Erosion Control Methods and the Effect on Beach Succession

By:

Liz Janke

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Abstract

The academic buildings of Carthage College loom dangerously close to the always changing shores of Lake Michigan. Erosion control methods have been implemented to support the shorelines so that Carthage is not lost to the lake, but what effect do these artificial structures have on erosion and vegetative succession of adjacent beaches? Because of the commonplace use of artificial erosion control methods and the possible increase of erosion and disturbance they pose to beaches, this paper examines succession at two different beach sites; one being Carthage College with artificial erosion control structures, the other Chiwaukee Prairie beach with a more natural shoreline. Both sites were sampled with continuous transects, recording percent cover and species diversity. Carthage College had a larger species diversity than Chiwaukee Prairie; however these were predominately invasive species as compared to Chiwaukee’s more natural late successional species. Based on these observations and results, Carthage College has an earlier successional beach than Chiwaukee Prairie as supported by the increased number of invasive species at Carthage. This decline in succession may be linked to the artificial structures employed by Carthage to assist in erosion control.

Specific Aims

Conservation efforts to aid in erosion control are increasing rapidly as society builds property closer to the waters edge to accommodate the ever growing population. But how do these methods, specifically artificial erosion control structures, disrupt natural beaches around them? If exposed to disturbance caused by unusual amounts of erosion, vegetative succession can regress into early stages. This paper aims to distinguish succession between two sites with different erosion control methods. Carthage College has an artificial structure known as riprap and the Chiwaukee beach which is a fairly natural beach with no erosion control structures. If the riprap is creating a reversal of succession then alternative erosion control methods will be proposed to help Carthage become a natural beach once again.

Introduction

Erosion is an ever increasing threat to the shores of Lake Michigan. With property being built closer to the shoreline and on the edges of bluffs, it is not surprising that society has taken an interest in erosion control methods. Erosion not only affects property, it also can destroy vegetation and disrupt natural morphological and vegetative processes. Beach succession is one such process influenced by erosion control methods. Early successional beaches are often times characterized by disturbed areas and are consistently littered with invasive species of vegetation. Granted some of these species
aid in stabilizing sediments and deter erosion; however they do tend to overtake native vegetation. Later successional beaches are a natural progression towards stability and include hardier tree species such as oak and hickory and there is a natural flow between vegetative zones. Often later successional areas have greater species diversity because of fewer human disturbances and controlled erosion.

In order to reduce erosion problems, humans have begun to construct artificial structures to displace erosive wave action and stabilize sediments. Some of these structures have the potential to damage adjacent beaches and the beaches they are supposed to protect through displacement of wave action and intercepting essential sediment deposits. Not to mention recent climate changes have led to more powerful storms and increased intensity in waves, which creates greater erosion problems. This increase in erosion on adjacent beaches can actually move succession backwards towards an early successional phase. It is imperative that we understand the mechanics behind erosion in order to effectively control and slow the potentially devastating and costly process not only for humans, but also vegetative ecosystems. This paper will examine two beaches, monitor succession on each, and propose erosion control methods to ensure natural stability for the future.

**Causes of Erosion**

Numerous types of erosive processes influence erosion on Lake Michigan and elsewhere. The three main causes are periods of intense storms, change in water levels, and wave action, all of which are interrelated.

*Intense Storms*

Periods of intense storms are a significant factor in the erosion of once stable shorelines. A series of storms in rapid succession are predominantly destructive, because the consecutive events occur on beaches that are already weak and destabilized (Bird, 1996). Weak beaches consist of loose sediment, and uprooted vegetation. Storms also can cause overwash and strip the backshore vegetation while subsequently undercutting the shoreline from beneath (Lorang and Stanford, 1993). Artificial erosion control structures are built to stabilize shorelines along much of Lake Michigan. However,
because longshore drifting of sediment is intercepted as accumulation by the structures, there is often beach erosion on the opposite side (Bird, 1996).

*Changes in Water Level*

Coastal submergence is frequently due to a rise of lake level. With higher water, deeper nearshore water is created and therefore generates more powerful wave action against the shoreline. Change in water level is usually caused by heavy precipitation combined with little evaporation. Generally Lake Michigan levels are lowest in the winter because most of the regions precipitation is frozen in place, and evaporation increases as dry winter air masses pass over the lake. Lake levels are higher in the summer after spring runoff of melting snow and ice refill the lake (Keillor, 1997). Bruun (1996) suggests that on beaches with an equal amount of sediment gain and loss, “a phase of lake level rise on a sedimentary coast will be accompanied by recession of the coastline as a volume of sediment is transferred from the backshore to the nearshore zone in such a way as to restore the transverse profile” (Bruun as cited in Bird, 1996, 78). It is important to note that shorelines with vegetation tend to uphold a degree of stability where undercutting occurs until erosion is so vast that slumping or large amounts of sediment move downhill by the force of gravity (Lorang and Stanford 1993).

*Wave Intensity*

Waves derive energy from the wind, and the power of waves is what makes a shoreline dynamic. Intensity can increase as a result of artificial structures because the structure reflects the waves straight back which causes dredging and scour along the neighboring beach (Bird, 1996). It has also been found that wave assaults have been stronger due to the change in climate which has produced storms of longer duration and higher intensity. Wave intensity is enhanced by strong winds from large storm events. If the lake level is high, it allows for storm waves to break higher on the shore (Keillor, 1997). When combined, these factors can cause greater erosion than each individual cause, which is why erosion control is necessary.

