ENVIRONMENTAL ANALYSIS AND DECISION ON THE NEED FOR AN ENVIRONMENTAL IMPACT STATEMENT (EIS)
Form 1600-1 Rev. 6-2001

Department of Natural Resources (DNR)

Region or Bureau Northeast
Type List Designation

NOTE TO REVIEWERS: This document is a DNR environmental analysis that evaluates probable environmental effects and decides on the need for an EIS. The attached analysis includes a description of the proposal and the affected environment. The DNR has reviewed the attachments and, upon certification, accepts responsibility for their scope and content to fulfill requirements in s. NR 150.22, Wis. Adm. Code.

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DREDGING IN DOOR COUNTY

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EXECUTIVE SUMMARY

In 1999 and 2000 there was a dramatic increase in dredging applications on Green Bay and Lake Michigan in Door County due to low water levels. The Department of Natural Resources (Department) received thirteen applications in 1997, seven in 1998, and they increased to sixty-nine in 1999 and eighty-two in 2000. It was the intention of the Department to conduct a study on the impacts of dredging once the solid pier environmental analysis was finished. However, applications dropped off slightly, and several Department staff retired, so a study was never completed. Applications again began to increase with forty-one in 2006 and forty-three in 2007 and water levels were expected to stay low. Department staff felt that it was a critical time to further study the impacts of dredging, and to assure that permit decisions did not conflict with the rights of the public.

All lakes in Wisconsin are governed by the Public Trust Doctrine. Under this doctrine, Wisconsin's lakes and rivers are owned in common by all Wisconsin citizens, and held in trust for the public by the Department of Natural Resources. Wisconsin citizens have the right to boat, fish, and hunt on Wisconsin's lakes and rivers, as well as enjoy the scenic beauty of these waters and to use them for recreation.

Owners of land that borders Wisconsin lakes or rivers, called "riparian" owners, enjoy additional rights. Riparian owners may use the shoreline, the water within the bordering lake or river, and have a right to access the bordering body of water and as long as none of these actions interferes with the rights of the public under the Public Trust Doctrine.

The Department protects the public trust by implementing regulations set forth in Wisconsin Statutes Chapter 30. Section 30.20 of the Wisconsin Statutes requires permits for dredging. The Department has a three tier permit process consisting of exemptions, general permits, and individual permits. The permit process for dredging new areas in lakes requires an individual permit. All individual permit applications require a 30 day public comment period through the publication of a class I notice in the local newspaper and direct notification of interested parties. The Department is also required to review these proposals for their environmental impacts under NR 150 Wisconsin Administrative Code.

The Department partnered with Lawrence University to study the impacts of dredging and decided that an Environmental Analysis (EA), under the provisions of NR 150 should be completed. The study and EA are specifically focused on the typical dredge channels proposed by private property owners along the shorelines of Green Bay and Lake Michigan in Door County, Wisconsin. These dredge channels are commonly 30 feet wide and extend from shallow water near shore to the depths needed for navigation. The length of the channels depends on how shallow the near shore area is and can be up to as much as 300 feet long. Further processing of individual permit applications for private properties was put on hold pending completion of the EA. General Permits for maintenance dredging activities and individual permit applications for areas with public uses were still processed.

A scoping meeting with Department staff was held to identify significant concerns and issues. These included short term, long term, and cumulative impacts on water quality, invasive species, macrophytes (aquatic plants), macroinvertebrates (animals without backbones that are larger than ½ millimeter including crayfish, mollusks, clams, and snails), and fish and wildlife habitat.

The data utilized in developing the EA is focused on the study conducted by Lawrence University. A literature search of studies related to biological and physical changes occurring as a result of dredging was conducted, but yielded few results.

The study found biological impacts to the near shore area of the shoreline where these channels were dredged. This near shore area is called the littoral zone. These shallow water areas provide important spawning, nursery, and life sustaining functions for a myriad of fish, water fowl, and other aquatic organisms. The evidence indicates dredging altered the natural habitat at all of the sites, and in some cases the alterations were permanent and harmful. While the significance or level of the harm is dependent on the type of natural habitat impacted, the cumulative impacts of the alterations could have dramatic negative impacts on the ecosystem. Consider if every property owner dredged their own channel every 100 - 200 feet along the shoreline, the natural habitat could be severely affected. Based on the 2007 aerial photos, there are at least 367 dredged channels on the beds of Green Bay and Lake Michigan in Door County alone.

The study found that although vegetation richness was higher at most of the previously dredged sites, there was more silt and fewer types of macroinvertebrates in dredged channels. Increasing diversity and habitat can be a good thing and beneficial, but the natural habitat that is there today is working. These changes most likely rendered some or all of these dredged channels unsuitable for fish spawning, especially in cobble substrate, and possibly affected their ability to function as nursery habitat. While one dredged channel is not likely to significantly change the habitat or reproductive potential of important fish species in near shore waters of the Door Peninsula, there is concern for the cumulative impact of the growing number of dredged channels. Dredging in bedrock causes irreversible changes in the habitat because bedrock can not be replaced. Dredging in sandy substrate increases the short term impacts due to the need to dredge more often.

The Department must adopt a precautionary approach to all changes to the native habitat which should include a full examination of alternatives to dredging. While the study showed that the impacts of dredging are somewhat variable, dependant upon substrate and protected vs. exposed sites, it is clear that dredging these channels is a disturbance to the natural environment. This conversion from a natural, primarily locally native environment to a potentially non-native, unnatural condition could potentially cause an increase of plants into areas where they previously were not found. This becomes increasingly significant when evaluating long term and cumulative impacts. Consequently, alternatives that have less of an impact must be identified and employed to help protect the ecosystem. Riparians should consider and seek out options that have less of an impact on the environment than dredging whenever possible, such as using marinas or mooring areas. In some areas the shoreline is conducive to conditions which will allow access by a longer portable pier or a tracking "marine railway" system, depending on the size of the boat. Several riparian owners joining together to construct one channel instead of many channels may be another option. Using public boat ramps is another alternative to dredging.

INTRODUCTION

Definition of "Dredging"
"Dredging means any part of the process of the removal or disturbance of material from the bed of a navigable waterways, transport of the material to a disposal, rehandling or treatment facility; treatment of the material; discharge of carriage or interstitial water; and disposal of the material. For the purpose of ch. 30, Stats., dredging does not include "de minimus" activities as defined in sub. (2)." (NR 345.03((5) Wisconsin Administrative Code).

Purpose of the Study

The primary impetus for the Department's preparation of this EA is to gather additional information on the cumulative impacts of dredging channels through the littoral zone of Green Bay and Lake Michigan in Door County. Consequently; effective January 9, 2008, all pending individual permit applications at private properties (10 of them initially) were put on hold until completion of this Environmental Analysis (EA). The applicants were given the opportunity to put their application on hold, or withdraw and get their fee back. All except one applicant decided to withdraw.

This EA is not a process to block future dredging projects. The Department has the responsibility to review and evaluate the impacts of alterations to public waterways. The physical, biological, and cultural effects of these alterations must be reviewed in light of the Department's responsibility to uphold the public trust doctrine. The purpose of this EA is to provide information to Department Staff and the public on the cumulative impacts of dredging on Green Bay and Lake Michigan.

Authorities and Approvals

The removal of material from the beds of a navigable (public) streams, rivers, or lakes requires a permit under Wisconsin Statutes Chapter 30.20. There are individual and general permits available for dredging navigation channels. The General permit is for maintenance dredging of previously dredged areas and the applicant has to meet all the standards in Wisconsin Administrative Code Chapter NR 345. This includes "dredging may not exceed the volume or extend beyond the dimensions of the previous dredge project". The general permit does not require a site inspection and must be issued within 30 days.

If an applicant can not meet all of the general permit standards in NR 345, an individual permit is needed. The individual permit process requires a 30 day public notice to be published in the local paper and sent to the adjacent riparian owners, the county, city, village, or township clerk; and any other interested members of the public. Comments or a request for a public informational hearing must be received within 30 days of the publication of the notice.

Permits can only be issued if the department finds that it will be consistent with the public interest in the lake or stream according to Wis. Stats. Ch. 30.20(2)(c). Public interest standards are:

1. Natural scenic beauty.
2. Potential for disruption of fish or wildlife habitat.
3. Impacts on wetlands or endangered resources.
4. Effects on water quality.
5. Adequacy of design, including potential for failure.
6. Reasonable use, including consideration of alternatives.
7. Compatibility with the trust doctrine.

8. Cumulative impacts.
9. Impacts on the ability of the public to exercise the incidents of navigation, including such things as canoeing, kayaking, fishing, waterskiing, snowmobiling, hiking and swimming.

Permits and approvals for dredging are also required from the U.S. Army Corps of Engineers through a General Permit (GP-01) or Individual Permit.

Each applicant's project proposal is evaluated on an individual basis. This EA was completed to bring together a group of experts to thoroughly review the individual and cumulative effects of dredging activities.

Public Trust Doctrine

Under Wisconsin's Constitution, Article IX, Section 1, the navigable waters in the State of Wisconsin are declared to be public waters to be held as "common highways and forever free" to the citizens of the State and the United States. From this constitutional provision there has grown a body of law referred to as the "Public Trust Doctrine".

The precepts which form the basis for this doctrine are outlined well in the case of Diana Shooting Club v. Husting, 156 Wis. 261(1914), where the Wisconsin Supreme Court stated:

> Navigable waters are public waters and as such they should inure to the benefit of the public. They should be free to all for commerce, for travel, for recreation, and also for hunting and fishing, which are now mainly certain forms of recreation. Only by so construing the provisions of our organic laws can the people reap the full benefit of the grant secured to them therein. This grant was made to them before the state had any title to convey to private parties, and it became a trustee of the people charged with the faithful execution of the trust created for their benefit. Riparian owners, therefore, took title to lands under navigable waters with notice of such trust and subject to the burdens created by it. It was intended that navigable waters should be public navigable waters, and only by giving members of the public equal rights thereon so far as navigation and its incidents are concerned can they said to be truly public. at p. 505.

Public rights have been broadly defined by the Wisconsin Supreme Court. In Muensch v. Public Service Commission, 261 Wis. 492 (1951), a landmark case which contains a lengthy discussion of the public trust doctrine relating to navigable waters in Wisconsin, the Court stated:

> Indeed, the courts have recognized, and now more than ever before recognize, the public's interest in pleasure and sports as a measure of public health . . .
>
> Many of the meandered lakes and streams of this state, navigable in law, have ceased to be navigable for pecuniary gain. They are still navigable in law, that is, subject to the use of the public for all the incidents of navigable waters. As population increases, these waters are used by the people for sailing, rowing, canoeing, bathing, fishing, hunting, skating, and other public purposes . . . .
>
> . . . . the enjoyment of scenic beauty is a public right to be considered . . . . at p. 507-508 (Emphasis in the original).

Under the Wisconsin Constitution, the statutes discussed below, and the common law as articulated by Wisconsin courts, the State of Wisconsin has a responsibility to assess the impacts of activities of private riparian owners on the "public rights" in our navigable waters. This is one of the underlying reasons the Department is conducting the EA in this instance.

In carrying out its responsibilities under the public trust doctrine, the courts have recognized the importance of considering the cumulative impacts of these projects. While individual channels may appear to have little impact, cumulatively, the impacts can be significant.

In the case of Sterlingworth v. DNR, 205 Wis. 2d 702(Ct. App., 1996), the Court of Appeals stated:

> Although nine additional boat slips may seem inconsequential to a proprietor such as Sterlingworth, we approach it differently. Whether it is one, nine or ninety boat slips, each slip allows one more boat which inevitably risks further damage to the environment and impairs the public's interest in the lakes. The potential ecological impacts include direct impacts on water quality and sediment quality alteration, as well as direct and indirect influences on flora and fauna. For this very reason, the consideration of "cumulative impact" must be taken into account. As was explained by the Supreme Court:
>
> A little fill here and there may seem to be nothing to become excited about. But one fill, though comparatively inconsequential, may lead to another, and another, and before long a great body of water may be eaten away until it may no longer exist. Our navigable waters are a precious natural heritage; once gone they disappear forever.... Hixon v. PSC, 1966.

In the Department's opinion, in limiting Sterlingworth's permit to twenty-five boat slips, carried out its assigned duty as protector of the overall public interest in maintaining one of Wisconsin's most important natural resources.

The Department must, in view of these concepts, consider the cumulative impacts of these individual projects on our navigable waters.

Riparian Rights

Under Wisconsin law, riparian property owners have specific rights to utilize their shoreline properties. These rights include, but are not limited to the right of access to water for boating, swimming, and recreation, including exclusive use of the shoreland to the water's edge, and the right to construct piers and similar structures. (Kent, 2001) Those rights are limited by the statutory limitations adopted by the Legislature in Chapter 30, Stats., discussed below, and by the public trust doctrine.

It is clear under Wisconsin law that rights of a riparian owner are qualified, subordinate and subject to the paramount interest of the state and the paramount rights of the public in navigable waters. State v. Bleck, 114 Wis. 2d at 467; Mayer v. Grueber, 29 Wis. 2d 168, 173-74 (1965). As clearly and repeatedly as the courts have asserted the conditional nature of riparian rights, so the courts have "jealously guarded the navigable waters of this state and the rights of the public to use and enjoy them." Delta Fish and Fur Farms v. Pierce, 203 Wis. 519, 523 (1931). No person, including a riparian owner, may destroy or impair navigable waters. State v. Adelmeyer, 221 Wis. 246, 256 (1936).

The rights of a riparian are also impacted by the concept of "reasonable use".

> This concept first appeared in Wisconsin law in the context of riparian rights in Timm v. Bear, 29 Wis. 254, 265 (1871), where the Court stated:
> "What constitutes reasonable use depends upon circumstances of each particular case and no positive rule of law can be laid down to define and regulate such use with entire precision ... In determining this question, regard must be had that the subject matter of the use, the occasion and the manner of its application, its object, extent and necessity for it, to the previous usage, and so also upon the size of the stream, the fall of water, its volume, velocity and prospective rise and fall are important elements to be considered."

This concept is again discussed in State ex rel. Chain O'Lakes P. Assoc.v. Moses, 53 Wis. 2d 579, 582 (1971) as follows:

> "The established rule of the common law was that every riparian owner of stream or lakeshore property had an equal right to the use of it for all reasonable and beneficial purposes, and it was this rule that early became the law in Wisconsin. The right of reasonable use of water was one of the rights assured owners adjacent to lakes and streams, others including the rights to accretions, relictions, pierages and wharfages. What constitutes a reasonable use, under the common-law test, is a factual determination, varying from case to case, and subject to a trust doctrine concept that sees all natural resources in this state as impressed with a trust for usage and conservation as a state resource."

As indicated in these cases, what constitutes a reasonable riparian use will vary from case to case. It is clear, however, that at some point a riparian use can adversely affect not only the rights of other riparians but also the rights of the public guaranteed by the public trust doctrine. This affect is not based solely on the physical changes to the public lakebed, although that certainly is a factor. It is also based on the cumulative impacts occurring when riparians intensively use relatively small amounts of riparian frontage. According to Just vs Marinette (56 Wis. 2d 7, 1972), a property owner does not have the inherent right to alter the natural environment of a parcel: "An owner of land has no absolute and unlimited right to change the essential natural character of his land so as to use it for a purpose for which it was unsuited in its natural state and which injures the right of others".

Dredging Regulations in other Great Lakes States

Michigan

Permits are required for dredging river and lake bottoms including the Great Lakes. There is a standard permit process and also a permit process for "minor project categories". There is a "minor project category" that includes dredging of previously dredged areas and dredging of not more than 300 cubic yards as long as the dredge spoil material is not polluted and will be disposed of at an upland site. The minor project permit requires a site inspection and allows for waiving public notice requirements for those projects that meet permit requirements.

The standard permit process requires a public notice be sent to the director of public health or the local health department; the county, city, village, or township clerk; the county drain or road commissioners; the local port commission, if any; and the two adjacent riparian property owners. Comments or a request for a public comment meeting must be received within 20 days of the issuance of the notice.

Permits are reviewed to determine the existing and potential adverse environmental effects. Permits can not be granted unless the department finds that the adverse effects to the environment, public trust, and riparian interests of adjacent owners are minimal and will be mitigated to the extent possible; and that there is no feasible and prudent alternative to the applicant's proposed activity which is consistent with the reasonable requirements of the public health, safety, and welfare.
(Source – 451-1994-III-1-THE-GREAT-LAKES-325 Michigan Statutes and R 322 Michigan Administrative Rule)

Minnesota

Permits are required for "excavating" activities in public waters which includes Lake Superior. There is a standard permit process and a general permit processes however it appears that there are no general permits available for "excavations". Minnesota has the option to delegate its permit authority to local units of government.

The standard permit process may include a site visit but does not have a public notice aspect. Projects that have an adverse impact are required to mitigate for the impacts.

The Minnesota goal is to ..."limit the excavation of materials from the beds of public waters in order to:

A. preserve the natural character of public waters and their shorelands, in order to minimize encroachment, change, or damage to the environment, particularly the ecosystem of the waters;
B. regulate the nature, degree, and purpose of excavations so that excavations will be compatible with the capability of the waters to assimilate the excavation; and
C. control the deposition of materials excavated from public waters and protect and preserve the waters and adjacent lands from sedimentation and other adverse physical and biological effects." (s. 6115.0200 Subp.1, Michigan Administrative Rule).

Permits are reviewed for a wide variety of criteria including reasonableness and practicability, life expectancy of the project, contamination and nature of excavated material, disposal of the excavated material, minimization of impact, and impacts on the physical and biological character of the water and surrounding shorelines. There are further defined criteria and standards for specific types of excavations. There are specific standards for example, for excavations for navigational access channels for recreational watercraft. "When shoreline conditions and wind, wave, and current conditions preclude access to navigable depths, excavations for navigational access shall be allowed provided the access channel shall not exceed four feet in depth, more than 15 feet in bottom width, and will not extend to an offshore water depth greater than four feet." (s. 6115.0201 Subp.4, Michigan Administrative Rule). (Source – 103G.245 Minnesota State Statutes and 6115 Michigan Administrative Rule)

Illinois

Permits are required for "construction" in public waters. Construction includes dredging activities. There is an individual formal permit process and statewide, regional, and general permits. Statewide and regional permits do not require a project proponent to contact the Division of Water Resources Management (Illinois Department of Natural Resources) but do require standards to be met. There is a statewide permit available for minor maintenance dredging. General permits still require a permit submittal. The standard individual permit process requires a notice to be released as a news item and be mailed to interested parties. Individuals have 21 days to comment.

Individual formal permits are reviewed and must meet certain standards. The standards focus on interference and/or obstruction of navigability, "encroachment" on a public waterbody and impacts to bank or shoreline instability on other properties. The permit process requires minimization and mitigation of adverse impacts. (Source - 17 Illinois Administrative Code CH. I, SEC. 3704)

Study Design

The Department contracted with Dr. Bart De Stasio from Lawrence University to study the effects of dredging. The Department designed the study to include short term, long term, and cumulative effects on habitat, macroinvertebrates (animals without backbones that are larger than ½ millimeter, including crayfish, mollusks, clams, and snails), macrophytes (aquatic plants), and sedimentation.

In an effort to minimize inconvenience to dredging applicants, the study was designed so that it could be completed within a single boating season, despite the fact that this decision did somewhat limit the analysis of the "long-term and cumulative impacts" objective of the study. Each site was sampled twice between May and September of 2008.

Sixty nine potential sites were identified with the following characteristics: previously dredged vs. undisturbed sites adjacent to dredged channels; exposed vs. protected; on Green Bay vs. Lake Michigan; and the substrates bedrock, cobble, and sand (Figure 1). Twenty four sites with a combination of all the characteristics were chosen and field analysis was conducted by Lawrence University students Ian McPherson and Edwin Mathews under the direction of their professor, Dr. De Stasio. In addition to the sites sampled for the characteristics listed above, an additional twenty sites were studied to account for the potential added effects of piers on habitat conditions and biological communities in dredged and non-dredged areas. The study was designed so that it could be completed within a single season to accommodate permit applicants, so each site was sampled twice between May and September 2008.

The report "Evaluating the potential long-term and cumulative impacts from dredging to accommodate boat access in Green Bay and Lake Michigan in Door County, Wisconsin" is attached as Appendix C.

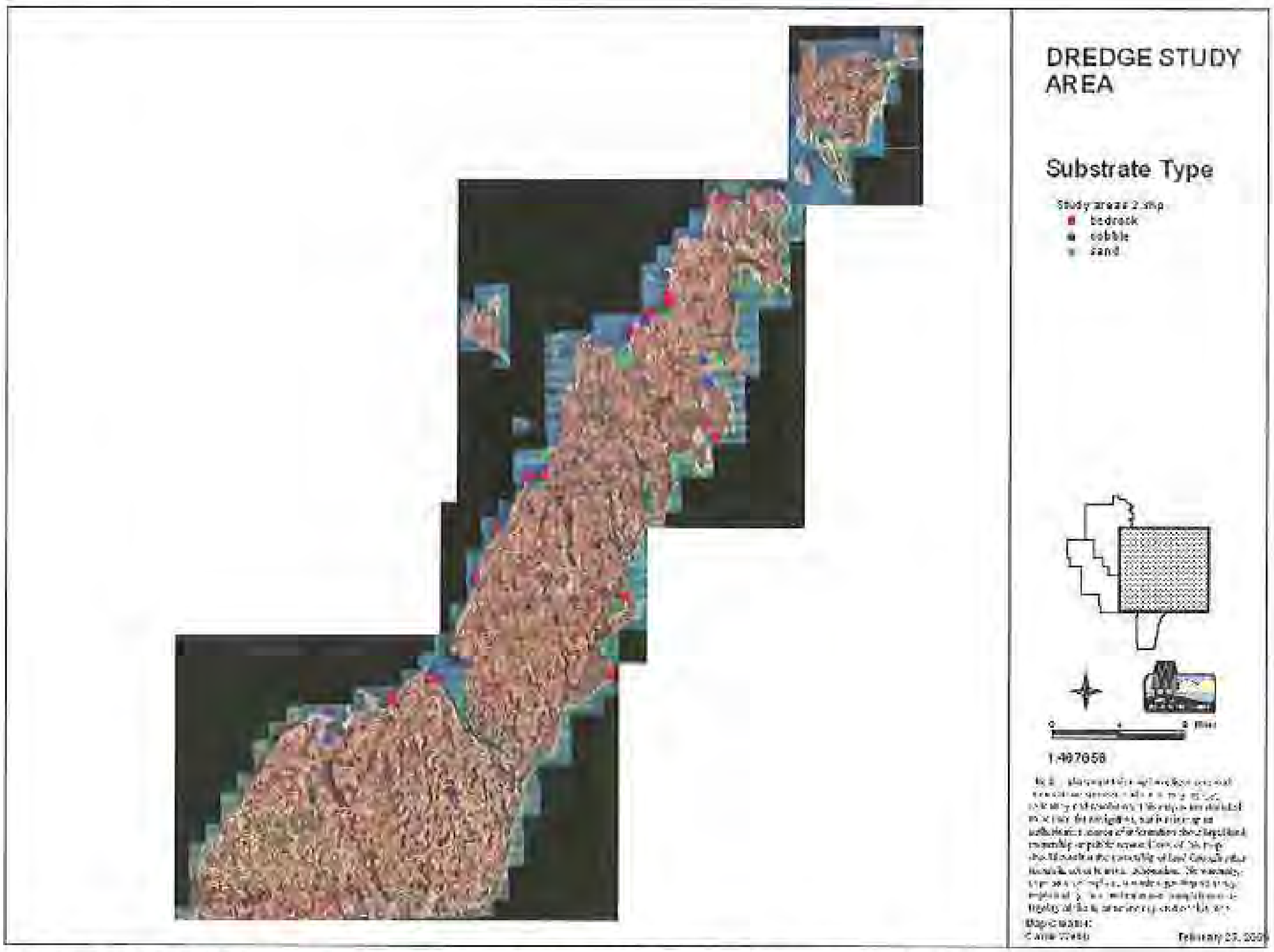

Figure 1. Dredge study area showing dredged channels by substrate type.

PROPOSED PHYSICAL CHANGES

Manipulation of Resources

The proposals for private dredging range from a few hundred to several thousand cubic yards in volume, and up to 300 feet from the water's edge. Proposed dredging applications vary from areas with and without solid piers, extending existing channels to brand new channels, in bedrock, cobble, and sand substrates. The most recent application proposals for private individuals are shown in Appendix A. An example of an area where several separate proposals for private channels were applied for is shown in Figure 2.

Figure 2. Four separate application proposals along 750 feet of shoreline

Temporary roads are often times used to gain access to the area to be dredged. While the road fill is mostly removed, without proper oversight, some native substrate will either be removed, or part of the road fill may be left on the lakebed. There may be disturbance of adjacent upland by equipment to access the construction site. This would be particularly detrimental in the bluff areas.

There are a variety of dredging and dewatering methods. Mechanical dredging involves machinery equipped with a bucket that reaches under water and scoops material from the bottom of the water body. Mechanical dredging uses one of three methods to remove sediment: clamshell, dragline, or excavator. Any of these methods can be used either from the shore or based on a barge on the water. Hydraulic dredging consists of excavating material by pumping it through a temporary pipeline to another location. This method acts like a giant floating vacuum cleaner that can remove sediment very precisely. The sediment slurry is then pumped through a pipeline to a disposal area and dewatered. It may take weeks or months for the material to dry. Regardless of the dredging method, the sediment will need to be dewatered. The excess water is usually returned to the dredged water body, but it must be of sufficient quality to meet state and federal water quality standards. Sediment can be dewatered by using a settling basin, geotextile tubes, or by mechanical means (McDougal, 2006).

The waste sites may need to be prepared to accept the material by clearing trees, building berms, or constructing roads to access the site. The water remaining in the spoils could be discharged into other waterways or wetlands nearby. Once dry, the spoils are often beneficially reused for activities like mine reclamation or land spreading on farm fields.

AFFECTED ENVIRONMENT

Physical Environment of the Study Area

Lake Michigan

Lake Michigan is the third largest Great Lake by surface area and the sixth largest freshwater lake in the world. The surface area covers 22,178 square miles, and it is 307 miles long and 30 to 120 miles wide. It has 1660 miles of shoreline consisting largely of sand and pebble beaches, and is bordered by Wisconsin, Michigan, Illinois, and Indiana. Lake Michigan averages 279 feet deep and reaches 925 feet at its deepest part. Because Lake Michigan is joined to Lake Huron at the Straits of Mackinac, they are considered one lake hydrologically. Many rivers and streams flow into Lake Michigan, and the major tributaries are the Fox-Wolf, the Grand, and the Kalamazoo. There is a diversion from the lake into the Mississippi River basin through the Illinois Waterway at the Chicago River.

In general, the northern part of the Lake Michigan watershed is covered with forests, sparsely populated, and economically dependent on natural resources and tourism, while the southern portion is heavily populated with intensive industrial development and rich agricultural areas along the shore. The world's largest freshwater dunes line the lakeshore. Millions of people annually visit the dunes and beaches at state and national parks and lakeshores (Lake Michigan Brochure, 1990, Michigan Sea Grant).

Green Bay

The bay of Green Bay is an elongated fresh water estuary, bordering northeast Wisconsin and the upper peninsula of Michigan. The water body is 120 miles in length, has an average width of 23 miles, and average depth of 65 feet. The bay extends from the city of Green Bay at its southwesterly limit to Little and Big Bay de Noc in Delta County Michigan at it's northeasterly limit. It is bordered by five Wisconsin Counties (Door, Kewaunee, Brown, Oconto, and Marinette) and Delta and Menominee counties in the State of Michigan. The total watershed drains approximately 15,500 square miles, or roughly one third of the Lake Michigan drainage basin. There are four Wisconsin river systems draining into the Bay of major importance (the Fox, Oconto, Peshtigo, and Menominee rivers). These major drainages are found on the south and west shores of the Bay. Of these four river systems, the Fox has the most influence on the waters of Green Bay because of the quality and volume of the water it discharges to the bay. The drainages on the east shore of the Bay include much smaller watersheds and are therefore not as significant as the west shore rivers.

The land surface of the two shorelines of Green Bay is in stark contrast to each other even though the bedrock materials are quite similar. The east shore is dominated by very steep, exposed rock ledges of Niagara Dolomite. The cliff faces range from a few feet of exposed escarpment to as much as 60 feet. In contrast, the west shoreline is bordered by very gradual topographic change where extensive wetland communities dominate the landscape.

The bottom materials of the Bay are a diverse mixture somewhat reflecting the major drainage ways emptying into the Bay. Bed materials include sand, silt, mud, gravel, cobble, rubble and bedrock. The Fox River drains extensive areas of clay and silt soils; therefore, these soil types dominate the southern and southwestern portions of the Bay. These sediments in turn influence the water quality and clarity of the southern end of the Bay. The western shore has bed materials of a sandy character, similar to the loads of materials carried in by the western rivers. The northeast shoreline has the majority of the rock, gravel, cobble, and bedrock substrate. Again, this is influenced by: the small watersheds feeding this side of the bay with their relatively small sediment loads; the nature of the land features in the area; the dominant water currents of the Bay; and the strength of wave energy to this shoreline.

The average elevation of the Bay of Green Bay is the same as that of Lake Michigan. The average over the last century has been about 580 feet above International Great Lakes Datum, 1985 (IGLD85). Water levels vary in this system by as much as 6.5 feet with the all time high recorded in October 1986 at 582.35 feet and the record low recorded in March 1964 at 576.05 feet. Seasonal, daily, and hourly fluctuating water levels raise concerns for shoreline property owners and other users of the system due to heavy erosion and property damage during high water periods and limited navigation during low water periods. For a typical boating season of May through October, this historic range is slightly reduced to 5.9 feet between the record high elevation of 582.35 feet, IGLD85 set in October 1986 and the record low elevation of 576.44 feet, IGLD85 set in March 1964.

Water elevations of the bay are further influenced by seiches. Seiches are back-and-forth or rocking like movements of the water body influenced by wind direction and strength, atmospheric pressure, water currents, etc. As evidence of the extent of these movements, the Fox River reverses its flow as far upstream as the De Pere dam which is seven miles upstream from the mouth of the river at the Bay of Green Bay. These localized movements can result in elevation changes of up to several feet in as little as one hour.

In addition to seiche movements, the Bay has a general circulation pattern in a counter clockwise direction. It is this circulation pattern that has a major influence on bottom sediment patterns and littoral drift movements in the near shore area. Eventually all of the water discharged into the Bay from its tributaries flows into Lake Michigan; however, the total discharge from the tributaries is small in comparison to water movements associated with seiches and circulation patterns. In spring and autumn, with weather dominated by winds out of the northeast, large volumes of Lake Michigan water enter the Bay. This southerly moving water generally follows the west shore to southern Green Bay and then turns north following the east shore. Water entering the Bay from the Fox River flows north and east and follows the east shore.

Water quality and clarity generally improves as you move from the southern end of the Bay, near the city of Green Bay, to the northern portion of Door County. This is primarily due to the quantity and quality of discharge from the Fox River and it's tributaries into the southern end of the Bay. The southern end of the bay has very poor water clarity and degraded water quality as the result of runoff from industrial, urban, and agricultural lands in the Fox/Wolf basin.

High nutrient loads and sediments that are added to the system and continuously suspended are the main problems of this area. These water clarity conditions improve dramatically heading north. The introduction of zebra mussels has had the effect of improving water clarity in some locations of the southern half of the bay all the way to Ellison Bay.

Spoil Deposit Locations

State and Federal laws limit where spoil material can be placed. In most cases, the placement of spoil material into navigable waterways, floodplains, or wetlands is not permittable. Most commonly the spoil material is beneficially reused as topsoil or to reclaim existing gravel pits. Because of the shallow bedrock, there are several gravel pits throughout Door County. In a few cases, the material is land spread over farm fields that could contain karst features, which are prevalent throughout Door County.

Biological Environment of the Study Area

The areas of potential disturbance are the nearshore areas of Green Bay and Lake Michigan along Door County. Water levels in Lake Michigan and Green Bay fluctuate naturally and unlike the high water years in the 1980's we have recently been experiencing low-water trends causing the shoreline to recede. Substrate types along coastal Door County vary from being predominately bedrock, to cobble and sand, which all have larger particle sizes than silt which is typically found more on inland lakes and rivers. Some coastal reaches are in bays and coves while other reaches are open-water shores exposed to greater influences of wave action. In general, the natural coastal shoreline along Door County has limited abundance and species of macrophytes (aquatic vegetation). Macrophytes are less abundant on bedrock substrate than cobble or sand substrates. Benthic (bottom dwelling) algae (e.g. *Cladophora* and *Chara*) require firm substrate for attachment and obtain their nutrients from the water column; consequently they are more abundant on bedrock reaches. Macroinvertebrates are most abundant in cobble substrates which provide abundant interstitial areas, stable substrate, well oxygenated water flow, and protection from wave action. Dreissenid mussels (zebra and quagga) are prevalent throughout Lake Michigan and Green Bay coastal areas.

