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DISTRIBUTION OF SHORE PROTECTION STRUCTURES AND THEIR EROSION EFFECTIVENESS AND BIOLOGICAL COMPATIBILITY

Co-principal investigators
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Ohio Lake Erie Commission's Lake Erie Protection Fund Grant Number LEQI 01-08 and Coastal Zone Management Act of 1972, as amended, administered by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration Grant Number NA03NOS4190096

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ABSTRACT

An inventory of shore structures along the Ohio Lake Erie coast began in 1996 and was finished in 2001. Data included the geo-referenced positions of each structure's ends, as well as structure type, composition, attributes, effectiveness, and dimensions. After merging the spatial and informational data-sets, a check of the spatial quality of the data began in 2002 and continued through 2003. The density distribution of the structures along the coast was compared to historical records and the continued armoring of Ohio's coast was documented. Dense protection along the mainland coast ranged from more that 60 percent to nearly 100 percent. An indicator for erosion effectiveness was developed and nearly 50 percent of the mainland structures are included in the "more effective structure/more effective composition" category. An indicator for biologic compatibility was also developed. This indicator ranked more than 50 percent of the mainland structures as "non-favorable structure/non-favorable composition" with respect to the biologic compatibility. To date, shore structures have been built for erosion protection and not for biologic compatibility and habitat restoration. Given the reality that shore development will continue, it is recommended that the construction of structures along the coast of Lake Erie not only consider effective erosion protection, but also consider enhancement of the biologic nearshore habitat.

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CONTENTS

I. Introduction
   a. Purpose
   b. Problems
   c. Approach
   d. Acknowledgements
II. Past Work
   a. Previous inventories by Ohio Geological Survey
   b. Other inventories
III. Methods
   a. Field sheets
      i. Datasheets
      ii. Field base maps
   b. Data collection
      i. Introduction
      ii. Time frame work performed
      iii. GPS
         1. Introduction
         2. Field procedure and equipment
         3. The GPS point verses the structure position
         4. Accuracy/Resolution evaluation of data
      iv. Numbering system for structures
      v. Field teams, training and size
      vi. GIS
         1. Geo-referenced photos
         2. Database management
      vii. Challenges
         1. Introduction
         2. Numbering system and structure type classification
         3. Changes to the shore structures during inventory
         4. Changes in the system and the equipment
   c. Quality Assurance/Quality Control Check
      i. Time frame work performed
      ii. GPS
      iii. Numbering system for structures
      iv. GIS
         1. Geo-referenced photos
         2. Database management

IV. Analysis
  a. Density distribution of shore structures, this study and previous work
  b. Indicators
    i. Introduction
    ii. Erosion effectiveness
    iii. Biological compatibility
    iv. Grouping multiple entry structures into indicators
V. Results
  a. Structure Density
  b. Erosion effectiveness indicator
  c. Biological compatibility indicator
VI. Conclusions
VII. References cited

FIGURES

1. Example of field datasheet
2. Mainland distribution of sparse structure density over time
3. Mainland distribution of dense structure density over time
4. Open lake islands distribution of sparse structure density over time
5. Open lake islands distribution of dense structure density over time
6. Sandusky Bay distributions of sparse structure density over time
7. Sandusky Bay distributions of dense structure density over time
8. Mainland erosion effectiveness indicator
9. Open lake islands erosion effectiveness indicator
10. Sandusky Bay erosion effectiveness indicator
11. Mainland biologic compatibility indicator
12. Open lake islands biologic compatibility indicator
13. Sandusky Bay biologic compatibility indicator

TABLES

1. Data groupings used for erosion effectiveness
2. Data groupings used for biologic compatibility
3. Structure density percent changes from the 1870's through the 1990's
4. Erosion effectiveness indicator
5. Biological compatibility indicator

ACRONYMS USED

CEA ---------- Coastal Erosion Area
GIS ---------- Geographic Information System
GPS ---------- Global Positioning System
LEPF --------- Lake Erie Protection Fund
ODNR ------ Ohio Department of Natural Resources
OGS --------- ODNR, Division of Geological Survey
Ohio EPA --- Ohio Environmental Protection Agency
PDOP -------- Precision Dilution of Position
QA/QC ------ Quality Assurance/Quality Control
REALM ----- ODNR, Office of Real Estate and Land Management
SSI ---------- Shore Structure Inventory
USACE ------ U.S. Army Corps of Engineers
USGS -------- U.S. Geological Survey

INTRODUCTION

PURPOSE

The purpose of this report is to summarize the work completed on the Shore Structure Inventory, to date. The specific goals of the project are:

1. Complete an inventory of shore protection structures for the Ohio mainland shore, Kelleys Island, and for North, Middle, and South Bass Islands.
2. Develop a Geographic Information System (GIS) containing all of the SSI data.
3. Develop a scoring system to rate extent of shoreline armoring.

PROBLEMS

The Ohio shoreline of Lake Erie is 297 miles (478 km) long and is densely developed with a large number of structures built along most of its shoreline. Structural protection began in the early 1800's with development of harbors, which were designed as aids to waterborne navigation. Although the harbor protection structures allowed for river mouths to stay open by reducing the littoral sediment transport into the river mouths, the harbors starved the adjacent, downdrift shoreline of sand. Sand acts as natural shoreline erosion protection, therefore the loss of littoral sediment downdrift of harbors accelerated shoreline erosion in these areas. To combat erosion, littoral property owners began armoring the shoreline. Because an artificial structure can create erosion downdrift of the structure, the affected shoreline, in turn, requires armoring to mitigate the ravages of wave energy directly breaking on the shoreline as opposed to dissipating along a beach. This domino effect of erosion and shoreline armoring continues to this day.

APPROACH

To further the Ohio Department of Natural Resources ODNR, Division of Geological Survey's (OGS's), documentation of armoring along Ohio's portion of the Lake Erie coast, the Lake Erie Geology Group inventoried the structures along the shoreline during the late 1990's. Since the last SSI was completed in the mid-1970's, many new structures have been built; also structures that existed in the 1970's have been removed, rebuilt and or buried.

This latest SSI is a physical accounting of structures built on or adjacent to the Ohio shore of Lake Erie that have, or can have, an affect on shoreline processes, one of which is coastal erosion. In the field, positional data was collected for each structure, along with the following attributes:

1. Structure type (revetment, seawall, breakwater (attached and offshore), groin, jetty, dock, pier, dike, retaining wall, boat ramp and miscellaneous structures).
2. Construction material (gabions, concrete (poured and slabs), construction rubble, steel (sheet piling, plates, tanks, cribs, barges), timber pilings and cribs, rip-rap rubble, stone blocks, and a variety of concrete modules as well as miscellaneous materials).

3. Estimated dimensions (height, width, length).
4. Effectiveness of the structure (good, average, poor).

County or U.S. Geological Survey (USGS) geo-referenced aerial photographs were obtained as base maps. These data were placed in a GIS for optimal analysis of the Ohio coast.

Density (distribution) of the manmade structures along the Ohio shore was tabulated and compared with previously published data. The shore structures were sorted in GIS to develop indicators for erosion effectiveness and biologic compatibility.

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PAST WORK

Hartley, 1964 reported the effects of large harbor structures on coastal processes along the Ohio shore and the potential need for construction of shore protection structures downdrift of large harbor structures. Carter, 1973 discusses the increasing numbers of smaller protection structures and their affects on the local coast. Carter, Benson, Guy, 1981 presented a historic look at the density of protection structures along the Ohio shore and these data were used for comparison in this study.

PREVIOUS INVENTORIES BY OHIO GEOLOGICAL SURVEY

OGS compiled shore erosion data for each of the eight Ohio counties along the Lake Erie coast in the mid-1970's. Most of these data were published (Carter and Guy, 1983, 1980; Benson, 1978; Carter, 1976). The Lorain, Cuyahoga and Ottawa County reports exist as file reports in the Lake Erie Geology Group of the OGS. Associated with each of these reports is an inventory of the shore structures along the Ohio coast in the early- to mid-1970's. Additional tabulations were made of the structures visible on the U.S. Lake Survey field sheets from 1876-77, and the U.S. Agricultural Adjustment Administration shoreline flight photos from the late-1930's.

OTHER INVENTORIES

The U.S. Army Corps of Engineers (USACE) produced reports that included shore protection structure inventories in the 1940-50's and 1960's for Ohio's Lake Erie coast (U.S. Army Corps of Engineers, 1945, 1950a, 1950b, 1952a, 1952b, 1952c, 1953a, 1953b, 1953c, 1954, 1963). The USACE and The Ohio State University also prepared a mainland shore structure inventory in the early 1980's using videotapes taken from a helicopter. This report was not widely distributed and much of the data was lost in a flood (personal communication Don Guy).

METHODS

FIELD SHEETS

Datasheets

A field check-box datasheet was developed and a similar Microsoft® Access database form was made. Following fieldwork, the data from the check-box datasheet were entered into the Microsoft® Access database form so both a paper and digital copy of the datasheet existed. Physical attributes of each structure were noted on the standard datasheet (Fig.1). These attributes included general information, structure type, composition, other attributes, effectiveness, and estimates of each structure's dimensions.