In areas where erosion is reduced, the next natural step is for succession to occur. This is important in both restoring natural ecosystems and eventually a natural means for erosion control. Without succession, beaches are more susceptible to erosive processes, and the disturbed area will cultivate nonnative and invasive species.
**Beach Succession**

Succession is the “sequential change in vegetation…either in response to an environmental change or induced by the intrinsic properties of the organisms” (Allaby, 2006). Essentially, vegetation progressively colonizes a new environment until a final equilibrium state or climax is reached. Succession goes through many stages also known as seral succession. The sequence of communities during succession is known as a sere, the type of sere is determined by the environment being colonized. Individual communities of each succession are the seral stages; the seral stages are not normally distinct but tend to merge into one another as the succession progresses. There are two main phases of succession; primary and secondary.

Primary succession takes place in an environment that previously had no community living in it, such as along beaches with sand or rock sites (Carter, 2005). This newly produced bare area is normally formed after a natural occurrence such as glaciation or after recently formed bodies of water, both of which are especially applicable to the processes that formed Lake Michigan and its morphology (Allaby, 2006). The successional stages are fairly clearly defined in primary succession environments.

Secondary succession is instigated by the disruption of a previously existing climax or late successional community by some major man-made or environmental disturbance. The interactions between plants and the environment tend to be less clear and successional stages are less discernible than primary successional stages (Allaby, 2006). The presence of invasive species signifies the retreat or beginning of an early successional stage as well.

Initial or early successional species known as pioneer species are distinguished by their small size, high growth rate, rapid population growth and wide dispersal (Smith and Smith, 2003). Pioneer species are those that appear on disturbed sites or in early stages of succession. In beach areas, they tend to be grasses which provide temporary stabilization, until more stable, woody vegetation grows (Gray and Leister, 1982). Invasive species are often found on disturbed sites because of their high growth rate and adaptability to virtually any environment. The late successional species are just the
opposite, having a lower rate of dispersal and colonization, larger sizes, longer lives and slower growth rates (Smith and Smith, 2003). The climax is the stable end community that is able to successfully reproduce in established environmental conditions.

Species Distribution

Normal succession of the dunes and beaches of Lake Michigan begins with the area nearest to the waters edge as open beach and from there succession proceeds with beach grasses, woody shrubs, followed by cottonwoods, then to pine to oak forest to oak-hickory forest and finally to beech-maple forest (Carter, 2005).

Species Diversity

Species diversity is ever-changing during succession. The number of species present in all successions progresses rapidly as plants and animals colonize the area. At first the increase in diversity is very rapid; however, in later seres the rate of increase decreases. Typically there is a decline in the diversity towards the end of the succession. This decrease is mostly due to increasing competition between species and means that it is the intermediate seres which contain the largest number of species present at any one time during the succession.

Studies done on secondary succession communities have shown that species diversity increases with the site age since time of abandonment or disturbance, where disturbance is measured as the amount of area exposed having no cover by such vegetation as shrubs or trees (Carter, 2005). Species richness (diversity) also tends to peak at intermediate levels of environmental disturbance and decreases as exposure increased (Keddy, 1983). Exposed shores may also have more generalists, due to a loss of large leafy (climax) plants on the shoreline (Keddy, 1983).

Native vs. Introduced Species

When implementing erosion control methods the choice of whether to use native or introduced species must be made. Native and introduced species each have their own advantages and disadvantages whether for aesthetic value or practical purposes. Native plants have evolved and adapted to the local soil and climate conditions and once established are well adapted to any fluctuations in the environment (Gray and Leister, 1982). Regrettably, placing native species into a habitat that is disturbed is often unsuccessful, and the species may die off. Also, the availability of purchasing native
species may be less because of the lack of demand or limited knowledge of their reproductive methods (Gray and Leister, 1982; Keddy, 1984).

Introduced species, on the other hand, are notorious for adapting to new environments quickly by outcompeting native species. Despite this, they are often preferred for revegetating erosion damaged areas because of their heartiness and the opportunity to bring in species from other countries that are adapted to the specific climate (Gray and Leister, 1982).

**Reducing Erosion**

An important facet in controlling and maintaining shoreline erosion is large woody debris or drift logs. These logs trap sediments brought in by waves and other material that would have been displaced by erosion. They account for a majority of accretion along beaches and to aid this process, they are progressively buried by windblown sand. The partially buried logs can support a new section of vegetation that grows on the sand trapped around the log. Drift logs, surrounded by sediment accretion over many years, may stabilize coastal shorelines against wave-induced erosion and hasten shoreline formation (Lorang and Stanford, 1993). This resulting accretion may also influence the succession of shoreline plants. Driftwood takes in freshwater and in turn, supplies nutrients for pioneer species in new shoreline habitats (Lorang and Stanford, 1993). On developed lakes, in particular, course woody debris is significantly less abundant and this is in part due to increasing residential development (Christensen et al., 1996)

**Artificial Restoration Alternatives to Minimize Erosion**

Numerous different methods are available to control erosion problems. The technical or artificial restoration methods are by no means the most natural, and while erosion is reduced, they still may leave beaches disturbed or overrun with invasive, pioneer species. In fact, shorelines with artificial structures tend to have no woody debris or hanging cover, which are essential elements in preventing erosion. These shorelines also have less floating and emergent vegetation than shore sites with no structures (Wisconsin Department of Natural Resources, 2005). Despite lack of vegetation,
artificial structures are efficient in preventing erosive processes on shorelines that are prone to erosion.

The conventional method of avoiding or impairing shoreline erosion is the use of riprap. Riprap is a “blanket of approximately sized stones, fitted to the slope and shape of the shoreline” (WDNR, 2005). The size of the stone is dependent on the wave height in feet and the slope of the shoreline. For example, according to Figure 1, if the shoreline is at a 3:1 slope and the average wave height is 4 feet, then the stone should be approximately 600 pounds and 1.9 feet in diameter (Gray and Leister, 1982).