Wave action provides a stress to organisms living in the coastal reaches. Frequent water movement, higher speed and near shore currents prevent fine sediment particles from accumulating. The growth of macrophytes is generally limited as well in these higher energy areas. Bedrock substrates are relatively harsh environments for organisms with less sediment accumulation and lower nutrient availability.

Some current boat access channels exist and often are cut through bedrock. Some of these channels extend out as much as 300 feet from the ordinary high water mark, and in some areas are located very close to each other (Figures 3 & 4).

Figure 3. Dredged channels

Figure 4. Dredged channels and historic sidecasting of spoil material, which is no longer allowed.

Most direct impacts from dredging will be in the area of the "littoral zone". Littoral zones comprise shallow water communities between the open water areas of a lake and the surrounding land. Technically, littoral zones begin on land where the water table lies only a foot or two below the soil surface, and extend to the maximum depth where rooted aquatic plants grow. The size of the littoral zone obviously depends on the characteristics of the water body. Littoral drift material is distributed along large waters as a result of wind and wave action, fetch (the length of the area where waves are being generated by the wind), seiche and ice heaves in late winter and early spring. This is a very dynamic process and changes occur daily, seasonally, as well as on an annual basis.

Plant growth is limited by light, nutrient availability, and substrate type. Growth of macrophytic vegetation, and the accompanying macroinvertebrate, zooplankton (tiny animals), and phytoplankton (free floating plants) communities, is often restricted to shallower depths due to natural lake fertility or cultural eutrophication (an abundant accumulation of nutrients). While the maximum rooting depth can vary greatly from one lake to the next, the shallow water area (littoral zone) is the more crucial habitat affecting lake productivity and biodiversity. These shallow water areas provide important spawning, nursery, and life sustaining functions for a myriad of fish, water fowl, and other aquatic organisms. The littoral zone on Lake Michigan and Green Bay is very small compared to the whole size of these water bodies. Scores of phytoplankton and zooplankton utilize rooted aquatic plant beds during all or part of their life cycles. "Invisible" but important residents of the littoral zone and components of the lake food web include attached algae, sponges, mollusks, crustaceans, microcrustaceans, insects, and forage fish such as darters which use bottom material in the littoral zone during their life histories. Nearshore areas link terrestrial and aquatic ecosystems and are crucial for sustaining amphibian and reptile populations.

The Great Lakes provide important critical habitat for fish, migratory birds, and a host of wildlife and plant species. The miles of shoreline make up a complex arrangement of ecosystems that contain a rich variety of natural features. Wetlands near the coasts provide rich habitat for plants and animals and greatly influence the larger ecosystem processes of the Great Lakes. As transition zones between land and water, coastal wetlands are often rich in species diversity and provide critical habitat for migratory and nesting birds, spawning fish, and rare plants. However, various types of development and recreation continue to impact coastal wetlands and limit their capacities to perform important ecosystem functions.

Wetlands throughout Wisconsin provide critical habitat for a diverse set of both aquatic and terrestrial plant and animal species. They serve as spawning grounds for fish, stopovers or staging grounds for migratory and breeding birds, and critical habitat for many rare plants and animals. A number of coastal wetland sites host extremely rich assemblages of flora and fauna, including dwarf lake iris (*Iris lacustris*) and Piping Plover (*Charadrius melodius*) both of which are rare globally. Some rare plant species such as the coast sedge (*Carex exilis*), English sundew (*Drosera anglica*) and marsh bedstraw (*Galium palustre*), a Wisconsin special concern species, are found only in coastal wetlands. Appendix B lists many of the rare plants and animals documented within the studied coastal zone along with their state and federal status, where applicable. Long-term monitoring stations along the Great Lakes have documented high concentrations of migratory birds, over 100 of which are Neotropical Migrants or birds that winter in the Neotropics or southward. The Great Lakes serve as migrant corridors and coastal wetlands offer critical food and shelter resources.

Numerous inventories and reports have been completed pertaining to coastal wetlands throughout Wisconsin. The Shivering Sands Area is located along the eastern coast of Door County, north of Sturgeon Bay. It is a complex and important landscape with a great diversity of coastal wetland ecosystems. There are several smaller sites that include the Bailey's Harbor Boreal Forest, Kangaroo Lake, Marshall's Point, Moonlight Bay Bedrock Beach, Mud Lake, The Ridges Sanctuary, and Toft

Point State Natural Areas. The primary wetland natural communities include dolomite pavement shoreline and cobble beaches, old beach ridges stabilized by conifer-hardwood forest and swales containing a variety of wetland communities, Great Lakes marsh, rich fen and sedge meadow, rich conifer swamp and boreal forest.

The fish communities of Lake Michigan and Green Bay are very diverse ranging from those associated with a large oligotrophic system, which has a sparse growth of algae and other organisms and a high oxygen content, to those associated with shallow water eutrophic estuaries, which has an abundant accumulation of nutrients that support a dense growth of algae and other organisms and a lower oxygen content. The fish typical of the Lake Michigan open water community include large pelagic (near the surface) and benthivore (feeding on bottom dwelling organisms) predators like chinook and coho salmon, brown, rainbow and lake trout, as well as burbot and lamprey. The open water fish community also includes several other trophic levels with fish species like lake and round whitefish, bloater chub, alewife, rainbow smelt, three species of sculpin, two species of stickleback, round goby, yellow perch, white and long nose sucker and many others. Some of these species are native while others are exotic but have become naturalized. Many of the species found in Lake Michigan also inhabit the open water areas of Green Bay off the northern portion of the Door Peninsula and move freely back and forth between the lake and bay. The near shore fish community of Lake Michigan and northern Green Bay include top predators like brown trout, smallmouth bass, and northern pike. Other species in the lower trophic levels include fish like rock bass, yellow perch, white perch, alewife and gizzard shad, spottail and emerald shiners, round goby, several species of darters, and many others. In addition to the movement of fish between the bay and lake there is also a movement of fish between the open water and near shore areas. Many of the typical open water fish species utilize the near shore area or tributary streams for spawning and/or nursery areas and many of the open water fish species are found in the near shore area on a seasonal basis. Progressing further south into Green Bay, the bay becomes shallower, more eutrophic, and tends to get warmer during the summer. There is no magic line of demarcation but a gradual continuum as you move northeast to southwest. As one progresses further south in the bay the species of fish start to shift so that by the time one gets to the southwest end of the bay there is a very different fish community than there was in northern Green Bay. On the south end of the bay top predators include walleye, channel catfish, northern pike, Great Lakes spotted musky, large and smallmouth bass. Fish in the other trophic levels include species like lake sturgeon, freshwater drum, yellow perch, white perch, white bass, troutperch, spottail and emerald shiners, several species of darters, round goby, common carp, and many others.

Cultural Environment of the Study Area

Social/Economic

The social and economic character of the Lake Michigan basin area is almost as diverse as the physical characteristics and the biology of the Great Lakes. The southern end of the Bay is dominated by the city of Green Bay. This is an industrial/commercial/urban center of northeastern Wisconsin. As you move north from the city of Green Bay, the landscape reflects a more rural and rural residential pattern of development. The shoreline of Green Bay, north of the city, is in a transition from being used as sites for seasonal recreation and summer cottages, to being used for year round homes and retirement homes. A larger community and industry are found at Sturgeon Bay on Green Bay's east shore. A number of still smaller communities are supported by residents who commute to larger cities, or by the tourist industry as exemplified by small communities north of Sturgeon Bay. North of the city of Green Bay, agricultural production, dairy product production, fruit growing, cash cropping, forestry, and other open space uses are found on the interior of Door County.

The waters of the Bay of Green Bay are important to the economy of the region. The port of Green Bay is a major commercial shipping center in the area. In addition, the population center in this region makes extensive recreational use of the waterway. The northern end of the Bay supports the tourist industry of Door County. The draw to this area has been the natural scenic beauty of this water body and the varied recreational opportunities this waterway provides.

Fishing activities, both sport and commercial are both very important recreationally and economically to the area. Major open water sport fisheries occur for trout and salmon, smallmouth bass, walleye, yellow perch, and Great Lakes strain of spotted musky. Ice fishing for yellow perch and walleye is also important seasonally and recently a large ice fishery for lake whitefish has developed. Yellow perch and lake whitefish also support economically important commercial fisheries.

Archaeology/History

There are many known and undocumented shipwrecks located near the shore in the Great Lakes. Twenty seven known shipwrecks at less than the 20 foot water depth are listed on Wisconsin's Maritime Trails database for Door County. More shipwrecks are being found all the time, including recently the scow schooner Ocean Wave, lost off Door County in 1869 (Baillod, 2004). These cultural resources are protected against unauthorized disturbance by various state (Wisconsin Statutes Chapters 44 and 157) and federal laws (Section 106 of the National Historic Preservation Act), and may be protected by local ordinances as well.

ENVIRONMENTAL CONSEQUENCES

Physical Impacts

Long term, cumulative impacts

There were clear and obvious differences between sites that had been previously dredged and those without any dredging history. At bedrock sites, dredging resulted in more bare rock coverage and less sediment. At cobble sites that were dredged there was significantly higher sediment and lower bare rock coverage. In sandy substrate, dredged locations had lower sediment coverage (De Stasio, 2009).

Particles size was significantly smaller and consisted of silt in the middle of the dredged channel more than at either the slope or adjacent to the channel. Overall, particle size was generally smaller at protected sites and at previously dredged locations. Particles were typically more rounded at dredged sites than at sites with no previous dredging history. Round particles often result in more highly compacted sediments, decreased oxygen permeability as well as reduced interstitial spaces. Sediments in the middle of dredged channels were the only place where black silt was observed and the only place that emitted a distinct odor of hydrogen sulfide (De Stasio, 2009).

Soft, small particle sized sediments such as silt can create a nuisance for water users. Complaints from the public regarding perceived negative changes such as an increase in plant or algae growth where it did not occur before, odor, or resuspension during recreational activities associated with soft sediments occur every open water season.

Short term impacts

Dredging is conducted using heavy equipment so there is the potential for a fuel spill as part of the dredging operation, whether it is due to equipment malfunction or falling through the ice. Transport of dredge spoils also presents a potential hazard if wet materials fall onto the roadways, causing slick surfaces. During the dredging, there will be dredging equipment and erosion control practices that will impact recreational use in the area.

Land spreading in areas with karst features could cause turbidity and other problems with the groundwater. Karst features are located in areas where the bedrock, usually limestone or dolomite, has the potential to be easily dissolved by surface water or groundwater. Karst landscapes have deep fractures, caves, disappearing streams, springs, or sinkholes. The exposed material at spoil sites could also be at an increased risk for the invasion of exotic species.

Biological Impacts

Long term, cumulative impacts

Dr. De Stasio (2009) found that the impact of dredging had different impacts depending upon the type of substrate at the dredged site. Dredged sites with bedrock had less sediment, less macrophytes, and more benthic (bottom dwelling) algae (e.g. *Cladophora* and *Chara*) adjacent to the channel. Dredged sites with cobble had more sediment and similar abundance of macrophytes. Dredged sites with sand substrate had less sediment but significantly more macrophytes.

Sediment:

Alterations along the near shore area of Lake Michigan and Bay of Green Bay such as dredging, construction of piers and breakwaters dramatically change the movement of longshore currents and distribution of littoral drift material. The dredged channels become a deposition zone for fine sediment and require periodic maintenance dredging. This results in an accumulation of smaller more round particles, higher organic content and higher nutrients resulting in increased macrophytes, especially in sites with cobble substrate (De Stasio 2009). Obstructions such as piers and breakwaters or areas that are dredged can create a shift in how littoral drift material accumulates or is deposited along the near shore. But perhaps if a solid pier is present dredging doesn't impact water movement as much. Decreased movement results in an accumulation of smaller more round particles, higher organic content and higher nutrients resulting in increased macrophytes (De Stasio 2009). These areas are also prone to lower oxygen, resulting in a different composition of organisms and chemistry at the substrate water interface.

Plants:

Macrophyte coverage is significantly affected by previous dredging at sites with substrate types of bedrock or sand. However, the effects of dredging had opposite effects at these two types of sites. At bedrock sites dredging resulted in higher benthic algae adjacent to the channel, but on sandy substrate, dredged locations had significantly higher area coverage by macrophytes and lower benthic algae. On bedrock substrate very few macrophytes were present and they were only found in non-dredged sites. Benthic algae coverage was approximately the same at dredged and non-dredged sites with a bedrock substrate, but there were significantly less benthic algae in the middle of dredge channels compared to adjacent areas. Algae coverage adjacent to the channel also was dramatically higher than at the non-dredged sites, indicating that dredging has lasting impacts on the areas outside of the channel as well. The middle of channels had significantly higher macrophyte coverage than adjacent areas in both cobble and sand substrate locations (De Stasio, 2009).

Vegetation richness was generally higher at previously dredged sites. At sites without piers there was a significantly higher number of plant species at dredged compared to non-dredged sites. On cobble substrate in locations without piers vegetation density on rakes was significantly higher in previously dredged than non-dredged sites. At sand substrate locations with piers, rake density was significantly higher at previously dredged sites. The presence of macrophytes reduces water flow, leading to further deposition and accumulation of sediment at dredged sites (De Stasio, 2009). Physical disturbance often increases the likelihood of invasive species encroaching into the disturbed area.

In some ecosystems, more diversity of aquatic plants can provide more opportunities for animals to utilize the habitats that the plants provide. For instance, one species, like *Vallisneria* provides starchy tubers that ducks like to eat, but *Chara* provides a large surface area for invertebrates to colonize. These invertebrates then provide food for certain fish species. If just one species were present, only the critters that utilize that plant for food, cover, or nursery area would be present at the site. More plant species often provides more aquatic life. Plants are essential to the spawning success of many fish species. Plants provide shade and refuge for near-shore animals. Plants photosynthesize, creating oxygen for animals that live in the littoral zone. Plant fruits and tubers provide food for mammals, waterfowl, insects, and fish. Plants use nutrients, making them less available for nuisance algae. Plant roots create networks that stabilize sediments.

<u>Benthic invertebrates:</u>
The composition and abundance of macroinvertebrates varied considerably between sites. The many variables: dredging history, substrate type, and presence or absence of piers had an inconsistent affect of the community. However, notable trends were observed. Dredged sites with sand substrate generally had higher numbers of taxa than non-dredged sites at sites without piers. Both substrate and site exposure did significantly affect abundance of the dominant macroinvertebrates: amphipods, midge fly larvae, and ostracods. Sites with piers showed a tendency to have higher abundances, especially at protected sites. Fewer taxa are found in sites with rounder sediment particles (De Stasio, 2009).

<u>Shorebirds and other wildlife:</u>
Many species of shorebirds utilize habitat along the shores of Green Bay during spring and fall migrations. Most species require mudflat and/or beach habitat, but a few prefer rock substrates. Dredging may remove small segments of desirable shorebird habitat. However, the greater impact would arise if the dredging then allowed for a significant increase in human activity near the site. Most shorebirds will not remain in areas where human disturbance is frequent. Also, several species of mollusks are documented in the waters off of Door County, and colonies could be significantly damaged by dredging. There could also be impacts to wildlife habitat at the disposal sites if the landscape is altered by removing trees and other vegetation utilized by wildlife.

<u>Fish:</u>
Suspended sediment in high concentrations can dislodge plants, invertebrates, and insects in the lake bed. This affects the food source of fish, and can result in smaller and fewer fish.

The near shore area most likely to be impacted by dredging is critically important to many of the species of fish discussed in the "Biological Environment of the Study Area" section of this EA. There are two specific areas of concern that should be highlighted in that the near shore area functions as critical spawning area for some of the species and as nursery areas for others. These are particularly vulnerable life stages in many of the fish species discussed and although we know that the habitat as it exists now supports the spawning and nursery area needs of these fish as evidenced by the healthy populations of these fish, we don't adequately know what level of manipulation or change would negatively impact the ability of the near shore area to support these same activities.

One known impact of dredging that would no doubt impact the ability of the near shore area to support spawning and nursery activities is the turbidity and suspended solids associated with almost all dredging activity. Suspended solids are known to negatively impact fish eggs during incubation and hatching. Although the sediment is suspended for a short time, the impacts can be long term. Many of the dredged channels need to be re-dredged on a routine basis, so the impacts can occur repeatedly.

Some of the more noteworthy species that this would impact include smallmouth bass, rock bass, lake whitefish, yellow perch, alewife, and smelt, but any species of fish that utilize the near shore area for spawning would be impacted. Suspended solids are also deleterious for many of the vulnerable early life stages of fish. Species of particular concern include smallmouth bass and lake whitefish, but would likely include any species of fish whose young are found in the near shore area when suspended solids were present.

With all of the fish species that are utilizing the near shore area for spawning or nursery area there is a large window of time that one or more fish species of concern are vulnerable. For example the spawning grounds for the North / Moonlight Bay stock of lake whitefish lies along the east side of the Door Peninsula from approximately the Baileys Harbor area north to the tip of the Peninsula. Lake whitefish spawning occurs in late October to mid November with the eggs incubating on site over winter, hatching out in early April. The lake whitefish fry then drift into many of the larger embayments (Baileys Harbor, Moonlight Bay, North Bay, and Rowleys Bay) where they spend the next couple of weeks to a month as very weak swimmers in a particularly vulnerable life stage. These same embayments are also important spawning areas for species like northern pike, smallmouth bass and many other species. Northern pike would be spawning in the near shore marshes immediately following ice out (late March through April) followed by smallmouth bass spawning from late May through early July as the near shore waters warm into the upper 50s and low 60s. Whereas the lake whitefish incubation and hatching is measured in months, small mouth bass incubation and hatching is measured in days. Smallmouth bass fry grow quickly enough to be out of the especially vulnerable life stage within a week or two of hatching. The cumulative effect of all of this activity is that on the lake side of the Door Peninsula there are vulnerable life stages of important fish species utilizing the near shore waters all the time from Late October through the following early July. On the bay side of the Door Peninsula there are no currently known important lake whitefish spawning or nursery areas and the impact of that is that the window of vulnerability to suspended solids on the bay side of the Door Peninsula is shortened to the ice out through early July period.

The dredged channels themselves could trap fish in them during low water periods, potentially causing mortality.

Dredging projects are capable of creating a large plume of suspended solids that could be disastrous to incubating fish eggs or the weak swimming early life stages of most of the fish species discussed (Figure 5).

Figure 5. Plume of sediment from dredging activities

There are already 367 known dredge channels in Door County. As documented in the dredge study (De Stasio) the dredged channels change the habitat of the area appreciably. Areas previously dredged were documented to accumulate quantities of fine sediment, have increased levels of silt, occasionally had lower oxygen levels, and increased amounts of vegetation. These changes most likely rendered some or all of these dredged channels unsuitable for spawning and possibly affected their ability to function as nursery habitat. While an individual dredged channel is not likely to change the habitat of the near shore waters of the Door Peninsula to significantly affect the reproductive potential of most of the important fish species, there is concern for the cumulative impact of all of the dredged channels impacting the ability of fish populations to be able to maintain their reproductive success. Not knowing what threshold of dredged channels will begin to affect the reproductive success, there is concern for the number of new dredged channels that are permitted. The cumulative impact could be devastating and we might not be able to predict when we are reaching the critical threshold before the damage is done.

Short term impacts

The short-term impacts from dredging are increased turbidity and burial of macroinvertebrates from settling particles. Dredged channels become deposition zones and require periodic maintenance dredging to maintain depth resulting in a recurrence of the short-term impacts.

The actual dredging operation impacts water quality by resuspending sediment, nutrients, and contamination into the water column. Depending on the flow characteristics, the resuspended material can form a plume and travel great distances. The plume of turbid water impacts fish and other aquatic life by reducing visibility and putting stress on the organism's ability to filter water. Early life stages (egg, larval) of many aquatic organisms can be detrimentally affected by increased sedimentation. (Rogers & Heisel, 2006) Nutrients accumulate in sediment and once disturbed by dredging become available for use for such things as hungry algae. The burst of nutrients has been known to trigger algal blooms and increase ongoing blooms. Algae blooms have their own set of impacts including decreasing water clarity and decreasing dissolved oxygen when decomposing. Sudden fluctuations in dissolved oxygen impact all aquatic animal life (Rogers & Helsel, 2006).

The additional particles in the turbid water during dredging actually cause irritation in the gills of fish. In some cases, if the irritation is great enough for a long period of time, the turbid water will cause mortality (Rogers & Helsel, 2006).

Suspended sediment directly affects fish populations in several ways:

- Suspended sediment decreases the penetration of light into the water. This affects fish feeding and schooling practices, and can lead to reduced survival.
- Suspended sediment in high concentrations irritates the gills of fish, and can cause death.
- Sediment can destroy the protective mucous covering the eyes and scales of fish, making them more susceptible to infection and disease.
- Sediment particles absorb warmth from the sun and thus increase water temperature. This can stress some species of fish.
- Settling sediments can bury and suffocate fish eggs. (Environment Canada)

The dewatering sites could be utilized by many types of wildlife. Once the project is completed and the site re-vegetated there should be no impact to the use of the site by wildlife. No adverse impacts to water quality are expected from the spoil dewatering. The dewatering will meet the WPDES discharge standards.

Summary of Biological and Physical Changes:

	NON-DREDGED	**DREDGED**
BEDROCK	less macrophytes	more algae adjacent to channels
	more sediment	larger particles w/piers
	larger particles w/o piers	particles more round at exposed sites
	vegetation richness higher w/piers	more bare rock

COBBLE	larger particles at protected sites	more sediment
	more bare rock w/o piers	particles more round at exposed sites
	particle more round at protected sites	vegetation richness higher

SAND	more sediment	more macrophytes
	more algae	particles more round at protected sites
	larger particles w/piers	vegetation richness higher

ALL SITES	more amphipods	rounder particles
	more midgefly w/ piers & protected sites w/o piers	vegetation richness higher w/o piers
	more ostracod w/o piers & protected sites w/piers	

Table 1. Summary of study results comparing dredged vs. non-dredged sites by substrate type.

Cultural Impacts

Long term, cumulative impacts

Dredged channels that can be used for boat access may increase property values for some riparian owners.

Dredging operations have the potential to adversely impact cultural resources, including, but not limited to archaeological sites and historic structures. These may be located at the dredged sites, spoil deposit locations, and equipment staging areas. Examples of impacts are destroying a shipwreck lying on the lakebed, covering a burial site with spoil material, or damaging an historic structure.

Long term impacts to recreation include people walking the shoreline in the water and encountering a deep channel where walking is common. If the channel can be seen, people have to find a way around it, if the channel is not obvious, people could be hurt or drown by falling into the deeper water in the channel, especially at bedrock sites where the drop off could be steep.

Short term impacts

Dredging and maintenance of channels provide jobs for local construction companies (although so would the construction of the alternatives).

Recreation could be impacted by dredged channels in the short term by causing turbid water during construction that could affect fishing, swimming, snorkeling, or just enjoyment of natural scenic beauty.

Summary of Adverse Impacts That Cannot Be Avoided

As Dr. De Stasio's study clearly shows, dredging causes permanent changes to the natural habitat. The following are the changes that have occurred in dredged channels:

- Sediment particles at dredged sites in all of the substrate types were more round, which results in decreased oxygen permeability, reduced interstitial spaces, and increases turbidity.
- Unpleasant odors occurred at some of the dredged sites with rounder particles and black silt.
- Highly compacted sediments can encourage the growth of aquatic macrophytes including invasive species such as Eurasian watermilfoil and Curly-leaf pondweed.
- Resuspension of silt during dredging
- Changes to the natural environment

DNR EVALUATION OF PROJECT SIGNIFICANCE

Environmental Effects and Their Significance

Long Term Impacts

The study demonstrates that dredging altered the natural habitat, but the significance of the impacts to the ecosystem as a whole are unknown based on the limitations of the one year study. Further studies are needed to define the significance of the cumulative impacts also. Intuitively, there will be a point at which the changes to the natural habitat will cause harm to the ecosystem and significant cumulative impacts. However, the existing habitat is currently working, so the Department must adopt a precautionary approach to all changes to the native habitat. Since some of these changes are irreversible, it is necessary to implement the Precautionary Principle: When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically. In this context, the proponent of an activity, rather than the public, should bear the burden of proof. The process of applying the Precautionary Principle must involve an examination of the full range of alternatives, including no action. (Hileman, 1998)

Cobble Substrate
The change in habitat is significant at cobble sites. The habitat is changed from large cobble substrate with little vegetation to finer sediment and more aquatic plants. At exposed sites, the particles are more round in dredged channels. While this change provides habitat for many habitat generalist type species, it destroys the type of habitat necessary for whitefish and other fish species who utilize this habitat for spawning. The impacts will be more severe in areas where this type of habitat is locally scarce.

Bedrock Substrate
At all bedrock sites, there were more algae adjacent to the dredged channels and more bare rock. Sediment particles are more round at exposed sites, increasing the impacts such as decreased oxygen permeability as well as reduced interstitial spaces. Dredging in bedrock is significant because it results in a more permanent change since bedrock can not be replaced.

Sand Substrate
Habitat changes at all of the sand sites were more macrophytes and more vegetation richness. Sediment particles were more round at protected sites, which increases the impacts. Dredging in sand is significant because it has many more short term impacts since the channels would need to be dredged out more often. Sand movement would result in the channels filling in quickly, requiring more maintenance dredging.

Short Term Impacts

Short-term impacts of dredging are significant and include increased turbidity and sedimentation of fines from particles settling out of the water column from the dredging activity which can negatively impact fish spawning, aquatic insects, mussels and other bottom-dwelling organisms. The suspended sediment can irritate the gills of fish, potentially causing mortality, and bury and suffocate fish eggs. Periodic maintenance dredging results in the short-term impacts being revisited as channels need to be re-dredged to maintain depth.

If dredging is done, environmental impacts could be minimized by:

- Avoid areas of critical or sensitive habitat, especially for endangered and threatened species or shipwrecks.
- Schedule dredging activities to avoid times of important fish and aquatic species spawning and nesting, and times when the nearshore area is being utilized as nursery habitat.
- Use properly designed disposal and erosion control methods to meet state and water quality standards.
- Use in-lake sediment curtains to contain resuspended sediment
- Avoid creating steep contours near banks to avoid bank slumping and to avoid the issue of people walking the shore and falling in.
- Prepare a plan to address the potential for invasive aquatic plant growth to colonize the dredge area if possible.
- Implement provisions to reduce sediment transport into, and within lake. (Rogers & Helsel, 2006)

Effects on Geographically Scarce Resources

The shorelines of the Door County peninsula are unique. This resource is not found in any other part of Wisconsin and with the exception of a few other places on the Great Lakes is not found anywhere else in the world. This uniqueness makes it even more important to ensure that Department decisions protect this resource.

Construction of the dredged channels could damage state and federally protected shipwrecks that lie on the lakebed if they were unknown and not listed on the registry. Dredged spoil deposits could impact historic structures or burial sites that are protected by law because they can never be replaced.

Reversible Effects

Dredging boat access channels in bedrock is irreversible. There is no known way to recreate bedrock. Dredging in cobble areas could be reversible but would require human efforts to replace the rock. Sand substrates that are dredged may recover over time naturally if not re-dredged. Littoral drift of sand would act to slowly fill in the dredged area, or a single storm event could fill in the channel within a 24 hour period in some cases.

Significance of Cumulative Effects

The study found that there were biological impacts to the near shore area of the shoreline where these channels were dredged. The study found that at all of the sites, the dredging harmed the natural habitat. While the significance or level of the harm is dependent on the type of natural habitat impacted, the cumulative impacts could become harmful to the ecosystem as a whole. Consider if every property owner dredged their own channel every 100 to 200 feet along the shoreline, the natural habitat would be severely affected. Based on the 2007 aerial photos, there are at least 367 dredged channels on the beds of Green Bay and Lake Michigan in Door County alone.

If the water levels remain low, the Department can reasonably anticipate a continued increase in the amount of requests to dredge new individual channels by private property owners. The potential of significant cumulative impacts is real.

Significance of Risk

De Stasio (2009) found that dredged sites that also contained permanent piers tended to have a lower abundance of macroinvertebrates, but otherwise the effects of piers to the environment were not separate from dredging impacts. This was a small study and a more comprehensive study would need to be conducted to evaluate the full impact of boat access dredging and piers along Door County coasts.

The observation of low-dissolved oxygen in the dredged channels may be a significant concern. The connection between decaying Cladophora collecting in trenches, dreissenid mussels (zebra and quagga), gobies and low oxygen conditions in the nearshore areas of eastern Lake Michigan (Michigan coast) have been suggested as a potential cause of the increased number of bird deaths from Type E botulism. (Dettloff, 2008) These dredged boat access channels have lower dissolved oxygen and may provide conditions conducive to type E botulism.

Discussion with a coastal engineer familiar with shoreline hydraulics on large waters would be helpful. A look at round goby habitat requirements would also provide valuable input. Habitat requirements for round gobies may be increased with dredging.

Significance of Precedent

This EA is being written to determine the direction the Department should go on issuing future private dredging permits on Green Bay and Lake Michigan. All permit decisions are reviewed on a case by case basis however the decisions that are made will set a perceived precedent. Permit decisions for similar projects in similar settings will result in similar permit decisions. It is critical to make sure decisions are made based upon the best available science taking into account individual project impacts as well as cumulative impacts.

Significance of Controversy Over Environmental Effects

There is a demand for boat mooring areas north of Sturgeon Bay. Every marina that was contacted north of Sturgeon Bay, excluding those in Sturgeon Bay, was full. People who have property on the water would like the convenience of having their boat moored at their property, and if the water is too low, that is not possible unless they dredge. If dredging is no longer allowed, the riparian owners will lose the convenience of having their boats moored to the dock in front of their property unless they can implement alternatives.

ALTERNATIVES

Access to boating in Green Bay and Lake Michigan is supported by the public. The challenge is to balance this desire with the unique natural shoreline of Door County. An alternative to numerous boat access channels along Green Bay and the Lake Michigan coasts is to improve the capability of fewer shared harbors and marinas, or having several property owners construct one channel instead of many that can be used by several riparian owners. This would limit the impact to the environment and take advantage of the boating support that can be provided by marinas and harbors. Some other alternatives that may work in certain areas are mooring a boat using a mooring buoy, using a longer temporary pier, or installing a tracking "marine rail" system that pulls a boat in and out of the water. A riparian also has the alternative of launching their boat at a public boat ramp. Obviously the tracking system and launching at a public boat ramp alternatives may have limitations for very large watercraft.

Capacity in the present public marinas may need to be expanded to replace the need for private dredged channels if private channels are no longer approved. This would both add to the tax base and generate greater income to marinas owned by local government. Some increased development could be expected within the area of the larger marinas. The business and smaller incorporated areas that provide public marinas and boat launch sites may be more active if there is room to expand the present marinas to make up for the lack of private individual dredged channels. While boating congestion is increased in marina areas, the public is aware of, and expects the resulting increased traffic, pollution, and safety concerns.

The no action alternative, of not being allowed to dredge new or expanded private, individual channels, would impact a riparian owner wanting the convenience of mooring their boat at their property. It could potentially prevent the increase in property value that dredging may provide, and reduce work for local contractors.

However, no dredging is probably the best option to keep the Great Lakes shoreline ecosystem in as natural of a state as possible. Once these shorelines are altered, they can never be returned to their previous state.

SUMMARY OF ISSUE IDENTIFICATION ACTIVITIES

Individuals consulted on the dredging study and EA development

From the Department of Natural Resources – Jim Doperalski, Environmental Analysis and Review Specialist, Mark Dudzik, Archaeologist, Steve Galarneau, Lake Michigan Program Coordinator, Mary Gansberg, Water Resources Management Specialist, Paul Garrison, Research Scientist, Joe Henry, Conservation Biologist, Kelley O'Connor, Lakeshore Basin Supervisor, Paul Peeters, Fisheries Team Supervisor, Jeff Pritzl, Regional Program Manager, and Kristy Rogers, Aquatic Habitat Expert. Others that were consulted were Tim Rasman, former DNR Water Quality Biologist, and Mike Toneys, former DNR Fisheries Supervisor.

Requests for comments on the Final Draft EA will be sent to the Wisconsin Historical Society, US Coast Guard, US Army Corps of Engineers, US Fish and Wildlife Service, Door County Planning Department, UW Sea Grant, and the dredging applicants.