Ohio Shore Structure Inventory Data Sheet

Structure Information:

County:_____ JOB (1990 frame #)_____ Collected by:_____

Structure #_____Transects: (1990 frame #) Beg._____ End_____

Time:___:____ ❒AM / ❒ PM (❒ EST / ❒ DST) Date:_____/_____/_____
Owner / Company:_____
Address:(STREET)_____(CITY)_____

Structure Type:
❒Revetment ❒Sea Wall ❒Attached Breakwater ❒Groin ❒Jetty
❒Dock ❒Pier ❒Offshore Breakwater ❒Dike ❒Retaining Wall
❒Boat Ramp ❒Other:_____

Composition:
❒Gabions ❒Concrete:(❒ Poured ❒Slabs) ❒Construction Rubble
❒Steel Sheet Piling ❒Steel Plate ❒Steel Tanks ❒Cribbing
❒Barges ❒Timber Pilings ❒Rip-Rap Rubble ❒Stone Block
❒Concrete Cubes Concrete Modules: (❒Campbell ❒Cone & Wedge ❒Great Lakes Construction ❒Bags and Tubes ❒Rings ❒Slabs) ❒Other:_____

Attributes:

❒Segmented ❒Uniform ❒Tapered ❒"L" or ❒"T" Shaped ❒Slush Cap ❒Splash Apron ❒Toe Protection: (❒Rip-Rap ❒Cubes ❒Construction Material

❒Stone Block ❒Gabions ❒Other:_____) ❒Other:_____

Effectiveness:

❒Good ❒Fair ❒Poor: (❒Out Flanked ❒Tilted ❒Large Cracks ❒Submerged ❒Falling Apart ❒Ruins) ❒Other:_____

Dimensions of Structure:
Length:_____ft. (shore parallel)
Width:_____ft. (shore parallel)
Length:_____ft. (shore perpendicular)
Width:_____ft. (shore perpendicular)
Height:_____ft. (from water to top of structure)

Sketch of Structure (optional)

not to scale

Emplacement Data: ❒Unknown ❒Construction ❒Repar ____/____/_____

Notes:_____

Prepared By: Division of Lake Erie Geology Group

Figure 1. Example of field datasheet

Structure datasheets evolved during the early part of the study, but the required data basically stayed the same (Fig. 1). Much of the field data is subjective in nature and dimensions are estimated. Height is relative to the water level at the time of collection on the day of record. The type of structure is also somewhat subjective because many of the structures along the shoreline grade from one type to another or include elements of both shore parallel and shore perpendicular structures. A structure was assigned a specific structure type by its dominant function; if there were parts of the structure that looked like they were built at the same time and were integral to the main structure, the sub-structures were not separately inventoried. An example is a seawall that had many short groins extending from its face; it was inventoried as only one structure, rather than multiple structures (at the discretion of the field crew).

Field base maps

The field base maps used for the SSI were the 1990 air photos that were created as the base for the Coastal Erosion Area (CEA) mapping dated 1997. These photos had transect lines overlaid onto them which were sequentially numbered on each frame from the Ohio/Pennsylvania State Line to the Michigan border and nominally spaced at 100-foot (30.5-meter) intervals along the bluff line. The field base maps were at a scale of 1 inch = 200 feet (1:2400) and were often enlarged to the nominal scale of 1 inch = 100 feet (1:1200) for easier notation of the structure location.

In the field, the approximate location of the structure was marked on the 1990 air photos with the transect lines. These transect lines were then used to give a unique identification to each structure. Structure numbers were based on the County name, CEA frame number, and the transect number where the structure was first encountered at the shore (for attached structures) or adjacent to the shore (for structures that were not attached to the shore). If more than one structure started between transects, the second structure was listed as "–2 ". For example, structure number Ash 299 32-2 started in Ashtabula County on frame number 299 between transects 32 and 33 and was the second structure that started between those two transects to be inventoried. Areas excluded from the inventory include rivers and creeks, inside the major harbor protection structures, the city waterfront of Sandusky, and Muddy Creek Bay in Sandusky Bay, East, Middle, and West Harbors in Ottawa County, and the smaller islands.

DATA COLLECTION

Introduction

The field plan was to collect descriptions and GPS positions for each shore structure along the 212 miles (341 km) of the Ohio mainland and Maumee Bay shoreline, plus the shoreline of the major open lake islands (33 miles, 53 km) and Sandusky Bay with Johnson Island (52 miles, 84 km). One of the project goals was to document the GPS location of at least both ends of the larger shore perpendicular or shore parallel structures; intermediate points were often taken to better define the shape of the structure. The first visit to a structure was used to set the characteristics of the structure (both type and composition). If return visits were made to that structure, missing data would be

added, but if the structure had been changed due to new construction, repair, removal, etc., those changes were not included in the inventory.

Time frame work performed

Fieldwork began in the fall of 1997 and continued through much of the mild winter. Two or three crews collected data during the summer of 1998 when the OGS had interns available. A single crew worked through the winters of 1998 and 1999 when possible. Fieldwork continued through the summers of 1999, 2000, and 2001.

GPS

Introduction-- GPS is a positioning system that is based on a constellation of 24 high-altitude satellites orbiting the earth. A position is calculated by measuring the distance from the unknown location on earth to a group of satellites whose positions are known. Distances are measured in spheres of time from each of the satellites in a group. The intersection of spheres from at least four satellites will provide an accurate location on the earth.

The accuracy of this point can be further improved using a method called differential correction. Differential GPS works by canceling out most of the natural and manmade errors that affect the GPS signals. This is done by applying the corrections to the signal position of a fixed reference receiver to the unknown location. These corrections are constantly changing; the data in common with all the data sets is Greenwich time.

Previous inventories did not have the technical capability available to easily collect absolute position of the shore structures along the coast. With the advent of the GPS, a geo-referenced position of each structure could be easily collected for this inventory.

Field procedure and equipment-- Some of the GPS points were collected with a Corvallas ® MC-GPS unit, but the majority of the points were collected with Trimble® TDC1 units. All GPS point positions were differentially corrected to improve accuracy of the location and the data were downloaded into a Microsoft® Excel spreadsheet. All points were converted into three coordinate systems (Latitude-Longitude, UTM, and State Plane) so coordinate systems conversions are not necessary.

The GPS units were set-up as pursuant to the manufacture's suggestions and point data were collected for at least 30 seconds at each location. Structure dimensions were paced off, measured on the field photos, or estimated by the field recorder and were not verified with the GPS positions.

The GPS point verses the structure position-- Field visits were made first from land. The team would walk the shoreline where possible, take GPS locations at the structure points, and fill out a datasheet for each structure located. If a point on a structure could not be reached, the alternatives were to:

1. Collect a GPS location near the point and describe the offset on the datasheet.
2. Note the uncollected point and return when survey conditions improve.
3. Note the uncollected point and collect the data during boat work at a later date.

Boat work was done with a 14-foot (4.3 meter) outboard with the GPS antenna attached to within three feet (1 meter) of the bow. The boat was brought as close as was possible to the structure point before data collection began.

Accuracy/Resolution evaluation of data-- The Trimble® TDC1 unit is reported to have approximately 10 to 16 feet (3 to 5 meter) accuracy with differential correction before selective availability was turned off (May 2, 2000). The use of a differential station over 100 miles (160 km) from the field location could add another three feet (1 meter) to the degradation of position. Field conditions (primarily wave and wind conditions) usually allowed for occupation of the points used to define the structure; however, in some instances (mostly with the boat), it was not possible to collect GPS data at the structure. Estimates of this error were usually noted on the datasheets or the position offsets were shown on the field photos. After processing much of the GPS data, it was discovered that a lockout of 6.0 for the Precision Dilution of Position (PDOP) did not provide repeatable results, and the PDOP lockout was lowered to 5.2. If the lockout had been lowered earlier, some of the difficulties encountered in overlaying the points onto the geo-referenced photos in the high bluff (eastern) area of the State may have been avoided. The north facing high bluffs, which can block and warp the satellite signal, presumably accentuates some of the errors in the GPS locations. This is because most of the satellites are orbiting south of Lake Erie. In summary, the worst-case combined positional accuracy of the points is estimated to be plus or minus 16 feet (5 meters) with the majority of the positions being much more accurate.

Numbering system for structures

Structures were first categorized as either shore parallel or shore perpendicular. A shore parallel structure was assigned both "E" and "W" points that represented the location of the first encounter point of the structure (lowest transect number Ash 299 32-2E) and the other end of the structure (Ash 299 33-2W), respectively. A shore perpendicular structure was assigned both "S" and "N" points that represented the shore and offshore ends of the structure, respectively. Intermediate points on a structure were taken to help define the structure shape, where there were changes in composition, to outline extensions from the main structure, and to generally better define the structure. Intermediate points were generally numbered sequentially for example Ash 299 32-2.1, 32-2.2. Some structures were defined as miscellaneous structures, which consisted of structures that were very small, poorly defined, and was assigned only one GPS point (Ash 287 34-1).