*Figure 1: Approximating size of riprap stones (Gray and Leister, 1982).*

The shape of the stone is essential, and is based on the velocity of the water or intensity of wave action. Coarse, angular rock is more successful at ground fortification than most other types (Hoag and Landis, 1999). It ensures that the stones will “knit” themselves together, which in turns molds the rocks into a system (Ontario Ministry of Agriculture, Food and Rural Affairs, 1985). This way if a high erosive force acts on a single rock, the
force is distributed throughout the whole system. Rounded stones are typically not used in erosion control methods due to their tendency to become unstable. Broken concrete is seldom used, however when used the rocks must be the same shape and size. Concrete must also be resistant to weathering, frost and water action and any reinforcement rods should be removed (OMAFRA, 1985). The type of stone that is required by the Department of Natural Resources is called armor stone and only certain quarries can provide it (Korte, 2006). A hard structure will modify the shoreline, and with riprap it has been shown that there is little diversity of habitat compared to a shoreline with a natural habitat. It also tends to “replace natural complex substrate elements with course substrates” (WDNR, 2005). Although consistently effective, riprap does have a few major drawbacks. The availability of appropriate-sized rocks, expense and complexity of quarrying, transportation, and placement of stone are all limiting factors in applying the riprap method (Gray and Leister, 1982). Riprap is normally used where long term stability is needed and where vegetation is not realistic. The destruction of adjacent beaches is another downfall of any artificial structure.

An alternative method is to add a seawall which does not use the heavy, large and expensive armor stones of riprap. Seawalls are vertical structures built from “timber, concrete, steel or aluminum sheet piling” (WDNR, 2005). They are installed parallel to the shore and intend to keep soil from slumping and prevent waves from pummeling the shore. They should not be used on shorelines with wave potential to overwash the seawall. One aspect to be wary of is that seawalls can lead to erosion of beaches in front of and adjacent to the structure. The seawall reflects the waves straight back, degrading the beach and the sediments get trapped and do not replenish the beach (Earth Revealed, 1992). Also, because it is an artificial erosion control method, seawalls are not natural and as stated with riprap, it “reduces natural complex habitat elements…and results in less habitat diversity” (WDNR, 2005).

Similar to riprap and seawalls, revetments are another artificial erosion control method to help protect shorelines. Revetments are structures, usually consisting of rock, placed on banks or bluffs in order to absorb the energy of incoming waves. Like seawalls, they protect the land behind them and may be either watertight or porous; to allow water to seep through after the wave energy has been dispersed (Korte, 2006).
Most revetments do not interfere with longshore drifting but can cause erosion on beaches in front of steeper revetments. As with all artificial erosion control methods, these are only short term solutions that do not restore ecosystems to their natural state; structures will all wear down eventually. These structures also degrade adjacent beaches and often times the beaches they were built to protect (Pilkey, 2003). Although artificial restoration of shoreline is initially more structurally sound than preliminary natural techniques, there are techniques to create a more natural shoreline, while providing adequate erosion control.

**Natural Restoration Alternatives to Minimize Erosion**

Biological control treatments consist of living and organic materials such as native grasses, forbs, as well as live stakes, posts, fiber rolls, and mats consisting of cut branches (WDNR, 2005). Adding vegetation improves water quality, reduces storm water run-off, enhances wildlife and fisheries habitat, improves aesthetics, and reduces noxious weed establishment. A few common biological erosion control methods include brush mattresses, live stakes, brush layering, fiber rolls and biodegradable breakwaters (Figure 2).

Brush mattressing involves placing 10-15cm of live cut branches along an eroding shoreline (Hoag and Landis, 1999). The ends are placed in a trench at the toe of the slope and secured by a wattle, which is a bundle of cuttings attached together (Figure 2, A). The cuttings then sprout and the resulting foliage and woody stems create a buffer to aid in the protection of shoreline from erosion.

Fiber rolls are cylindrical tubes made out of coconut husk and bound together with plastic netting, or coconut twine (Figure 2, B). The method works particularly well on shorelines with sloughing, the downward movement of sediment, problems because it traps sediments in the rolls. Herbaceous plants are then planted into and behind the rolls so that in 6-10 years when they decompose, these plants, and their root system, will have greatly increased shore stabilization (WDNR, 2005).

Live stakes or pole cuttings use live, vegetative cuttings, usually well rooted species to revegetate shorelines, as seen in Figure 2, C (WDNR, 2005). The cuttings are placed vertically or at a slight angle in the ground and placed deep enough to extend
below the roots of competing vegetation (Hoag and Landis, 1999). Most commonly willows, poplars and cottonwoods are used because they tend to flourish in moist soil as cuttings (Gray and Leister, 1982).

Brush layering is achieved by alternating layers of live cuttings and soil along the slope of an eroding shoreline (WDNR, 2005). The branches are placed perpendicular to the slope and when they sprout, the roots stabilize the shoreline. Another option is to insert green branches of shrubs or trees on successive horizontal rows or contours on the face of the slope (Gray and Leister, 1982).

Biodegradable or temporary breakwaters are installed offshore of the shoreline area. They are intended to be protective, resulting in inactive and sluggish water behind the wall to allow for newly planted vegetation to take root. It is commonly constructed from coir fiber, willow stakes or jute, which are all biodegradable material (WDNR, 2005).

Figure 2: Natural Erosion Control Methods: A) Brush Mattressing, B) Fiber Rolls, C) Live Stakes (Hoag and Landis, 1999)

Integrating Natural and Technical Restoration Approaches

The combination of natural and artificial techniques is an efficient method in stabilizing the shore with solid structures but also with natural root systems. One method
is known as vegetated armoring. This method “integrates biological and technical methods” of shore protection (WDNR, 2005). Vegetated armoring structures imitate a specific natural environment through the use of vegetation and woody debris. A benefit of this technique is that it encourages faster and stronger natural vegetative cover. Also, rock is typically integrated to increase the substrate size and therefore creates ideal habitats for fish and invertebrates. A disadvantage to this technique is reduced or slower establishment of vegetation near the waters edge.

