously, the WDNR was able to provide municipalities with up to \$200,000 for dam removal or repair (WDNR website), but the \$11.5 million allocated to this program has all been used and no additional funds are available (Associated Press, 2002). In Wisconsin, dam repair and

maintenance is up to three times more expensive than removal when post-removal restoration costs are not included (Born and others 1998).

We used the legacy of dam removal in Wisconsin as an example to explore the question of why some dams are removed while many more dams are repaired. We were interested in how removed dams differed from remaining ones. In addition, we hoped to determine what factors might influence a repair versus removal decision process once the discussion about how to deal with an aging dam has begun. Our initial hypotheses were related to the physical attributes of the dam/impoundment combinations and we expected that smaller, older dams with shallow impoundments would be the most likely to be removed. We used an initial set of interviews with dam removal stakeholders to identify potential drivers of dam removal patterns. We then used a dam inventory database to statistically analyze the identified variables. Finally, we used follow up interviews to verify and explain our database findings.

## **Methods**

### Database Information

The Wisconsin Department of Natural Resources maintains an electronic database of more than 3,800 dams (both existing and removed) in the State of Wisconsin, available at <http://www.dnr.state.wi.us>. Information available from this database includes physical, geographical, social, and management data. We used this information to address multiple hypotheses about the pattern of removal across the state and through

time. Our first hypothesis was that dam removals result from a cascade of events that begins with an initial opportunity or 'trigger' event.

We identified factors that may act as the trigger event by conducting informal interviews with WDNR staff. In general, we conducted the interviews by phone or by visiting to the staff member's office. All staff we interviewed told us which factors they considered to be important determinants of dam removal and explained why each factor was important. All the information given was qualitative; no data were recorded. We do not report findings from the interviews in the results section. Instead, we described the important factors below in the Methods section, and used all other interview information to explain results from statistical analysis on the dam database.

We used the interview information as a primary step to narrow the database by removing all dams without data on factors that WDNR staff suggested may be important. In addition, we removed any dam listed as 'large', and as a consequence, restricted our analysis to 'small' dams, or those less than 6ft (2m) in height or those with an impoundment less than 150 acre-feet. Any dams were eliminated from analysis if data were missing from these fields (both removals and existing dams). We eliminated approximately 1,300 dams prior to analysis, leaving 2,533 dams with complete data for analysis.

### Important Factors

WDNR staff described four factors that might be important: dam inspections, the dams' geographic region, the dam physical characteristics, and dam ownership.

Individual categories within these main factors are listed in Table 3.1.

Inspections were grouped into 3 categories: Whether the dams were inspected at all (Inspected), whether the dam was inspected between 1985 and 2001 (Inspected after 1985), and whether the dam was inspected between 1990 and 2001 (Inspected after 1990). All dams in the Inspected after 1990 category are in the Inspected after 1985 category, and all dams in both Inspected after 1990 and Inspected after 1985 categories are in the Inspected category.

The geographic region variables were based on the WDNR's current geographic management units (GMU's). However, these units were instated in 1997. As a consequence, any dams removed prior to 1997 may have been in a different WDNR management region than they are currently listed. Therefore, we used the current GMU's as a way to incorporate geographic regions, not management, into our models. The counties in each geographic region are listed in Table 3.1.

Ownership variables were grouped into 5 categories: Private/Utilities, Municipalities, State, Federal, and Other. A comprehensive list of dam owners under these category headings are listed in Table 3.1. Lastly, we defined physical variables as those that described size or age. These variables were limited to dam height (ft), dam impoundment size (acre-ft), and dam age (yrs).

### Data Analysis

We used logistic regression to build statistical models that can determine which of several physical, geographical, and social (ownership) variables can best describe which dams are removed. Logistic regression uses either continuous (e.g. time) or categorical (e.g. whether a dam was inspected or not) data to build a statistical model that best fits a binary response (either a dam was removed or not). Logistic regression models are fitted using the maximum likelihood method (Chatterjee and others 2000). For more on uses of logistic regression in ecology, see Manel and others (2001). The logistic regression function in SYSTAT (SYSTAT 9.0, SPSS, Inc.) provides the odds ratio as well as a prediction table. The odds ratio represents how much the logit (or ratio of positive responses: negative responses, or in our case, dams removed: dams not removed) responds to incremental changes in a given parameter. For a continuous independent variable, an odds ratio of 1.05 for a parameter estimate means that for a one-unit change in the parameter, while all others are constant, the logit will increase by 5%. Or, as applies to our work, the odds that a dam will be removed increases by 5%. For dichotomous variables, the odds variable has a slightly different interpretation. If a dichotomous parameter estimate has an odds ratio of 1.05, this means that a dam with the characteristic described by the parameter has a 5% greater chance of being removed than a dam without the characteristic.