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COMMENTS FROM THE PUBLIC

PUBLIC COMMENT	DEPARTMENT'S RESPONSE
Two people asked if more effort should be placed on water level control on the Great Lakes as a whole to eliminate the need for dredging	*That issue is not part of this study and not under the Department's jurisdiction.*
Several people were concerned about the Schauer Park project which would most likely involve dredging. The feasibility study did not contain environmental impacts and they are concerned about damage to the aquatic ecosystem.	*Comment noted*

There was a concern that there was no mention in the study about sewer or septic systems, natural vs. highly landscaped shorelines, recent construction, impacts by chemical use, or landscape structures.	*The Department only had the time and money to study the dredged channels themselves and not any potential impacts from upland activities.*
One person wondered if the Department would more likely approve a maintenance project, and that there should be a difference in review depending on if the property has a solid pier or not.	*General permits are available for maintenance dredging of previously dredged channels and are approved if the project meets all the standards.*
There were five misconceptions that the Department is placing a "moratorium" on all proposed dredging, or banning all future dredging.	*There never was a moratorium, all applications for new channels were put on hold during the study. The Department will continue to review applications on a case by case basis once the final EA is approved.*
Three people were concerned about having an expensive solid pier that they would not be able to utilize if dredging was no longer allowed. There were concerns that their money would go to waste because solid piers are taxed, and that their property values would be lowered.	*General permits are available for maintenance dredging of previously dredged channels and are approved if the project meets all the standards. All dredging projects projects will continue to be reviewed on a case by case basis.*
Several people were concerned about their rights to access the water as riparian owners would be taken away.	*There is no inherent right to alter the natural environment for a purpose for which that environment is naturally unsuited. Riparian owners do not have the right to dredge, they only have the right to reasonable use.*
Five individuals mentioned that there are actually more fish in and near dredged channels and therefore provide good fish habitat.	*Comment noted.*
One person thinks the Department is restricting dredging based on flawed environmental studies.	*Dredging applications will continue to be reviewed on a case by case basis.*
Two people thought that private dredged channels should no longer be allowed, with exceptions for public facilities that show more public benefits than adverse impacts.	*Comment noted.*
One person read the consultant's review of the study and EA and is concerned that the Department's analysis is flawed and contradictory to past activities, such as changing the natural environment.	*Responses to the consultant's review below.*
Several people didn't like that private riparian owners were singled out in this study.	*Only private channels were studied because one, the Department had a very short timeframe to do the study, and two, because generally the public benefits of public facilities outweigh the negative impacts of dredging. In most cases the public does not benefit from privately dredged channels on the public waters.*
Mitigation was mentioned to alleviate impacts.	*Comment noted.*

One person was not in favor of the EA because it could eliminate future dredging.	*Dredging applications will continue to be reviewed on a case by case basis.*
Summary of a letter received by a representative of Riparian Owners and Marine Operators Association, Inc:	
• Implied that it was the goal of the Department to limit dredging.	*The goal of the study and EA was to find out if there were any impacts from dredging.*
• Asks why if there are negative impacts that the same policies don't apply to public projects.	*Generally there are more public benefits on public facilities that outweigh the negative impacts.*
• Review shows beneficial impacts.	*More biota does not necessarily mean a beneficial effect, especially on a system that is working with the existing biota. .*
• Wants the Department to consider literature on the impacts of zebra mussels that shows that mussels filter half the water in the Great Lakes every day, so therefore the issue of turbidity from dredging projects cannot have a significant impact.	*Short term impacts exist and can be observed during dredging operations.*
• Mitigation – timing of projects to avoid fish spawning, silt fences, etc.	*Dredging is already limited during the spawning season, and erosion control measures do not always work, especially during rough water conditions.*
• Implied that the study was not representative of the impacts as the dredging was done before mitigation efforts were used.	*Many of the sites studied were newly dredged channels*
Review by EA Engineering, Science, and Technology:	
Overall impressions	
• DNR's position seems to be that change is not natural and therefore bad.	*There was no attempt to categorize all changes as bad or adverse, but in some cases they are. Modifications made to page 3 and 25.*
• Changes were not found at all of the sites.	*The EA states this.*
• Changes only affected physical condition, not biota; changes to biota are beneficial.	*Changes were observed to the biota. Based on experience and other studies, changes to the physical condition do change the biota, even though this study did not show this. A change in biota is not necessarily good, especially on a system that is working with existing biota.*
• DNR is confusing changes with adverse impacts.	*Modifications made to pages 24 and 25.*

• Consultant concludes that since areas lack a benthic community, then dredging either has no effect or a beneficial effect.	*As the EA states, impacts to the benthic community were insignificant.*
• Authors of the EA say that increased macrophytes are bad and DNR has taken opposite opinion on inland lakes.	*The study was conducted on the Great Lakes, not an inland lake. The Department doesn't encourage more plants on inland lakes, the Department only wants to avoid the reduction of plants.*
• EA fails to address what percentage of the littoral zone could be affected.	*This is beyond the scope of the study, and is irrelevant since the impacts were not clear.*
De Stasio Report	*This was not a study conducted by the Department so there is no response from the Department, but Dr. Bart De Stasio had the following responses to the comments:*
• The consultants state that the plant and macroinvertebrate data were placed into "categories" and could therefore not be transformed to fulfill normality assumptions.	*This use of the term "categories" is vague and incorrect in this case given the common use of the term in statistics. The data were collected as count data in that they are ordinal (the count data are ordered from lower to higher groups consistently) but just on a different scale. For instance, the macroinvertebrate count groupings are geometric, as are data collected on a logarithmic or exponential scale. It is well established that these kinds of data can fulfill normality assumptions sufficient for ANOVA, as was the case with this data set. The plant density data were analyzed with a non-parametric test where normality is not assumed, so their comment is in error on both of these issues.*
• Increased vegetation richness is a beneficial not an adverse impact; increased abundance of vegetation is a beneficial, not an adverse impact; dredging either had no impact or a positive impact; and changes to the biota from dredging are either non-existent or positive.	*The use of the terms "beneficial" or "positive" is biased and inadequately defined. Considering increased diversity as always being "beneficial" is a common misuse of this measure of biological communities. My report made it clear that increased macrophyte diversity could also be the result of undesirable changes as have occurred with biological invasions or other disturbances (pg. 50). The meaning of these terms should be defined more carefully with respect to this issue. If increased diversity and abundance of macrophytes causes increased need for dredging to keep channels clear for boat use, or causes a nuisance for boaters in other ways, then it is not a beneficial change.*
Dredging EA	
• EA says dredging "harmed the natural environment", but it changed, not harmed it.	*In some cases, changes were adverse. Modifications made to pages 3 and 25.*

• Made no attempt to estimate how much of the littoral zone might be dredged.	*This is beyond the scope of the study, and is irrelevant since the impacts were not clear.*
• EA says the littoral zone is 3 feet deep but it extends much further.	*The study was conducted out to the point where plants were no longer present. Modifications made to page 16.*
• The list of rare plants and animals implies that those species would be at risk, but not all occur in Door Co.	*The public does not have access to the data that shows where the species are located. The EA says "many" of the species listed, it does not imply all species are located in Door County.*
• Sees no reason why more diversity of aquatic plants is not beneficial in Door Co.	*No evidence to the contrary, the consultant did not provide data to support this statement. Diversity is the measure of the distribution of species in a community. Higher diversity would occur when there are several dominant or common species and only a few rare species. Low diversity occurs when there is only 1-2 dominant species and many rare species. Low diversity communities are more fragile because the loss of the 1 or 2 dominant species strongly affects the whole community. Therefore, diversity is not a good indicator of whether or not a plant community is beneficial to the environment.Species richness is the total number of species present in the community. It is possible to have high richness and low diversity. For example, there may be 20 species but only 1 species has more than one individual present. This community is unstable as the loss of the one dominant would have a large impact on the community. Conversely, a community could have 20 species but 5-6 are dominant species. This community would have the same richness as the previous example but the diversity would be much higher and the community more stable.*
• Discussion of benthic invertebrates on p. 20 provides no basis to conclude dredging adversely impacts them.	*The EA did not state this*
• Discussion of fish impacts is speculation – impacts from a temporary increase in turbidity are unlikely.	*This is not speculation, statements were base on literature and experience.*
• Consultants suggest that the increased plant growth would likely be beneficial.	*Some fish species utilize areas with vegetation at different life stages, some species only use areas void of vegetation throughout their life cycle.*
• Effects of dredging on plants and benthos are beneficial.	*May be beneficial on inland lakes, but not necessarily on the Great Lakes. Modifications made to pages 24 and 25.*

• Whitefish do not spawn in waters "that shallow", so it that species won't be affected.	*The Department has evidence from ongoing studies that whitefish larvae use shallow embayments.*
• Discussion about the significance of dredging is speculation.	*Not speculation, there is plenty of evidence that dredging causes turbidity.*
One person thought that removing the silt with contaminants would be good for water purification.	*It's not likely that the sediment is contaminated in Door County outside of the Sturgeon Bay area.*
Question of the EA should have been how can dredging be completed in the most environmentally safe manner and what bed surface is most beneficial to fish and plants.	*Comment noted*
Summary of a letter from an attorney for Anderson & Kent, S.C.:	
• Wis. Admin. Code § NR 150.22(1)(d) requires that an environmental assessment be "written in plain language and should use appropriate graphics to aid decision-makers and the public." The document in its present form fails to meet the standard established in the rule.	*The Department feels that Wis. Admin. Code § NR 150.22(1)(d) has been met. Scientific terms such as benthic, macroinvertebrates, and littoral zones as well as acronyms such as EA have been defined in the document so that individuals not familiar with these terms or acronyms would be able to understand the term when used. Pictures showing the type of dredging projects discussed in the environmental analysis and a summary table of potential physical changes was included in the document.*
• It is unclear from the draft environmental assessment what proposed action of the DNR is being reviewed.	*There is no specific DNR action that triggered this environmental analysis. Under Wis. Admin. § NR 150.20(2)(e), Generic EA or EIS, an environmental analysis may be completed to assess the environmental effects of actions likely to be repeated on a recurring basis or actions which have relevant similarities such as common timing, impacts, alternatives, methods of implementation or subject matter. Considering the number of private dredging proposals over the last several years and the fact that there were 10 current private dredging proposals when Lawrence University was first contracted to conduct the study the DNR feels these types of proposals are likely to be repeated.*

• The environmental assessment does not meet the DNR's own legally enacted criteria for what must be contained in an environmental assessment. It is meant to be an analytical document that allows both environmental and economic factors to be considered. Wis. Admin. Code § NR 150.22(1)(b). It is not supposed to be a justification of an action, but a disclosure of adverse environmental effects of the action. Wis. Admin. Code § NR 150.22(1)(c).	*The environmental analysis is not intended to justify any action nor is it intended to propose new policy. As stated in the environmental analysis on page 4 under the section, Purpose of the Study, "This EA is not a process to block future dredging projects", on page 7 under Riparian Rights, "what constitutes a reasonable riparian use will vary from case to case", and on page 27 under the section Significance of Precedent, "All permit decisions are reviewed on a case by case basis", the document is not meant to deny future proposals. Rather the document is meant to provide an environmental review of potential environmental effects from repeated private dredging projects so DNR can make an informed decision on future private dredging proposals.*
• Specific requirements regarding the content of the environmental assessment are found at Wis. Admin. Code § Code NR 150.22(2). Based on my review of the document, these criteria are not satisfied. For instance, there is no discussion of the degree of risk or uncertainty in predicting effects, no discussion of how to control alleged effects, no discussion of the consistency of the proposed policy with local, state and federal governments, or the degree of controversy over the effects. The document fails the DNR's own standards and should be rejected for that reason alone.	*The document does recognize there are limitations to the conclusions of the study and on page 27 under the section Significance of Risk it states "This was a small study and a more comprehensive study would need to be conducted to evaluate the full impact of boat access dredging and piers along Door County coasts". In the alternatives section of the document there is a discussion of what can be done to avoid and minimize the potential for the environmental effects from multiple private dredging projects. This section mentions the potential impacts from denial of private dredging proposals.*
Some people just "power through" the silt purposely to dredge.	*Comment noted*
Would like the Department to continue to approach each request for dredging individually.	*That is the Department's intent.*
One person believes that the long term benefits of docks and dredging far outweighs the short term negative impacts, because the negative impacts can be eliminated by using a silt curtain or avoiding certain time periods.	*Comment noted*
Comment that there are economic benefits since the value of lakeshore properties is so high, and the high taxes benefit everyone in Door Co., along with creating jobs.	*This was mentioned in the EA. on page 24.*

One person thought it is better to get the silt out of a channel and disturb it once rather than every time a boat goes through it.	*Comment noted*
One person thought that a continuing study is needed to determine the consequences of dredging.	*The Department agrees that further studies are needed.*
One person thinks that if you had a dredging permit in the past, you should be allowed to reapply.	*A General permit for maintenance dredging is available for people who have received permits in the past. If the applicant meets all the standards, the permit is issued.*
There was an objection to making dredging more restrictive because the DNR already has a moratorium on solid piers and the number are not expanding, and because invasive species are here to stay anyway.	*There is no moratorium on solid piers.*
One person thought the study was swayed because the Department paid for it, that the Department is not interested in being fair and objective, has a long history of trying to take away riparian rights.	*Comment noted*
Comment that the recommendations made by the Department are not based upon the scientific data in the DeStasio report. No person or persons from the Department are listed as directly responsible for the report, and wonders who interpreted the research.	*The author is listed on the first page, and the contributors are listed at the end of the EA.*
One person feels that the study and EA ignored long term beneficial effects to fisheries and increased biodiversity that could be established with mitigation techniques such as lining channels with cobble.	*The Department did not have the time or the money to study impacts to fish or explore mitigation techniques. To minimize the impacts to applicants, the study was limited to one year.*
One person was concerned that preventing all dredging at private properties would lead to "midnight dredging". He believes dredging should be better controlled but not prohibited.	*Comment noted*

DECISION (This decision is not final until certified by the appropriate authority)

In accordance with s. 1.11, Stats., and Ch. NR 150, Adm. Code, the Department is authorized and required to determine whether it has complied with s.1.11, Stats., and Ch. NR 150, Wis. Adm. Code.

Complete either A or B below:

A. EIS Process Not Required ☒

The attached analysis of the expected impacts of this proposal is of sufficient scope and detail to conclude that this is not a major action which would significantly affect the quality of the human environment. In my opinion, therefore, an environmental impact statement is not required prior to final action by the Department.

B. Major Action Requiring the Full EIS Process ☐

The proposal is of such magnitude and complexity with such considerable and important impacts on the quality of the human environment that it constitutes a major action significantly affecting the quality of the human environment.

Signature of Evaluator	Date Signed
Carrie Webb	6/18/09

Number of responses to news release or other notice:

Certified to be in compliance with WEPA	
Environmental Analysis and Liaison Program Staff	Date Signed
James P. Dopun[illegible]	6/18/09

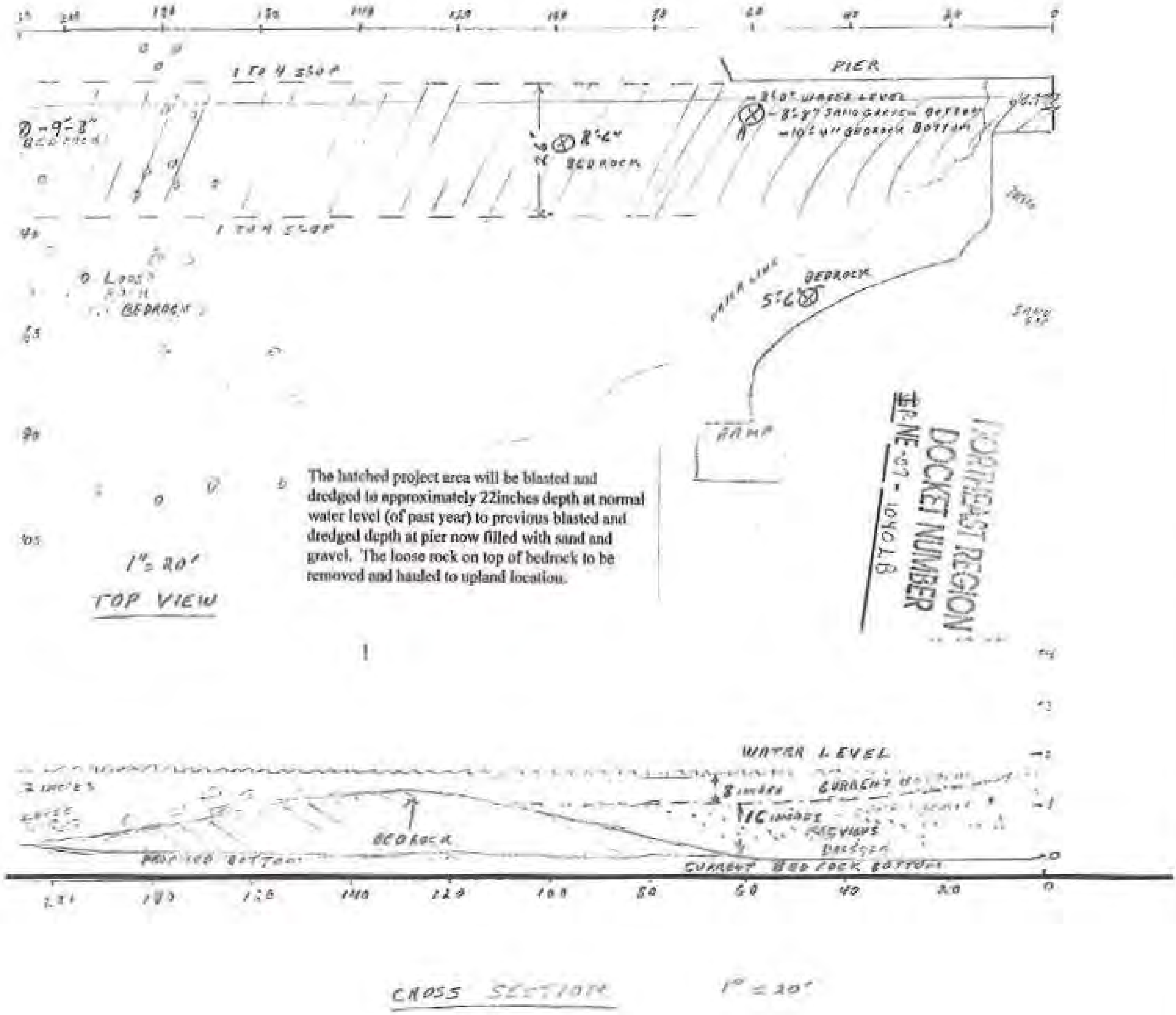
NOTICE OF APPEAL RIGHTS

If you believe you have a right to challenge this decision made by the Department, you should know that Wisconsin statutes, administrative codes and case law establish time periods and requirements for reviewing Department decisions.

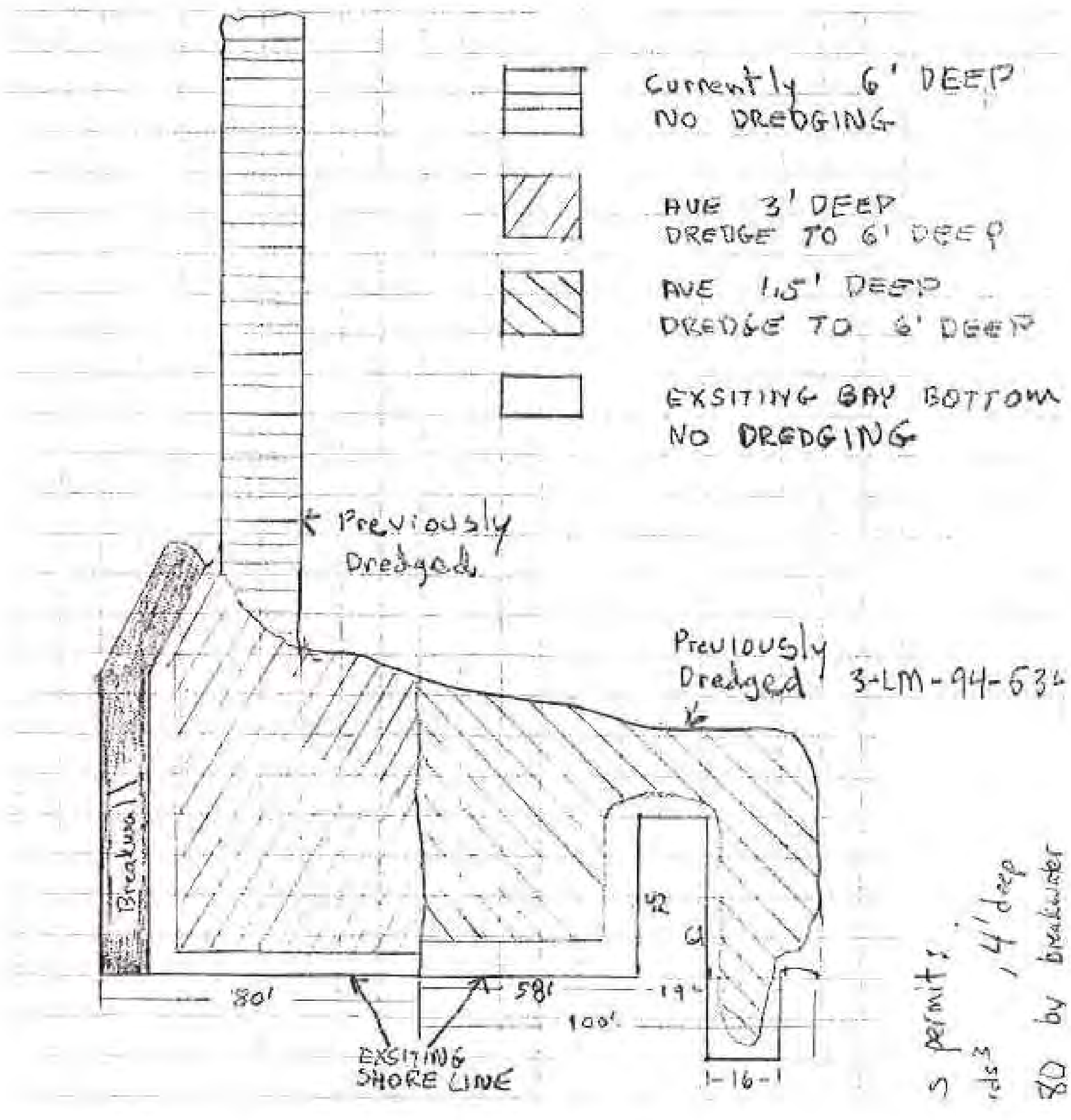
To seek judicial review of the Department's decision, ss. 227.52 and 227.53, Stats., establish criteria for filing a petition for judicial review. Such a petition shall be filed with the appropriate circuit court and shall be served on the Department. The petition shall name the Department of Natural Resources as the respondent.