Another example is vegetated riprap, which adds vegetation into the gaps and joints of the rock. A long metal probe is used to create a pilot hole in the joints of riprap, where a long cottonwood or willow tree is then inserted (WDNR, 2005). This method is a prime example of a combination of artificial and biological restoration and is a compromise between vegetation buffers and riprap.

The most difficult part of implementing erosion control methods is deciding which method to use. The following case studies are examples of different erosion problems and how each was appropriately addressed.

**Case Studies**

**Lake Forest**

Lake Forest, Illinois is no exception to the erosive processes of Lake Michigan. Their mile-long beachfront and bluffs have been devastated because of deep offshore lake morphology, intense waves and violent storms (Bukro, 1997).

Erosion problems began in 1885 when the Waukegan Harbor was built (Bukro, 1997). The harbor interrupted the southerly flow of sand that once refilled the beaches as they were washed out by waves. Now the loss of sand does not effectively displace the waves’ destructive force. Lake Michigan has been fracturing the hard clay bottom that lies underneath, and waves have cut into 5 or 6 feet of the clay floor, leaving incredibly deep water just offshore (Bukro, 1997). According to the planning Chief of the Chicago District, Philip Bernstein, “The deeper the water is, the more severe the waves,” (Bernstein, Philip as cited in Bukro, 1997).

A proposal was made to armor the lake bottom just offshore with a 12-to-15 inch layer of rocks in 6-to-20 feet of water (Bukro, 1997). Bernstein stated that this paving
design “is the only thing that will work” (Bernstein, Philip as cited in Bukro, 1997). Bernstein is also trying to organize a study to see how the cobblestones react in storms. The seawalls and revetments placed on the lakefront properties have already been replaced five or six times since the turn of the century (Bukro, 1997). If all goes according to plan, this method that is currently in place will delay the rapidly increasing erosion and decrease the frequency of seawall replacement.

**Concordia University Mequon, WI**

Concordia University in Wisconsin is located along 2,720 feet of Lake Michigan shoreline. Its bluffs are a familiar sight along not only this stretch but also along numerous other sections of Lake Michigan. Unfortunately the all too common combination of erosion and private property too close to the edge has led to massive sediment loss and a danger to property and students.

The problem bluff is at a nearly 45º angle and has become dangerous for students, the buildings located only 50 yards away and the native shoreline. The bluff itself is 135 feet tall and receding a few acres every decade due to erosion (Korte, 2006). A major problem is that of groundwater as opposed to surface runoff. The ground water continuously runs out the side of the bluff and causes slumping. Slumping occurs on steep hillsides along distinct fracture zones often with materials like clay which is a majority of the Concordia bluff. Once released, the soil particles may move quite rapidly downhill, and in this case, the slump is caused by water weakening the slope beneath. Also, intense wave action is washing away the bluff toe at an alarming 20,000 tons every year, therefore causing undercutting along with the slumping (Concordia University Wisconsin, 2005).

Concordia is now implementing an $8 million shoreline and bluff stabilization project that is to be complete in the fall of 2006 (CUW, 2005). The purpose of this project is to reestablish the natural lakeshore environment. Before any construction was done the University had JJR, a landscape planning and engineering specialist, and Kingston University, Ontario help with vegetative studies and the modeling of different restoration options. The results were presented to the Environmental Protection Agency and WDNR, the bluff stabilization project was passed, and construction of the bluff
began in the summer of 2005 (Korte, 2006). The bluff was excavated to a 26° angle by hauling away over 350,000 m² of soil, and an underground pipe was built to carry water from subterranean seepage into a perched wetland near the shore (CUW, 2005). A revetment was constructed at the high water mark along the entire shoreline property of Concordia. The revetment is 15 feet wide at the base and 10 feet high (Korte, 2006). When there is low water, the revetment acts as a break wall against waves. It was built with armor stone which is the stone from quarries that only the DNR approve of. It was concluded that a beach was the best means to protect the bluff, and coastal wetlands were also constructed adjacent to the beach in hopes to restore rare and natural wildlife (CUW, 2005). Native vegetation was also planted along the bluff to encourage natural stabilization of the bluff and to increase the aesthetic value. If the design works as planned, the bluffs of Concordia University will return to a more natural state and eventually will restore the native vegetation and wildlife as was the goal. The erosion control methods implemented by Concordia are necessary precautions taken to ensure a natural future for their shoreline. These two cases of Concordia and Lake Forest are prime examples of how erosion control methods are beneficial and necessary to protect and stabilized shoreline. In order for Carthage College to have a less disturbed and more natural shoreline for the future, it should begin to consider integrated erosion control methods, instead of artificial structures only.

**Objectives**

Erosion control methods are commonplace along Lake Michigan. But what effect do they have on adjacent beach erosion and vegetative succession? In this paper, I will examine two separate sites (beaches at Carthage College and Chiwaukee Prairie), to determine how riprap has effected erosion at Carthage’s beach and subsequent succession. I expect to find a later successional beach at Chiwaukee and early or secondary succession at Carthage College as well as lower species diversity, with less invasive species at Chiwaukee beach. Consequently I hope to propose an erosion control method to preserve Carthage’s beach for the future.