Prediction tables use the model estimates to create metadata from which to compare to actual data. Prediction tables are therefore able to give an estimate of how well the model fits, in percent of correct predictions. In the literature, this is known as sensitivity. For ease of interpretation and to avoid confusion with sensitivity analysis (which we do not perform), we will call the quantity described above Percent Correct.

We use Percent Correct as the main estimator of model performance, while we use the odds ratio of individual parameters to estimate their influence on the model performance. We used t-tests on specific variables that we found to be important variables in logistic regression analysis

## **Results**

### All Dams: Which factors contribute most to dam removal?

We determined if there are factors that contribute to dam removal when all 2,533 dams are included in analysis. We found that Inspected as well as Dams Inspected after 1985 were significant predictors of dam removal (both p-values  $<0.05$ ), while Dams Inspected after 1990 was not (p-value  $>0.5$ ) (Table 3.2). When all dams inspection variables are included, the model accurately predicts 3.1% of the removals; when only Dams Inspected after 1985 is included, the model accurately predicts 3% of the removals (Table 3.2). The odds ratio of this parameter, when all 3 inspection variables were included, indicated that dams that were inspected after 1985 are 1.5 times more likely to be removed than those inspected prior to 1985 or those inspected after 1990. Dam Age was the only significant predictor of dam removal when only physical variables are included in analysis (p-value  $<0.01$ ). However, all physical variables allowed the model to successfully predict 4.7% of the removals (Table 3.2). When removals are predicted by geographic region or by dam owner, no variables were significant (all p-values  $>0.13$ ). However, the S. Central Region does contribute to the model that best describes dam

removal with all dams included in analysis. This model includes Dam Age, and Inspected after 1985, and S. Central Region variables, and predicts 6.8% of the removals (Table 3.2).

#### Factors leading to Dams Inspected After 1985

Following the above analysis, we sought to predict which factors led to inspections after 1985. We found that physical attributes, geographic region, and dam ownership all influence Dams Inspected after 1985 (Table 3.3). When the 7 most influential of these variables are used as predictors, the best model accurately predicts 45.5% of dams inspected after 1985, higher than all models for each individual variable group (Table 3.3). Dams that are owned by municipal and federal governments are especially likely to be inspected, being 2.6 and 5 times, respectively, more likely to be inspected than dams that are not owned by municipalities or the federal government (odds ratios = 0.269 and 0.328 for dams that are not owned by municipal and federal governments, respectively) (Table 3.3).

#### Dams Inspected After 1985: Which factors contribute most to dam removal?

Of dams that were inspected after 1985, the chance that a dam gets removed increases as the dam gets older and as the impoundment size gets smaller (Table 3.4). For every year the dam ages, the odds it gets removed increases by 2.2% when all other physical variables are held constant. Likewise, for every increase in dam impoundment

acre-feet, the odds the dam is removed decreases by 1%. The model can only predict 8.1% of removals when only physical variables are included in analysis. The S. Central region of the state is the only significant geographic predictor (p-value = 0.02, all others: p-value>0.15). Dams in this region are more than 3 times as likely to be removed than in other geographic regions. However, the model only accurately predicted 8% of all removals when all geographic regions are included. Dam ownership does not significantly contribute to dam removals (all p-values>0.2).

The best model for dam removal includes the S. Central geographic region, dam age, and impound size variables (Table 3.4). This model only accurately predicts 12.6% of all removals. However, dams in the S. Central region are 2.2 times as likely to be removed than all other dams when dam age and impound size variables are held constant (odds ratio for dams not in S. Central region =0.446).

#### Importance of Individual Variables

The S. Central Region variable appears consistently in models that best describe Inspections after 1985, Removal (all dams) and Removal (dams inspected after 1985). More dams have been removed in this region than all others (Figure 3.1). However, the S. Central Region has the lowest proportion of dams inspected (22%), and the second lowest proportion of dams inspected after 1985 (18%), relative to the total number of dams in the region (Figure 3.2). A large proportion (79%) of the dams inspected in the S. Central Region have occurred after 1985 compared to only 43% in the W. Central Region (Figure 3.3). The S. Central Region has the highest ratio of inspections after 1985 to

removals (7.3:1) while the lowest ratio occurs in the Northern Region (32.3:1) (Figure 3.4).