APPENDIX A. APPLICATION PLANS

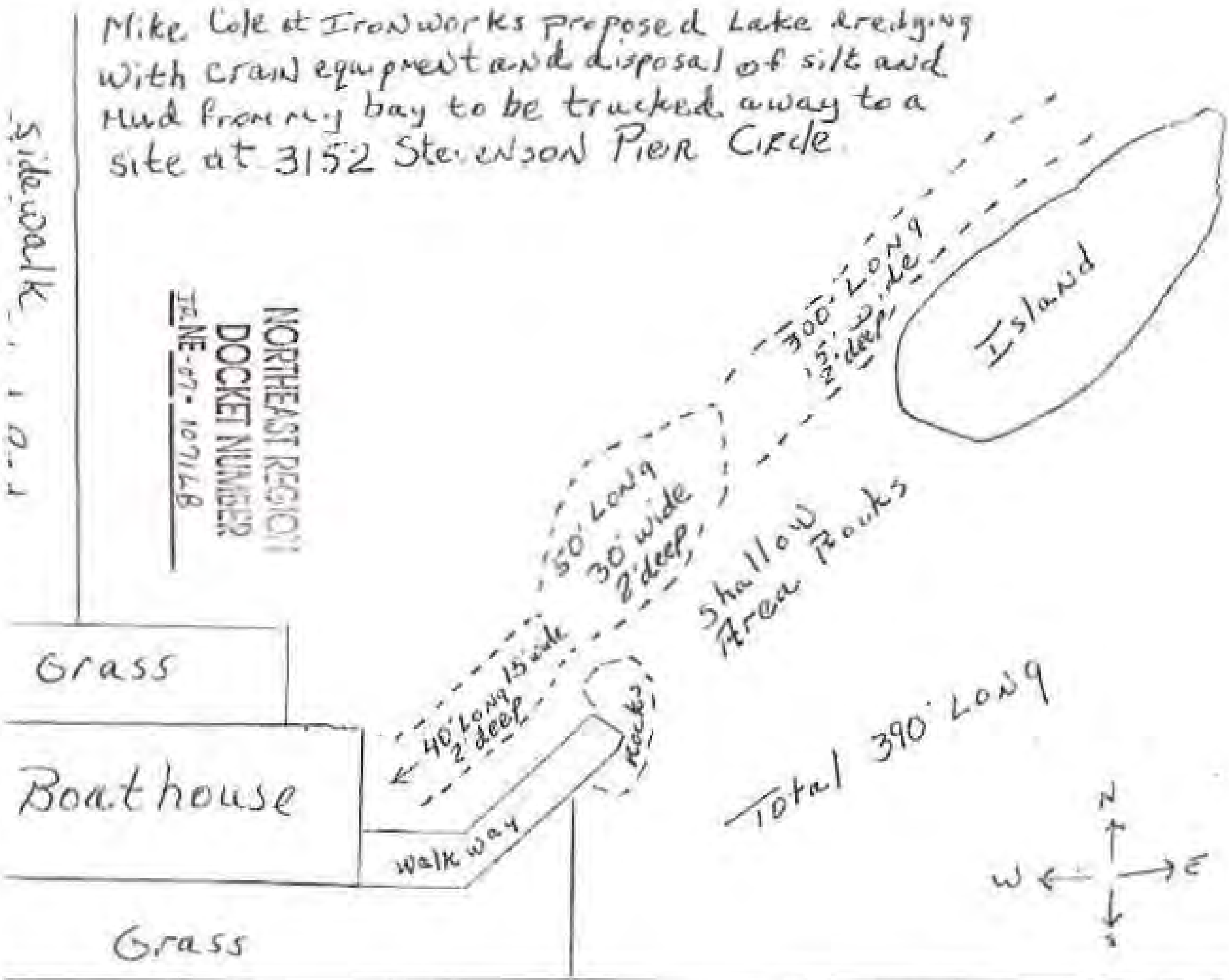
Roalkvam Rd. Town of Nasewaupee



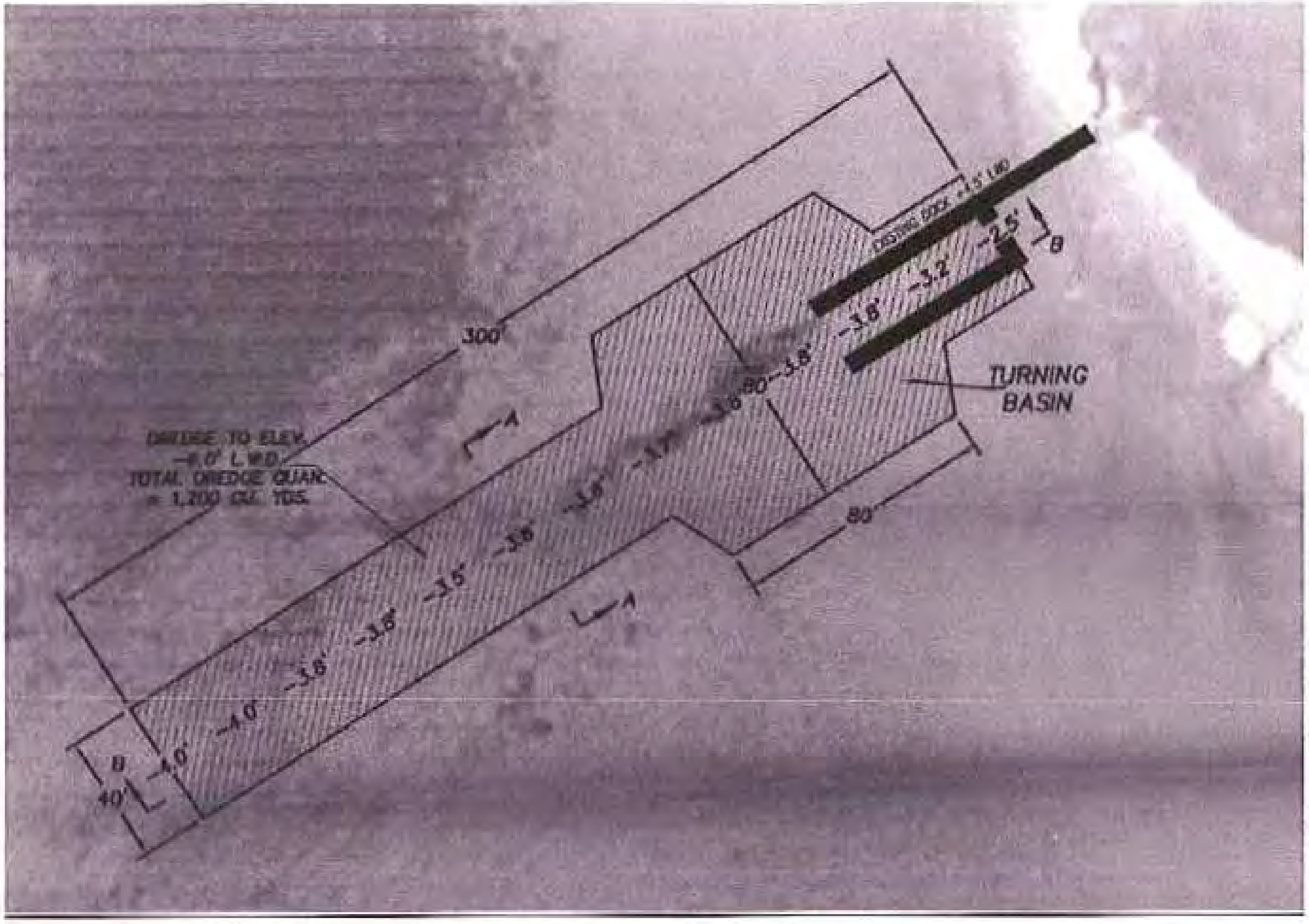
Squaw Island Rd. Town of Gardner



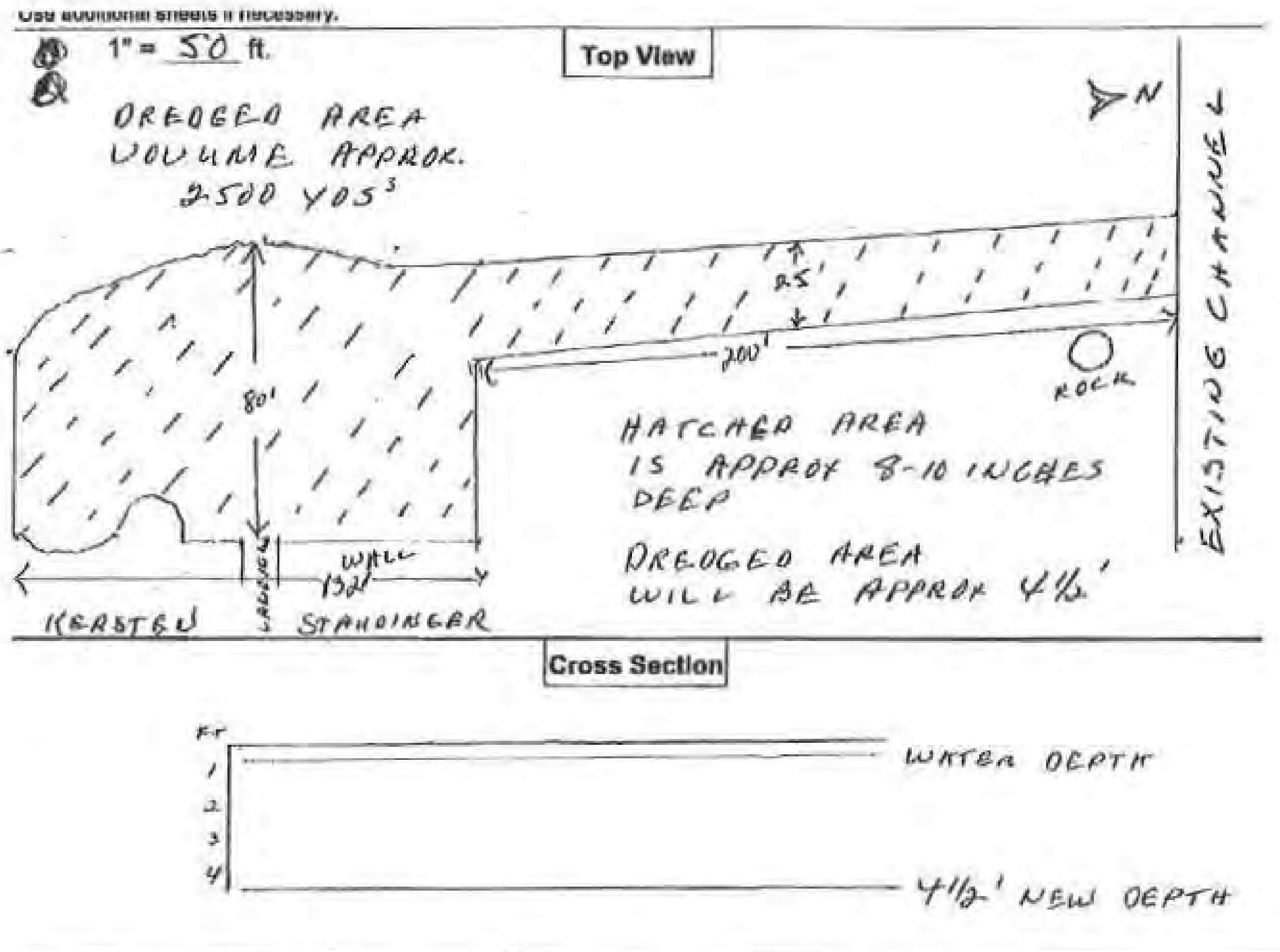
Squaw Island Rd. Town of Gardner



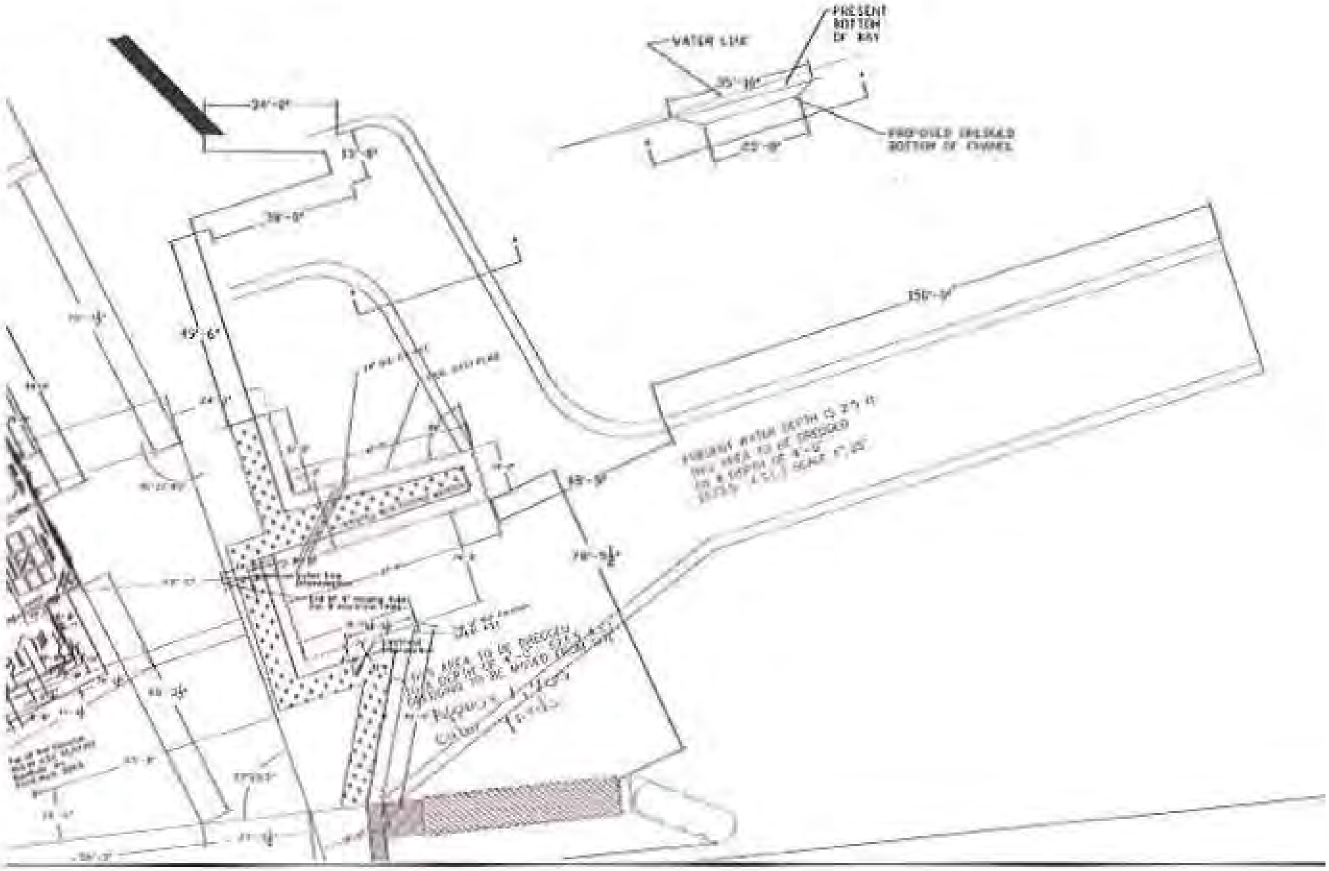
Cove Rd. Sturgeon Bay



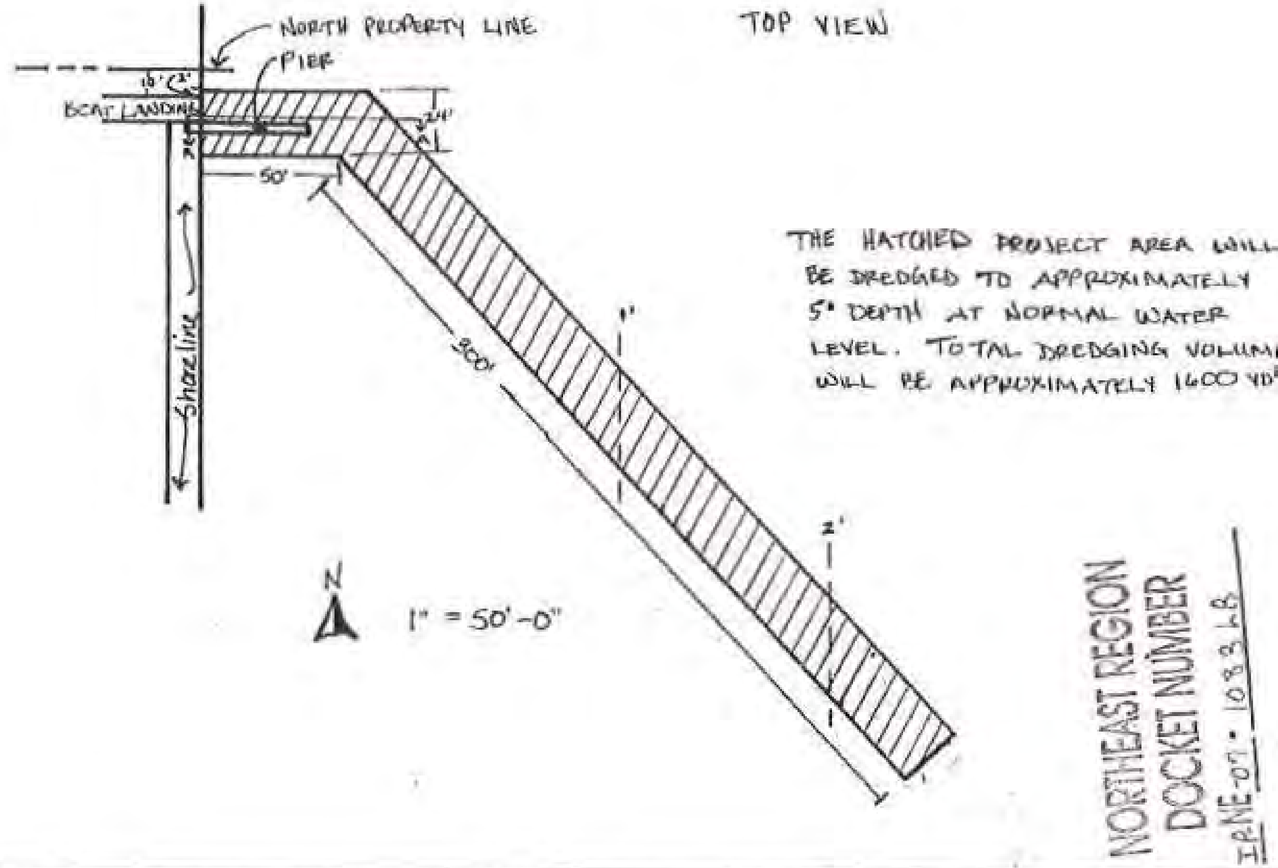
Stevenson Pier Rd. Town of Gardner

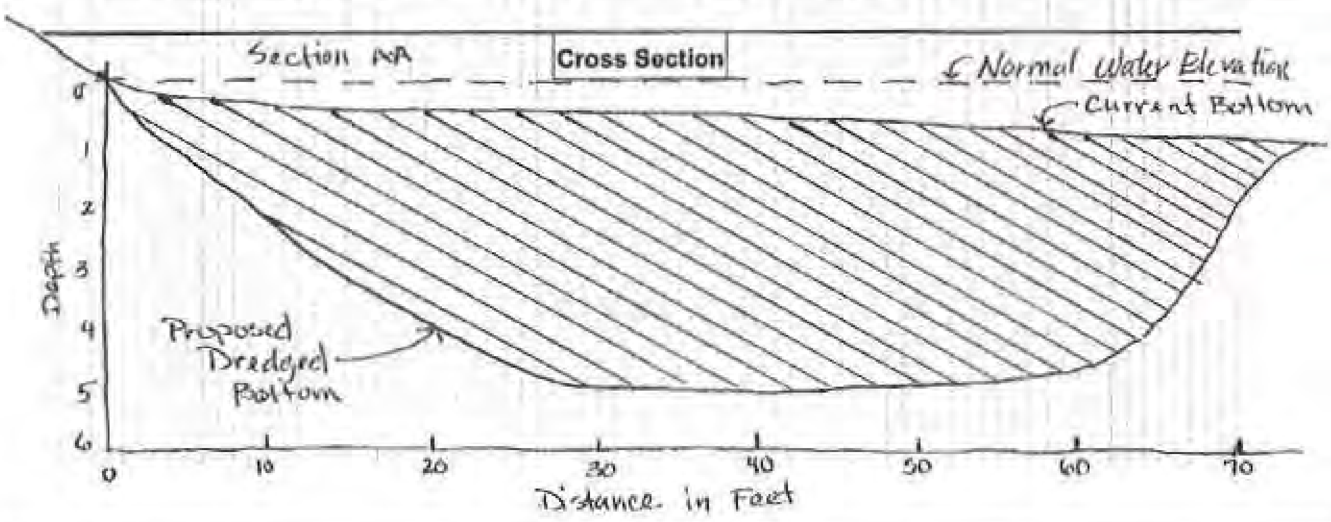


Squaw Island Rd. Town of Gardner (original proposal)

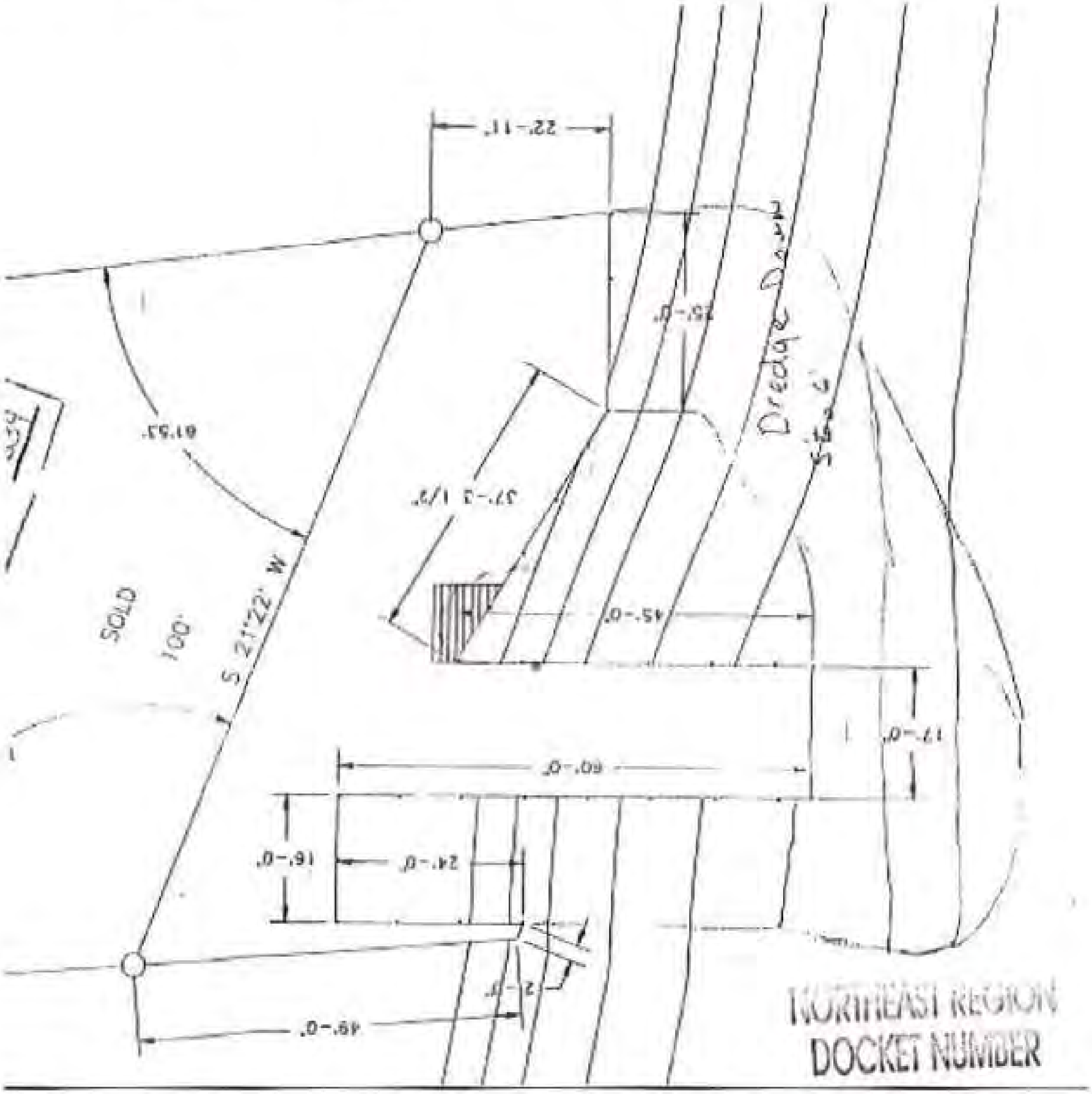


Squaw Island Rd. Town of Gardner

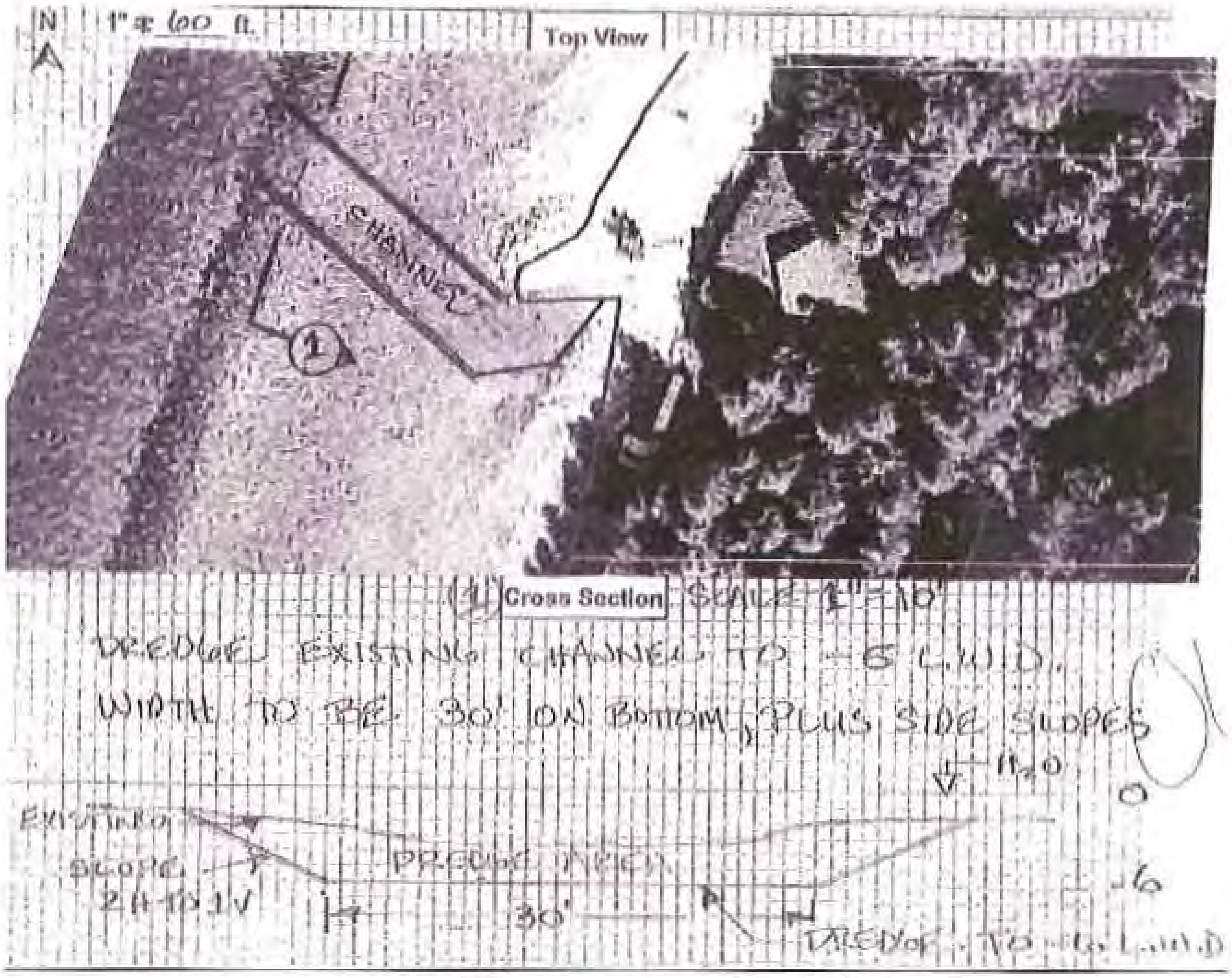




Squaw Island Rd. Town of Gardner



North Shore Rd. Ephraim



APPENDIX B. Rare animals and plants tracked by the Natural Heritage Inventory Program that have been documented within the Coastal Zone.

Group	Common Name	Scientific Name		State Status	Federal Status
Beetle					
	Beach-Dune Tiger Beetle	*Cicindela hirticollis rhodensis*		SC/N	
	A Water Scavenger Beetle	*Cymbiodyta acuminata*	*	SC/N	
Bird					
	Henslow's Sparrow	*Ammodramus henslowii*		THR	
	Long-Eared Owl	*Asio otus*		SC/M	
	Pine Siskin	*Carduelis pinus*		SC/M	
	Swainson's Thrush	*Catharus ustulatus*		SC/M	
	Evening Grosbeak	*Coccothraustes vespertinus*		SC/M	
	Black-Throated Blue Warbler	*Dendroica caerulescens*		SC/M	
	Cape May Warbler	*Dendroica tigrina*		SC/M	
	Yellow-Bellied Flycatcher	*Empidonax flaviventris*		SC/M	
	Acadian Flycatcher	*Empidonax virescens*		THR	
	Merlin	*Falco columbarius*		SC/M	
	Connecticut Warbler	*Oporornis agilis*		SC/M	
	Gray Jay	*Perisoreus canadensis*		SC/M	
	Barn Owl	*Tyto alba*		END	
	Tennessee Warbler	*Vermivora peregrina*		SC/M	
	Great Egret	*Ardea alba*	*	THR	
	Great Blue Heron	*Ardea herodias*	*	SC/M	
	Lesser Scaup	*Aythya affinis*	*	SC/M	
	Redhead	*Aythya americana*	*	SC/M	
	American Bittern	*Botaurus lentiginosus*	*	SC/M	
	Common Goldeneye	*Bucephala clangula*	*	SC/M	
	Red-Shouldered Hawk	*Buteo lineatus*	*	THR	
	Piping Plover	*Charadrius melodus*	*	END	LE
	Black Tern	*Chlidonias niger*	*	SC/M	
	Northern Harrier	*Circus cyaneus*	*	SC/M	
	Yellow Rail	*Coturnicops noveboracensis*	*	THR	
	Snowy Egret	*Egretta thula*	*	END	
	Common Moorhen	*Gallinula chloropus*	*	SC/M	
	Common Loon	*Gavia immer*	*	SC/M	
	Bald Eagle	*Haliaeetus leucocephalus*	*	SC/FL	"LT,PD"
	Least Bittern	*Ixobrychus exilis*	*	SC/M	
	Common Merganser	*Mergus merganser*	*	SC/M	
	Red-Breasted Merganser	*Mergus serrator*	*	SC/M	
	Black-Crowned Night-Heron	*Nycticorax nycticorax*	*	SC/M	
	Osprey	*Pandion haliaetus*	*	THR	
	American White Pelican	*Pelecanus erythrorhynchos*	*	SC/M	
	Red-Necked Grebe	*Podiceps grisegena*	*	END	
	Louisiana Waterthrush	*Seiurus motacilla*	*	SC/M	

	Caspian Tern	*Sterna caspia*	*	END	
	Forster's Tern	*Sterna forsteri*	*	END	
	Common Tern	*Sterna hirundo*	*	END	
	Hooded Warbler	*Wilsonia citrina*	*	THR	
Bug					
	A Water Measurer	*Hydrometra martini*	*	SC/N	
Butterfly					
	Mottled Dusky Wing	*Erynnis martialis*		SC/N	
	Broad-Winged Skipper	*Poanes viator*		SC/N	
	Bog Fritillary	*Boloria eunomia*	*	SC/N	
	Swamp Metalmark	*Calephelis muticum*	*	END	
	Two-Spotted Skipper	*Euphyes bimacula*	*	SC/N	
	Dion Skipper	*Euphyes dion*	*	SC/N	
	Dorcas Copper	*Lycaena dorcas*	*	SC/N	
	Bog Copper	*Lycaena epixanthe*	*	SC/N	
	Mulberry Wing	*Poanes massasoit*	*	SC/N	
Caddisfly					
	A Bizarre Caddisfly	*Lepidostoma libum*	*	SC/N	
Dragonfly					
	Lake Darner	*Aeshna eremita*	*	SC/N	
	Green-Striped Darner	*Aeshna verticalis*	*	SC/N	
	Arrowhead Spiketail	*Cordulegaster obliqua*	*	SC/N	
	Swamp Darner	*Epiaeschna heros*	*	SC/N	
	Amber-Winged Spreadwing	*Lestes eurinus*	*	SC/N	
	Ski-Tailed Emerald	*Somatochlora elongata*	*	SC/N	
	Forcipate Emerald	*Somatochlora forcipata*	*	SC/N	
	Hine's Emerald	*Somatochlora hineana*	*	END	LE
	Black Meadowhawk	*Sympetrum danae*	*	SC/N	
	Violet-Masked Glider	*Tramea carolina*	*	SC/N	
Fish					
	Lake Sturgeon	*Acipenser fulvescens*	*	SC/H	
	American Eel	*Anguilla rostrata*	*	SC/N	
	Bloater	*Coregonus hoyi*	*	SC/H	
	Least Darter	*Etheostoma microperca*	*	SC/N	
	Banded Killifish	*Fundulus diaphanus*	*	SC/N	
	Longear Sunfish	*Lepomis megalotis*	*	THR	
	Redfin Shiner	*Lythrurus umbratilis*	*	THR	
	Greater Redhorse	*Moxostoma valenciennesi*	*	THR	
Frog					
	Blanchard's Cricket Frog	*Acris crepitans blanchardi*	*	END	
	Bullfrog	*Rana catesbeiana*	*	SC/H	
Grasshopper					

	Blue-Legged Grasshopper	*Melanoplus flavidus*		SC/N	
	Lake Huron Locust	*Trimerotropis huroniana*		END	
	Seaside Grasshopper	*Trimerotropis maritima*		SC/N	
Leafhopper					
	Red-Tailed Prairie Leafhopper	*Aflexia rubranura*		END	
Mammal					
	Northern Myotis	*Myotis septentrionalis*		SC/N	
	Pigmy Shrew	*Sorex hoyi*	*	SC/N	
Moth					
	Oithona Tiger Moth	*Grammia oithona*		SC/N	
	Phyllira Tiger Moth	*Grammia phyllira*		SC/N	
	An Owlet Moth	*Macrochilo bivittata*		SC/N	
	Liatris Borer Moth	*Papaipema beeriana*	*	SC/N	
	Silphium Borer Moth	*Papaipema silphii*	*	END	
Other					
	Bird Rookery			SC	
	Migratory Bird Concentration Site			SC	
Plant					
	Striped Maple	*Acer pensylvanicum*		SC	
	Climbing Fumitory	*Adlumia fungosa*		SC	
	Roundstem Foxglove	*Agalinis gattingeri*		THR	
	Pale False Foxglove	*Agalinis skinneriana*		END	
	Prairie Milkweed	*Asclepias sullivantii*		THR	
	Maidenhair Spleenwort	*Asplenium trichomanes*		SC	
	Cooper's Milkvetch	*Astragalus neglectus*		END	
	Prairie Dunewort	*Botrychium campestre*		END	
	Moonwort Grape-Fern	*Botrychium lunaria*		END	
	Mingan's Moonwort	*Botrychium minganense*		SC	
	Spoon-Leaf Moonwort	*Botrychium spathulatum*		SC	
	Prairie Indian Plantain	*Cacalia tuberosa*		THR	
	American Sea-Rocket	*Cakile edentula*		SC	
	Low Calamint	*Calamintha arkansana*		SC	
	Sand Reed-Grass	*Calamovilfa longifolia var magna*		THR	
	Cuckooflower	*Cardamine pratensis*		SC	
	Beautiful Sedge	*Carex concinna*		THR	
	Handsome Sedge	*Carex formosa*		THR	
	Smooth Black Sedge	*Carex nigra*		SC	
	Richardson Sedge	*Carex richardsonii*		SC	
	Dune Thistle	*Cirsium pitcheri*		THR	LT
	Crinkled Hairgrass	*Deschampsia flexuosa*		SC	
	Thickspike	*Elymus lanceolatus ssp psammophilus*		THR	
	Seaside Spurge	*Euphorbia polygonifolia*		SC	
	Western Fescue	*Festuca occidentalis*		THR	
	Yellow Gentian	*Gentiana alba*		THR	

	Northern Comandra	*Geocaulon lividum*		END	
	Limestone Oak Fern	*Gymnocarpium robertianum*		SC	
	Dwarf Lake Iris	*Iris lacustris*		THR	LT
	Large-Flowered Ground-Cherry	*Leucophysalis grandiflora*		SC	
	Broad-Leaved Twayblade	*Listera convallarioides*		THR	
	American Gromwell	*Lithospermum latifolium*		SC	
	Fly Honeysuckle	*Lonicera involucrata*		END	
	Fir Clubmoss	*Lycopodium selago*		SC	
	Indian Cucumber-Root	*Medeola virginiana*		SC	
	Clustered Broomrape	*Orobanche fasciculata*		THR	
	One-Flowered Broomrape	*Orobanche uniflora*		SC	
	Chilean Sweet Cicely	*Osmorhiza chilensis*		SC	
	Small-Flower Grass-Of-Parnassus	*Parnassia parviflora*		END	
	Pale Beardtongue	*Penstemon pallidus*		SC	
	Pale Green Orchid	*Platanthera flava var herbiola*		THR	
	Hooker Orchis	*Platanthera hookeri*		SC	
	Large Roundleaf Orchid	*Platanthera orbiculata*		SC	
	Braun's Holly-Fern	*Polystichum braunii*		THR	
	Bird's-Eye Primrose	*Primula mistassinica*		SC	
	Giant Pinedrops	*Pterospora andromedea*		END	
	Small Yellow Water Crowfoot	*Ranunculus gmelinii*		END	
	Northern Black Currant	*Ribes hudsonianum*		SC	
	Canada Gooseberry	*Ribes oxyacanthoides*		THR	
	Sand Dune Willow	*Salix cordata*		END	
	Tea-Leaved Willow	*Salix planifolia*		THR	
	Tufted Club-Rush	*Scirpus cespitosus*		THR	
	Torrey's Bulrush	*Scirpus torreyi*		SC	
	Heart-Leaved Skullcap	*Scutellaria ovata*		SC	
	Low Spike-Moss	*Selaginella selaginoides*		END	
	Bluestem Goldenrod	*Solidago caesia*		END	
	Sticky Goldenrod	*Solidago simplex var gillmanii*		THR	
	White Mandarin	*Streptopus amplexifolius*		SC	
	Small-Flowered Woolly Bean	*Strophostyles leiosperma*		SC	
	Lake Huron Tansy	*Tanacetum huronense*		END	
	Reflexed Trillium	*Trillium recurvatum*		SC	
	Purple False Oats	*Trisetum melicoides*		END	
	Narrow False Oats	*Trisetum spicatum*		THR	
	Northern Wild-Raisin	*Viburnum cassinoides*		SC	
	Smooth Black-Haw	*Viburnum prunifolium*		SC	
	Long-Spur Violet	*Viola rostrata*		SC	
	Round-Leaved Orchis	*Amerorchis rotundifolia*	*	THR	
	Swamp-Pink	*Arethusa bulbosa*	*	SC	
	Lake-Cress	*Armoracia lacustris*	*	END	
	Slim-Stem Small-Reedgrass	*Calamagrostis stricta*	*	SC	
	Autumnal Water-Starwort	*Callitriche hermaphroditica*	*	SC	
	Floating Marsh-Marigold	*Caltha natans*	*	END	
	Fairy Slipper	*Calypso bulbosa*	*	THR	
	Assiniboine Sedge	*Carex assiniboinensis*	*	SC	
	Hair-Like Sedge	*Carex capillaris*	*	SC	

	Crawe Sedge	*Carex crawei*	*	SC	
	Coast Sedge	*Carex exilis*	*	THR	
	Elk Sedge	*Carex garberi*	*	THR	
	Northern Bog Sedge	*Carex gynocrates*	*	SC	
	Shore Sedge	*Carex lenticularis*	*	THR	
	Livid Sedge	*Carex livida var radicaulis*	*	SC	
	False Hop Sedge	*Carex lupuliformis*	*	END	
	Michaux Sedge	*Carex michauxiana*	*	THR	
	Many-Headed Sedge	*Carex sychnocephala*	*	SC	
	Sparse-Flowered Sedge	*Carex tenuiflora*	*	SC	
	Sheathed Sedge	*Carex vaginata*	*	SC	
	Ram's-Head Lady's-Slipper	*Cypripedium arietinum*	*	THR	
	Small Yellow Lady's-Slipper	*Cypripedium parviflorum*	*	SC	
	Showy Lady's-Slipper	*Cypripedium reginae*	*	SC	
	Tufted Hairgrass	*Deschampsia cespitosa*	*	SC	
	English Sundew	*Drosera anglica*	*	THR	
	Slenderleaf Sundew	*Drosera linearis*	*	THR	
	Flat-Stemmed Spike-Rush	*Eleocharis compressa*	*	SC	
	Spike-Rush	*Eleocharis mamillata*	*	SC	
	Slender Spike-Rush	*Eleocharis nitida*	*	END	
	Capitate Spikerush	*Eleocharis olivacea*	*	SC	
	Few-Flower Spikerush	*Eleocharis quinqueflora*	*	SC	
	Robbins Spikerush	*Eleocharis robbinsii*	*	SC	
	Marsh Willow-Herb	*Epilobium palustre*	*	SC	
	Downy Willow-Herb	*Epilobium strictum*	*	SC	
	Marsh Horsetail	*Equisetum palustre*	*	SC	
	Variegated Horsetail	*Equisetum variegatum*	*	SC	
	Russet Cotton-Grass	*Eriophorum chamissonis*	*	SC	
	Hairy Fimbristylis	*Fimbristylis puberula*	*	END	
	Marsh Bedstraw	*Galium palustre*	*	SC	
	Lesser Fringed Gentian	*Gentianopsis procera*	*	SC	
	Vasey Rush	*Juncus vaseyi*	*	SC	
	Marsh Blazing Star	*Liatris spicata*	*	SC	
	Auricled Twayblade	*Listera auriculata*	*	END	
	White Adder's-Mouth	*Malaxis brachypoda*	*	SC	
	Adder's-Tongue	*Ophioglossum pusillum*	*	SC	
	Marsh Grass-Of-Parnassus	*Parnassia palustris*	*	THR	
	Arrow-Leaved Sweet-Coltsfoot	*Petasites sagittatus*	*	THR	
	Smooth Phlox	*Phlox glaberrima ssp interior*	*	END	
	Heart-Leaved Plantain	*Plantago cordata*	*	END	
	Leafy White Orchis	*Platanthera dilatata*	*	SC	
	Prairie White-Fringed Orchid	*Platanthera leucophaea*	*	END	LT
	Pink Milkwort	*Polygala incarnata*	*	END	
	Seaside Crowfoot	*Ranunculus cymbalaria*	*	THR	
	Brown Beakrush	*Rhynchospora fusca*	*	SC	
	Whip Nutrush	*Scleria triglomerata*	*	SC	
	Low Nutrush	*Scleria verticillata*	*	SC	
	Marsh Ragwort	*Senecio congestus*	*	SC	
	Ohio Goldenrod	*Solidago ohioensis*	*	SC	

	Northern Bur-Reed	*Sparganium glomeratum*	*	THR	
	Waxleaf Meadowrue	*Thalictrum revolutum*	*	SC	
	Veined Meadowrue	*Thalictrum venulosum*	*	SC	
	Sticky False-Asphodel	*Tofieldia glutinosa*	*	THR	
	Common Bog Arrow-Grass	*Triglochin maritima*	*	SC	
	Slender Bog Arrow-Grass	*Triglochin palustris*	*	SC	
	Hidden-Fruited Bladderwort	*Utricularia geminiscapa*	*	SC	
	Northeastern Bladderwort	*Utricularia resupinata*	*	SC	
Salamander					
	Four-Toed Salamander	*Hemidactylium scutatum*	*	SC/H	
Snail					
	Pleistocene Catinella	*Catinella exile*		SC/N	
	A Land Snail	*Catinella gelida*		SC/N	
	Sculpted Glyph	*Glyphyalinia rhoadsi*		SC/N	
	Brilliant Granule	*Guppya sterkii*		SC/N	
	Cherrystone Drop	*Hendersonia occulta*		THR	
	Dentate Supercoil	*Paravitrea multidentata*		SC/N	
	White-Lip Dagger	*Pupoides albilabris*		SC/N	
	Black Striate	*Striatura ferrea*		SC/N	
	Eightfold Pinecone	*Strobilops affinis*		SC/N	
	A Land Snail	*Succinea bakeri*		SC/N	
	Oval Vallonia	*Vallonia excentrica*		SC/N	
	Tapered Vertigo	*Vertigo elatior*		SC/N	
	Midwest Pleistocene Vertigo	*Vertigo hubrichti*		END	
	Iowa Pleistocene Vertigo	*Vertigo iowaensis*		SC/N	
	Six-Whorl Vertigo	*Vertigo morsei*		SC/N	
	Deep-Throated Vertigo	*Vertigo nylanderi*		SC/N	
	Boreal Top	*Zoogenetes harpa*		SC/N	
Snake					
	Northern Ringneck Snake	*Diadophis punctatus edwardsii*		SC/H	
	Butler's Gartersnake	*Thamnophis butleri*		THR	
Turtle					
	Wood Turtle	*Clemmys insculpta*	*	THR	
	Blanding's Turtle	*Emydoidea blandingii*	*	THR	

Evaluating the potential long-term and cumulative impacts from dredging to accommodate boat access in Green Bay and Lake Michigan in Door County, Wisconsin.