Field teams, training and size

An experienced Survey staff member accompanied each of the teams collecting field data during the early stages of the project, helping to develop and modify the field datasheet and standardize the data collection methods. Later, experienced field team members were relied upon to teach newer members the collection processes. A definition sheet, with both verbal descriptions and a drawing of each of the structure types was provided in each field pack for reference by the field team and expanded field descriptions and sketches of complex structures were encouraged.

Field crews were generally two to three people. Along the eastern end of the Ohio shore, where the bluffs are significantly higher, a field crew commonly consisted of one person with the GPS receiver, a second person filling out the datasheet, and a third person working along the bluff top (with radio contact) to follow along with the vehicle and to talk with landowners. In the low-to-moderate bluff areas, a two-person crew was sufficient if a third person was not available. A two-person crew was required for the boat work.

GIS

Geo-referenced photos -- In order to create a GIS product, a geo-referenced photo base map for the SSI data was needed. Originally the geo-referenced base aerial photography used in this project was the ODNR 1997 coastal flight. The ODNR 1997 photos were to be geo-referenced to the same if not better accuracy as the USGS standards for a 1:1600 scale with a one-foot resolution and projected in US State Plane, Ohio Northern Zone, North American Datum 1983, International Feet. Subsequent to the 1997 flight, accurate geo-referenced photos were acquired from each lakefront county and are now being used as the base photos.

Database management -- The original GIS product was created from the corrected GPS Microsoft® Excel data for each CEA frame. Next the Microsoft® Excel data was converted into a GIS point shapefile in either ArcView® or ArcInfo® and then projected in the US State Plane, Ohio Northern Zone, North American Datum 1983, International Feet. Each of the shapefiles had a legend that denoted the shore parallel and shore perpendicular structures with their intermediate points. This created a GIS product that gave the spatial location for each structure and the structures identification number from the CEA frame and transects. It was then possible to access details about each structure by using the identification number provided in GIS and cross-referencing the identification number in the Microsoft® Access database.

Challenges

Introduction-- Many challenges were encountered during the collection and processing of the inventory data; the most obvious of which is fieldwork took place over a number of years so the data are not as synoptic as desired. Additionally, the inventory was started during a time of high lake levels so some submerged structures were not inventoried because they could not be seen making comparisons with previous

inventories difficult. Questions to consider when attempting a shore structure inventory include:

- How should the structure be numbered?
- How should the structure be classified?
- How should a change in a structure during the course of the inventory be managed?
- How should technology changes be handled?

Numbering system and structure type classification -- Structures inventoried during previous structure inventories tended to be relatively simple. However, many of the structures found in this study did not clearly fit into the simple definitions, either because they had been altered in reconstruction or were designed as complex structures. Frequently, dimensions of a structure did not provide obvious classification of the structure to a specific type. For example, sheet piling originally extended out into the lake 50 feet (15 meters) as two groins and was subsequently enclosed and filled. The two groins and the seawall were effectively changed to a single fill area with walls extending from the offshore edge back to the shore (shore returns) and the structure has approximately the same dimensions alongshore as offshore. Should this structure be inventoried as a shore parallel or shore perpendicular structure? It could be classified as a pier, a very wide groin, or a seawall with shore returns.

Complex structures are also difficult to name; for example, consider a shore parallel structure with a submerged concrete slab as toe protection (in the water), protecting a stone revetment at the waters edge, extending to just below the top of a seawall, which is capped by a concrete slab that extends back to a retaining wall with a cobble splash apron. In addition, there is a concrete structure extending from the midpoint of the wall with cleats on the surface. What is the classification of the structure and how many structures should be inventoried for this one stretch of shore?

Complex structures were often grouped together and an overall sense of shore protection was noted. The above structure should have been inventoried as a seawall (shore parallel structure) with toe and splash protection; the groin/dock would have been noted with two intermediate points.

Another complex example is a seawall with four evenly spaced, equal length groins. This was generally inventoried as one shore parallel structure rather than as one parallel and four perpendicular structures. In many areas, one structure type would simply blend into another type or there would be a gradual change in composition. At the discretion of the field team, the structure(s) could be inventoried as one structure or two or more structures. For this project, structures were designated as either shore parallel or shore perpendicular chosen by an estimate of its major influence on the environment.

A similar grouping was required within the composition field. The structure was categorized by its major compositions and minor components were not considered.

The "E", "W", "S", and "N" designations of the compass directions for the ends of the structures worked well until the field crew reached the first harbor where the system was not applicable. In addition, the "E", "W", "S", and "N" designations didn't work along the north side of Sandusky Bay and around the islands. Since many structures had already been labeled with these letter designations, the lettering system

was retained, but the letters were generic and have no association with compass directions.

For a shore parallel structure, the first point inventoried, relative to the frame and transect numbers, was labeled as E and the other end was labeled as W; intermediate points were usually numbered sequentially. For shore perpendicular structures, the shore end was labeled as S and the offshore end was N. Another source of numbering confusion was encountered at complex structures, where some structures had an E and W and a S, or where there were intermediate points that also had a N or S designation.

The islands posed another numbering dilemma because some of the CEA frames and transects were numbered in a clockwise direction (North and Middle Bass) around the islands and others were numbered in a counter-clockwise direction (South Bass, Kelley, and Johnson). For this study, the established CEA numbered frames and transects were followed.

Changes to the shore structures during inventory -- Structures were often modified between the time they were originally inventoried by land and the time when they were inventoried by boat. Some structures that were not visible on the first visit became visible on a second visit due to changes in water levels or in some cases the structure failed and was no longer present. The overall philosophy was that once a frame was finished and the structures were put into the inventory, subsequent changes seen on later visits were not taken into consideration. Therefore, a structure was effectively inventoried on the first visit to a given location; subsequent visits added data but not structures.

Changes in the system and the equipment -- GPS Selective Availability was discontinued on May 2, 2000 (during the fieldwork), which changed the available accuracy of the data points. Differential stations for correcting the data were added during the project, which changed the accuracy available for differentially corrected data points. Multiple field crews used three types of GPS receivers during fieldwork. Some crews used slightly different parameters for data collection and storage.

QUALITY ASSURANCE/QUALITY CONTROL CHECK
Time frame work preformed

A Quality Assurance/Quality Control (QA/QC) check of all the data began in 2002 when geo-referenced photos became available. The QA/QC task continued through most of 2003. The relative position of each point on a frame was evaluated relative to the geo-referenced photos. Following the QA/QC, some structures were revisited to clear up inconsistencies in the data set.

GPS

During the QA/QC phase of the project, two Trimble® GPS Pathfinder Pro XRS units with sub-meter accuracy and multipath rejection technology were acquired. These units provide real-time differential locations and an improved positional accuracy. The

real-time differential allows for navigation to the previously collected position, thus speeding up fieldwork at some locations.

Numbering system for structures

Within the QA/QC process many of the complex structures had to be renumbered to stay within the system previously mentioned. In the original fieldwork some structures had an E, W, and S designation or intermediate points that also had N and S designations. These points were renumbered to be consistent with the shore parallel and shore perpendicular designations. Sketches of the structures on the field datasheets and the shapes drawn on the field base photos were essential to making appropriate adjustments.

GIS

Geo-referenced photos – During the QA/QC of the data it was discovered there were complications with the 1997 ODNR geo-referenced photos being used as the base map that rendered them unsuitable for the SSI. Where possible, County Auditor geo-referenced photos were used as the base photo in the QA/QC check. Where county photos were not available, the USGS geo-referenced photos were used. The geo-referenced photos from county flights, had a 2-foot (0.6 meter) or better resolution, or for Ashtabula County, the USGS geo-referenced photos had a 3.3-foot (1 meter) resolution. All of the geo-referenced photos were in US State Plane, Ohio Northern Zone, North American Datum 1983, International Feet.

Quality Assurance/Quality Control (QA/QC) checks consisted of overlying the shapefile onto geo-referenced digital air photos to determine if the GPS locations were within 16 feet (5 meters (33 feet, 10 meters for Ashtabula County due to the USGS geo-referenced photo base)) of the photo location of the structure. The 16 feet (5 meters) was based on the combined accuracy expected from the field crews positioning, the GPS units, the differential station correction, and the photo base. If the visual location of the GPS point was within 16 feet (5 meters) of the base photo position of the same point then no changes were made to the point location. If the positions were not within 16 feet (5 meters) of each other then the field position was reassessed as to its accuracy. Field sheets and field photos were consulted as well as other airphotos that were taken near the time of the fieldwork. If a position location could not be resolved using these techniques, the structure was marked for repeat fieldwork to get a GPS location within tolerance.