Logistic regression analysis also indicates that older dams and those with smaller impoundments are more likely to be removed than newer ones and those with larger impoundments. The average age of removed dams is significantly older than dams not removed (paired t-test,  $t=9.066$ ,  $df=32$ ,  $p\text{-value}<0.001$ ). In contrast, the average size of dam impoundments (log transformed) behind non-removed dams is significantly smaller than impoundments behind removed dams (paired t-test,  $df=32$ ,  $p\text{-value}<0.001$ ). This contradicts our findings from the logistic regression analysis. However, we were unable to log transform the impoundment size variable in logistic regression because negative numbers (those impounds less than 1 acre-foot) cannot be used in logistic regression.

## **Discussion**

### The role of the regulatory agency

Follow up interviews with WDNR staff suggested that some of our findings could be explained by the history and structure of the regulatory agency. The WDNR is the primary state authority responsible for regulating dams under State Statute 31.19 and the Water Power Law created in 1917. The legislature requires the WDNR, through the Dam Safety Program, to inspect dams on navigable waterways and once every 10 years, except for dams regulated by a federal agency.

A mandated portion of each inspector's reports provides information on the possibility of dam failure, potential liability that dam owners may face, and steps that should be taken to amend the problem. Individual dam inspectors may also include information on the possible benefits of choosing dam removal as a remediation option such as: reduced liability; repair and removal cost estimates; habitat restoration; water quality; and improved recreational opportunities. The quality and type of information on potential costs and benefits of dam removals are not uniform for all inspection reports. The dam inspection report may be the main source of information available to a dam owner at the time the decision to repair or remove a dam is made. Dam inspections may trigger the dam removal process by providing a source of information regarding the potential costs and benefits of dam removal and possible financial assistance. If this is the case, dam removal is more likely in situations where more information about the ecological impacts of dams or the potential funding sources available for removal were included in an inspection report.

The history of WDNR regulation changes certainly changed patterns of inspection and may have also influenced patterns of removal. River regulation and river ecology have historically come under the purview of disparate regulatory agencies. Inspection engineers have not been assigned to work with ecologists and fish biologists in state or federal agencies, and the result has been a predictably varied management regime. Until recently, the dam safety inspector's appointed job was specifically to ensure the safety and structural integrity of dams, and not to include consideration of biologic and ecologic aspects of river regulation in their inspections. Prior to 1986, inspection fees, based on the size of the dam, were paid by the dam owner and funded the dam inspection program.

As a consequence of this funding arrangement, the WDNR often prioritized inspection of large dams to fund the program, while preserving some inspections to fund future years. This pattern changed with the inception of a municipal dam grants program that paid for the inspection of dams of any size owned by municipalities. There are currently 13-14 dam inspectors assigned to areas of the state. With an agency re-organization that occurred in 1997, some inspectors are currently in interdisciplinary teams where they have opportunity to invite input from personnel with varied areas of expertise to provide detailed accounts of potential costs and benefits of a particular project. Inspectors in more isolated offices or with higher inspection quotas may not include this information in their reports. This variation in the quality and type of information in inspection reports is likely to be biased such that inspectors working in regions close to the central bureau in the state capital may be more likely to include more information and consequently present a larger opportunity for dam removal.

#### Comparing the predictive models to interviews

Dams that are old with small impoundments, and have been recently inspected by an engineer working in the S. Central Region of the state may be more likely to be removed. But even under these conditions, only a small percentage of dams are removed compared to the number repaired. Inspection may be an opportunity for a removal process to be triggered, but many additional factors contribute to the ultimate decision to breach a dam. The best model we can develop from data available on all the dams and removals in the state is still a fairly poor predictor of dam removal. This strongly suggests

that the attributes we assessed are not the only major factors determining whether a dam is retained or removed. The other chief consideration is individual or organizational involvement in the decision making process.

Local residents can greatly influence the dam removal decision. Communities are often strongly opposed to dam removal, especially in cases where the removal is perceived as a threat from an entity outside of the local community (American Rivers and others, 1999). One of the more common arguments for keeping a dam concerns the affinity that people develop for their local environment. People who grew up in a community surrounding the reservoir often get upset at the prospect of losing what has always been a prominent feature of the local landscape. While the man-made reservoir may constitute a 'degraded' environment from an ecological perspective, it constitutes the 'natural' environment from a social perspective – particularly in cases where the dam has been in place for generations.