Final Report

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Introduction

Recent low water trends on Lake Michigan and the Bay of Green Bay have caused the shoreline to recede from private and public piers and docks in many communities along the coastal areas of Door County, WI. As a result of these trends requests for permits for dredging for boat access to existing piers continue to increase. Some current dredged boat access channels extend out as much as 100 m from the Ordinary High Water Mark, and are often cut through bedrock. In addition, depending on the site location and water level regime, maintenance dredging is often required to keep these channels open. Intuitively, there are concerns about the short-term, long-term and cumulative impacts of creating and maintaining these boat access channels. There is little information in the scientific or management literature pertaining directly to this issue. Increased turbidity of the water immediately following dredging clearly has negative short-term impacts on benthic communities that may be covered by settling particles (e.g. Germano & Cary 2005). Attenuation of light is also a potential short-term problem for aquatic plants (Davis & Brinson 1980, Dennison et al. 1993, Wood & Armitage 1997, Best et al. 2001). In addition, it is clear that sediment can accumulate in dredged channels more than in adjacent areas, evidenced by the need to re-dredge channels periodically (Germano & Cary 2005). However, there are essentially no studies of the long-term impacts of dredging boat access channels on aquatic habitats or biological communities. Concerns have been expressed by staff of the Wisconsin Department of Natural Resources and others, particularly in regard to dredging for private boat access; e.g., are these disturbances exacerbating the establishment and spread of invasive species; are these changes negatively impacting other indigenous species.

Based on the lack of background information in the literature and the concerns over the potential longer-term impacts, it was determined that a study was needed to accurately determine and document the effects of dredging boat access channels on habitat quality and biological communities. The primary objective of the current study was to evaluate the cumulative impacts of these dredgings on sediment characteristics, aquatic plant communities, benthic macroinvertebrate communities, and the occurrence of aquatic invasive species at locations on the Green Bay and Lake Michigan shorelines of Door County, WI.

Methods

Study Design and Site Selection:

The study was designed to evaluate the potential long-term and cumulative impacts from dredging to accommodate boat access in Green Bay and Lake Michigan in Door County. WI. In order to accomplish this objective within a single season, as necessitated by the permitting issuance timeline, comparisons were made among sites with differing histories of dredging, exposure and substrate type on the Green Bay and Lake Michigan shorelines of Door County, WI. This approach uses a snapshot study of sites that were previously dredged as a surrogate for long-term monitoring studies of sites following dredging. In consultation with the WI DNR staff, 69 potential sites were identified with the following characteristics:

- Previously dredged sites (with various times since dredging last occurred)
- Natural sites adjacent to previously dredged sites and proposed dredge sites.
- Exposed sites (relatively unprotected from wave action)
- Protected sites (located in bays)
- Various predominant substrate types (bedrock, cobble, sand)

We selected 24 sites that represented all except one of the 12 possible combinations of the above three factors (dredge history, exposure, and substrate type; see Table 1 and Appendix Table A1). No sites were identified that were located in exposed areas with sand as the predominant substrate and which had been previously dredged. Each site was sampled twice between May and September 2008. Site selection also ensured that locations from both the Green Bay and Lake Michigan sides of Door County were included in the study.

Table 1. Experimental design grid showing sites without a pier selected for study in summer 2008 in Door County, WI. Note that no sites were available that were in an exposed location with a sand substrate and that had been previously dredged. Principal author of the study design was Steve Galarneau, WI DNR.

PROTECTED BAY	Bedrock	Cobble	Sand
Previously dredged	90. Moonlight Bay 23. Sawyer Harbor	84. North Bay 17. Little Sturgeon Bay	81. North Bay 72. Sand Bay
Undisturbed	92. Moonlight Bay 24. Sawyer Harbor	16. Little Sturgeon Bay 83. North Bay	101. Baileys Harbor 80. North Bay 33. Egg Harbor 71. Sand Bay

EXPOSED (OPEN COAST)	Bedrock	Cobble	Sand
Previously dredged	113. Whitefish Point 30. Egg Harbor	11. Little Sturgeon Bay 45. Ephraim	*None available*
Undisturbed	112. Whitefish Point 65. Sister Bay	12. Little Sturgeon Bay 44. Ephraim	120. Egg Harbor 111. Whitefish Bay

Table 2. Experimental design grid showing sites with a pier present selected for study in summer 2008 in Door County, WI. Note that no sites with a solid pier were available that were in an exposed location with a sand substrate and that had not been previously dredged. Principal author of the study design was Steve Galarneau, WI DNR.

PROTECTED BAY	Bedrock	Cobble	Sand
Previously dredged	91. Moonlight Bay 37. Egg Harbor	15. Little Sturgeon Bay 85. North Bay	100. Baileys Harbor
Undisturbed	31. Egg Harbor 93. Moonlight Bay	21. Sawyer Harbor	34. Egg Harbor 102. Baileys Harbor

EXPOSED (OPEN WATER)	Bedrock	Cobble	Sand
Previously dredged	52. Little Sister Bay 64. Sister Bay	47. Ephraim 69. Sister Bay	121. Egg Harbor 110. Whitefish Bay
Undisturbed	53. Little Sister Bay 63. Sister Bay	68. Sister Bay 48. Ephraim	*None Available*

In addition to the sites sampled for the three factors listed above, an additional set of 20 sites was selected to account for the potential added effects of piers on habitat conditions and biological communities in dredged and non-dredged areas (Table 2). These additional sites were sampled at least once during the summer.

Sampling Procedures at each Site:

Sample transect placement – Three sample transects were established at each site to provide coverage of the pertinent features of the location. Transects were oriented perpendicular to the shoreline and extended from just below the current water's edge to just beyond the depth of rooted macrophyte growth (Figure 1). At locations without any rooted macrophytes transects extended out 30 m from the water's edge.

Transects were spaced at five meter intervals along the shoreline at sites with no previous dredging history. At previously dredged locations one transect was situated in the center of the dredged channel, another on the sloped edge of the channel, and the third was placed next to the channel. This arrangement ensured incorporation into our study of known habitat heterogeneity derived from dredging activity.

Within each transect, samples and information were collected in three10-m long regions located along the transect: 1) near-shore, 2) at the deepest end of the dredged area or at the deepest macrophyte depth at non-dredged sites, and 3)
half way between the near-shore and deep ends of the transect.

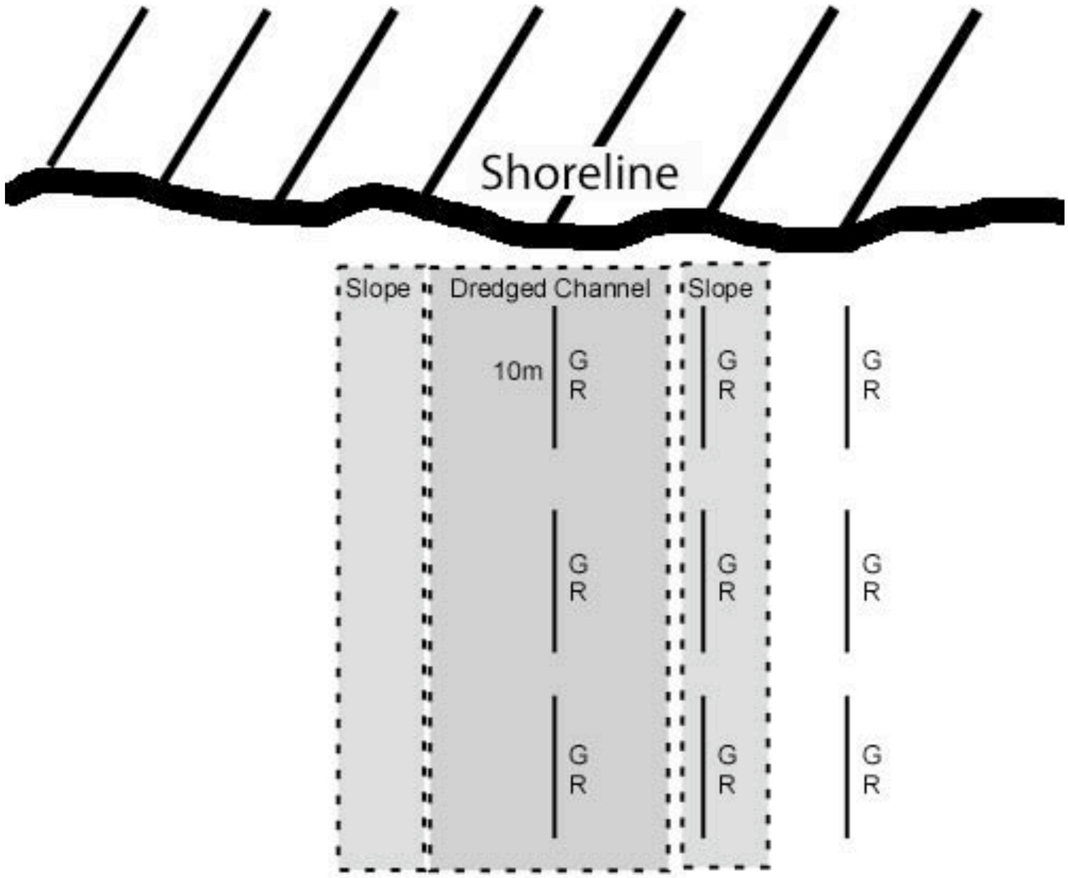

Figure 1. Diagram of transect placement and sample collection locations. The transects (each 10 m long) were laid perpendicular to the shoreline, spaced 5 m apart along the shoreline. Transects were placed in the middle of the channel, along the sloped edge of the channel, and just adjacent to the channel. Underwater video surveys were conducted along each 10 m transect. Duplicate grab samples (G) and duplicate vegetation rake samples (R) were collected near the middle of each transect. At sites that were not previously dredged the transects were placed similarly along the shoreline at the selected site.

Sediment characteristics – In each of the three regions along each transect duplicate sediment samples were collected using either an Ekman bottom grab sampler (0.15m X 0.15m box size) or by hand using a section of PVC pipe of equivalent area. Using either method approximately the top 10 cm of sediment was collected. In the field determinations were made by the same observer at all sites. Particle size determinations were made according to the Wentworth classification using a field particle comparison card (Appendix Table B1; Environment Canada 2002). Presence or absence of each particle size was assessed and used to determine the weighted average particle size for each sample. Particle shape was determined using a roundness scale ranging from 0 to 6 with higher values indicating rounder particles (Appendix Figure B1), and sediment colors were assessed against an even white background. Sediment odor was also noted if present.

Video transects – Video recording of each transect was performed while snorkeling or using SCUBA with a Sony 8mm video camera enclosed within an underwater camera housing. Weighted sections of plastic chain, 10 m long, were laid along each region of the transect as a guide. The camera was held approximately 0.5 m above the sediments providing a viewing diameter of at least 0.5 m of the benthic surface. Video surveys were conducted along each of the three regions of each transect. In the laboratory, the videos were converted to digital files using a Memorex DVD recorder. Digital still images from the DVD were analyzed to determine area coverage characteristics. Ten images, evenly spaced at 1 m intervals along the chain recorded in each region of transects, were quantified for surface characteristics. Each still image was quantified by securing a transparency printed with a 10-by-10 grid over the image displayed on the TV monitor. Each of the resulting 100 squares was assessed and classified as consisting of one of four types: 1) bare rock, 2) sediment, 3) attached benthic algae, and 4) macrophytes. Classification was determined as the majority coverage of the four types in a given square. The resulting data provided an estimate of the percent coverage for the image of the four surface types.

Aquatic vegetation sampling – In addition to the percent coverage data derived from the video transects, aquatic vegetation was also assessed using a standard rake sampling procedure (Deppe & Lathrop 1992). A weighted double-headed rake was pulled approximately 2 m along the bottom at each location. The rake was 35 cm wide, contained 14 teeth on each side, each of which was 5 cm long. Duplicate rake samples were collected near the center of each region along transects, producing 18 rake samples were site. Rake fullness was determined using a 0-3 fullness scale (Herman 2007): 0= no vegetation on teeth, 1=a few plants on rake head, 2=rake head approximately half full, and 3=rake head full or overflowing.

All specimens recovered in rake sampling were identified to the species level using standard keys and photographs (Fasset 1957, Voss 1985, Borman et al. 1997). Additional visual surveys were conducted to assemble a complete species list of emergent, floating and submerged and attached vegetation at each site.

Benthic macroinvertebrate sampling: The composition and abundance of the benthic macroinvertebrates was determined primarily in the grab samples used to determine sediment particle characteristics. In the laboratory the complete grab sample was examined for macroinvertebrates. Individuals were categorized into broad taxonomic groupings using Pennak (1989), Merritt and Cummins (1996), and Thorp and Covich (1991). Abundance was determined using a scale from 0 – 4: 0=no individuals observed, 1=one individual observed, 2=2 - 10 individuals observed, 3=11 – 99 individuals observed, and 4=100 or more individuals observed in a sample.

Data Handling and Statistical Analysis:

Field data were recorded on waterproof sampling field data sheets. Data were later checked for completeness and accuracy. Data obtained in the laboratory were entered into project lab notebooks. Data were later entered into Microsoft Excel spreadsheets for initial summary and analysis. Further statistical analysis was performed using the SPSS software package (ver. 16.0).

Data were tested for heteroscedasticity, kurtosis, and normality. If needed, data were transformed with an appropriate procedure prior to conducting ANOVA tests. A full factorial ANOVA (Type III) was run initially on the full data set. When significant interactions were observed separate ANOVA tests were conducted on parsed data according to the appropriate treatment categories. Hierarchical classification (i.e. cluster) analysis was used to determine natural grouping of sites based on macrophyte and macroinvertebrate data. Derived groupings were then compared to experimental treatment characteristics (i.e. dredging history, substrate type, and site exposure).

Results

Video Surveys of Transects:

Results from video surveys of the three transect lines established at each site show clear differences among sites located on different substrate types as well as among sites with differing dredging history (Figure 2). Sites in protected areas with bedrock as the main substrate had over 50% of the area as bare rock, with an additional 20 – 30% as sediment without vegetation. There was an additional 20% of the area in both previously dredged and undisturbed sites covered by benthic algae (primarily *Cladophora*). On bedrock substrate, macrophytes were only found in non-dredged sites. In contrast, at locations with cobble substrates the coverage by benthic algae and macrophytes was reversed, with 10 - 15% of the area covered by macrophytes and essentially no benthic algae. Similarly, at sites with sand as the primary substrate, macrophytes were found on 15 – 35% of the area with essentially no benthic algae observed. Macrophytes covered a higher percentage of the area at dredged sites than at non-dredged sites in the sandy substrate locations.

As expected from these overall patterns, the video survey data demonstrated that there are significant effects of all factors and interactions in the full data set ($P<0.01$ for all effects). Separate analyses based on each factor show that macrophyte coverage is significantly affected by previous dredging at sites with substrate types of bedrock or sand (Table 3, P-values less than 0.05). However, the effects of dredging had opposite effects at these two types of sites. More macrophytes were found on non-dredged areas on bedrock substrate while dredged areas showed more macrophytes at sites with a sand substrate (Figure 2 & 3a). Benthic algae coverage did not differ significantly at bedrock

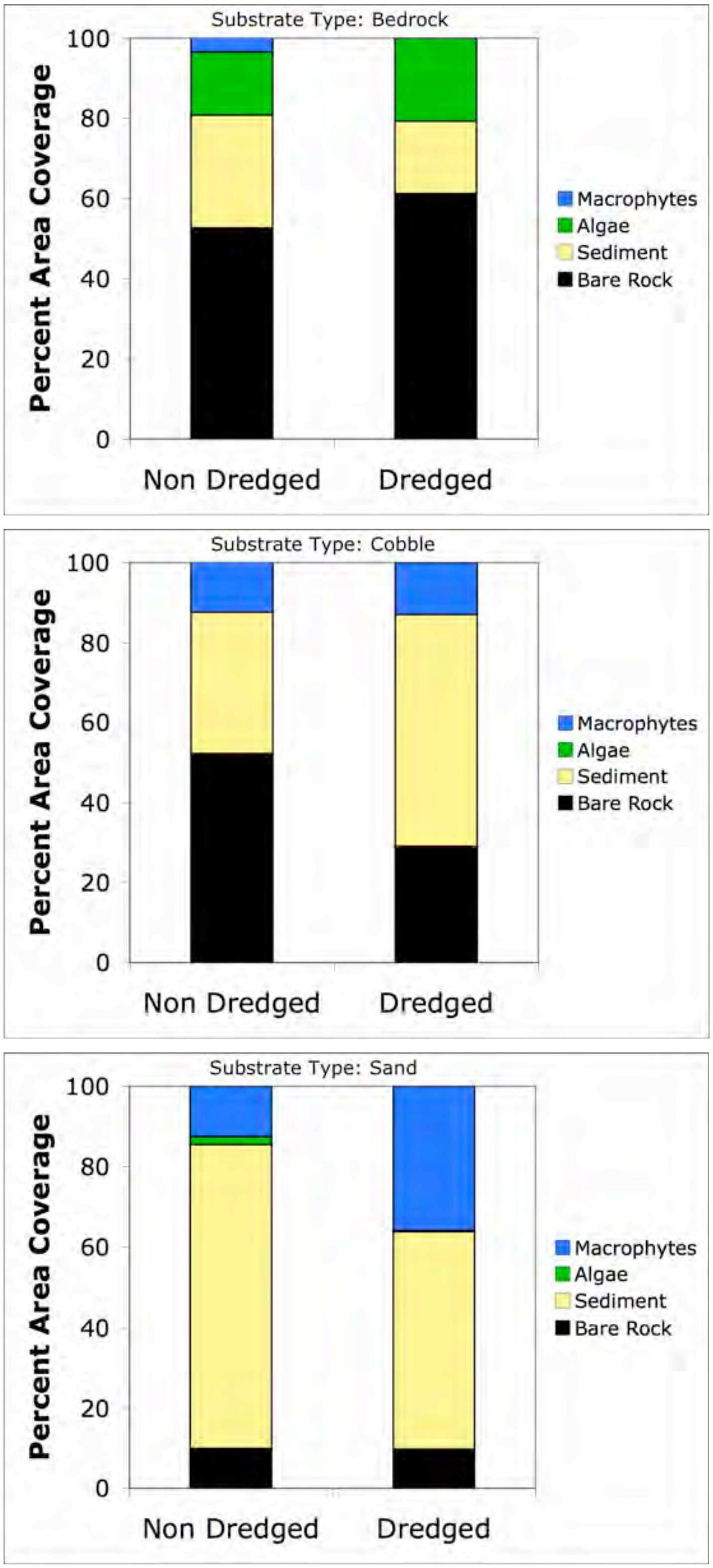

Figure 2. Mean percent area covered by bare rock, sediment, macrophytes and benthic algae estimated by video surveys at sites with bedrock (top), cobble (middle), and sand (bottom) substrate types at protected sites during summer 2008.

Table 3. Analysis of Variance (ANOVA) results for separate tests of the effects of dredging on the area coverage of benthic algae, macrophytes, sediment, and bare rock for protected sites with no piers during summer 2008. Values in table indicate the P-value for the between treatment effect in a one-way ANOVA. Significant effects of dredging on variables are indicated with asterisks (*=significant, **=highly significant).

Variable Measured	**Bedrock (df=1,88)**	**Cobble (df=1,58)**	**Sand (df=1,178)**
Algae	0.101	None	0.002 **
Macrophytes	0.001 **	0.844	<0.001 **
Sediment	0.005 **	<0.001 **	<0.001 **
Bare Rock	0.053	<0.001 **	0.947

Table 4. One way analysis of variance (ANOVA) results for separate tests of the effects of Channel Position on area coverage estimated by video surveys for algae, macrophytes, sediment and bare rock on dredged sites in protected areas. The data employed are for sites without piers. Significant effects of Channel Position on each variable are indicated with asterisks (*=significant, **=highly significant).

Dependent Variable	**df**	**Mean Square**	**F-ratio**	**P-value**
Algae	2,117	858.43	5.937	0.004 **
Macrophytes	2,117	3890.78	5.499	0.005 **
Sediment	2,117	4163.23	3.924	0.022 *
Bare Rock	2,117	1827.33	2.012	0.138

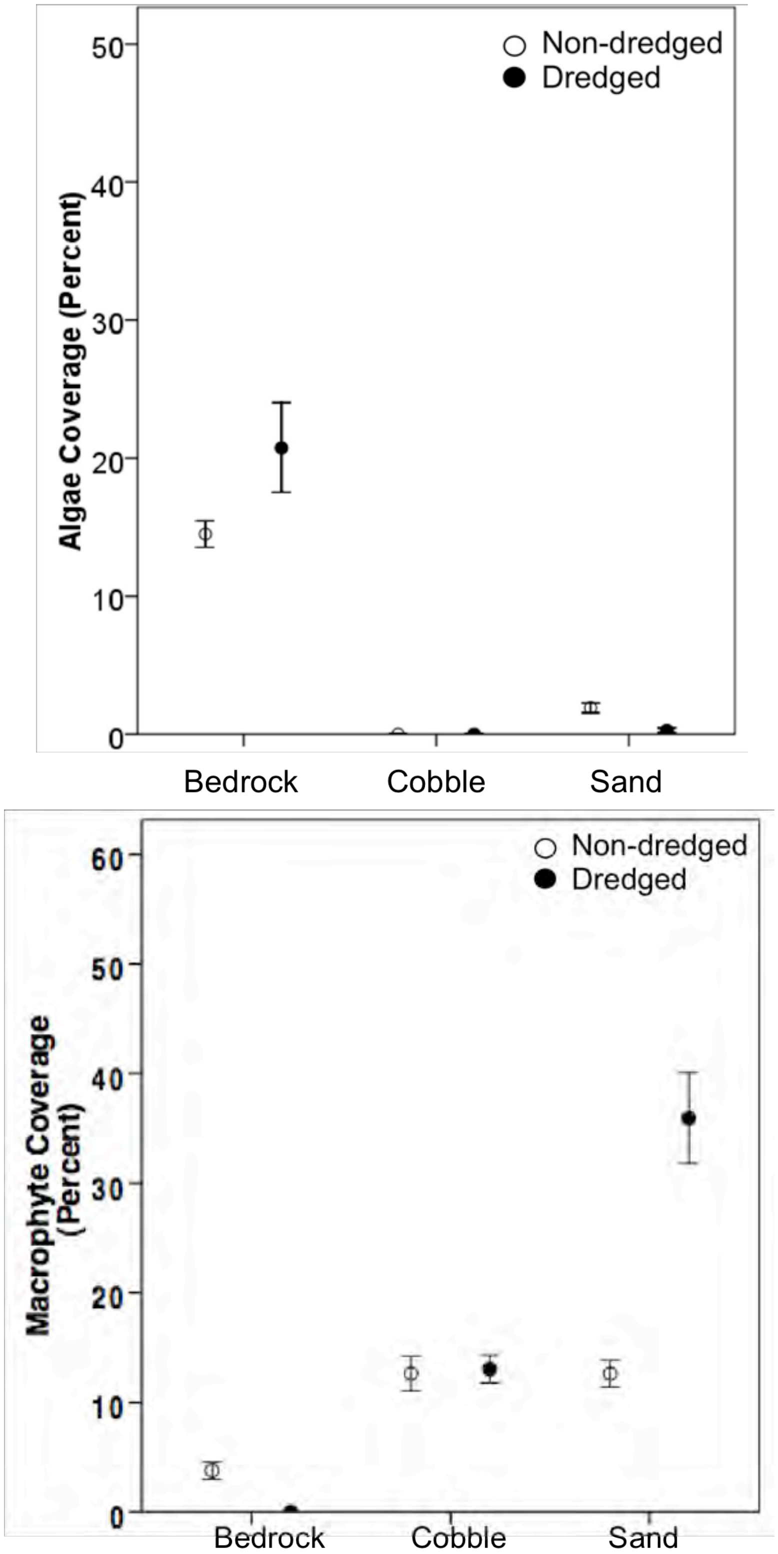

Figure 3a. Percent area covered (mean +/- 1 SEM) by benthic algae (top) and macrophytes (bottom) on three types of substrate (bedrock, cobble, sand) based on video transect analysis at sites without piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate sites previously dredged.

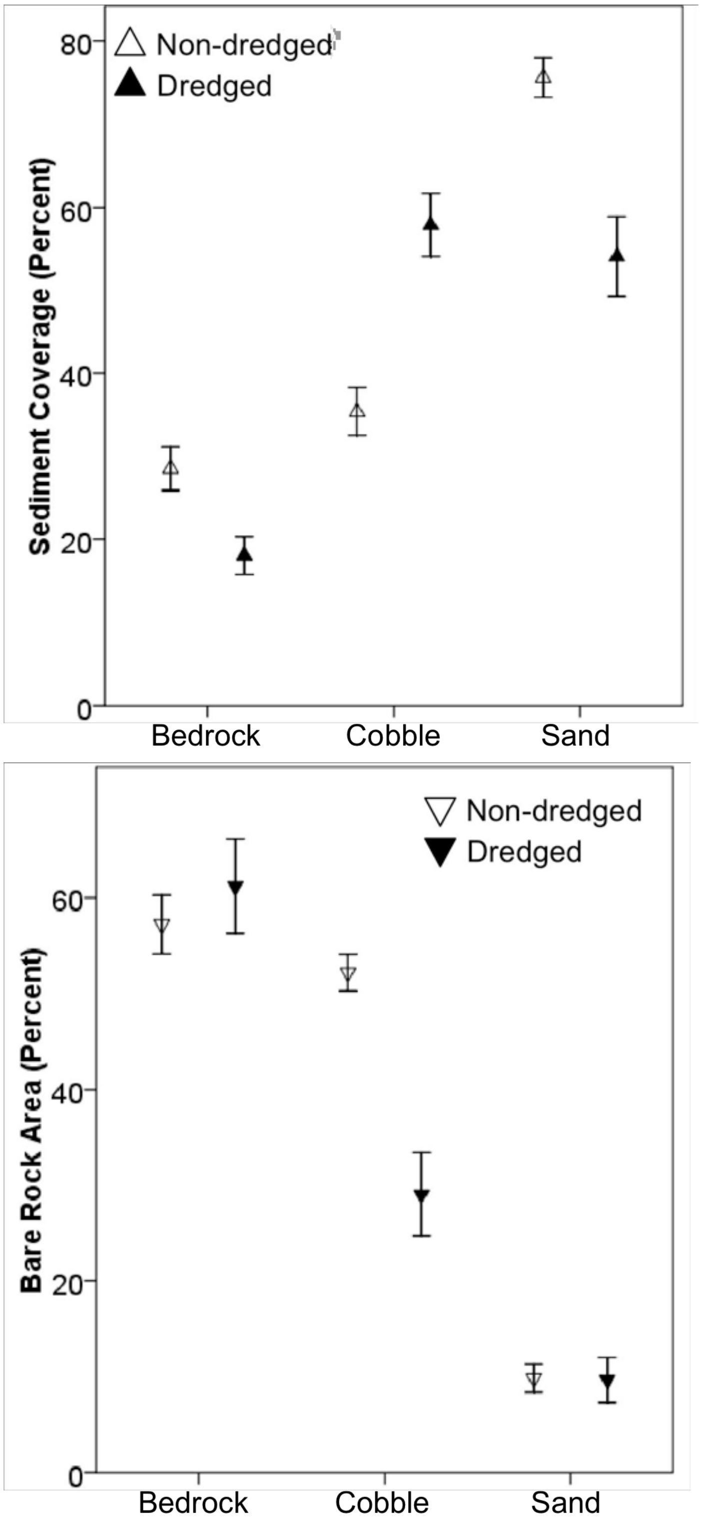

Figure 3b. Percent area covered (mean +/- 1 SEM) by sediment (top) and bare rock (bottom) on three types of substrate (bedrock, cobble, sand) based on video transect analysis at sites without piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate sites previously dredged.

or cobble sites, but algae was significantly higher at non-dredged sites with a sandy substrate (Figures 2 & 3a). Finally, dredging significantly changed the relative area of coverage on all three types of substrate; 1) on bedrock sites dredging resulted in higher benthic algae and bare rock coverage and less sediment and macrophyte area, 2) at cobble sites there was significantly higher sediment and lower bare rock coverage, and 3) on sandy substrate, dredged locations had significantly higher area coverage by macrophytes and lower benthic algae and sediment coverage (Figures 2 & 3).

Dredged channels displayed significant differences in bottom coverage compared to adjacent non-dredged areas, as indicated by the significant effects of Channel Position on coverage by benthic algae, macrophytes and sediment observed in the ANOVAs for each variable (Table 4). The middle of channels had significantly higher macrophyte coverage than adjacent areas in both cobble and sand substrate locations (Figure 4), most likely due to increased amounts of smaller grained sediment in the channels (see below). Locations with bedrock substrate had essentially no macrophyte growth overall (Figures 2 & 3). Although overall benthic algae coverage was approximately the same at dredged and nondredged sites with a bedrock substrate (20% coverage when all transects are averaged), there was significantly less benthic algae in the middle of dredged channels compared to adjacent areas at bedrock sites (Figure 5). Benthic algae coverage in the transects adjacent to the channel also was dramatically higher than at the non-dredged sites, indicating that dredging has lasting impacts on the areas outside of the channel as well (Figure 5; adjacent transects = 42.5 +/14.08, non-dredged sites = 15.72 +/- 1.44). At the sites with bedrock, area covered by sediment and bare rock was higher in the middle

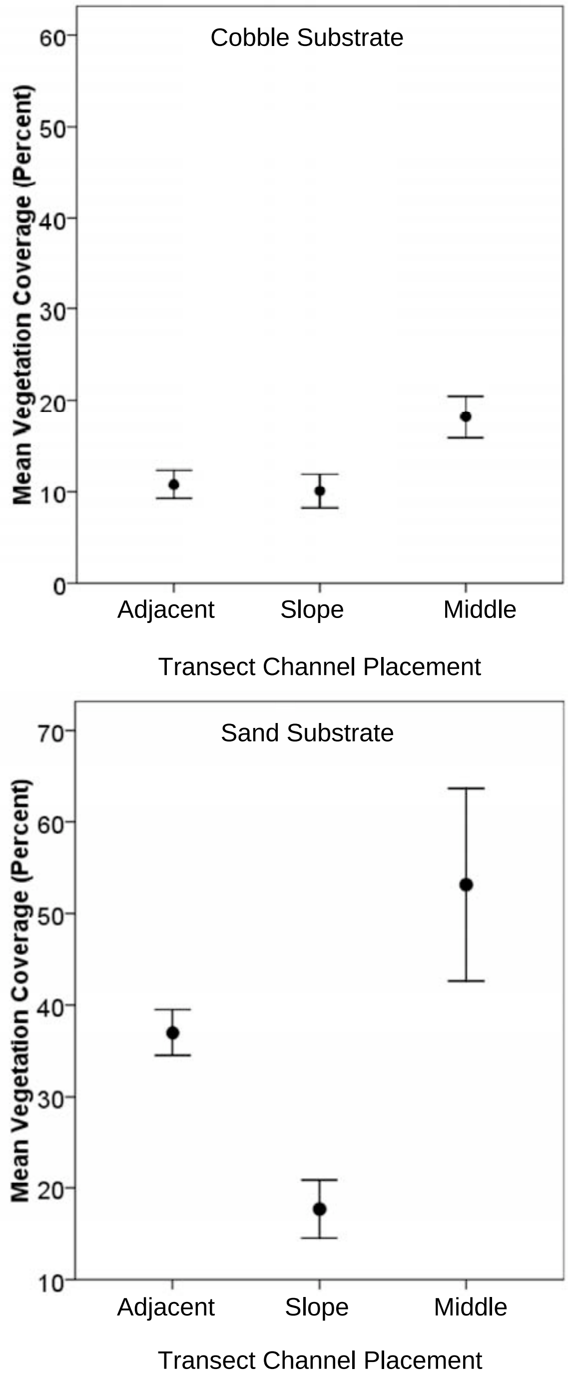

Figure 4. Percent area covered (mean +/- 1 SEM) by macrophytes at sites with cobble (top) and sand (bottom) substrate at three dredged channel positions (adjacent to channel, channel slope, middle of channel) based on video transect analysis at sites without piers during summer 2008.