**Erosion History at Carthage College**
Carthage College is located along 2,850 feet of scenic Lake Michigan shoreline. Unlike Concordia, Carthage does not have the steep and unstable bluff formations but instead is located incredibly close to the shoreline. Carthage was moved to Kenosha from Carthage, Illinois in 1962 where it began the construction of the campus. Lentz Hall was supposed to be built on the West side of Campus Drive, but instead was built on the East; as a result of its close proximity to the lake it was flooded in a storm in 1969 (Hoare, 2006). In response to this storm, a dike known as Dutchman’s Dike, was built to try and control the wave actions along the shoreline and to protect the structures (Hoare, 2006). Lake Michigan experienced high water levels in the 1950’s, 1973-1974 and in 1997-1999 and low water levels from 1963-1965 as seen in Figure 3 (Keillor, 1997). The low water levels that can be seen starting around 2000 are due to change in climate with less rain but increased evaporation.

*Figure 3: Lake Michigan Water Levels from 1860-present (NOAA, 2006).*

In response to higher lake levels in the 1970’s Carthage and Southeastern Wisconsin began to implement erosion control methods. The primary method was the placement of riprap along the shoreline, and as stated by Bill Hoare, Carthage just “threw in riprap because it was a fad along the entire southeastern shoreline of Lake Michigan” (2006). Historical records are nonexistent so somewhere between 1980 and 1985 riprap was
added to the northern shoreline of Carthage’s campus. The actual riprap rock came from the Racine quarry, and above the riprap line numerous green ash trees were planted not because they were native species but because they were inexpensive (Hoare, 2006). Underneath the layer of rock a fabric was laid as well to help prevent a washout of sediments through the riprap (Gray and Leister, 1982, Hoare, 2006). Overall Carthage spent about $100,000 on its shoreline to try to avoid future threats from erosion (Hoare, 2006).

_Threats to Carthage from Erosion_

A major concern that led to the development of the erosion control method was the decrease in shoreline. From this loss, other issues could follow including the destruction of academic and residential buildings near the lake, threat of flooding, and instability of soil leading to safety issues.

Because the academic buildings at the North end of campus were about 50-100m away from the lake, riprap was only placed in that vicinity, notably leaving the South beach fairly clear of large riprap. This is another potential problem because the riprap tends to intercept longshore drifting from intense storm events and therefore could lead to further erosion on the downdrift side or in this case, campus’ southern beach (Bird, 1996). This decrease in shoreline and proximity to the lake is hazardous during intense storms, such as in 1969, where overwash and flooding can occur (Hoare, 2006). If no riprap was in place the soil stability would become a safety problem and the possibility of no beach or shoreline access would be more realistic (Gray and Leister, 1982).

Carthage has had riprap along its shoreline since at least 1985. A pertinent concern, however, is whether riprap is the best form of shoreline protection. Erosive processes on Carthage’s beach have led to an early succession of vegetation, as compared to Chiwaukee’s late succession, and this is in part due to the riprap that was supposed to curb Carthage’s erosion. For both Carthage and Chiwaukee’s shorelines, natural erosion control is a feasible method in helping each beach reach the ultimate climax community.

_Study Sites_
Lake Michigan borders 5 states and is the largest freshwater lake completely within the United States. The average depth is 279 feet and has a surface area of over 22,000 square miles (Thompson, 2003). Lake Michigan was formed during the Wisconsin glaciation as glaciers advanced across what is now called the Great Lakes Region, scouring the land. As the glaciers receded, large glacial lakes were formed from melting ice. Lake Michigan has diminished from its original size over time yet its significance to both human and natural ecosystems remains strong. The strongest and fastest currents found in Lake Michigan are concentrated around the edge of the lake in a narrow breaking wave zone, starting in water depths between 18 to 20 feet deep and extending to the beach. This zone is also the location of the greatest volume of sand transport or littoral drift. The littoral drift relies on storm activity to move the sediments through wave action. Erosion rates are dependent on combinations of all Lake Michigan’s components as well as the influence of man-made structures.

The southern part of Carthage College’s campus is predominately beach strewn with rocks that has been severely disturbed by intense management with riprap and cement for fortification. It is an early successional beach with little visible progression between stages and much of the forest area floor is covered with invasive weeds.

The Chiwaukee Prairie beach is a more natural beach squeezed between two fortified points, undergoing a more natural seral succession. According to Dr. Scott Hegrenes, the beach experienced a blow out from a previous storm and therefore succession is restarting towards the southern end of the beach, but in the northwest portion the vegetation was not completely obliterated. In this paper, I will examine the differences in succession between Carthage College and Chiwaukee beaches, and propose an erosion control method to preserve Carthage’s beach for the future.

**Materials and Methods**

An area of approximately 27 x 35 m was measured on the Chiwaukee Prairie beach site. The waterline was used as a reference x-axis and the 0m mark was at the south end of the beach. Transects were marked every 3 meters starting at 0m and ending
at 27m, totaling 10 transects (Fig. 4). Transect 1 was at x=0, transect 2 was at x=3 and so forth. The y-axis was chosen based on the visible succession of the beach and allowed for enough data along each transect to fully see the succession.

**Figure 4:** Outline of how transects were laid out and dimensions used to measure out transects.

Each transect was measured using a continuous method, which records absence and presence of vegetation and percent cover along a transect. Along the transect ground cover was recorded to the nearest hundredth of a meter precision. Ground cover was then broken into categories (Figure 5 and 6) to represent the progression of succession. If a vegetative species was located along a transect, that also was recorded along with the species name if known. Species that were unknown were bagged and labeled with the transect number and unknown number. For the forested area, above cover was also recorded. Any tree or shrub branch that hung over the transect was considered above cover and the distance was recorded. Chiwaukee Prairie was sampled on March 30\textsuperscript{th}, 2006 by Doctor Joy Mast’s Field Methods class. Because of the cold spring most new species were not yet emergent but the remnants of vegetation from the previous year were identifiable and recorded.