Natural resource managers have increased their use of place attachment in their efforts to understand the affinity that people develop for particular natural areas (Cantrill, 1998). Place attachment is variously defined as an emotional bond between people and their environment (Altman and Low, 1992), the emotional linkage of individuals to a particular environment (Hunter, 1978), and emotional investment in place (Hummon, 1992). A related concept, sense of place, has been defined in quite similar ways. Tuan (1974) defined sense of place as the affective bonds between individuals and particular places that vary in intensity; Steele (1981) defines it as a geographic setting combined with the personal experiences of a perceiver and Williams (1995) regards sense of place as the product of imbuing meaning to a location. Generally, place attachment and sense

of place allude to the emotional and symbolic identification that people have with a given locale.

As dams age, more communities are faced with controversy over what action to take. The controversy surrounding dam removal is in fact not altogether different from the controversy that attends dam construction. Dam construction creates considerable disruption at the geographic, economic, and cultural levels. Similarly, when a dam is removed, disruption may occur at the geographic (loss of 'natural' environment), economic (decline in lakeshore real estate values, businesses catering to lake-specific recreational activities), and cultural (loss of familiar landscape) levels. Through time, the environment created by a dam may come to have symbolic relevance to surrounding communities. Consequently, just as affected populations resist dam construction projects, so too do affected populations resist dam removal projects. Evaluation of how place attachment influences dam removal decisions would be useful in framing decision-making processes but to date, no work of this type has been done.

In addition to WDNR inspection reports providing technical, educational and financial assistance to dam owners, the involvement and advocacy of non-governmental organizations may complement or substitute for the WDNR inspection as a triggering process for dam removal. In particular, these organizations may provide critical resources for private small dam owners who constitute the largest percentage of dam owners in the state. Although the state has allocated funds for a program targeted specifically at these small private owners, these funds have not been made available to date.

Recently, non-profit organizations such as American Rivers, The River Alliance of Wisconsin and Trout Unlimited have launched campaigns to either advocate dam removal or help inform dam owners about the pros and cons of removal. Non-profit environmental organizations are probably not influential in determining trigger events to dam removal, such as an inspection, or targeting for environmental concerns. However, private organizations do influence the process once a dam has had a trigger event such as a failed inspection and becomes a potential candidate for removal. They perform community education and outreach by holding public talks, act as experts in public hearings, comment on administrative documents, and provide fact sheets outlining the economic and ecologic benefits to removal (pers com, Helen Sarakinos, Small Dams Manger for The River Alliance of Wisconsin). This input is likely to influence rates of dam removal. Although these organizations do not directly determine inspections or cause dam removals, they may have an influence on the attitude of the people involved in the process and in that way change the final decision to repair or remove a small dam on a case-by-case basis. Growth of these organizations may influence future removals but their effects on the numbers of removals we observed in this study is likely to be only modest as these programs are relatively new.

## **Conclusion**

Dam removal is more prevalent and has a longer history in Wisconsin than in any other state in the country. Growing ecological literature says that dam removal may be a powerful restoration tool if it is implemented in a deliberate and calculated way. Yet

removals here are occurring in a piecemeal fashion. Decisions about river restoration are made on a case-by-case basis as the result of decision-making processes that may not be informed of all the options and consequences of each choice. If dam removal is going to be evaluated as a real solution to the problem of aging dams, there are three entities that need to exist in every decision making process. The first is a regulatory agency that can, and is required to, uniformly assess ecological impact of dams along with their assessment of dam safety and structural integrity. The second is a funding source available to dam owners, including private owners, which can be used for removal or repair. The third is an interested party available to collect and collate relevant information about different remediation options and make them available in a comprehensible form to decision makers and all relevant stakeholders.

If our regression model cannot predict dam removal a more accurate model of the dam removal process, as described to us by a regional DNR dam inspection engineer, might be this:

$$\text{Dam Removal} = O + E + F + P_1 + P_2$$

Where:

**O = Opportunity** or impetus for change

**E = Economics**

**F = Fortitude:** time investment by an interested party

**P<sub>1</sub> = Place attachment and Community pressure**

**P<sub>2</sub> = Political involvement**

Where opportunity could be an inspection, a structural failure or any event that questions the status quo of a particular structure. Economics mostly comes into play in the form of funding availability and total cost of removal. Fortitude is equivalent to leadership by an interested individual or organization who can gather information and track the project to completion. Public and political involvements are the input given by stakeholders and outside parties to the decision making process that could sway the decision makers to take a particular action.