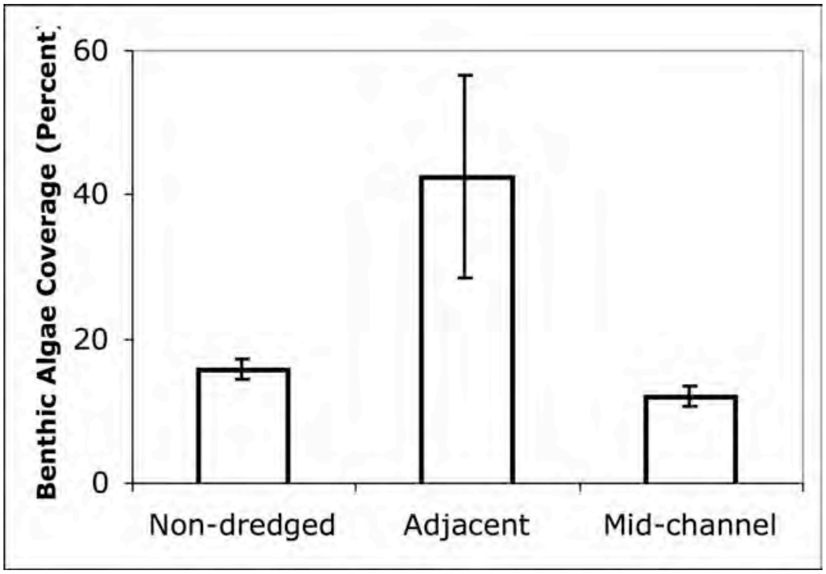

Figure 5. Percent area covered (mean +/- 1 SEM) by benthic algae at sites with bedrock substrate adjacent to dredged channel, in the middle of channel, and at non-dredged sites. Data are based on video transect analysis at sites without piers during summer 2008.

Table 5. Analysis of variance (ANOVA) results for the full dataset on sediment particle size. A Type III ANOVA model was employed for this analysis. Significant effects of source factors are indicated with asterisks (*=significant, **=highly significant).

Source	**df**	**Significance Level**
Dredge	1	0.001 **
Substrate Type	2	0.001 **
Exposure	1	0.001 **
Dredge X Substrate	2	0.145
Dredge X Exposure	1	0.192
Substrate X Exposure	2	0.001 **
Dredge X Substrate X Exposure	2	0.001 **

of channels (88.1% +/- 2.25) than in adjacent areas (57.5% +/- 4.03), indicating that dredging modifies the habitat in terms of sediment as well as biotic relationships.

Particle Size Analysis:

There were clear effects of Dredging, Substrate type and site Exposure on the size distribution of particles observed during the study. Analysis of variance on the full dataset indicated that each of these factors had highly significant effects on particle size, but that there were also significant interaction effects between all three factors (Table 5). Essentially the same results occurred when only non-pier sites were included in the analysis. The only difference was that the interaction terms (Dredge X Substrate) and (Dredge X Exposure) had P-values of 0.067 and 0.001 respectively. Due to the significant interaction effects, the data were parsed and analyzed separately to determine the effects of Dredging history according to Substrate type and Exposure level and the differences within dredged channels compared to area adjacent to the channels.

Particle size was significantly smaller in the middle of the dredged channel than at either the slope or adjacent to the channel (Figure 6, Table 6). A shift from an average grain size of over 6 (gravel and very course sand particles, 2-5 mm) to 4.5 (medium sized sand, 0.25 – 0.5 mm) occurred in moving from the undisturbed sites adjacent to the dredged channel into the middle of the channel. Particles in the middle of the channel were significantly smaller compared to those either on the sloping sides of the channel (LSD posthoc test; $P=0.003$) or in the adjacent areas ($P<0.001$). In addition, only the middle of channels contained measurable amounts of the smallest particles observed (silt,

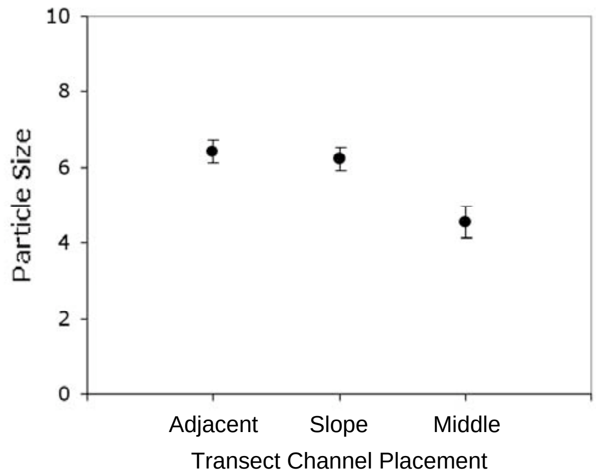

Figure 6. Sediment particle grain size (mean +/- 1 SEM) in grab samples from dredged sites without a pier at three positions relative to three dredged channel positions (adjacent to channel, channel slope, middle of channel) during summer 2008.

Table 6. One way analysis of variance (ANOVA) results for effects of Channel Position on sediment particle size. The data employed are for sites without piers and that had been dredged previously. The highly significant effect of Channel Position is indicated with asterisks.

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	**P-value**
Between Groups	83.676	2	41.838	8.709	<0.001 **
Within Groups	759.003	158	4.804		
Total	842.679	160			

Table 7. One way analysis of variance (ANOVA) results for separate tests of the effects of Dredge history on sediment particle size. The data employed are for sites without piers. Significant effects of dredging for each Exposure/Substrate combination are indicated with asterisks (*=significant, **=highly significant).

Exposure	**Substrate Type**	**df**	**Mean Square**	**F-ratio**	**P-value**
Exposed	Bedrock	1	24.465	2.979	0.093
Exposed	Cobble	1	1.805	0.747	0.391
Exposed	Sand	1	20.382	3.779	0.066
Protected	Bedrock	1	16.441	4.811	0.033 *
Protected	Cobble	1	22.927	10.947	0.002 **
Protected	Sand	1	5.096	1.348	0.251

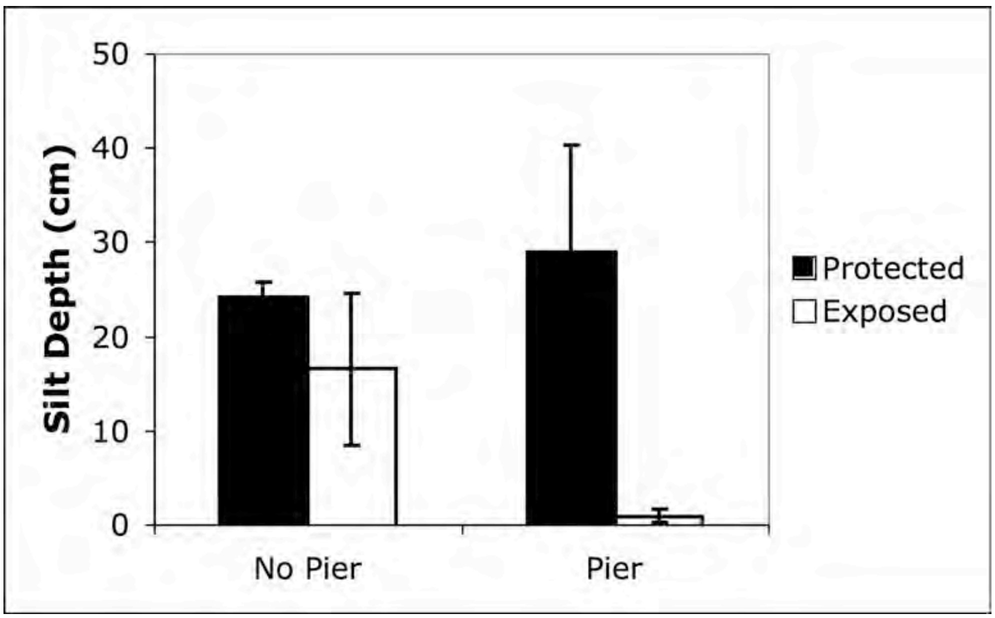

Figure 7. Depth of silt (mean +/- 1 SEM) in the middle of dredged channels at sites without piers or with piers, in protected and exposed locations during summer 2008.

grain size < 0.063 mm). The depth of silt in the middle of the channels varied from 0 to 76 cm, and tended to be deepest in the protected areas (Figure 7).

A higher abundance of smaller sized particles at protected sites was also reflected in the significant differences among dredged and non-dredged sites with bedrock and cobble substrates (Table 7, Figure 8). There was a similar trend at sites with bedrock in exposed areas, but the effects of dredging there were only marginally significant ($P=0.093$; Figure 8). At sites with piers, significantly smaller particles occurred at previously dredged sites on sandy substrates also (Figure 9). Overall, particle size was generally smaller at protected sites and at previously dredged locations.

Particle Shape, Color and Odor:

The shape of particles was significantly affected by Dredge history at exposed cobble areas and at protected locations with all three types of substrate (Table 8). Particles were typically more rounded at dredged sites than at sites with no previous dredging history, as demonstrated by higher shape values at previously dredged locations (Figure 10). There was no significant effect of position in channels on shape measures ($P>0.5$) but sediments in the middle of dredged channels were the only place where black silt was observed and the only sediments that emitted a distinct odor of hydrogen sulfide (e.g. rotten eggs).

Vegetation Composition Analysis:

A total of 24 taxa of vegetation (macrophytes plus benthic macroalgae) were recorded at the sites studies (Table 9). Eight of the species occurred in more than 10% of all the sites sampled. Among these eight widespread groups are two species that are

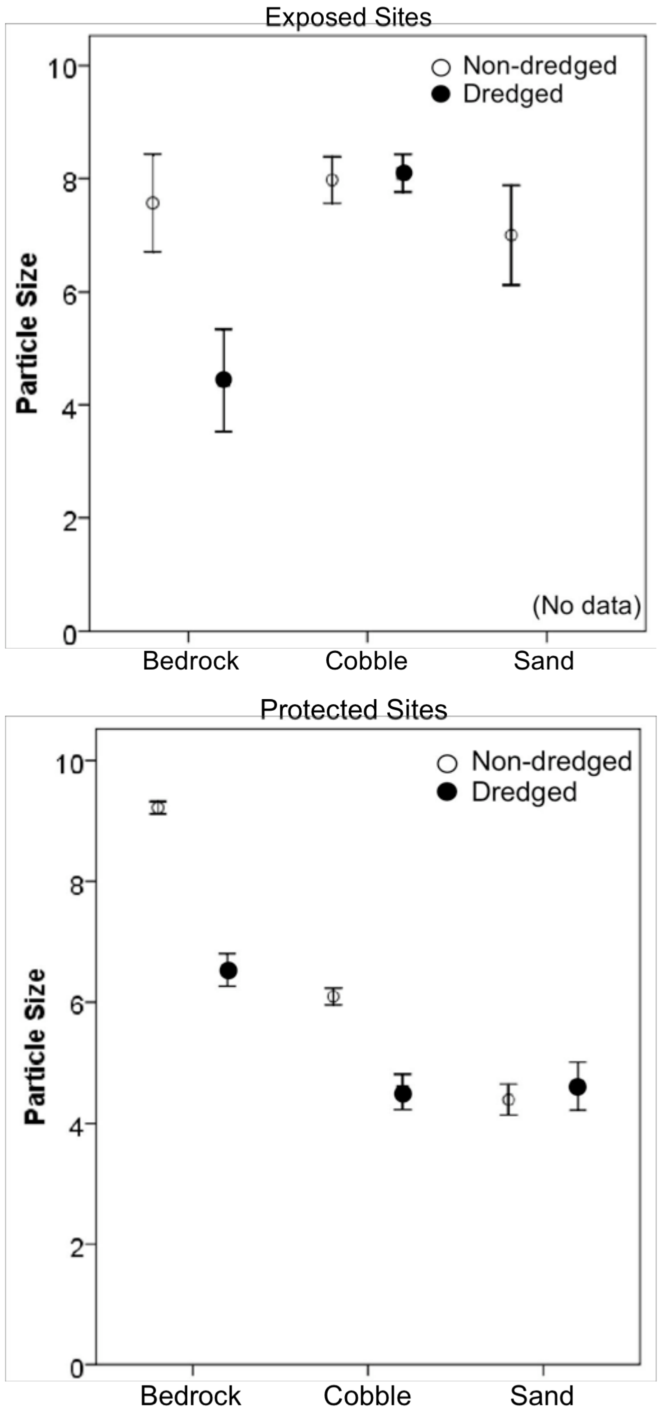

Figure 8. Sediment particle grain size (mean +/- 1 SEM) in grab samples from exposed (top) and protected (bottom) sites on three types of substrate (bedrock, cobble, sand) at locations without piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate sites previously dredged. No sites in exposed locations with sand substrate and that had been dredged were available.

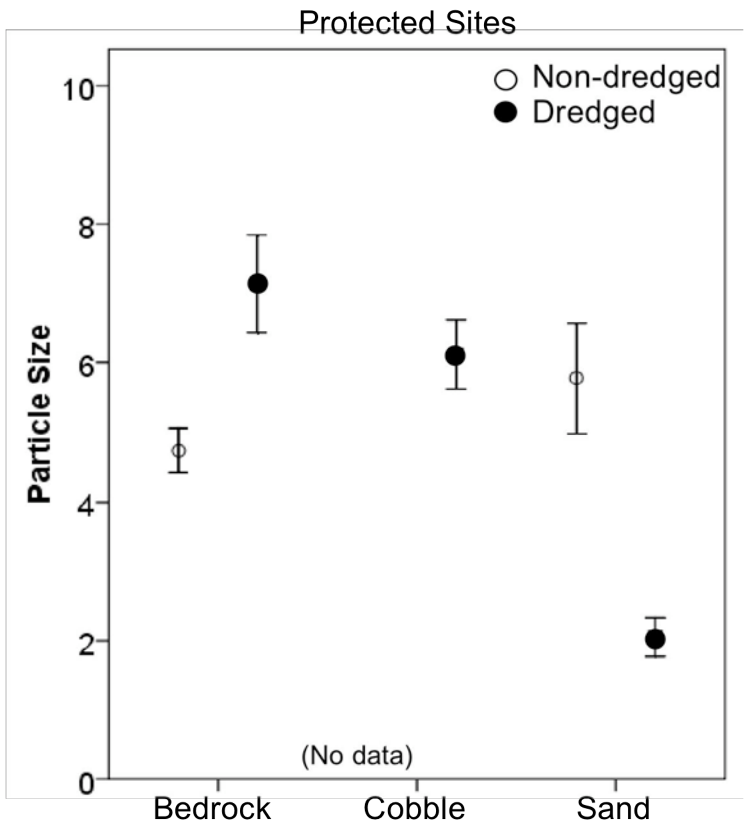

Figure 9. Sediment particle grain size (mean +/- 1 SEM) in grab samples from protected sites on three types of substrate (bedrock, cobble, sand) at locations with piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate sites previously dredged. No data were obtained for sites on cobble substrate that had not been dredged.

Table 8. One way analysis of variance (ANOVA) results for separate tests of the effects of Dredge history on sediment particle shape. The data employed are for sites without piers. Significant effects of dredging for each Exposure/Substrate combination are indicated with asterisks (*=significant, **=highly significant).

Exposure	**Substrate Type**	**df**	**Mean Square**	**F-ratio**	**P-value**
Exposed	Bedrock	1	0.333	1.000	0.423
Exposed	Cobble	1	2.025	7.043	0.017 *
Exposed	Sand	1	No data		
Protected	Bedrock	1	0.409	7.364	0.024 *
Protected	Cobble	1	1.071	4.197	0.045 *
Protected	Sand	1	2.575	16.644	<0.001 **

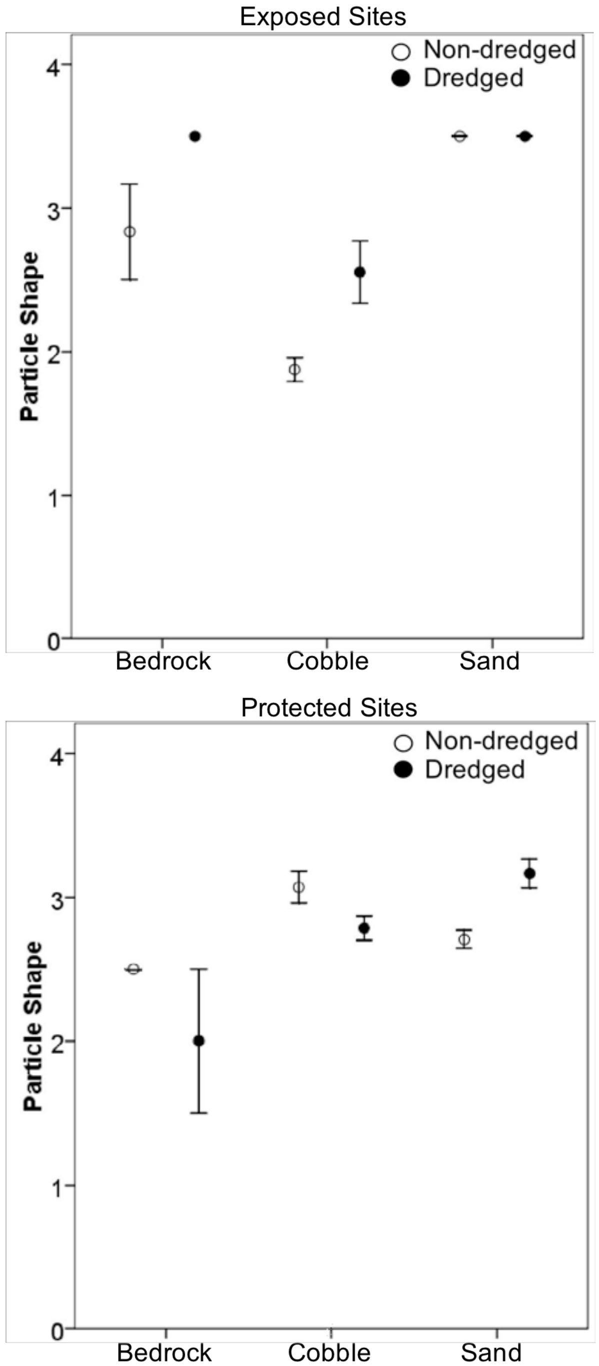

Figure 10. Sediment particle shape (mean +/- 1 SEM) in grab samples from exposed (top) and protected (bottom) sites on three types of substrate (bedrock, cobble, sand) during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate sites previously dredged. Higher shape value indicated more rounded particles.

Table 9a. Composition of vegetation observed at sites along the Green Bay shoreline of Door County, WI during summer 2008. Presence of taxa during at least one of the sampling days is indicated by the value 1. Aquatic invasive species are highlighted. Site numbers for dredged sites are in bold italics. See Table A1 and Figure A1 for site location details.

Taxa	***11***	12	***15***	16	***17***	21	***23***	24	***30***	31	33	34	***37***	44	***45***	***47***	48	***52***	53	63	***64***	65	68	***69***
Carex comosa, Bristly sedge																								
Ceratophyllum demersum, Coontail									1															
Ceratophyllum echinatum, Spiny hornwort							1																	
Chara coronata, Muskgrass			1	1	1	1	1			1		1		1	1	1	1	1				1	1	1
Cladophora sp.	1	1		1		1		1	1		1	1	1		1	1	1	1	1	1	1	1	1	1
Elodea canadensis, Common waterweed			1			1	1																	
Heteranthera dubia, Water star-grass																								
Juncus effusus, Soft rush																								
Myriophyllum spicatum, Eurasian water-milfoil			1	1	1	1	1	1	1			1	1		1	1	1	1			1	1	1	1
Potamogeton crispus, Curly-leaf pondweed				1	1	1	1		1												1			1
Potamogeton diversifolius, Water-thread pondweed							1																	
Potamogeton richardsonii, Clasping-leaf pondweed					1	1						1												
Potamogeton zosteriformis, Flat-stem pondweed				1	1	1	1								1	1	1	1	1			1	1	
Najas flexilis, Bushy pondweed						1	1																	
Ranunculus flammula, Creeping spearwort																								
Ruppia cirhossa, Ditch grass																								
Sagittaria brevirostra, Midwestern arrowhead																								
Schoenoplectus pungens, Three-square																								
Schoenoplectus subterminalis, Water bulrush										1				1		1		1					1	
Scirpus americanus, Chair-makers rush																								
Spirogyra sp./Spirotaenia sp.																								
Stuckenia pectinata, Sago pondweed			1		1	1						1				1	1	1				1	1	
Vallisneria americana, Wild celery			1	1	1	1	1	1				1				1	1					1		1
Zannichellia palustris, Horned pondweed																								
Total Taxa	1	1	5	6	7	10	9	3	4	2	1	6	2	2	4	7	6	6	2	1	3	6	6	5

Table 9b. Composition of vegetation observed at sites along the Lake Michigan shoreline of Door County, WI during summer 2008. Presence of taxa during at least one of the sampling days is indicated by the value 1. Aquatic invasive species are highlighted. Site numbers for dredged sites are in bold italics. See Table A1 and Figure A1 for site location details.

Taxa	71	***72***	80	***81***	83	***84***	***85***	***90***	***91***	92	93	***100***	101	102	***110***	111	112	***113***	120	***121***
Carex comosa, Bristly sedge						1														
Ceratophyllum demersum, Coontail																				
Ceratophyllum echinatum, Spiny hornwort																				
Chara coronata, Muskgrass	1	1	1	1	1	1	1			1	1								1	
Cladophora sp.					1	1	1	1	1	1			1	1	1		1	1	1	1
Elodea canadensis, Common waterweed																				
Heteranthera dubia, Water star-grass												1								
Juncus effusus, Soft rush											1									
Myriophyllum spicatum, Eurasian water-milfoil	1	1	1	1		1		1		1										1
Potamogeton crispus, Curly-leaf pondweed		1						1											1	
Potamogeton diversifolius, Water-thread pondweed																				
Potamogeton richardsonii, Clasping-leaf pondweed		1																		
Potamogeton zosteriformis, Flat-stem pondweed	1	1		1		1													1	1
Najas flexilis, Bushy pondweed																				
Ranunculus flammula, Creeping spearwort		1																		
Ruppia cirhossa, Ditch grass	1										1			1						
Sagittaria brevirostra, Midwestern arrowhead						1														
Schoenoplectus pungens, Three-square						1														
Schoenoplectus subterminalis, Water bulrush			1	1	1	1													1	
Scirpus americanus, Chair-makers rush						1														
Spirogyra sp. /Spirotaenia sp.															1	1				
Stuckenia pectinata, Sago pondweed																			1	
Vallisneria americana, Wild celery		1		1		1														
Zannichellia palustris, Horned pondweed	1																			
Total Taxa	5	7	3	5	3	10	2	3	1	3	3	1	1	2	2	1	1	1	6	3

considered aquatic invasive species (Table 10). *Myriophyllum spicatum* (Eurasian water-milfoil) was recorded in 56.8% of the sites and *Potamogeton crispus* (Curly-leaf pondweed) occurred at almost a quarter of the locations sampled. Of the 10 sites with Curly-leaf pondweed 7 had been previously dredged, suggesting that disturbance at dredged areas may contribute to the increased prevalence of invasive species. The nuisance macroalgae *Cladophora* sp. was observed at over 70% of the sites studied.

Vegetation richness (i.e. number of species) was generally higher at previously dredged sites (Figure 11). The only sites with more than six species present were sites with a dredging history (except for one site at Sawyer Harbor with a solid Pier). At sites without piers there was a significantly higher number of plant species at dredged (mean = 6.7 species) compared to nondredged sites (mean = 3.1 species; t-test $P=0.019$, $df=8$). There was no statistically significant difference due to dredging history at sites with a pier present ($P>0.05$, $df=8$).

Based on vegetation composition sites could be clustered according to previous dredge history. By grouping sites based on similarities of species composition, clustering analysis can suggest "natural" assemblages that arise from the vegetation analysis. There were three natural groupings of sites defined by the cluster analysis using data for sites with piers (Figure 12). The sites connected by low "dissimilarity" on the dendrogram have similar vegetation composition and share species in common. The most closely related set of sites based on species composition were seven sites that had no previous dredging history (Nondredged Grouping 1). All of these sites had no macrophytes and only benthic algae as the resident vegetation (Table 11). A second set of nondredged sites (9 total) was also identified, and had a more diverse plant association that included

Table 10. Percent of all sites where vegetation taxa were observed for sites with values greater than 10%. Aquatic invasive species are highlighted.

Taxa	Occurrence (Percent)
Cladophora sp.	72.7
Chara coronata, Muskgrass	56.8
Myriophyllum spicatum, Eurasian water-milfoil	56.8
Potamogeton zosteriformis, Flat-stem pondweed	38.6
Vallisneria americana, Wild celery	31.8
Potamogeton crispus, Curly-leaf pondweed	22.7
Schoenoplectus subterminalis, Water bulrush	22.7
Stuckenia pectinata, Sago pondweed	22.7

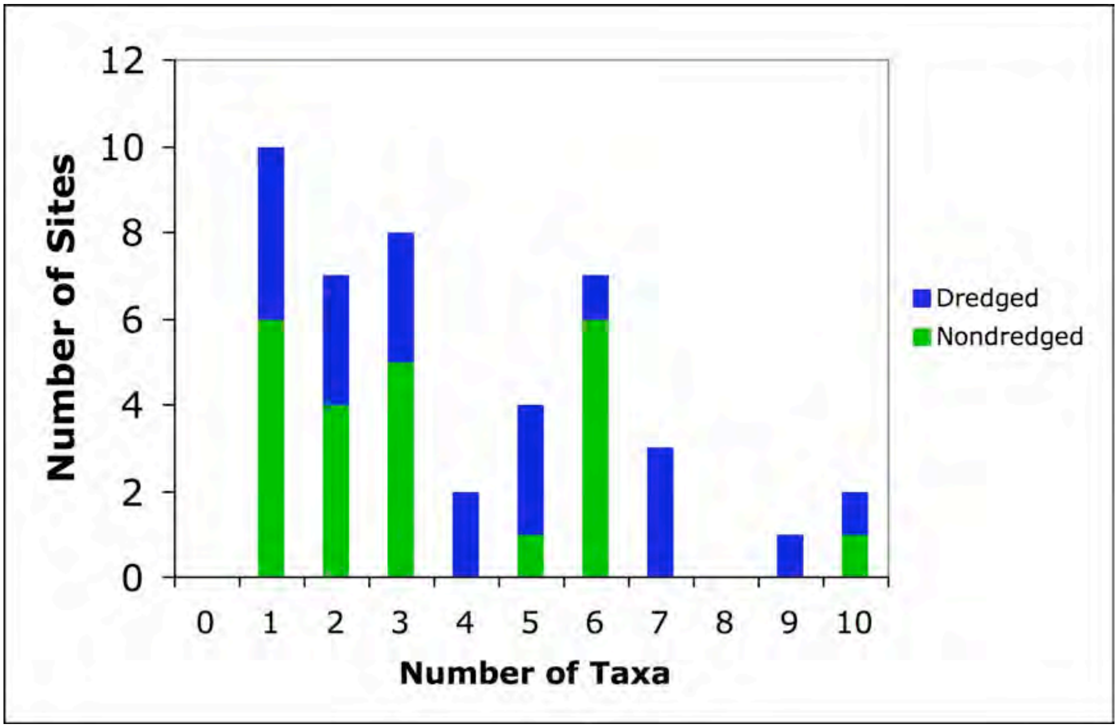

Figure 11. Number of macrophyte and benthic algae taxa recorded at dredged and nondredged sites during the summer of 2008.

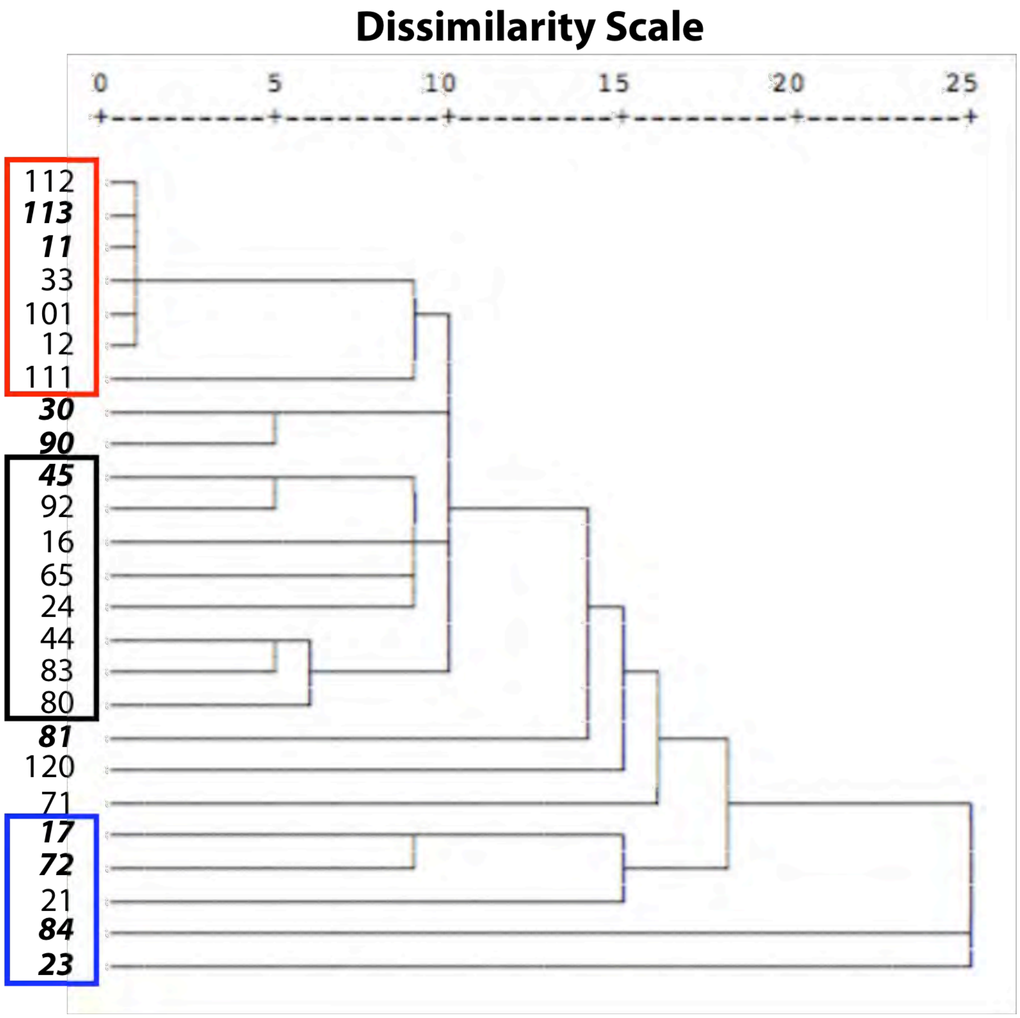

Figure 12. Dendrogram of sites without piers resulting from a clustering analysis based on vegetation composition using the centroid method of defining groupings. The group of sites outlined in red have no dredge history (Nondredged Grouping 1), those boxed in black also have no dredge history (Nondredged Grouping 2) and those surrounded by the blue box were previously dredged or in protected locations (Dredged/Protected Grouping).

Table 11. Plant associations observed at sites in groupings defined by cluster analysis using a centroid agglomerative method.