The Carthage College beach was then studied in the same manner on April 11, 2006. A landmark for reference was an approximate 50x50m plot set aside for ecological succession to proceed naturally created by Doctor Hegrenes. A replicate of the 27 x 35m grid from Chiwaukee was created starting at the North edge of Doctor Hegrenes’s plot.
which is outlined by rocks and at the southern end of the beach. However in order to fully view the succession, transects were changed from 35m to 45 m. A visible rock line (parallel to the water line) was used as the reference x-axis for the grid (Fig. 4). Transects were created starting at 0 m and ending at 27m and ran 45m up the y-axis. The continuous method was again used to record ground cover, species, and above cover.

From each transect the species diversity (richness) and total percent cover was calculated. Relative importance (p_i) values were calculated in order to measure equitability and dominance of each species for the two separate sites. The percent similarity and coefficient of community was then calculated to compare similarity between the two sites based on species present.

**Results**

The percent cover for each cover type varied greatly (Figure 5) at Carthage College beach. Sand, rock/pebbles, leaf litter, fire pits, and large rocks had a combined nonliving cover of 82.9%, while combined invasive species was at 35.6. It is important to note that the beach grass found on Carthage’s beach is *Poaceae*, a common backyard grass, and not the same species found at Chiwaukee Prairie. Above cover was measured but was not significant enough to add as a category.

*Figure 5: % Cover for each cover type and species present at Carthage College.*
Continuing with the percent cover, Chiwaukee Prairie beach also had a large percent of nonliving sand and pebbles cover (Figure 6), and the site also had a greater percentage of leaf litter which was mainly red oak leaves. Also included in the nonliving category is the presence of woody debris on the Chiwaukee beach, which signifies natural erosion control. There is 0% invasive species at Chiwaukee as opposed to Carthage’s 35.6% of the total cover and 100% of total species. The beach grass, *Ammophila breviligulata*, is a native dune species that acts as a sand binder even when partially buried by sediment. The red oak and sand cherry, a native dune species, combined with no invasive species suggests a later successional site.

*Figure 6: % Cover for each cover type and species present at Chiwaukee Prairie.*
The relative importance (Table 1, 2) represents how significant each species is to the site. Accordingly, as $p_i$ increases, the greater the importance for that specific species. Carthage College had the highest $p_i$ values for beach grass; invasive species were present yet the site was predominately beach and therefore invasives were not a significant cover type yet. Chiwaukee Prairie also had a high importance value of beach grass and other species were minimal again because the site is first and foremost a beach. These values are needed to compare the similarity between the two sites.
Table 1: Percent cover for each cover type at Carthage College; the relative importance is the individual % cover in a sample area divided by the total % cover in a sample area.

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<tr>
<th>Ground Cover Type</th>
<th>Density (ni)</th>
<th>Log (ni)</th>
<th>Rel. Imp. (pi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>27.12</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Rock/Pebbles</td>
<td>21.1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Leaf Litter</td>
<td>20.04</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Leaf Litter/Brush</td>
<td>6.23</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Leaf Litter/Sand (Dist. Rd.)</td>
<td>7.26</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fire Pit (Dist)</td>
<td>0.63</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Large Rock</td>
<td>0.53</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Invasive Beach Grass (Poaceae)</td>
<td>33.24</td>
<td>1.522</td>
<td>0.933</td>
</tr>
<tr>
<td>Garlic Mustard (Alliaria petiolata)</td>
<td>1.32</td>
<td>0.122</td>
<td>0.037</td>
</tr>
<tr>
<td>Weed</td>
<td>0.03</td>
<td>-1.509</td>
<td>0.001</td>
</tr>
<tr>
<td>Boxelder (Acer negundo)</td>
<td>0.01</td>
<td>-1.959</td>
<td>0.000</td>
</tr>
<tr>
<td>Lambsquarters (Chenopodium album)</td>
<td>0.22</td>
<td>-0.654</td>
<td>0.006</td>
</tr>
<tr>
<td>Chicory (Cichorium intybus)</td>
<td>0.46</td>
<td>-0.335</td>
<td>0.013</td>
</tr>
<tr>
<td>Black Locust (Robinia pseudoacacia)</td>
<td>0.18</td>
<td>-0.752</td>
<td>0.005</td>
</tr>
<tr>
<td>Creeping Buttercup (Ranunculus repens)</td>
<td>0.08</td>
<td>-1.108</td>
<td>0.002</td>
</tr>
<tr>
<td>Green Ash (Fraxinus pennsylvanica)</td>
<td>0.08</td>
<td>-1.108</td>
<td>0.002</td>
</tr>
<tr>
<td>Total</td>
<td>118.522</td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>Total % Cover spp.= 35.63</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Percent cover for each cover type at Chiwaukee Prairie; the relative importance is the individual % cover in a sample area divided by the total % cover in a sample area.

<table>
<thead>
<tr>
<th>Ground Cover Type</th>
<th>Density (ni)</th>
<th>Log (ni)</th>
<th>Rel. Imp. (pi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>37.13</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sand/Pebbles</td>
<td>18.83</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Leaf Litter (Red Oak)</td>
<td>13.42</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Leaf Litter (Red Oak)</td>
<td>12.47</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Native Beach Grass (Ammophila breviligulata)</td>
<td>26.64</td>
<td>1.426</td>
<td>0.968</td>
</tr>
<tr>
<td>Sand Cherry (Prunus pumila)</td>
<td>0.83</td>
<td>-0.083</td>
<td>0.030</td>
</tr>
<tr>
<td>Red Oak (Quercus spp.)</td>
<td>0.06</td>
<td>-1.244</td>
<td>0.002</td>
</tr>
<tr>
<td>Total</td>
<td>109.38</td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>Total % Cover spp.=27.52</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Species diversity was measured for both sites and while the number of species increased at Carthage College, the higher equitability factor shows that the resources are more evenly divided between species than at Chiwaukee Prairie beach and that there are less dominant species (Table 3). The dominance value has an inverse relation to equitability;
therefore Chiwaukee has the more dominant species since \( .87 \leq .94 \). The more dominant species usually are the most noticeable and take up the most space and the beach grass was definitely noticeable in clumps and scattered at the Chiwaukee beach.