We found that it is difficult to predict dam removal using past removals as a guide and that no particular feature of an individual dam makes it a likely candidate for removal. In the absence of any major drivers determining patterns in dam removal, there is opportunity for the growing body of ecological information to guide decisions about where future removals should occur. Removals can be expensive in terms of both money and time invested by all parties involved. To ensure that limited resources allocated to dam removal are bringing the most restoration benefit, efforts should be targeted towards rivers that have the best chance of recovering ecological functions after a dam removal.

Organizations or individuals interested in implementing coordinated dam removal as a river restoration technique need to be aware of the details of the decision making process and of the complexity of factors beyond safety, cost and ecology that influence the eventual state of the river in question. A good example of a focused restoration effort is the 4 consecutive removals of aging dams on the Baraboo River in Central Wisconsin. The final removal in 2002 connected approximately 120 miles of main stem river and the effort is expected to improve fish habitat and swiftwater recreation opportunities on the

river (American Rivers 2000, WDNR website). This example could be used as a model for other river systems.

### **Additional acknowledgements for this chapter**

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Table 3.1. Variables used in logistic regression. Only Physical Variables are continuous. All others are dichotomous.

<b>Physical Variables (units)</b>	Dam Size (Feet)	Dam Age (Yrs)	Impoundment Size (Acre-Feet)		
<b>Ownership</b>	<b>Private/Utility:</b> <i>Private, Cranberry Bog, Utility, Lake Association</i>	<b>Municipal:</b> <i>County, City, Township, Village</i>	<b>State:</b> <i>Department of Natural Resources, Department of Transportation</i>	<b>Federal:</b> <i>Forest Service, Department of Defense, Department of the Interior</i>	<b>Other:</b> <i>Core of Engineers, County Land Conservation District, Statutory Drainage District</i>
<b>Geographic Region: Counties (No.)</b>	<b>South Central</b> <i>Crawford, Richland, Columbia, Jefferson, Dane, Rock, Green, Lafayette, Grant, Iowa, Sauk, Dodge (12)</i>	<b>Southeast:</b> <i>Sheboygan, Washington, Waukesha, Walworth, Kenosha, Racine, Milwaukee, Ozaukee (8)</i>	<b>West Central:</b> <i>St. Croix, Dunn, Chippewa, Clark, Pierce, Pepin, Eau Claire, Buffalo, Trempealeau, Jackson, Marathon, Portage, Wood, Adams, Juneau, Monroe, Lacrosse, Vernon (18)</i>	<b>Northeast:</b> <i>Marinette, Oconto, Menominee, Shawano, Door, Kewaunee, Waupaca, Outagamie, Brown, Manitowoc, Calumet, Winnebago, Fond du Lac, GreenLake, Marquette, Waushara (16)</i>	<b>North:</b> <i>Bayfield, Douglas, Ashland, Iron, Vilas, Forest, Florence, Oneida, Langlade, Lincoln, Taylor, Price, Rusk, Sawyer, Washburn, Barron, Polk, Burnett (18)</i>
<b>Inspection Schedule</b>	Inspected?	Inspected Post 1985?	Inspected Post 1990?		

Table 3.2. Models describing inspection after 1985: Numbers after the parameter name indicate that the model tests for the significance of the parameter by analyzing the dams that do not have the parameter characteristic (1 for dams with the characteristic, 0 for dams without). Parameter names that are followed by 'alone' indicate that the parameter failed tolerance checks when grouped with other variables, and as a result were analyzed alone.

Model	Parameter name	Parameter Estimate	p-value	Odds ratio	Percent correct
Ownership	Private/Utilities (0)	-0.496	0.055	0.609	<b>35</b>
	Municipal (0)	-1.694	0.000	0.184	
	State (0)	-0.988	0.000	0.372	
	Federal (0)	-1.432	0.000	0.239	
	Other (0) Alone	0.902	0.000	2.464	
Geography	North (0)	0.262	0.003	1.299	<b>27</b>
	W. Central (0)	1.032	0.000	2.807	
	N. East (0)	0.055	NS	1.056	
	S. Central (0)	0.607	0.000	1.835	
	S. East (0) Alone	-0.546	0.000	0.579	
Physical Characteristics	Age	-0.027	0.000	0.973	<b>28.8</b>
	Height	0.042	0.000	1.042	
	Impoundment Size	0.000	0.000	1.000	
Best	Municipal (0)	-1.114	0.000	0.328	<b>45.5</b>
	State (0)	-0.675	0.000	0.509	
	Federal (0)	-1.312	0.000	0.269	
	W. Central (0)	0.960	0.000	2.613	
	S. Central (0)	0.436	0.000	1.546	
	Age	-0.023	0.000	0.977	
	Height	0.115	0.000	1.122	