Database management –After the QA/QC check, a new GIS product was produced that consisted of the GPS data in Microsoft® Excel and all of the data from the Microsoft® Access database, thus having a GIS product that had all the GPS information and the Microsoft® Access datasheets information. All of the GPS Microsoft® Excel spreadsheets for a county were combined into a single spreadsheet. This new spreadsheet had a column added for a unique identifier that consisted of the CEA frame, transect number, and the structure numbers. This unique identifier already existed in the Microsoft® Access database. This allowed for the Microsoft® Access database and the Microsoft® Excel spreadsheet to be combined to form one new sheet that had all of the GPS and field sheet information. The new data sheet was then brought into either

ArcView® or ArcInfo® and made into a point shapefile. Now any point in the shapefile could be identified and indicate the type of structure and its spatial location. The point shapefile was then converted to a line shapefile to better show the structure's shape and to easily differentiate the structures from each other.

ANALYSIS

DENSITY DISTRIBUTION OF SHORE STRUCTURES, THIS STUDY AND PREVIOUS WORK

The structures built along the Ohio shore are not evenly distributed. Changes in this distribution have an affect on shore and nearshore properties. The density of structures from this project was calculated and compared to the results of a report by Carter, Benson and Guy (1981). This report compared the density of shore structures along the Ohio mainland shore between the 1870's, 1930's, and 1970's. Their tabulation was categorized into three structure densities along the shore and tabulated by county. The structure density categories are:

- Sparse (<1/3 of shore protected),
- Moderate (1/3 to 2/3 of shore protected)
- Dense (>2/3 of shore protected).

Carter, Benson, and Guy (1981) reduced the shoreline lengths by the distances where no bluff recession data existed for Erie, Ottawa, and Lucas Counties. Similarly, in this study, the same reaches were omitted from the length calculations for Erie, Ottawa, and Lucas Counties. The density of protection was calculated by assigning each 100-foot (30.5 meter) unit of shore (between CEA transects) as either protected or unprotected, based on the presence or absence of structures. The units were subsequently grouped into density classes using a moving window of three units (300 feet, 91.4 meters). If all the unit densities were the same, that length (300 feet, 91.4 meters) was assigned a density category (sparse or dense). If two units were alike and one was different, the length was assigned to the moderate density class.

INDICATORS

Introduction

Structure type and composition information from the SSI Microsoft® Access database were used to build erosion effectiveness and biological compatibility indicators. For each of the indicators, the structure types and the structure compositions were grouped into classes with "good" or "bad" attributes with respect to the indicator being built (see specifics below). For simplification, the structures other attributes that were listed on the field data sheets were not used in this grouping process.

Erosion effectiveness

This indicator was built from grouping structure types and compositions into "more and less-effective" groups. More-effective types were those that were assumed to protect the shore from erosion better than the less-effective types in all geological settings, assuming the structure was built correctly. More-effective compositions were

those that were expected to provide better protection to the coast for a longer duration while causing the least degradation of the structure. The type and composition groupings use for the erosion effectiveness indicator are listed in Table 1.

Table 1. Data groupings used for erosion effectiveness

Structure type		**Composition**	
More-effective	*Less-effective*	*More-effective*	*Less-effective*
Revetment	Groin	Rip-Rap Rubble	Construction Rubble
Attached Breakwall	Jetty	Stone Blocks / Concrete Block	Steel Sheet Piling
Offshore Breakwater	Dock	Concrete Poured	Steel Plates
Dike	Pier	Concrete Slabs	Steel Tanks
Sea wall	Retaining Wall	Concrete Modules	Steel Barges
	Boat Ramp	Steel Cribbing	Timber Pilings
		Timber Cribbing	Gabions

From the erosion effectiveness groupings, a four-tiered indicator ranking system for erosion effectiveness was developed. The four indicator rankings for erosion effectiveness are listed below and are in order of the most favorable index as number one (1) and least favorable index as number four (4):

1. More-effective structure and More-effective composition,
2. More-effective structure and Less-effective composition,
3. Less-effective structure and More-effective composition
4. Less-effective structure and Less-effective composition.

Ranking two and three were based on the assumption that with a mix of more-effective and less-effective structure and composition, that a more-effective structure type, even if it were made of a less-effective composition, would protect the shore better that a less-effective structure type made of a more-effective composition.

Biological compatibility

Roger Thoma (personal communication 8/28/03), a Fisheries Biologist formerly with the Ohio Environmental Protection Agency (Ohio EPA) grouped biologic compatibility into favorable and non-favorable classes for both structure type and composition (Table 2).

Table 2. Data groupings used for biologic compatibility

Structure type		**Composition**	
Favorable	*Non-favorable*	*Favorable*	*Non-favorable*
Revetment	Sea wall	Rip-Rap Rubble	Concrete Poured
Attached Breakwall	Groin	Construction Rubble	Concrete Slabs
Offshore Breakwater	Jetty	Stone Blocks / Concrete Block	Steel Sheet Piling
Dike	Dock	Gabions	Steel Plates
	Pier		Steel Tanks
	Retaining Wall		Steel Cribbing
	Boat Ramp		Timber Cribbing
			Steel Barges
			Timber Pilings
			Concrete Modules

From the biological compatibility groupings, a four-tiered indicator ranking system for biological compatibility was developed. The biological indicators are listed in order of the most favorable index as number one (1) and the least favorable index as number four (4).

1. Favorable structure and Favorable composition
2. Non-favorable structure and Favorable composition
3. Favorable structure and Non-favorable composition
4. Non-favorable structure and Non-favorable composition

Ranking two and three were based on the presumption that a non-favorable structure type made of a favorable composition was a better substrate for the biologic community that a favorable structure type made of non-favorable composition.

Grouping multiple entry structures into indicators

If a structure had multiple entries in "structure type" or an entry in "other structure" type, the original datasheet was used to verify the data and provide information to make an informed decision as to which group it belonged. OGS file aerial photography was also used to help make this choice. Once a decision was made, the structure was assigned to its dominant structure type and then assigned to either the more-effective or less-effective category (erosion) or favorable/non-favorable (biologic) for the grouping by structure type.

If a structure had multiple entries in "composition" or an entry in "other composition", the number of more-effective and less-effective (erosion) or favorable and non-favorable (biologic) compositions were counted, the structure was assigned to either the more-effective or less-effective (erosion) or favorable or non-favorable (biologic) category by the greater number count. Because rip-rap is very beneficial to both indexes it was treated preferentially and given a count of two when considering where to place a structure with multiple compositions. If the number counts were equal, the structure was left in either the more-effective/more-effective or less-effective/less-effective (erosion) indicator ranking depending on its original location (favorable/favorable or non-favorable/non-favorable for biologic). To reclassify structures originally classified as "other composition", the notes on the original datasheet were reviewed to determine the majority count, and the structure was assigned to either the more-effective or less-effective (erosion) or favorable or non-favorable (biologic) composition category.

RESULTS

STRUCTURE DENSITY

It is evident that structure density has changed from the 1870s to the late 1990s (Table 3, Figs. 2 and 3). In all the Lake Erie shoreline counties, there has been a decrease in the shoreline that is sparsely protected and an increase in shoreline that is densely protected. Moderate protection has not been dominant in any of the time periods.

Table 3. Structure density percent changes from the 1870's through the 1990's

	1870's[1]			1930's[1]			1970's[1]			1990's[2]			mainland	
	sparse	mod	dense	sparse	mod	dense	sparse	mod	dense	sparse	mod	dense	coast miles	mainland not measured[3]
Mainland														
Ashtabula	100	0	0	70	22	8	73	15	12	32	6	62	27.67	
Lake	100	0	0	76	19	5	70	24	6	28	4	69	31.12	
Cuyahoga	88	1	11	53	6	41	47	15	37	14	2	83	29.75	
Lorain	100	0	0	63	30	6	52	17	31	14	8	79	22.10	
Erie	100	0	0	38	49	14	31	44	25	9	4	87	22.08	37%
Ottawa	99	0	1	96	4	0	56	19	25	16	6	78	36.06	9%
Lucas	100	0	0	78	17	5	47	13	41	1	0	98	21.89	12%
Islands													coast miles	
Kelleys				100	0	0	100	0	0	55	6	39	10.87	
South Bass				88	1	11	76	5	22	39	9	52	9.83	
Middle Bass				98	0	2	86	3	11	37	11	53	7.50	
North Bass				98	1	1	97	0	3	73	6	21	4.98	
Sandusky Bay														
Eri & San Co.				57	19	23	26	30	44	24	2	74	23.15	
Ottawa Co.				92	3	5	59	12	29	8	4	87	17.75	
Johnson Is.				92	1	7	83	3	14	0	3	97	2.69	

[1]Data for the 1870's, 1930's, and 1970's are from the Ohio Geological Survey Reports of Investigation noted in the previous inventory section of the text and from the file reports also listed in the text, and from Carter et al, 1981

[2]Data for 1990's calculated using modified County Report technique, see text

[3]Mainland not measured is shore length not used by Carter et al, 1981 for calculations because complete data set was not available