**Table 3: Values for Species richness, equitability and dominance between Carthage College and Chiwaukee Prairie. The larger the Ec, the more evenly divided the resources between species; the smaller the C, the more dominant species are at a given site.**

<table>
<thead>
<tr>
<th>Diversity Measure</th>
<th>Calculations for Carthage</th>
<th>Results for Carthage</th>
<th>Calculations for Chiwaukee</th>
<th>Results for Chiwaukee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species richness (S)</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Equitability (Ec)</td>
<td>9/(1.522-(-1.959))</td>
<td>2.58</td>
<td>3/(1.462-(-1.244))</td>
<td>1.11</td>
</tr>
<tr>
<td>Dominance (C)</td>
<td>( \text{sum}(p_i)^2 )</td>
<td>.87</td>
<td>( \text{sum}(p_i)^2 )</td>
<td>.94</td>
</tr>
</tbody>
</table>

At the Carthage College beach site, 9 different species were recorded, and all were invasive species that thrive on disturbed areas (Table 3, Figure 7). The boxelder and green ash trees are both native to Wisconsin but flourish on disturbed sites. Beach grass and garlic mustard were the most abundant at 33.2 and 1.3%. All other species were minimal, yet present, and if sampled later in the spring would probably be have a greater percent cover as the growing season progressed. Chiwaukee Prairie beach had a total of only 3 species, none of which were invasive (Table 3, Figure 8). It is clear that there is far less species than at the Carthage site and yet it too is dominated by beach grass, although it is a different species. None of the species at Chiwaukee are invasives, whereas Carthage had 9 invasive species, 2 being native to Wisconsin.
Figure 7: Species diversity and % cover by each at Carthage College beach, all of which are invasive, yet the boxelder and green ash trees, are both native to Wisconsin.

Figure 8: Species diversity and % cover of each at Chiwaukee Prairie beach.
The similarity measure (Table 4) shows how the two sites, Carthage and Chiwaukee, are similar. The two areas are 0% similar based on the species $p_i$ values. The coefficient of community relates the similarity of species between the two sites and at 0% similarity these sites clearly have no species in common.

**Table 4: Percent similarity between Carthage College and Chiwaukee Prairie sites as well as the Coefficient of Community.**

<table>
<thead>
<tr>
<th>Similarity Measure</th>
<th>Calculation</th>
<th>Result for Carthage vs. Chiwaukee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Similarity</td>
<td>$1 - 0.5 \left( \sum</td>
<td>p_{iA} - p_{iB}</td>
</tr>
<tr>
<td>Coefficient of Community</td>
<td>$2(0)/(3+9)$</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Discussion**

The Carthage College beach site studied is adjacent to a riprap structure. According to a comparison of aerial photographs taken in 1974, 1987 (post riprap) and 2000, erosion is occurring faster at the southern beach (Mekash, 2005). This also takes into account the fluctuations of lake levels which expose different amounts of shoreline. Because 2000 was a low water year the true extent of erosion could be observed.

Chiwaukee Prairie beach is protected by two fortified points and is not a beach adjacent to an artificial structure. Therefore, the beach has fewer disturbances than Carthage College and this allows for a natural seral succession.

Succession was studied at each site and the species composition and presence is the most suggestive evidence of what stage each beach is in. The presence of 9 invasive species at the Carthage beach suggests an early successional beach. Each species supports this in its own unique way. For example, the boxelder and green ash trees are both native to the southeastern region of Wisconsin but are known invaders and are especially acclimated to highly disturbed forests. The black locust tree is a nonnative invasive species that was planted in the 1900’s because of its aggressive growth pattern and extensive root system that discourages erosion. It is also found in disturbed areas such as degraded forests. Chicory is an introduced species that is ecologically invasive as
well. It is shade intolerant and grows well on disturbed beaches or open areas where other plants cannot grow. Although some of these species can aid in sediment binding, the majority displace native vegetation and wildflowers by creating an ecosystem not indigenous to the region. The number of invasives alone suggests an early successional beach.

The high level of equitability at Carthage suggests that resources are spread evenly between the numerous species, which implies that species are scattered and few dominant species are present. Conversely, Chiwaukee’s resources are not spread as evenly throughout species, which suggests that the more dominant species are present and using the resources. Chiwaukee had the more dominant species which provide more food and cover for animals above ground, but also have a deep root system below ground. They aid in stability and can reduce storm water runoff and improve water quality.

The species composition at Chiwaukee Prairie beach was quite different than Carthage. Red Oak was the dominant tree as suggested by the large amount of leaf litter remnants from the previous autumn. Although it did not have the largest percent cover it was a noticeable tree and if above cover were taken into account it would be substantial. An important component of deciduous forests, the Red Oak is found throughout Wisconsin and is a sign of later successional stages. The sand cherry shrub is native to coastal dunes and beaches in Wisconsin. It is a natural sand stabilizer and again is common in later successional stages. Another species that was present near the forest area, but did not cross a transect, was Quaking Aspen (Populus tremuloides). This tree flourishes in disturbed areas and this is consistent with the previously mentioned storm blow out and the renewed succession along the edge of the forest. These trees are shade intolerant and will eventually give way to the more dominant red oaks surrounding them. The dominant beach grass at Chiwaukee was Ammophila breviligulata a common dune species native to the shores of Lake Michigan. The long rhizomes form a system of roots that keep sand from blowing away.