Table 3.3. Models describing dam removals with all dams included in analysis: See Table 2 for notes on the numbers after the parameter name

Model	Parameter name	Parameter Estimate	p-value	Odds ratio	Percent correct
Ownership	Private/Utilities (0)	-5.709	NS	0.003	<b>2.3</b>
	Municipal (0)	-6.503	NS	0.001	
	State (0)	-5.930	NS*	0.003	
	Federal (0)	-5.789	NS	0.003	
	Other (0) <i>Alone</i>	5.973	NS	392.606	
Geography	North (0)	0.223	NS	1.250	<b>1.7</b>
	W. Central (0)	0.350	NS	1.420	
	N. East (0)	-0.145	NS	0.865	
	S. Central (0)	-0.218	NS	0.840	
	S. East (0) <i>Alone</i>	0.914	NS	0.914	
Physical Characteristics	Age	-0.035	0.000	0.966	<b>4.7</b>
	Height	0.024	NS	1.024	
	Impoundment Size	-0.004	NS	0.966	
Inspection	Inspected (0)	-0.602	0.036	0.548	<b>3.1</b>
	Inspected after 1985 (0)	-0.666	0.013	0.514	
	Inspected after 1990 (0)	0.045	NS	1.046	
Best	S. Central (0)	-0.436	0.029	0.647	<b>6.8</b>
	Age	-0.031	0.000	0.068	
	Inspected after 1985 (0)	-0.706	0.000	0.494	

Table 3.4. Models predicting dam removal of dams inspected after 1985.

Model	Parameter name	Parameter Estimate	p-value	Odds ratio	Percent correct
Ownership	Private/Utilities (0)	0.188	NS	1.201	<b>6.0</b>
	Municipal (0)	-0.371	NS	0.690	
	State (0)	-0.398	NS	0.671	
	Federal (0)	-0.517	NS	0.596	
	Other (0)	6.227	NS	532.077	
Geography	North (0)	-0.142	NS	0.867	<b>8.0</b>
	W. Central (0)	-0.693	NS	0.500	
	N. East (0)	-0.649	NS	0.522	
	S. Central (0)	-1.216	0.022	0.296	
	S. East (0) <i>Alone</i>	0.693	NS	2.000	
Physical Characteristics	Age	-0.022	0.004	0.978	<b>8.1</b>
	Height	-0.012	NS	0.988	
	Impoundment Size	-0.010	0.034	0.990	
Best	S. Central (0)	-0.800	0.001	0.449	<b>12.4</b>
	Age	-0.019	0.016	0.981	
	Impoundment Size	-0.012	0.031	0.988	