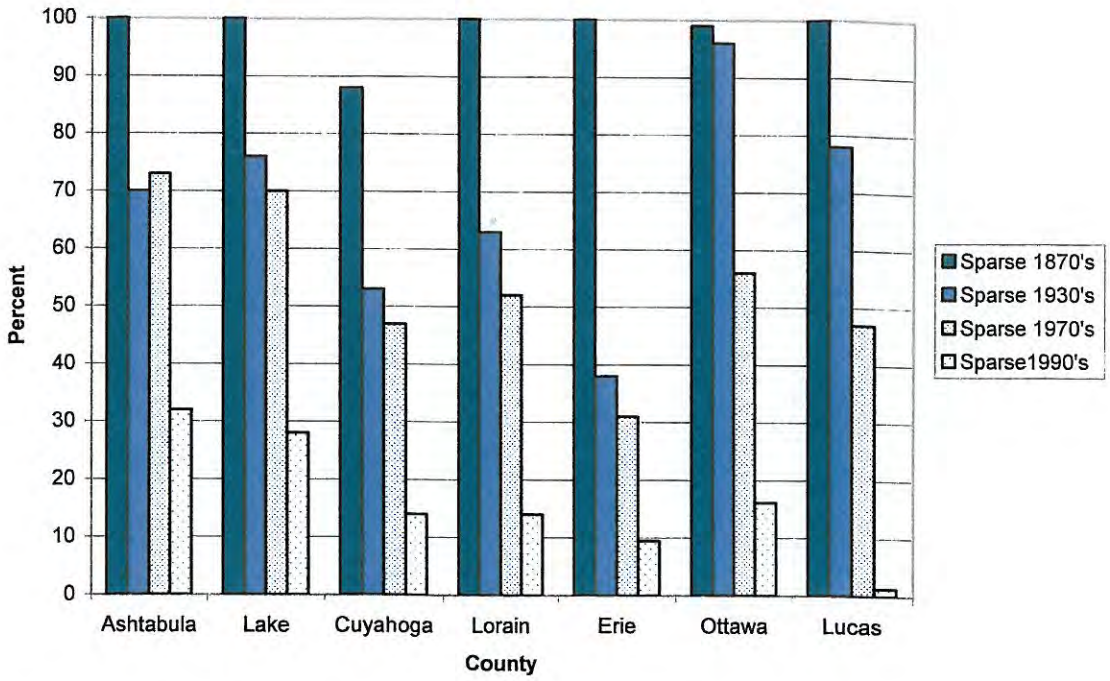

Figure 2. Mainland distribution of sparse structure density over time.

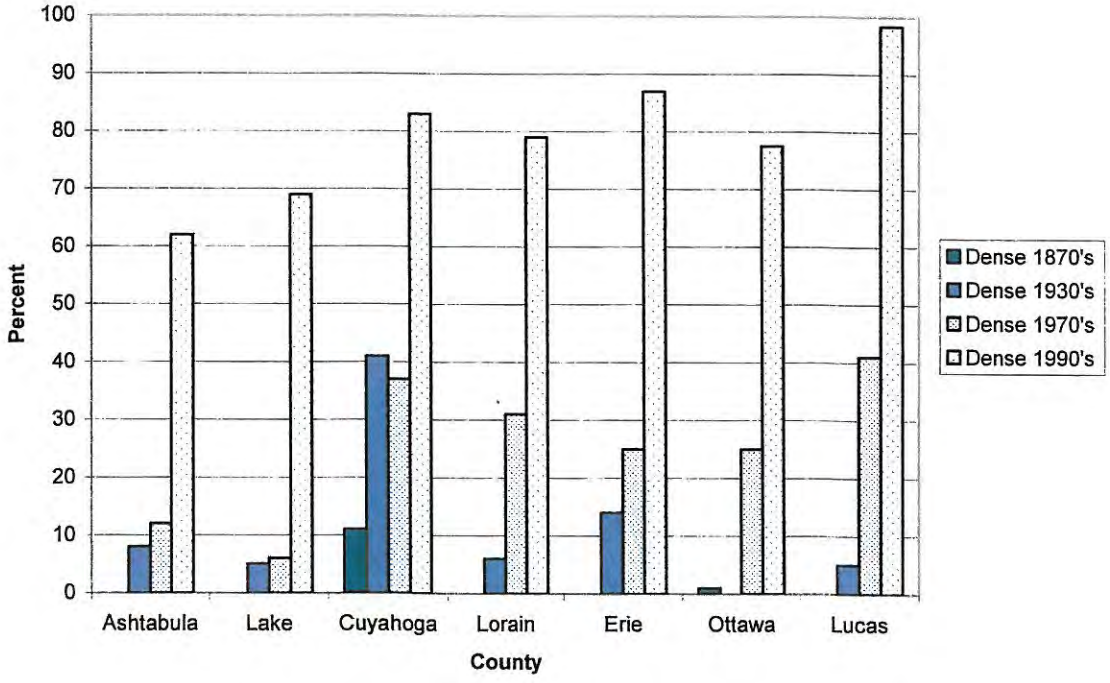

Figure 3. Mainland distribution of dense structure density over time.

Lucas County has the most dense shore protection (almost 100 percent), and it is anticipated that the remainder of the mainland shore counties will follow that growth pattern (Fig 3). This trend is extended to both the open lake islands and Sandusky Bay (Figs. 4 -7). The trend is not at all surprising given the continued development of the coast and the fact that problems arising with the placement of one structure tend to lead to construction of adjacent structures.

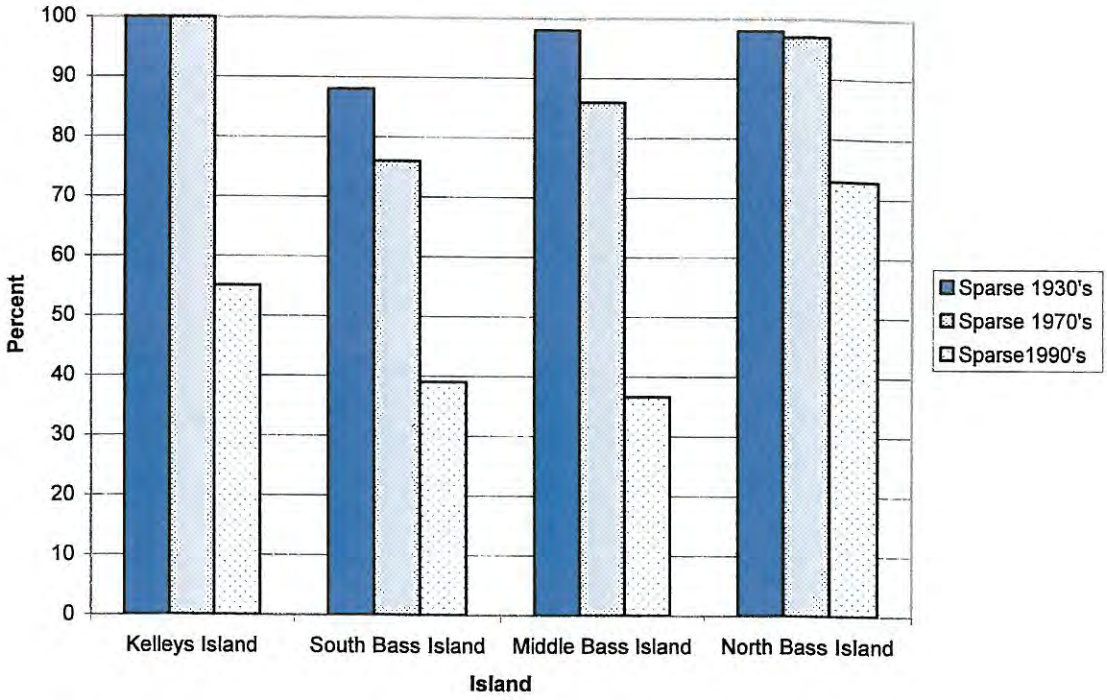

Figure 4. Open lake islands distribution of sparse structure density over time.