Results for Sites without Piers:

Dredged/Protected Sites Grouping
Chara coronata, Muskgrass
Elodea canadensis, Common waterweed
Myriophyllum spicatum, Eurasian water-milfoil
Potamogeton crispus, Curly-leaf pondweed
Potamogeton richardsonii, Clasping-leaf pondweed
Potamogeton zosteriformis, Flat-stem pondweed

Nondredged Grouping 1
Cladophora sp.
Spirogyra sp./*Spirotaenia* sp.

Nondredged Grouping 2
Chara coronata, Muskgrass
Cladophora sp.
Myriophyllum spicatum, Eurasian water-milfoil
Potamogeton zosteriformis, Flat-stem pondweed
Schoenoplectus subterminalis, Water bulrush
Vallisneria americana, Wild celery

Results for Sites with Piers:

Dredged Grouping
Chara coronata, Muskgrass
Cladophora sp.
Myriophyllum spicatum, Eurasian water-milfoil
Potamogeton crispus, Curly-leaf pondweed

Bedrock/Sand Grouping
Chara coronata, Muskgrass
Cladophora sp.
Potamogeton zosteriformis, Flat-stem pondweed
Ruppia cirhossa, Ditch grass

Cobble Grouping
Chara coronata, Muskgrass
Cladophora sp.
Myriophyllum spicatum, Eurasian water-milfoil
Potamogeton zosteriformis, Flat-stem pondweed
Schoenoplectus subterminalis, Water bulrush
Stuckenia pectinata, Sago pondweed
Vallisneria americana, Wild celery

Cladophora and Eurasian water-milfoil, but also Wild celery, Muskgrass, and Water bulrush. Finally, the third grouping contained previously dredged sites that included both invasive plant species (Eurasian water-milfoil and Curly-leaf pondweed) and four other native species.

Similar groupings were derived for sites with piers. There were three clear groupings with this dataset also, based on dredging history and substrate type (Figure 13). Locations with cobble substrate clustered together, as did sites with bedrock and sand. The plant associations in these sites were very similar to the associations defined with the nonpier sites, with the species list for the cobble group being identical except for one species to that observed in the Nondredged Grouping 2 from the nonpier data (Table 11). Sago pondweed was found at all sites in the Cobble Grouping with piers, but not in the nonpier sites included in the Nondredged Grouping 2 set. The dredged groupings in both datasets were very similar, containing Muskgrass, Eurasian water-milfoil, and Curly-leaf pondweed. Finding the same associations of vegetation in dredged grouping in both pier and non-pier data indicates that in this study dredging generally leads to similar vegetation communities that are distinct from those found in non-dredged areas.

Vegetation Abundance Analysis:

There were significant effects of dredging on vegetation abundance, as measured by rake density sampling, in both the exposed and protected sites (Table 12). On cobble substrate in locations without piers rake density was significantly higher in previously dredged than non-dredged sites (Figure 14). We did not have any sites with sand substrate and no pier that had been dredged, so it was not possible to assess effects for

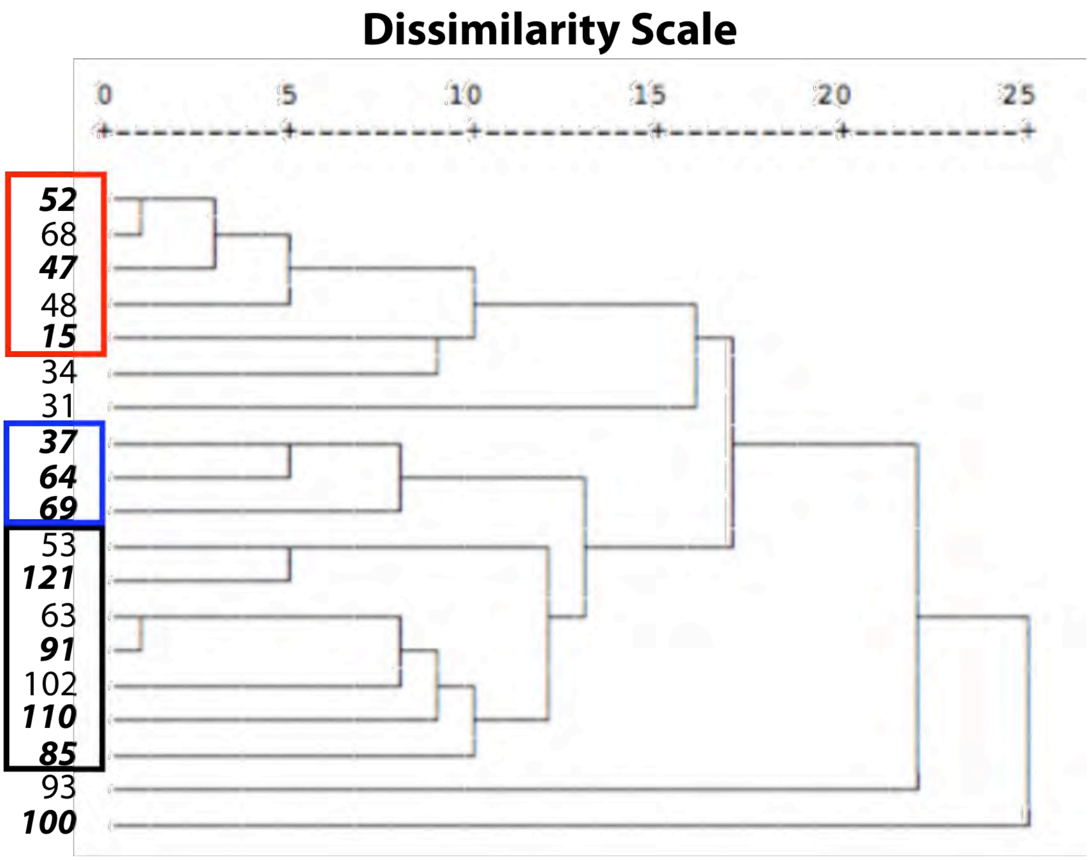

Figure 13. Dendrogram of sites with piers resulting from a clustering analysis based on vegetation composition using the centroid method of defining groupings. The group of sites outlined in red have a cobble substrate type, those boxed in blue are previously dredged sites, and those surrounded by the black box are found on either bedrock or sand substrates.

Table 12. Results from separate Kruskal-Wallis tests run for the effects of Dredge history on vegetation density in rake samples. Significant effects of dredging for each Exposure/Substrate combination are indicated with asterisks (*=significant, **=highly significant).

Exposure	Substrate Type	df	Chi-Square	P-value
Exposed	Bedrock	1	2.797	0.094
Exposed	Cobble	1	5.498	0.019 *
Exposed	Sand	1	9.395	0.002 **
Protected	Bedrock	1	6.129	0.013 *
Protected	Cobble	1	1.669	0.196
Protected	Sand	1	3.285	0.070

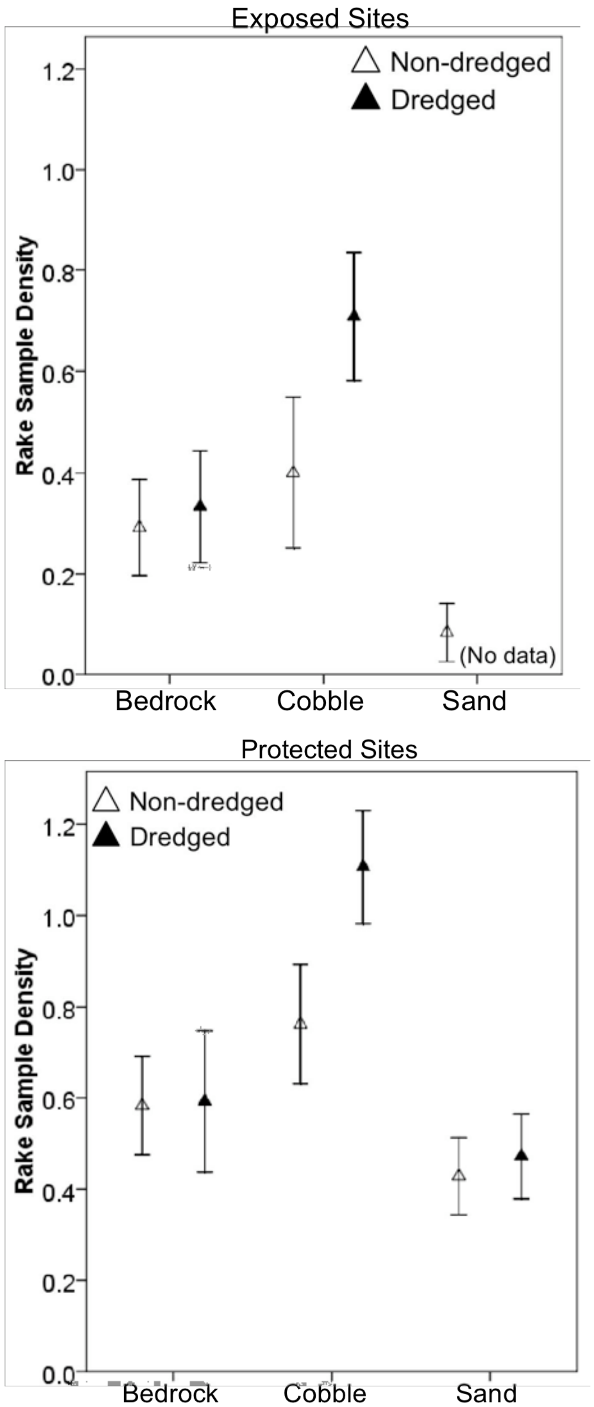

Figure 14. Density of vegetation (mean +/- 1 SEM) in rake samples from exposed (top) and protected (bottom) sites on three types of substrate (bedrock, cobble, sand) at locations without piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate sites previously dredged.

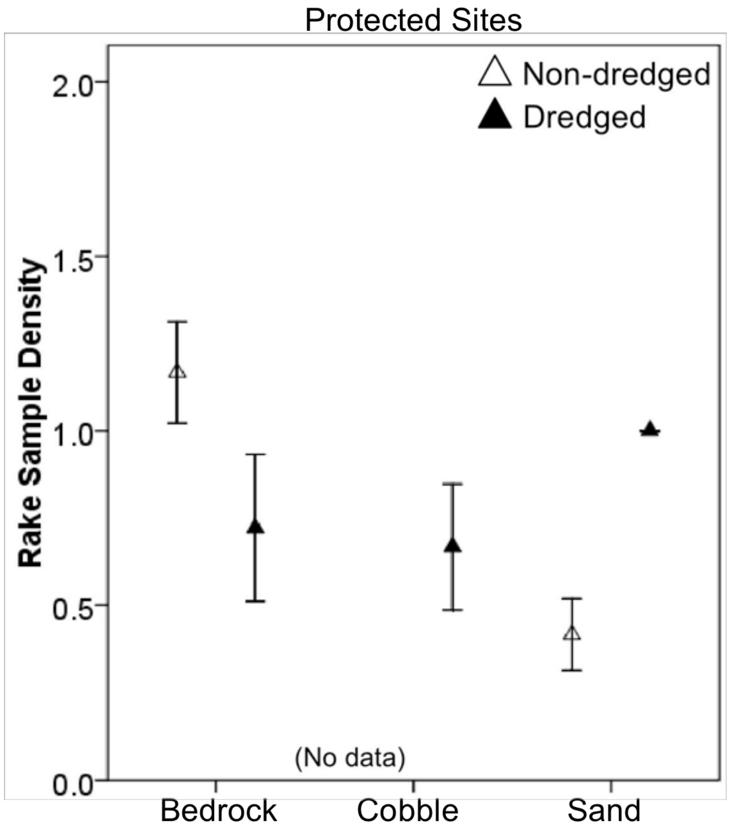

Figure 15. Density of vegetation (mean +/- 1 SEM) in rake samples from protected sites on three types of substrate (bedrock, cobble, sand) at locations with piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate previously dredged sites. No data were obtained for sites on cobble substrate that had not been dredged.

this combination. At locations with sand substrate with piers, vegetation density on rakes was significantly higher at previously dredged sites (Figure 15). There was no overall significant effect of position in the channel on rake density ($P>0.05$ for all effects).

Benthic Macroinvertebrate Analysis:

The benthic invertebrates collected in grab samples were enumerated into 11 broad taxonomic categories (Table 13). There were from 0 to 8 groups identified in any one site. The most diverse sites in terms of number of taxa occurred at sites with cobble substrates. Of the top six sites ranked according to taxa richness, 5 were sites with cobble substrate. The most frequently occurring taxa were midgefly larvae, found in 79% of the sites, and amphipods observed in 49% of the locations sampled (Table 14). Dredging history did not significantly affect the number of taxa observed at a site except in the sandy substrate areas (Table 15). Dredged sites with sand substrate generally had higher numbers of taxa than nondredged sites (mean dredged = 3.40 taxa, nondredged = 2.63) based on sites without piers. The only aquatic invasive species recorded among the benthic invertebrates was the zebra mussel (*Dreissena polymorpha*). Live specimens were found only in about 9% of the sites examined. However, nearly half of the sites did contain evidence of dead zebra mussels (i.e. shells) in either the sediment, rake or video transect samples (19 out of 44 sites).

There was no significant effect of dredging on any of the individual macroinvertebrate abundances, but both substrate and exposure of locations did significantly affect abundance for amphipods, midge fly larvae and ostracods (Table 16). Although abundances were not significantly different overall at dredged and nondredged

Table 13a. Composition and abundance of benthic macroinvertebrates observed at sites along the Green Bay shoreline of Door County, WI during summer 2008. Values represent the average abundance index value estimated in grab samples. Aquatic invasive species are highlighted. Site numbers for dredged sites are in bold italics. See Table A1 and Figure A1 for site location details.

Taxa	***11***	12	16	***17***	21	***23***	24	***30***	31	33	34	***37***	44	***45***	***47***	48	***52***	53	63	***64***	65	68	***69***
Amphipods		3	1	2	1	1			3	3	3		2	2				1					2
Flatworms				2																			
Isopods			1									1		2									
Leech				1																			
Mayfly nymph					1	1			1			1	1		1								1
Midgefly Larvae	2		2	2	2	2		1	2	2	3	2	2	3	2	1	2	2			3		2
Water Mite		2	2	2	1	2					2		1										1
Nematodes				2	2	2			3	3	2		2										
Ostracods	2		1	2	3	3				2	2		2	1									1
Tubifex larvae				1					2	1		1	2	1	2	2							
Zebra Mussel	2		2			2		2															
TOTAL TAXA	3	2	6	8	6	7	0	2	5	5	5	4	7	5	3	2	1	2	0	0	1	0	5

Table 13b. Composition and abundance of benthic macroinvertebrates observed at sites along the Lake Michigan shoreline of Door County, WI during summer 2008. Values represent the average abundance index value estimated in grab samples. Aquatic invasive species are highlighted. Site numbers for dredged sites are in bold italics. See Table A1 and Figure A1 for site location details.

Taxa	71	***72***	80	***81***	83	***84***	***85***	***90***	***91***	92	93	***100***	101	102	***110***	111	112	***113***	120	***121***
Amphipods	1	1	2	2	1	2				3	1			2						
Flatworms																				
Isopods									1											1
Leech	1																			
Mayfly nymph		1			2															1
Midgefly Larvae	2	3	3	3	3	3	3	3	3	3	3	2	3	3			1			3
Water Mite			1	2						1										2
Nematodes		2	2	2	3			1												2
Ostracods			1	2	2			1	1		1									
Tubifex larvae		2																		2
Zebra Mussel																				
Total Taxa	3	5	5	5	5	2	1	3	3	3	3	1	1	2	0	0	1	0	0	6

Table 14. Percent of all sites where benthic invertebrate taxa were observed. Aquatic invasive species are highlighted.

Taxa	Occurrence (Percent)
Amphipods	48.8
Flatworms	2.3
Isopods	11.6
Leech	4.7
Mayfly nymph	23.3
Midgefly larvae	79.1
Water Mite	27.9
Nematodes	30.2
Ostracods	37.2
Tubifex larvae	23.3
Zebra Mussel	9.3

Table 15. Results from Kruskal-Wallis tests for the effects of Dredge history on macroinvertebrate taxa richness in grab samples from sites without piers. Significant effects of dredging for each Exposure/Substrate combination are indicated with asterisks (*=significant, **=highly significant).

Exposure	Substrate Type	df	Chi-Square	P-value
Exposed	Bedrock	1	0.333	0.564
Exposed	Cobble	1	0.288	0.592
Exposed	Sand	1	9.395	0.002 **
Protected	Bedrock	1	1.607	0.205
Protected	Cobble	1	0.046	0.830
Protected	Sand	1	8.667	0.003 **

Table 16. Analysis of variance (ANOVA) results for the full dataset on A) Amphipod, B) Midgefly, and C) Ostracod abundance. A Type III ANOVA model was employed for these analyses. Significant effects of source factors are indicated with asterisks (*=significant, **=highly significant).

A) Amphipod Abundance

Source	df	Significance Level
Dredge	1	0.070
Substrate Type	2	0.125
Exposure	1	0.001 **
Dredge X Substrate	2	0.239
Dredge X Exposure	1	0.853
Substrate X Exposure	2	0.002 **
Dredge X Substrate X Exposure	2	0.002 **

B) Midgefly Abundance

Source	df	Significance Level
Dredge	1	0.652
Substrate Type	2	<0.001 **
Exposure	1	<0.001 **
Dredge X Substrate	2	0.096
Dredge X Exposure	1	0.245
Substrate X Exposure	2	<0.001 **
Dredge X Substrate X Exposure	2	0.058

C) Ostracod Abundance

Source	df	Significance Level
Dredge	1	0.491
Substrate Type	2	0.041 *
Exposure	1	0.030 *
Dredge X Substrate	2	0.547
Dredge X Exposure	1	0.941
Substrate X Exposure	2	0.489
Dredge X Substrate X Exposure	2	0.945

sites, this is not unexpected because abundances were measured on a geometric scale giving rise to large variances. Considering the geometric nature of the abundance scale, it is important to note the trends for some groups. For instance, amphipods were generally less abundant at previously dredged sites, by a 5- or 10-fold difference depending on location (Figure 16). Similar patterns were observed for midge fly larvae and for ostracods as well (Figures 17 & 18). In addition, exposed sites typically had lower abundances of macroinvertebrates than protected locations, and sites with piers had lower abundances than those without piers.

Consistent with the abundance patterns noted above, the cluster analysis based on community composition of the macroinvertebrate taxa identified groupings that differed based on substrates and exposure locations, but also defined some groups based on dredging history. There were two clear groupings in the nonpier data set. One grouping included sites that had either bedrock or sand substrates (Figure 19). These sites were essentially devoid of benthic invertebrates (Table 17). The other grouping included sites that had not previously been dredged and contained various taxa such as amphipods, nematodes, ostracods and midgefly larvae. For the sites with piers, one grouping was defined by sites in exposed areas, all of which did not have benthic invertebrates in grab samples (Figure 20). A second grouping was for sites that were previously dredged, and contained exclusively midgefly larvae and amphipods.

Particle grain size and shape were correlated with some aspects of the macroinvertebrate data. There was a significant overall positive correlation between particle grain size and amphipod abundance (Pearson Correlation Coefficient, $r = 0.245$, $n=72$, $P=0.011$). Both particle size and particle shape were negatively correlated with the

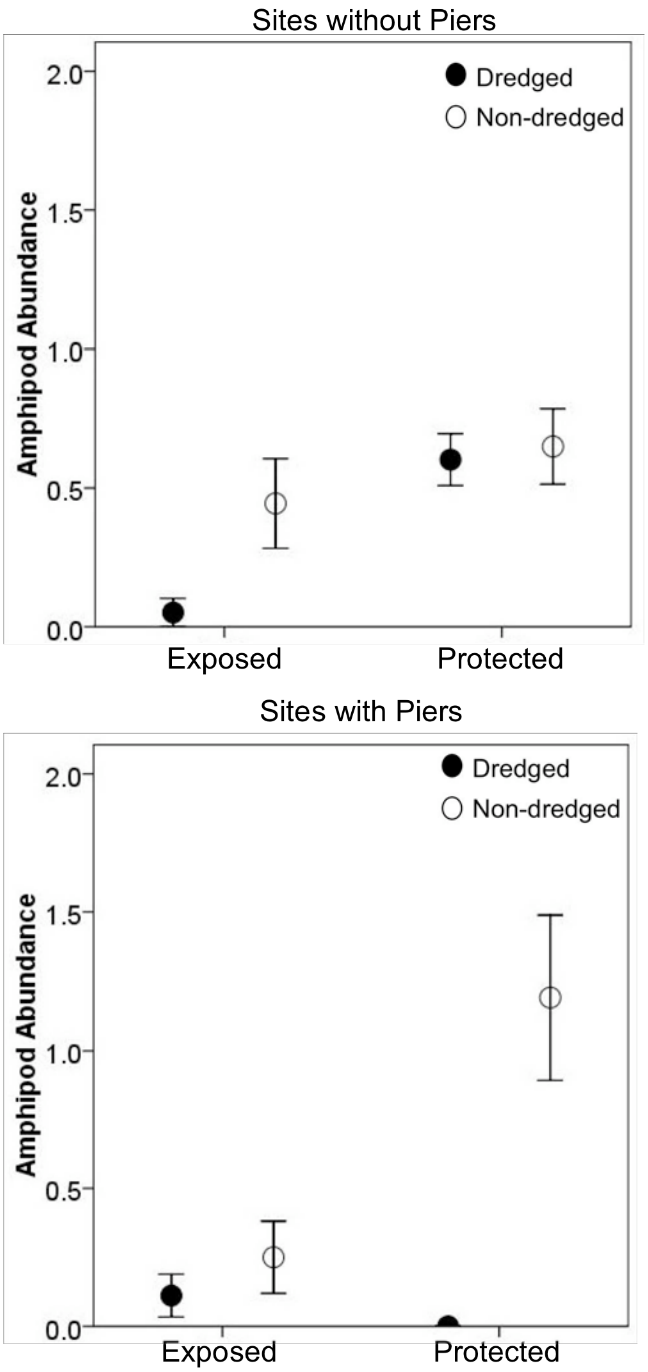

Figure 16. Amphipod abundance (mean +/- 1 SEM) in grab samples from exposed or protected sites at locations without (top) or with (bottom) piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate previously dredged sites.

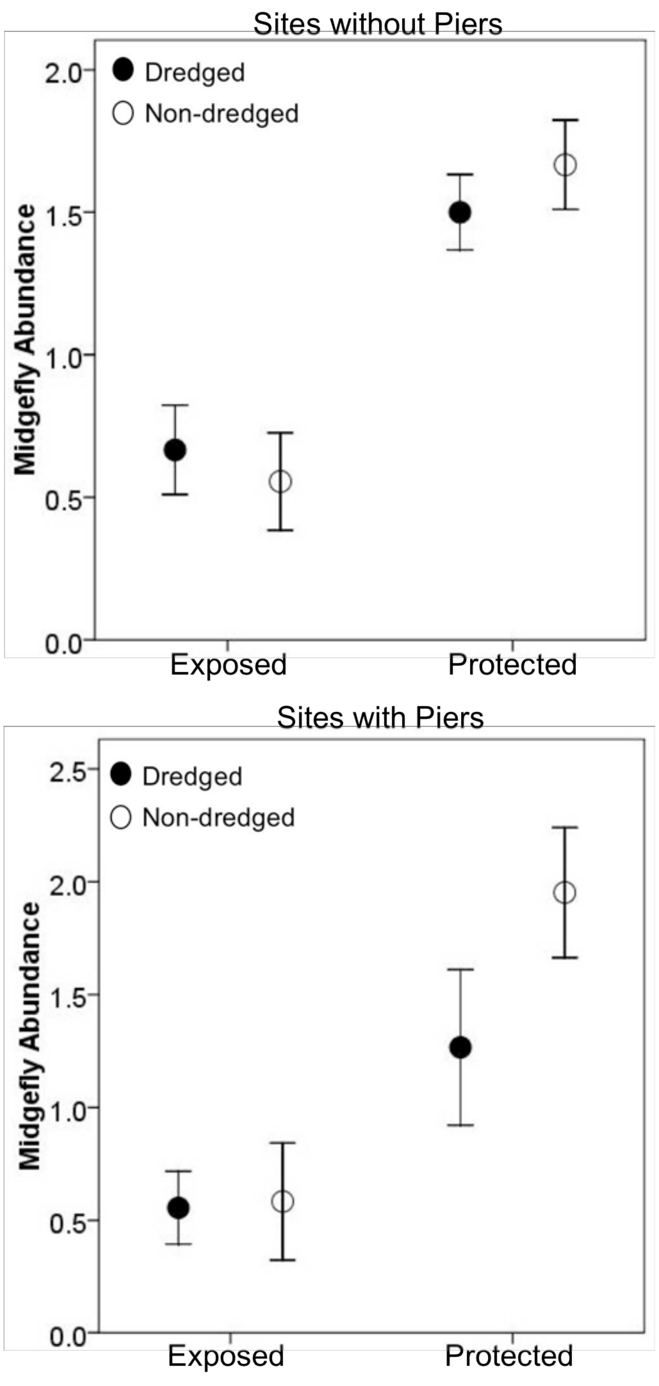

Figure 17. Midgefly abundance (mean +/- 1 SEM) in grab samples from exposed or protected sites at locations without (top) or with (bottom) piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate previously dredged sites.

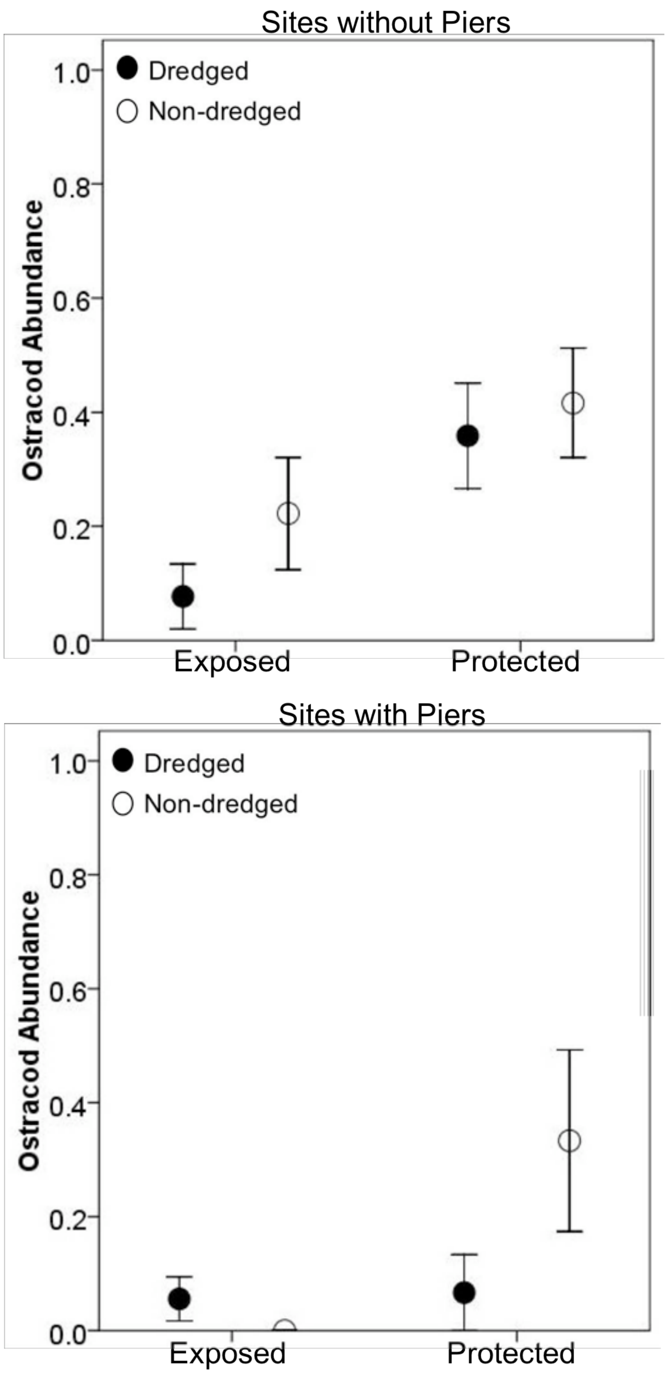

Figure 18. Ostracod abundance (mean +/- 1 SEM) in grab samples from exposed or protected sites at locations without (top) or with (bottom) piers during summer 2008. Open symbols indicate non-dredged sites, filled symbols indicate previously dredged sites.

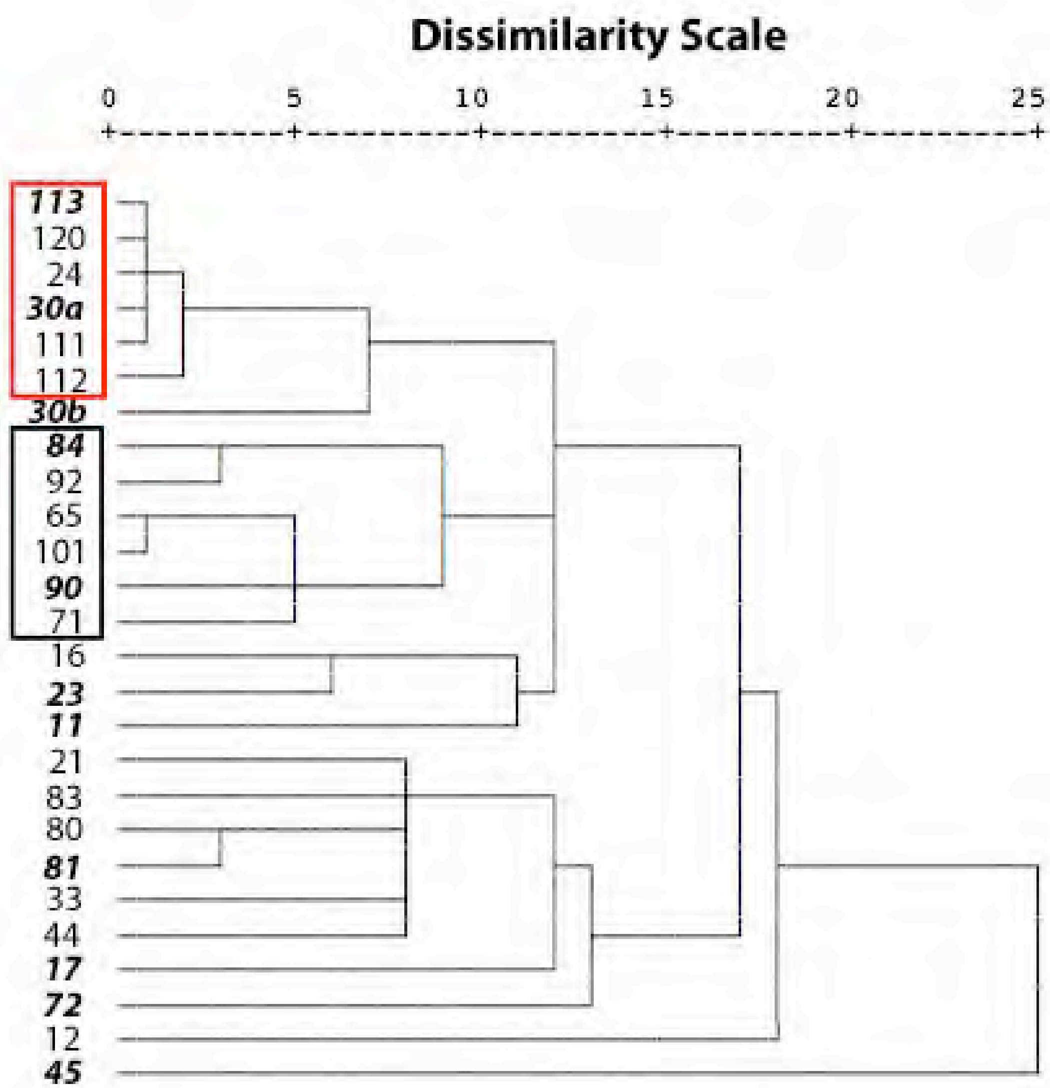

Figure 19. Dendrogram of sites without piers resulting from a clustering analysis based on macroinvertebrates using the centroid method of defining groupings. The group of sites outlined in red occurred on bedrock or sand, while those boxed in black primarily have no dredge history.

Table 17. Benthic macroinvertebrate associations observed at sites in groupings defined by cluster analysis using a centroid agglomerative method.