Although species diversity was less at Chiwaukee, this supports the idea that species diversity decreases in later successional stages because of increased competition. Dominant, climax species need larger amounts of resources and have the potential to take
resources away from the smaller, grasses and shrubs belonging to earlier seral stages. But in return, these climax species give shelter, food, sediment stabilization from roots and protection from storm runoff. The high amount of species at Carthage would seem to say that it is a healthy environment. But in analyzing the types of species at Carthage it shows that all species are invasive and pioneer species. In a disturbed area such as Carthage, pioneer species and many weedy species will grow in order to stop the damage being done. These species propagate quickly to increase population as fast as possible. Once the disturbed area becomes more stable, native vegetation will begin to overtake the invasive species and a natural succession can begin.

One species not recorded at either site, but is known to successfully propagate at both is the sea rocket (*Cakile edentula*). This plant is associated with the early stages of sand dune succession, its fast growth and short vegetation period means it is well adapted to unstable habitats. Normally it is found in a ring around the Chiwaukee beach and scattered on the shores of Carthage’s beach. This suggests that Carthage is in the early stages of beach succession while Chiwaukee has already moved on to later stages with stable amounts of the sea rocket plant.

Aspects that need to be considered are the time of year when the research was done. For both sites not all of the plants were sprouting yet due to a cold spring and with some species, the immature plant identification was difficult. If done later in the season it would ensure that most plants would be flowering and easily identifiable. Also the plot choice could have an effect on the species present. The plot choices for this experiment were based on known reference points or confined because of limited area, but if moved in any direction the percent cover or cover type could change. If done again, the transects would go further into the forested area to identify species deeper in the woods. This would almost guarantee the full scope of succession to be recorded. In addition to studying succession on both sites, it would be prudent for future experiments to evaluate the rates of erosion. That way if the riprap was indeed causing a greater amount of sediment loss it could be compared to the erosion rates of a natural beach. The erosion factor would also link disturbance to vegetative succession patterns of each beach.

Based on the number of invasive species present at Carthage College it suggests that the beach has been disturbed to some degree, and has retreated into an early
successional beach. It is difficult, however, to determine if the disturbance was caused by erosion from the riprap, man-made disturbances or a combination of both.

Artificial erosion control methods can lead to erosion of beaches in front of and adjacent to the structures. Claims have been made that hard barriers increase erosion on adjacent areas of the beach, either by reflecting wave energy or by trapping sand that would otherwise move horizontally along the beach. There are numerous states that actually outlaw seawalls, riprap and other "hard solutions" because they destroy beaches (Pilkey and Coburn, 2003). This increase in erosion also appears to have significant impact on the nature and distribution of vegetation patterns. The disturbance caused by erosion can actually lead to a decline in vegetative succession. In fact, sea level rise has been found to cause a retreat in forests due to increased erosion and burial by sand.

There are approaches for Carthage to implement in order to decrease the erosion on the beaches in front of and adjacent to the riprap. One method that has been applied to hundreds of miles on the Great Lakes beaches and ocean shorelines is the demolition of riprap and seawalls and the addition of an undercurrent stabilizer (Holmberg, 2005). Undercurrent stabilizers are shore-perpendicular, low-profile structures that consist of concrete filled, geotextile tubes. The rounded shape of stabilizers reduces the amount of wave reflection created when intense waves reach the shore. Wave reflection is a primary reason that structures such as walls, riprap and revetments damage adjacent beaches and scour their own foundations. Undercurrent stabilizers’ less reflective nature creates a low energy strand of beach. Since fast water picks up sand and slow water deposits sediments, the low energy beach will be the most likely place where deposition of suspended sediment particles will occur. Through this deposition of sediment the beach width and height is enlarged, and hopefully vegetative succession would return to normal (Holmberg, 2005).

Another option involves keeping the already present riprap but integrating biological aspects. For example, the idea of vegetated riprap is an entirely feasible concept. This simply involves creating pilot holes into gaps in the riprap and then inserting a cottonwood or willow sapling into the hole. When the tree begins to grow the root network will not only bind sediments, but also holds any unstable riprap in place.
Along the beach itself plots such as those started by Dr. Hegrenes should be protected so that foot traffic and students do not disrupt the growth of native grass species. The removal of invasive species such as garlic mustard and lambsquarters could bring back native wildflowers and ground cover. These species would eventually lead into the next sere of succession barring any unforeseen disturbances.

Conclusion

Artificial erosion control structures have been shown by others to have an adverse effect of nearby beaches. Carthage College’s beach has had an increase of erosion since the addition of a riprap structure. Erosion has had a marked effect on the succession of shoreline vegetation. The number of invasive species present at Carthage suggests a disturbed beach and an early successional stage. In addition, the sheer number of species recorded signifies a disturbed beach that is trying to restart succession with numerous, highly reproductive pioneer species. It cannot be assumed that the disturbance is caused solely by the riprap structure. Human disturbance and foot traffic is another factor that needs to be taken into account. The Chiwaukee Prairie beach has minimal artificial erosion control structures and is one of the few late successional beaches in the area. Species diversity was low, as a result of larger, more dominant species, all of which are native to the area and are representative of late beach or dune succession. Each species found has characteristics of natural soil stabilizers and represents the different zones of succession.

Thus, vegetative succession is affected by disturbance, whether it be human or increased erosion from artificial structures. What was an inherently natural beach has become overrun with invasive species and regressed into an early succession. Through new conservation minded technologies and increased environmental awareness, the erosive forces from riprap can be diminished. It would be beneficial to compare the erosion rates of Carthage’s beach post riprap, to rates at Chiwaukee’s more natural beach to determine if the riprap is indeed causing enough erosion to cause the disturbance that has affected vegetative succession.
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