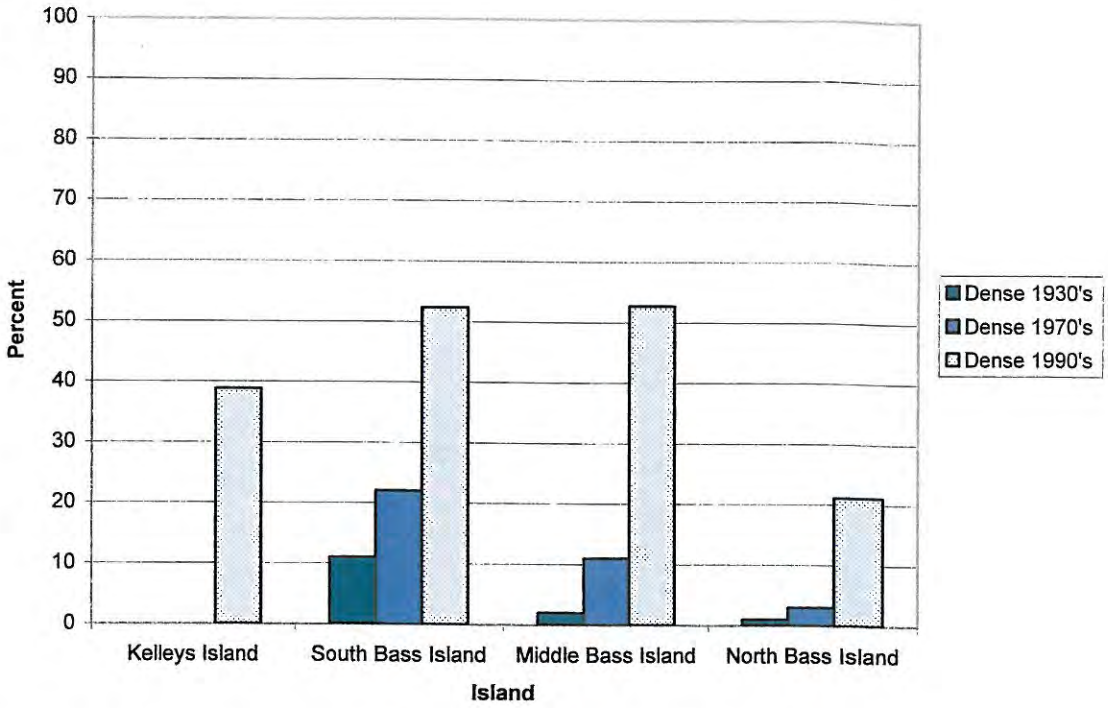

Figure 5. Open lake islands distribution of dense structure density over time.

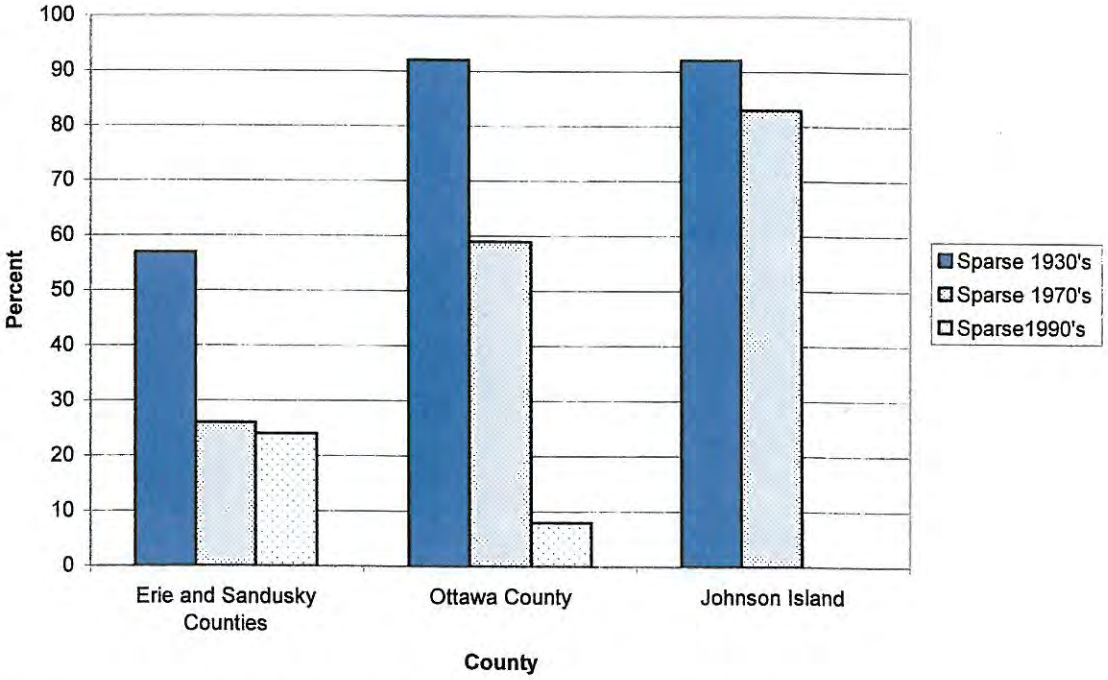

Figure 6. Sandusky Bay distribution of sparse structure density over time.

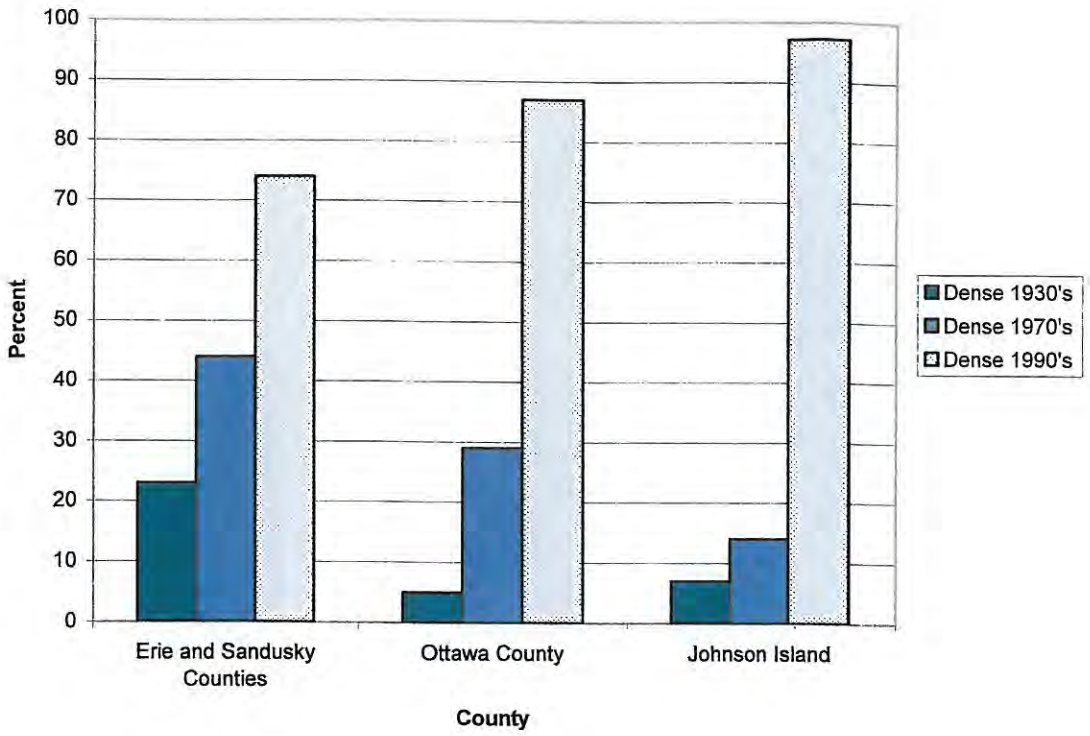

Figure 7. Sandusky Bay distribution of dense structure density over time.

EROSION EFFECTIVENESS INDICATOR

The percent values for each indicator ranking are shown in Table 4. Data are segregated by county, individual open lake island, and Sandusky bay and are summarized by total mainland shore, total open lake islands and total Sandusky Bay. Although there is variability in the data, the trends show the more-effective structure and composition categories are present in the greatest percentage across the state (generally greater than 50 percent) (Fig. 8). This is logical because most of the structures are built for erosion abatement.

The second most populated indicator is #3 (less-effective structure and more-effective composition). This suggests that there are many less-effective shore protection structures being built that are constructed of the more-effective materials.

The remainder of the structures fell into the remaining two indicators in about the same frequencies, #2 (more-effective structure and less-effective composition) and #4 (less-effective structure and composition). These same trends are also apparent when looking at the results of both the open lake islands and Sandusky Bay shore structure erosion effectiveness (Figs 9 and 10).