Site without Piers

Bedrock/Sand Grouping
No benthos

Nondredged Grouping
Midgefly Larvae
Amphipods
Nematodes
Ostracods

Sites with Pier

Exposed Grouping
No benthos

Dredged Grouping
Midgefly Larvae
Amphipods

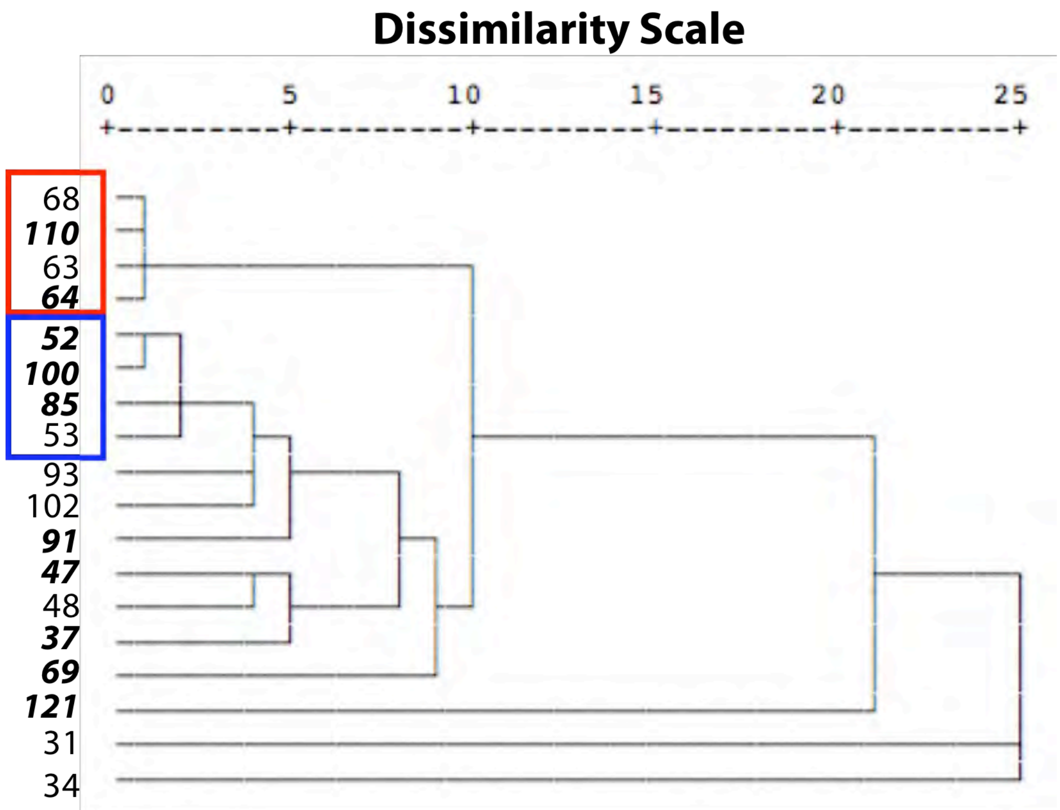

Figure 20. Dendrogram of sites with piers resulting from a clustering analysis based on macroinvertebrates using the centroid method of defining groupings. The group of sites outlined in red are all exposed sites, and those surrounded by the blue box were previously dredged.

total number of macroinvertebrate taxa (size: r= -0.20, n=287, P=0.001; shape: r= -0.194, n=152, P=0.017). These data indicate that more amphipods and midge fly larvae are normally found in sites with larger grain sizes, but that fewer taxa overall will be found in these sites. In addition, fewer taxa are found in sites with rounder sediments particles.

Conclusions and Summary

Dredging Effects:

There were clear and obvious differences between sites that had been previously dredged and those without any dredging history. Previously dredged sites exhibited the following characteristics compared to non-dredges sites:

- significantly smaller sediment grain size and rounder particles
- significantly greater amounts of silt and occasional low oxygen conditions (up to 70 cm of silt was observed in the middle of dredged channels)
- higher amounts of vegetation and more extensive coverage of sediment by vegetation (with greater coverage in the middle of the channel)
- significantly greater number of plant species (more than twice as many species on average)
- distinct vegetation composition, including two invasive plant species (Eurasian water-milfoil and Curly-leaf pondweed) and Muskgrass
- at bedrock sites, significantly more benthic algae such as *Cladophora* in areas adjacent to dredged channels compared to mid-channel or non-dredged sites
- trend towards lower macroinvertebrate abundance but higher diversity

These differences demonstrate that there have been long-term and cumulative impacts of dredging on both physical and biological characteristics of near shore environments around Door County, WI. These differences are distinct from the expected effects of the varying exposure and substrate conditions that occur along the shoreline.

The significantly greater abundance of smaller particles observed at previously dredged sites supports the conclusion that dredged channels accumulate smaller particles. Based on the settling characteristics of particles in moving water, this is likely due to reduced flow in channels and subsequent retention of smaller particles (Wood & Armitage 1979). In addition, the observed higher abundance of rounder particles in previously dredged locations is also consistent with previous expectations. Rounder particles generally sink faster because of reduced resistance (McAnally 2000, Germano and Cary 2005). Rounder particles also usually indicate longer exposure to eroding forces, likely during transport. In addition, sorting processes that typically occur during settling based on flow velocity differences also help explain the higher prevalence of smaller, rounder particles at dredged locations (Environment Canada 2002, Germano and Cary 2005). Round particles often result in more highly compacted sediments, decreased oxygen permeability as well as reduced interstitial spaces. This could be one possible explanation of the strong smell of sulfur observed in some of the dredged channels where large amounts of black silt had accumulated.

Higher abundance of smaller particles was also related to increased macrophyte density at previously dredged sites, especially on cobble and sand substrates. Previous work has shown that macrophytes reduce water speed and overall water movement, as well as trap sediment among their leaves and stems (Fonesca & Fisher 1986). In addition, fine sediment is often generated by the decomposition of macrophytes (Wood & Armitage 1997).

Based on these data the following explanation of the effects of dredging, especially in locations with cobble and sand substrates, seems reasonable. Construction of a dredged channel produces a new depression in the near shore environment that has numerous consequences: 1) the channel becomes an environment with reduced water flow, 2) this lower flow environment results in increased deposition of smaller, rounder particles, 3) macrophytes can establish themselves in these lower flow environments, 4) the presence of macrophytes further reduces water flow, leading to further deposition and accumulation of sediment.

A further effect of dredging was an increased diversity and density of macrophytes. It is well documented that both physical disturbance and invasions by exotic species often result in increased diversity in aquatic ecosystems (Pickett & White 1985, Ward & Ricciardi 2007). The clustering analysis identified previously dredged sites as having a distinct vegetation composition. This association included both of the invasive macrophyte species documented in this study (Eurasian water-milfoil, and Curly-leaf pondweed). Although we did not measure densities of individual macrophyte species, others have shown that stands of invasive macrophytes are denser than native species (Kelly & Hawes 2005), especially Eurasian water-milfoil (e.g. Budd et al. 1995). In addition, another long-term effect of channel dredging can be increased nutrient availability for macrophytes following disturbance of the sediment (Davis & Brinson 1980).

Macroinvertebrate abundance tended to be lower in previously dredged sites, but the high amount of variability among exposure conditions and substrate types resulted in non-significant dredge effects overall. The trends towards lower abundances, especially for amphipods and midge fly larvae, are even more interesting because expectations from other studies would suggest that just the opposite should have been observed based on macrophyte densities. Overall, macrophyte density is typically positively correlated with macroinvertebrate abundance, often due to increased oxygenation of the sediments by roots and increases in food sources derived from decaying plant material (Sagova et al. 1983, Sagova-Mareckova 2002, Strayer et al. 2003). Invasive plant communities often harbor higher diversity and density of macroinvertebrates as well (Kelly & Hawes 2005), which may help explain the significantly higher taxon diversity at locations with sand substrate. Macrophyte species with finely dissected leaves, like the invasive Eurasian water-milfoil, are especially known to harbor increased densities of macroinvertebrates like midge fly larvae (Gerrish & Bristow 1979). However, exposure and substrate conditions have been shown to be two key factors determining community structure in macroinvertebrates, and this appeared to be the case in this study as well.

Exposure Effects:

Sites exposed to waves and currents from either Green Bay or Lake Michigan generally shared some common characteristics based on the results of this study. Exposed sites exhibited the following traits compared to protected sites:

- larger particle sizes and a more rounded particle shape
- lower vegetation density based on both rake density and area coverage

- higher abundance of benthic algae, especially adjacent to previously dredged channels
- lower macroinvertebrate density and diversity

Stress from wave action is the most likely reason for the effects of exposure conditions on the characteristics studied. Higher speed and more frequent water movement are known to sort sediments and prevent accumulation of smaller particles (Wood & Armitage 1997, McAnally 2000). Exposure to waves and currents can also prevent establishment and growth of macrophytes. Even once established, fragmentation of leaves and stems by wave action can be a significant factor limiting the growth of macrophytes in exposed sites (Davis & Brinson 1980). Exposure is also a major factor determining macroinvertebrate composition, with fewer taxa able to survive the mechanical stresses in areas with higher wave energy (Barton & Hynes 1978, Metzler & Sager 1986, Tolonen et al. 2001). Plus, the lack of macrophytes can further contribute to lower density and diversity of macroinvertebrates by failing to provide refuges from predatory fishes (Tolonen et al. 2001). Overall, the stress encountered in exposed coastal shorelines appears to preclude the development of extensive macrophyte and macroinvertebrate communities. As a result, the negative effects of dredging on these aspects of biological communities will likely be less severe in exposed sites than in protected locations.

Substrate Effects:

In addition to the clear overall effects of dredging and exposure, there were also obvious differences among sites with different types of substrate.

- macrophytes were more abundant on cobble and sand than on bedrock sites

- benthic algae was more abundant on bedrock than cobble or sand
- sites with cobble substrate contained the highest diversity of macroinvertebrates
- amphipod abundance was positively related to sediment particle size

Locations with primarily a bedrock substrate are relatively harsh environments for organisms. The lower macrophyte abundance at bedrock sites is consistent with previous work showing that these environments are less suitable for root growth and attachment and can have lower nutrient availability for plant growth (Davis & Brinson 1980). However, benthic algae such as *Cladophora* and *Chara* can thrive in these environments because they require solid surfaces for attachment and derive their nutrients directly from the water (Dodds & Gudder 1992). This could also explain why benthic algae were more abundant outside of the dredged channels because the smaller, loose particles in the middle of channels would provide a less suitable substrate for the algae. Consequently, dredging impacts will be related more to benthic algae abundance and coverage in areas with primarily bedrock substrates and less with macrophyte effects.

Cobble and sand provide a better substrate for macrophyte growth because they can provide more stability for root establishment and higher nutrient availability than areas with primarily a bedrock substrate (Davis & Brinson 1980). Between cobble and sand substrates, cobble areas exhibited higher growth of macrophytes overall, likely due to both higher stability for root and rhizome production and higher nutrient retention and availability. Cobble substrates have a wider particle size range and contain more organic matter than sand substrates generally (Davis & Brinson 1980, Wood & Armitage 1997). While sand may be a poorer environment for macrophyte growth, we did observe significant increases in macrophytes in previously dredged locations with primarily a sand substrate. Macrophytes were significantly higher in abundance and area coverage in the middle of dredged channels. This is likely due to the accumulation of smaller particles of a more organic nature (i.e. silt) in channels, providing increased nutrients for plant growth compared to adjacent sandy areas. A problem with extensive macrophyte growth in areas with cobble and sand substrates is thus an important long-term and cumulative impact of dredging.

Sites with cobble substrate exhibited the highest diversity and abundance of macroinvertebrates. It is well documented that increased heterogeneity of physical space provides more refuges from predation for macroinvertebrates (Barton & Hynes 1978, Tolonen et al. 2001), and the cobble substrates provide this kind of habitat. This is further supported by the significant positive correlations between amphipod abundance and particle size in this study. This is consistent with results in other studies showing positive correlations of amphipods and sediment grain size (Barton & Hynes 1978, Sagova et al. 1983, Sagova-Mareckova 2002). Because cobble areas had higher abundances overall of macroinvertebrates, it is also not surprising that the negative effects of dredging on macroinvertebrates were more obvious in these locations.

Pier Effects:

Testing the for effects of piers was not part of the original design of this study, but we were able to sample an additional set of sites with piers that fulfilled most of the desired aspects of our study at least once during the summer. Based on this limited set of data, it was observed that sites with piers showed a tendency to have higher abundances of macroinvertebrates, especially at protected sites. In addition, there was a trend of greater impact of dredging on abundance of amphipods, midge fly larvae and ostracods.

Aside from these differences, there was no clear effect of piers that was separate from the dredging, exposure or substrate type effects. However, a more extensive study focused on this topic would be required to make any definitive conclusions about this topic.

Finally, some features of sites were not significantly affected by previous dredging. There was no significant difference in occurrence of invasive plants or zebra mussels at previously dredged versus non-dredged sites. This was mainly due to the wide distribution of these species. The invasive plant species documented, Eurasian water-milfoil Curly-leaf pondweed, were occurred commonly in the waters around Door County (documented in over 50% and more than 25% of the sites, respectively). Live specimens of zebra mussels were found in only 9% of the shallow near shore zones examined, but shells of dreissenid mussels were found in over 50% of the sites, as expected based on the common prevalence of mussels in these locations following the successful invasion of Green Bay and Lake Michigan almost two decades ago.

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Evaluating the potential long-term and cumulative impacts from dredging to accommodate boat access in Green Bay and Lake Michigan in Door County, Wisconsin.

Final Report

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Table of Contents

Appendix A – Sampling Sites

Table A1. Site numbers and locations for all sites sampled during summer 2008. Assignment of each site to experimental design categories is indicated in Table 1 and Table 2.

Site	Location	North Coordinate	West Coordinate
11	Little Sturgeon Bay - 3810 Rocky Shores Dr	44” deg, 51’ 8.9”	87 deg, 33’ 16.0”
12	Little Sturgeon Bay - 3766 Rocky Shores Dr	44 deg, 51’ 8.5”	87 deg, 33’ 9.6”
15	Little Sturgeon Bay - Squaw Island	44 deg, 49’ 15.7”	87 deg, 33’ 23.9”
16	Little Sturgeon Bay - 3300 Squaw Island Rd	44 deg, 49’ 43.1”	87 deg, 33’ 24.7”
17	Little Sturgeon Bay - 3476 Stevenson Pier Rd	44 deg, 50’ 7.9”	87 deg, 32’ 26.0”
21	Sawyer Harbor - 4460 Cabots Pt Road	44 deg, 53’ 10.6”	87 deg, 25’ 38.8”
23	Sawyer Harbor - Potawatomi Park ramp	44 deg, 52’ 43.2”	87 deg, 25’ 35.5”
24	Sawyer Harbor - near Potawatomi Park ramp	44 deg, 52’ 40.8”	87 deg, 25’ 27.6”
30	Egg Harbor - Point Creek Circle & Shore Dr.	44 deg, 3’ 7.3”	87 deg, 18’ 13.4”
31	Egg Harbor - Point Creek Circle	45 deg, 3’ 8.3”	87 deg, 17’ 57.9”
33	Egg Harbor beach	45 deg, 2’ 45.9”	87 deg, 17’ 6.5”
34	Egg Harbor - 7783 Horseshoe B Road	45 deg, 2’ 50.4”	87 deg, 17’ 2.2”
37	Egg Harbor - Door County Land Trust	45 deg, 3’ 14.2”	87 deg, 16’ 58.4”
44	Ephraim - 10251 N Shore Rd	45 deg, 10’ 10.2”	87 deg, 10’ 23.4”
45	Ephraim - 10267 N Shore Rd	45 deg, 10’ 16.2”	87 deg, 10’ 29.3”
47	Ephraim - 10325 N Shore Rd	45 deg, 10’ 24.8”	87 deg, 10’ 32.3”
48	Ephraim - 10345 N Shore Rd	45 deg, 10’ 27.6”	87 deg, 10’ 28.9”
52	Little Sister Bay - 723 Little Sister Rd	45 deg, 11’ 31.1”	87 deg, 8’ 49.5”
53	Little Sister Bay - 735 Little Sister Rd	45 deg, 11’ 32.5”	87 deg, 8’ 44.9”
63	Sister Bay - Island View cottages	45 deg, 11’ 59.9”	87 deg, 7’ 13.1”
64	Sister Bay - Heritage Harbor	45 deg, 12’ 7.1”	87 deg, 7’ 11.5”
65	Sister Bay - 10983 STH 42	45 deg, 12’ 15.3”	87 deg, 7’ 10.3”
68	Sister Bay - 11429 Beach Ln N	45 deg, 13’ 28.6”	87 deg, 7’ 23.1”
69	Sister Bay - 11477 Beach Ln N	45 deg, 13’ 38.1”	87 deg, 7’ 18.0”
71	Sand Bay Town park	45 deg, 12’ 42.5”	87 deg, 2’ 25.4”
72	Sand Bay - 11078 Sand Bay Lane	45 deg, 12’ 31.5”	87 deg, 2’ 24.3”
80	North Bay - 9881 NORTH BAY RD	45 deg, 8’ 59.1”	87 deg, 3’ 37.8”
81	North Bay ramp	45 deg, 9’ 2.9”	87 deg, 3’ 46.3”
83	North Bay - 9511 North Bay Dr	45 deg, 7’ 54.3”	87 deg, 4’ 29.8”
84	North Bay - 9452 N Bay Dr	45 deg, 7’ 42.2”	87 deg, 4’ 25.2”
85	North Bay - 9372 CTH Q	45 deg, 7’ 38.5”	87 deg, 4’ 22.5”
90	Moonlight Bay – Nelson, south of ramp	45 deg, 4’ 49.4”	87 deg, 4’ 5.1”
91	Moonlight Bay - town ramp	45 deg, 4’ 54.3”	87 deg, 4’ 4.8”
92	Moonlight Bay - near ramp	45 deg, 4’ 57.4”	87 deg, 4’ 5.8”
93	Moonlight Bay - north of ramp	45 deg, 5’ 3.4”	87 deg, 4’ 49.8”
100	Baileys Harbor Marina	45 deg, 3’ 57.9”	87 deg, 7’ 16.2”
101	Baileys Harbor - 8090 STH 57	45 deg, 3’ 49.6”	87 deg, 7’ 15.8”
102	Baileys Harbor - 8048 STH 57	45 deg, 3’ 41.3”	87 deg, 7’ 20.0”
110	Whitefish Bay ramp	44 deg, 54’ 20.8”	87 deg, 12’ 55.2”
111	Whitefish Bay - anywhere near ramp	44 deg, 54’ 9.7”	87 deg, 12’ 58.7”
112	Whitefish Point - N of Mohr	44 deg, 52’ 46.6”	87 deg, 12’ 20.9”
113	Whitefish Point - 4242 Glidden	44 deg, 52’ 37.8”	87 deg, 12’ 16.2”
120	Egg Harbor - S of Schneider	45 deg, 4’ 18.9”	87 deg, 16’ 54.9”
121	Egg Harbor -Schneider, 8215 White Cliff Rd	45 deg, 4’ 24.0”	87 deg, 16’ 52.8”

Little Sturgeon Bay, Sites 10 -17

Sawyer Harbor, Sites 20 - 24

Figure A1a. Aerial photographs of sites in Little Sturgeon Bay and Sawyer Harbor, WI.

Figure A1b. Aerial photographs of sites in Egg Harbor, WI.

Ephraim, Sites 40 - 48

Little Sister Bay, Sites 50 - 53

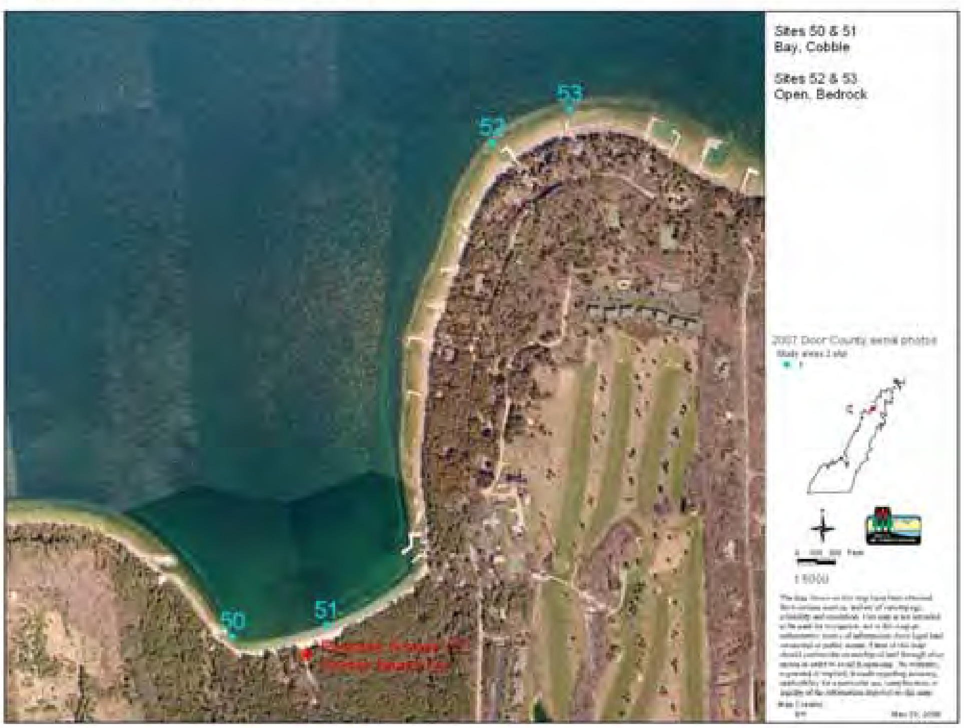


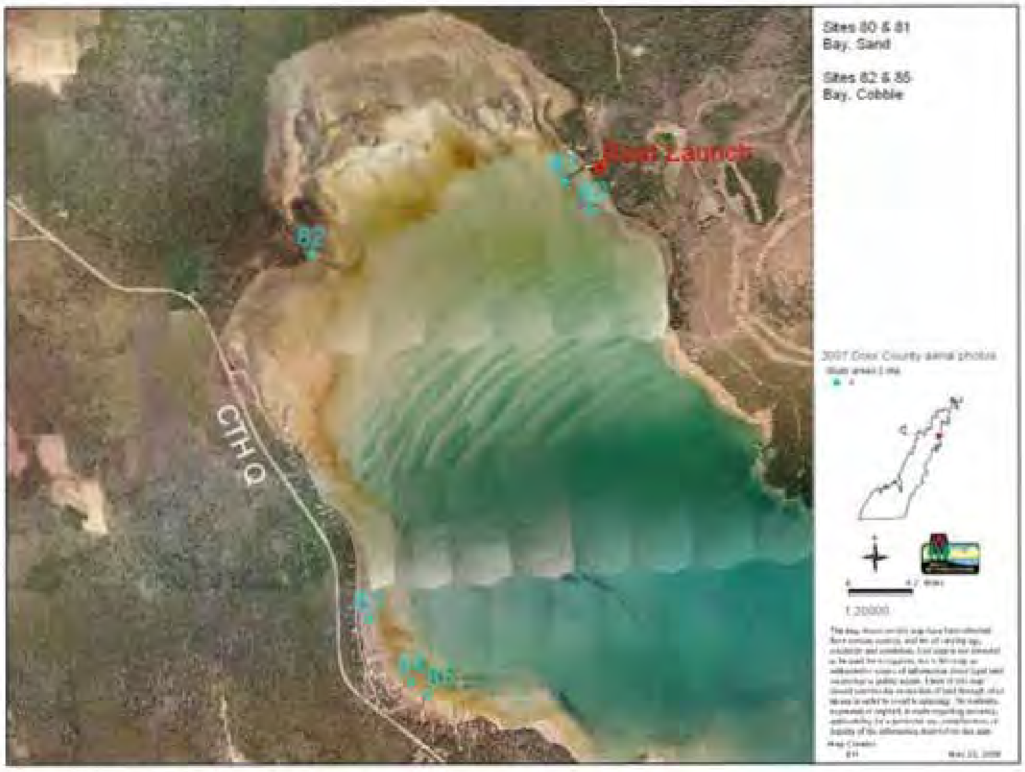
Figure A1c. Aerial photographs of sites in Ephraim and Little Sister Bay, WI.

Sister Bay, Sites 60 - 69

Sand Bay, Sites 70 - 73, Bay, Sand

Figure A1d. Aerial photographs of sites in Sister Bay and Sand Bay, WI.

North Bay, Sites 80 - 85



Moonlight Bay, Sites 90 - 93, Bay, Bedrock

Figure A1e. Aerial photographs of sites in North Bay and Moonlight Bay, WI.

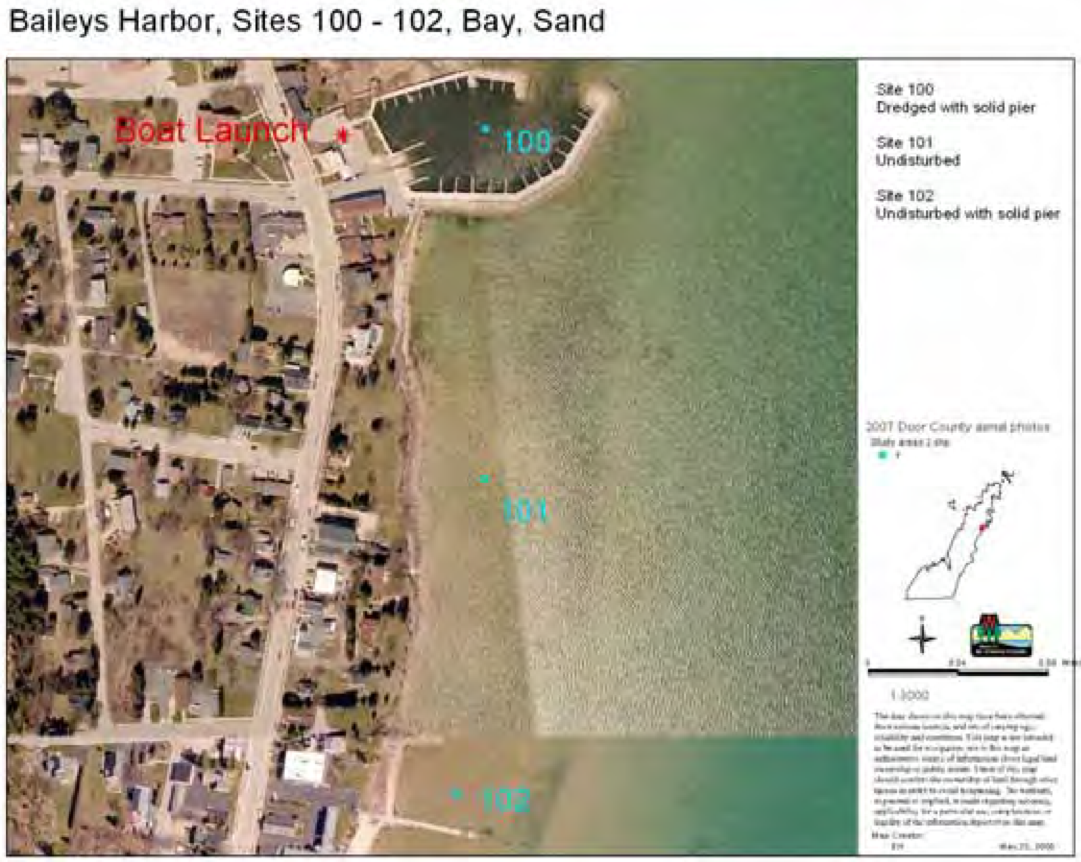


Figure A1f. Aerial photographs of sites in Baileys Harbor, WI.

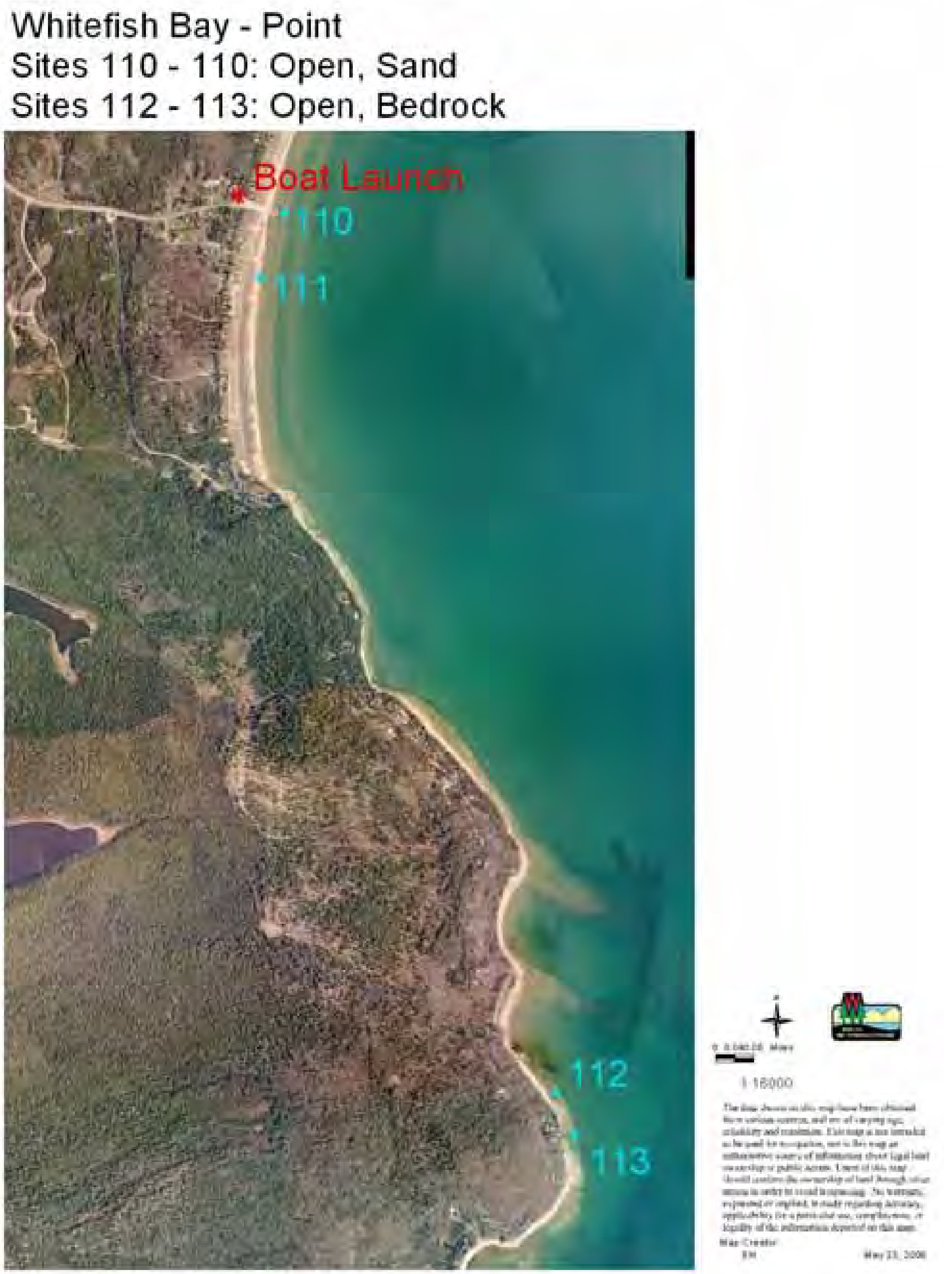


Figure A1g. Aerial photographs of sites in Whitefish Bay, WI.

Appendix B. Sediment Characteristics Analysis

Table B1. Particle size classification scale and weighting factors used for sediment analysis. Modified from Wentworth (1992), US ACE (1996) and Environment Canada (2002).

Class	Criterion	Size	Weighting Factor
Coarse	Boulders	600 mm +	10.0
	Cobbles	250-600 mm	9.0
	Pebbles	75-250 mm	8.0
	Gravel	2-75 mm	7.0
	Very coarse sand	1-2 mm	6.0
	Coarse sand	0.5-1 mm	5.0
	Medium sand Fine	0.25-0.5 mm	4.0
	sand	0.125-0.25 mm	3.0
	Very fine sand	0.063-0.125 mm	2.0
Fine	Silt	< 63 um	1.0
	Clay	< 4 um	0.5

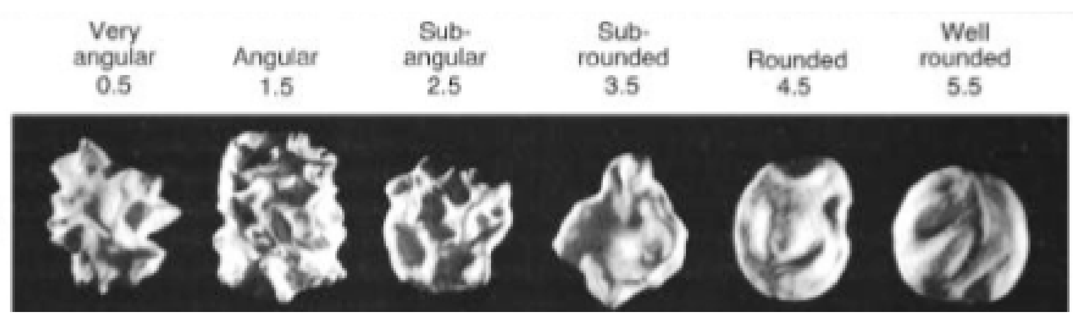


Figure B1. Roundness scale used to characterize sediment particle shape. Taken from Environment Canada (2002)