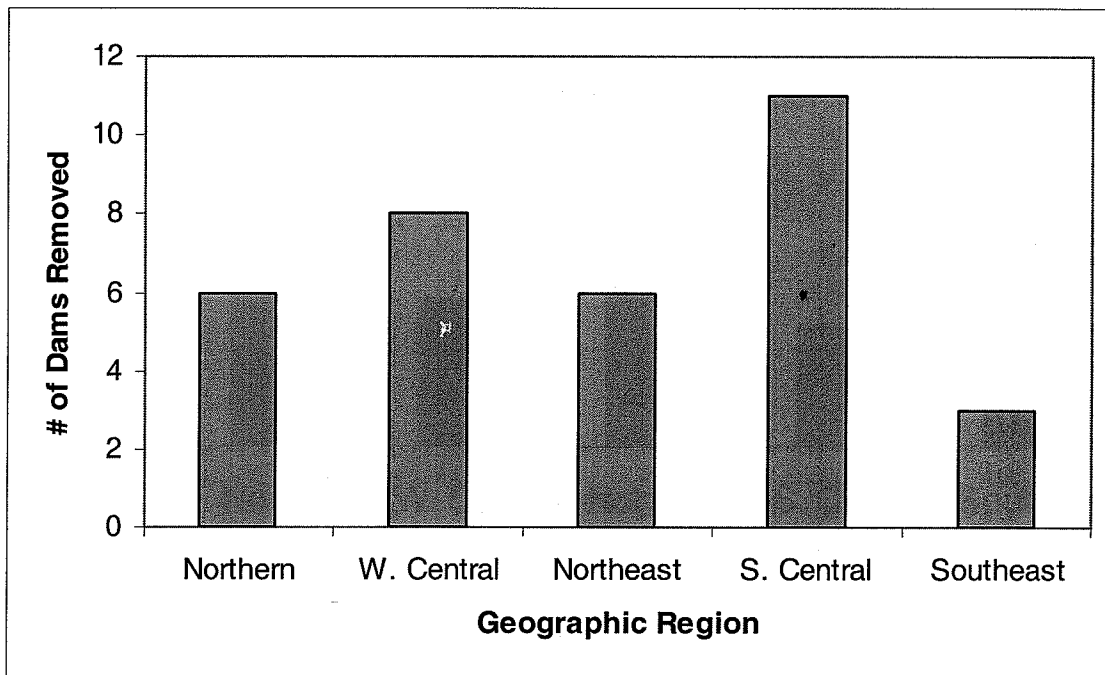


Figure 3.1. Number of dams removed by geographic region.

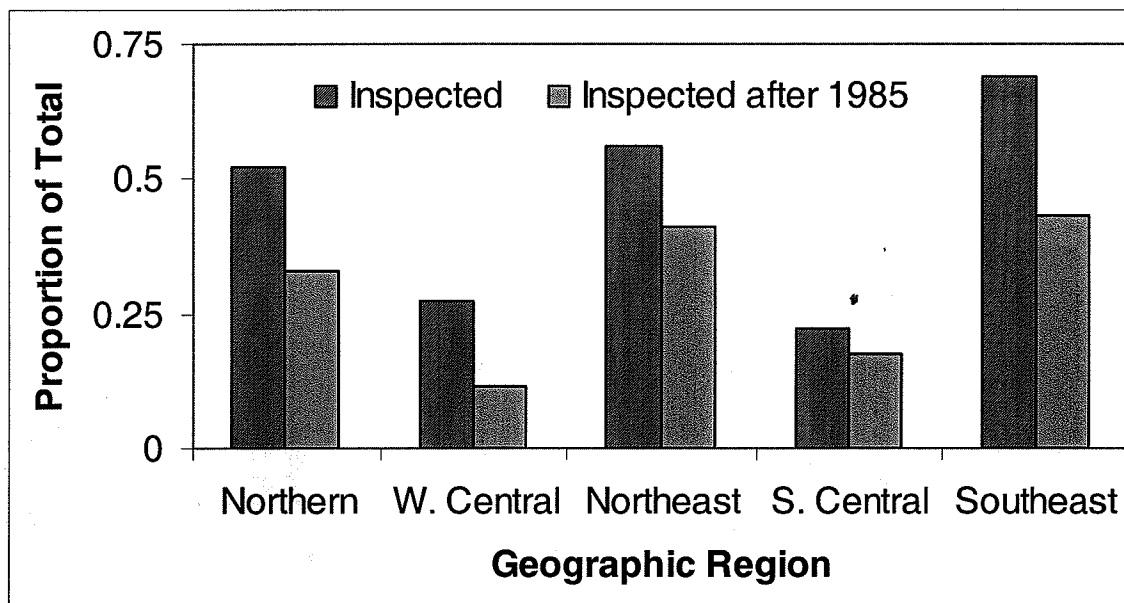


Figure 3.2. Proportions of all dams inspected, and those inspected after 1985 by geographic region.