Table 4. Erosion effectiveness indicator

Table 4. Erosion effectiveness indicator

EROSION PROTECTION				
INDICATOR AND RANKING	More-effective structure and composition **1**	More-effective structure and less-effective composition **2**	Less-effective structure and more-effective composition **3**	Less-effective structure and composition **4**
Mainland shore percent of shore structures				
Ashtabula County	43	16	34	7
Lake County	50	22	23	5
Cuyahoga County	53	11	32	4
Lorain County	52	17	25	6
Erie County	43	9	42	6
Ottawa County	55	15	17	12
Lucas County	40	13	20	28
Total Mainland shore	49	15	27	8
Islands (open lake) percent of shore structures				
Kelleys Island	44	5	39	12
South Bass Island	50	5	34	10
Middle Bass Island	48	8	35	10
North Bass Island	53	11	16	21
Total Open Lake Islands	48	6	35	11
Sandusky Bay percent of shore structures				
Erie County	56	14	22	9
Sandusky County	56	5	36	2
Ottawa County (Bay)	47	9	34	9
Ottawa County (Johnson Island)	36	5	48	11
Total Sandusky Bay	48	9	34	9

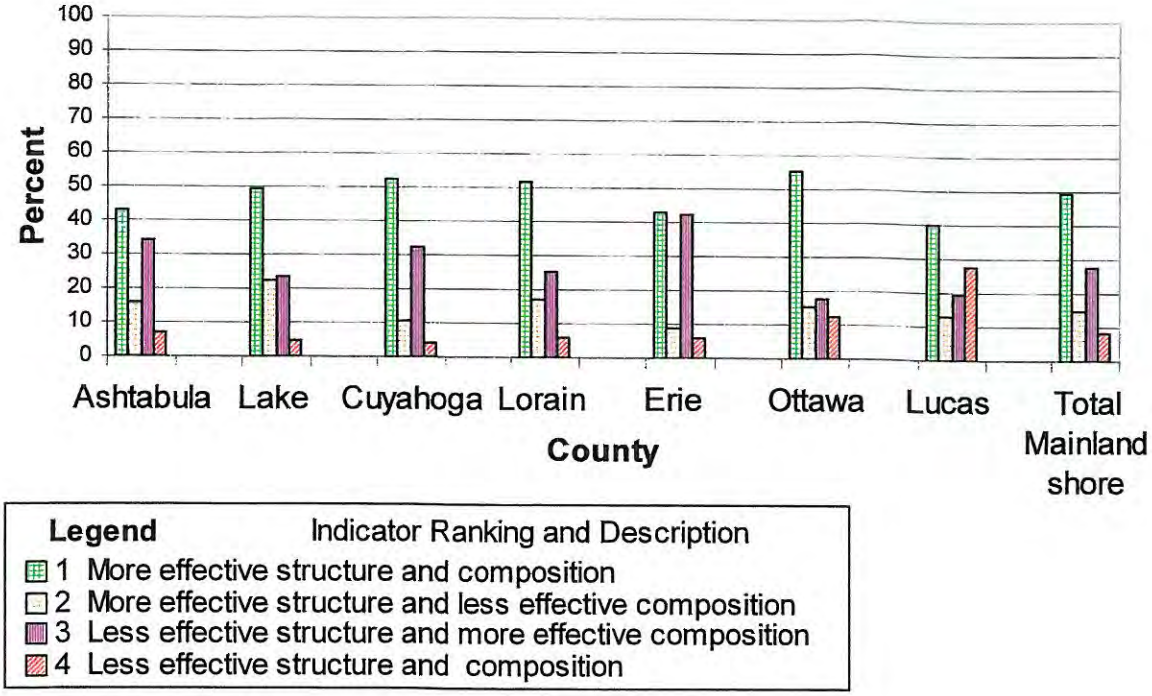

Figure 8. Mainland erosion effectiveness indicator.

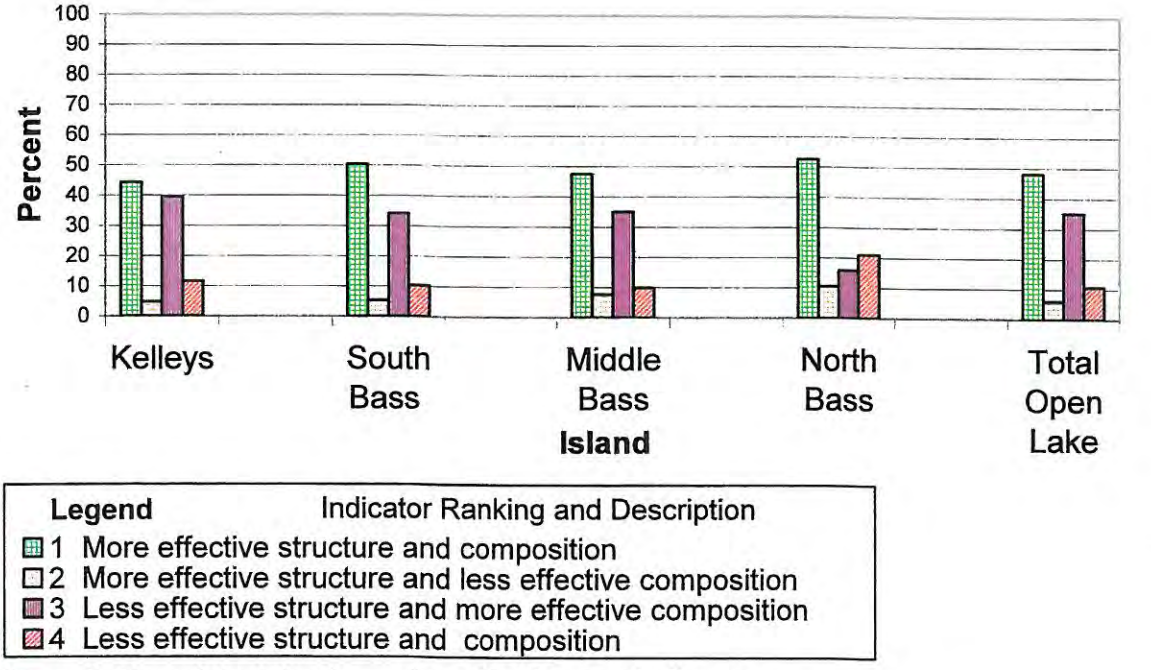

Figure 9. Open lake islands erosion effectiveness indicator.

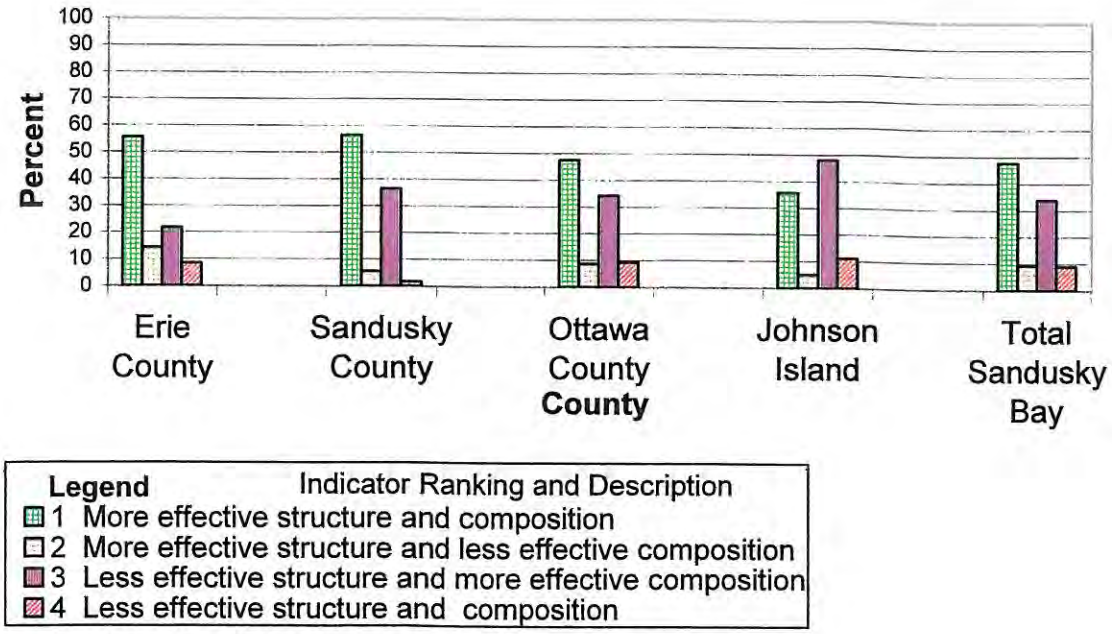

Figure 10. Sandusky Bay erosion effectiveness indicator.

BIOLOGIC COMPATIBILITY INDICATOR

The percent values for each indicator ranking are shown in Table 5. Data are separated by county, individual open lake island and Sandusky bay and are summarized by total mainland shore, total open lake islands, and total Sandusky Bay. Although there are variability in the data, the trends indicate the non-favorable structure and composition are present in the greatest percentage across the state (generally greater than 50 percent). This is logical because most of the structures were built for erosion control, and did not consider the impact to nearshore biologic communities.

Graphical representations of biologic compatibility indicator are illustrated in Figures 11, 12 and 13. These figures show similar indicator trends across the state and confirm that the totals (mainland, open lake islands and Sandusky Bay) are very representative of the individual county components with only minor variations.

A graph of the biologic compatibility indicator for the whole mainland shore (Fig 11) shows that most of the structures are predominantly indicator #4 (non-favorable structure and composition), which comprises more that 50 percent of the coastal structures. The second most populated indicator is #1 (favorable structure and composition). The remainder of the structures are distributed into #2 (non-favorable structure and favorable composition) and #3 (favorable structure and non-favorable composition) categories. Individual counties generally follow the biologic compatibility indicator sequence of the entire mainland shore (#4, #1, #2, and #3). The same sequence of biologic compatibility indicators (#4, #1, #2, and #3) are visible when looking at the data from both the open lake islands and Sandusky Bay (Figs 12 and 13).

Table 5. Biological compatibility indicator

BIOLOGICAL COMPATIBILITY

INDICATOR AND RANKING	Favorable structure and composition 1	Favorable structure and non-favorable composition 3	Non-favorable structure and favorable composition 2	Non-favorable structure and composition 4
Mainland shore percent of shore structures				
Ashtabula County	14	15	8	64
Lake County	19	12	7	61
Cuyahoga County	28	13	15	45
Lorain County	21	7	12	61
Erie County	20	4	20	56
Ottawa County	31	5	14	50
Lucas County	31	6	9	54
Total Mainland shore	24	8	12	56
Islands (open lake) percent of shore structures				
Kelleys Island	27	1	35	37
South Bass Island	14	6	2	78
Middle Bass Island	10	8	10	71
North Bass Island	26	0	21	53
Total Open Lake Islands	16	5	13	66
Sandusky Bay percent of shore structures				
Erie County	43	1	16	40
Sandusky County	40	4	18	38
Ottawa County (Bay)	35	3	20	43
Ottawa County (Johnson Island)	22	0	18	60
Total Sandusky Bay	35	2	18	45

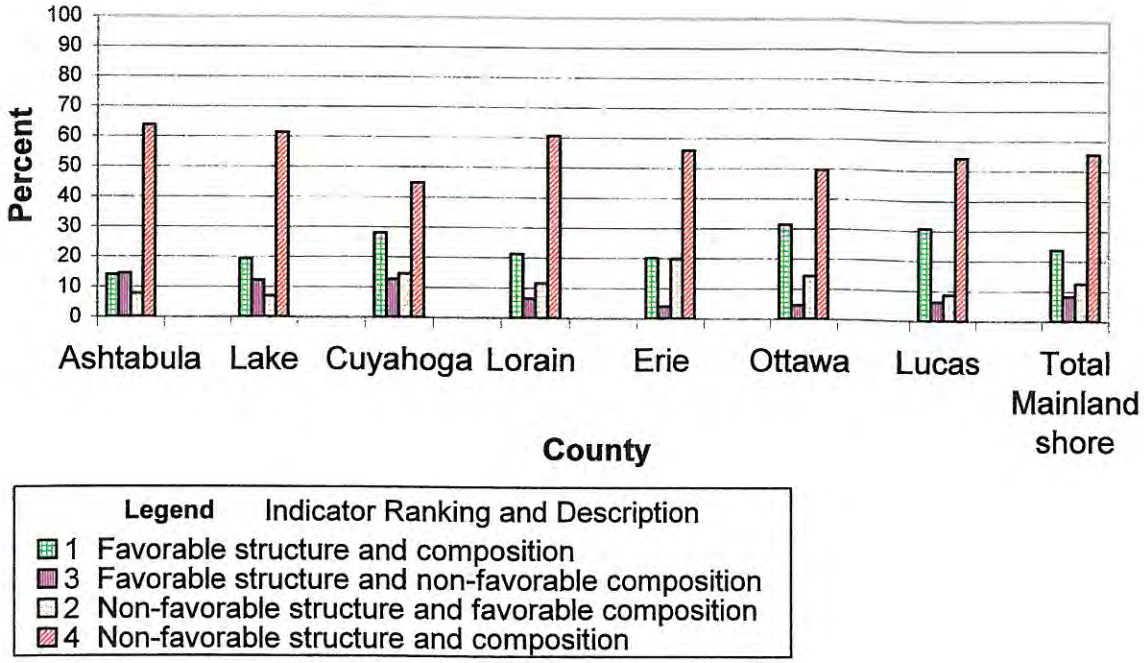

Figure 11. Mainland biologic compatibility indicator.

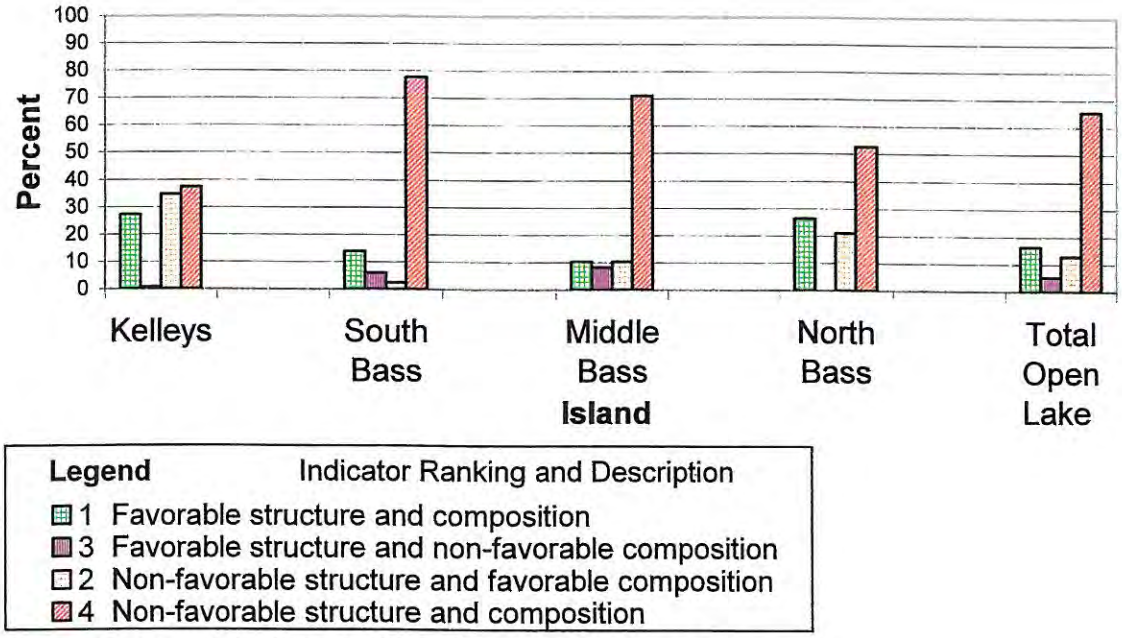

Figure 12. Open lake islands biologic compatibility indicator.

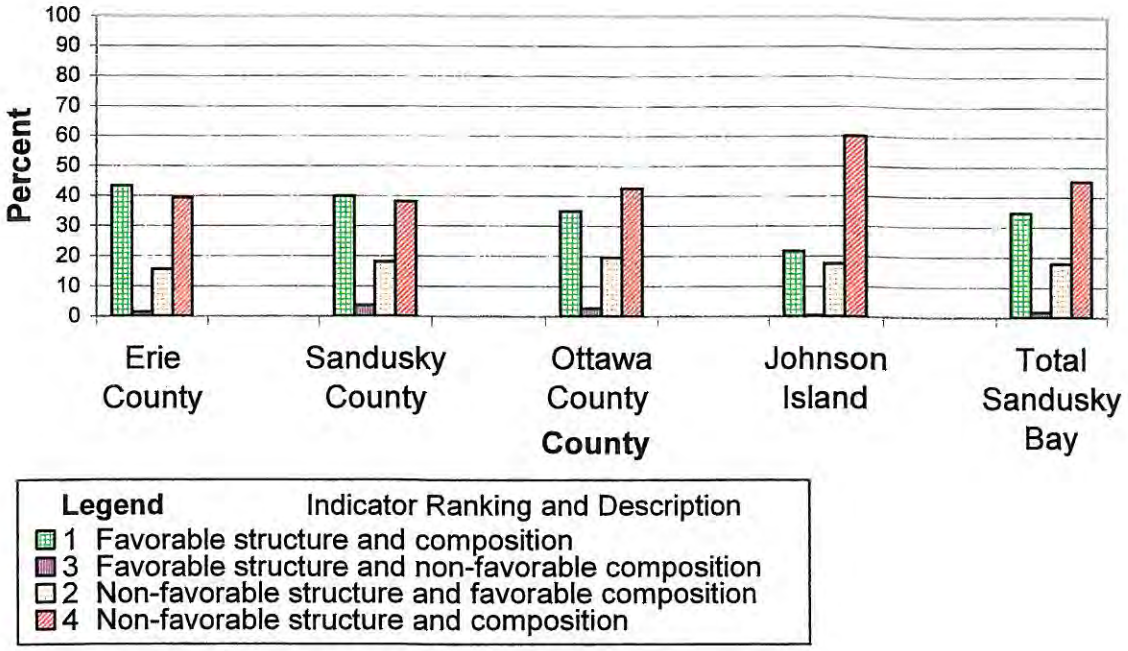

Figure 13. Sandusky Bay biologic compatibility indicator.

CONCLUSIONS

The Ohio shoreline cannot be returned to the unprotected "natural" shore that existed before development began in the 1820s. Even if returning the shore to "natural" conditions were an option, an unprotected shore does not provide the best erosion protection. Given this reality, it is recommended that future shore protection structures along the coast of Lake Erie be designed to effectively decrease erosion while providing for biological compatibility for the many organisms that use the nearshore habitat during part of their lifecycle. Moving toward a biologically enhanced nearshore habitat is an essential component to restoration of the Lake Erie ecosystem.

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