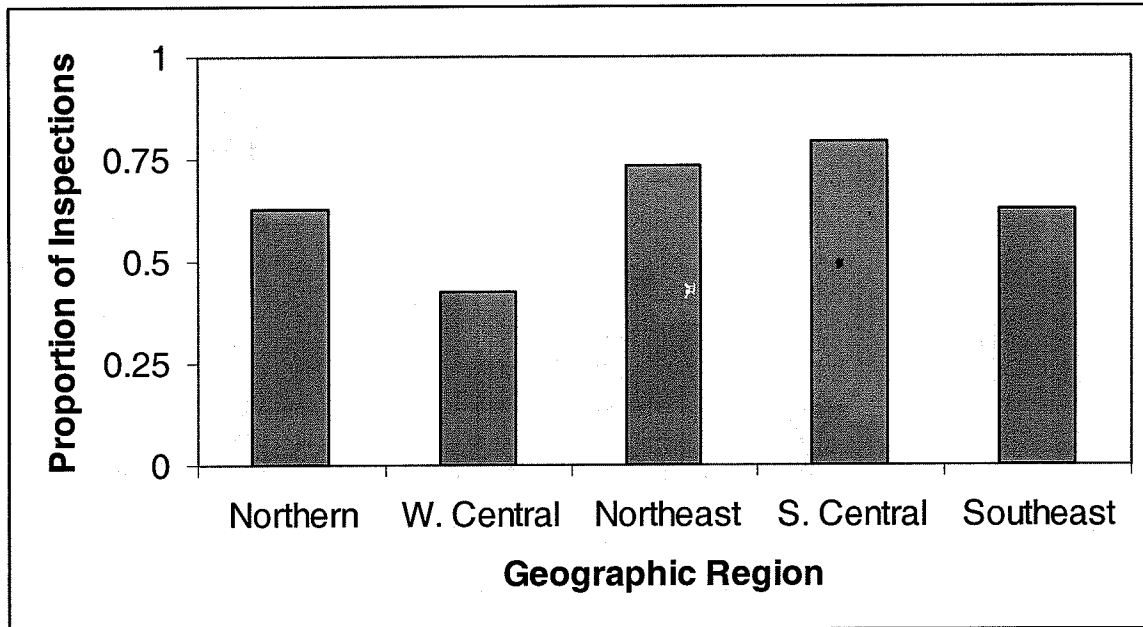


Figure 3.3. The proportion of all inspections conducted after 1985

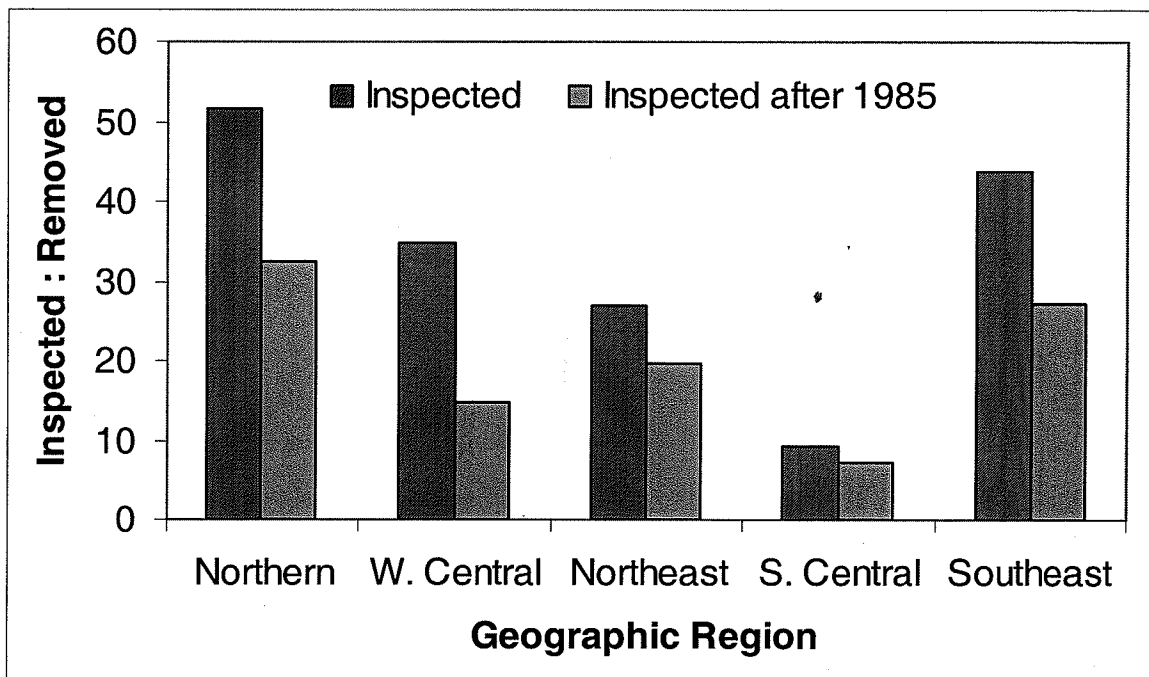


Figure 3.4. Ratio of dams inspected to dams removed by region. Higher ratios indicate fewer removals for a given number of inspections.

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